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Scientific opinion on the import of *Musa* fruits as a pathway for the entry of non-EU Tephritidae into the EU territory

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Abstract

Following a request from the European Commission, the EFSA Panel on Plant Health examined evidence as to whether the import of fruits of *Musa* (bananas and plantains) could provide a pathway into the EU for *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) or other non-EU Tephritidae for which *Musa* is a host. Relevant scientific and technical information, including unpublished information provided to the EFSA Panel on Plant Health by the European Commission from research conducted in Cabo Verde, were taken into account. The majority of EU imports of *Musa* fruit comes from Ecuador, Colombia and Costa Rica where *B. dorsalis* does not occur. Commercial *Musa* fruits are harvested at 'green stage one' before they begin to ripen naturally. Postharvest processes are designed to ensure that only high quality, unripe fruit are exported. Green stage one fruit are transported to the EU in controlled conditions and stimulated to ripen when exposed to exogenous ethylene in ripening rooms in the EU. There is no evidence that any Tephritidae can naturally infest commercial varieties of *Musa* fruit at green stage one or earlier. When experimentally infested with eggs of Tephritidae, larvae fail to develop in green stage one fruit. Physical and chemical changes that occur during fruit ripening enable *B. dorsalis* and 11 other species of Tephritidae to oviposit and develop in *Musa* at later stages of fruit development. Reports of *B. dorsalis* or other Tephritidae infesting bunches of *Musa* fruit are a consequence of the fruit being left to develop beyond green stage one in the field. There is no evidence that commercially grown fruits of *Musa*, for export to the EU, provide a pathway for the entry of non-EU Tephritidae. Passengers bringing *Musa* fruit from countries where Tephritidae can infest ripened *Musa* fruit do however provide a potential pathway for the entry of non-EU Tephritidae into the EU territory.

Keywords: Bananas, fruit flies, harvesting, plantains, quarantine, ripeness

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Summary

Following a request from the European Commission, the EFSA Panel on Plant Health examined evidence as to whether the import of fruits of *Musa* (banana and plantains) could provide a pathway for the introduction of *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), the oriental fruit fly, or other non-EU Tephritidae, into the territory of the EU. The Terms of Reference (ToR) specified that industry practices in relation to the harvest, storage and transport of fruits of *Musa*, before they enter the Union territory, be taken into account.

Literature searches were conducted in English, French and Spanish, the languages most commonly used in countries exporting *Musa* fruits to the EU. Relevant scientific and technical information, including unpublished information provided to the EFSA Panel on Plant Health by the European Commission from a study conducted in Cabo Verde, were taken into account.

Banana is grown in over 130 countries around the world and whilst primarily a tropical fruit, it is also grown in the subtropics and in greenhouses at latitudes outside of the subtropics. Production in the tropics occurs all year round.

The vast majority of *Musa* cultivars are derived from crosses between *M. acuminata* and *M. balbisiana*. Due to the long history of hybridisation, there are now approximately 130 recognised *Musa* varieties, although due to undocumented varieties in South-east Asia, there may be as many as 500 cultivars in the world. The Cavendish subgroup of cultivars which includes 'Grande Naine', 'Dwarf Cavendish', 'Williams' and 'Valery' dominates the international trade in banana; 'False Horn' is the plantain variety that is predominantly imported by the EU.

Most banana production is consumed locally. Fifteen percent of world production is exported with the EU being one of the three main export markets alongside the USA and Japan. The EU sources ~ 70% of imported bananas from South and Central America, specifically from Ecuador, Colombia and Costa Rica. Côte d'Ivoire and Cameroon are important suppliers of dessert bananas to the EU from Africa. Ecuador and Colombia provide more than 90% of plantains imported into the EU. According to FAOSTAT Uganda and Côte d'Ivoire are the main sources of plantains and cooking bananas to the EU from Africa, although they provide relatively small amounts, e.g. 1.1% and 0.3% of such EU imports in 2019, respectively.

The Von Loesecke scale is used to describe the development of banana fruit maturing and ripening on a scale consisting of seven classes and is based on peel colour. Harvesting of bananas for export to the EU always takes place during stage one, also called 'mature green' when the fruit reaches the diameter required for harvesting. Harvesting of plantains also occurs during mature green stage one. If harvested later than stage one, the fruit will begin to ripen naturally, synthesising and releasing ethylene during transport. As a consequence, the fruit will not reach the EU in a suitable state for marketing because early ripening leads to a shortened shelf-life. However, when harvested at stage one, ripening can be delayed by storing and shipping the fruit in controlled conditions, 13–15°C with low oxygen and high carbon dioxide concentrations. For this reason, the harvesting of banana and plantains for export always takes place when fruits are at mature green stage one.

On arrival in the EU, fruit can continue to be stored for a few days and are ripened in ripening rooms where the fruit is exposed to exogenous ethylene over 4–7 days. During the ripening process, the peel changes colour from green to the more familiar yellow.

Twelve species of non-EU Tephritidae can infest ripening *Musa* fruits, i.e. infest fruits at ripening stages beyond the mature green stage one. Eleven species belong to the genus *Bactrocera* and are distributed mainly in tropical Asia and Oceania. The polyphagous species *B. dorsalis* is the most widespread and occurs in all of tropical Asia, most of Africa and tropical islands in the Pacific Ocean, including French Polynesia and Hawaii. It continues to spread in Africa. It is not present in South or Central America where the EU sources the majority of bananas and plantains. However, *B. dorsalis* is present in African countries that export *Musa* fruit to the EU. The twelfth species of Tephritidae able to infest ripening *Musa* is *Ceratitis cosyra* (Walker), which occurs in sub-Saharan Africa.

Studies examining whether Tephritidae can infest green stage one bananas can be found from the early 20th century. There have also been more recent studies using field cages around bunches of bananas and in which the population density of Tephritidae was artificially high. Under such conditions, females attempt oviposition in green mature stage one fruit. Oviposition punctures cause an exudate to be released from the peel which seals the wound and can prevent females from laying an egg in the sealed puncture. Eggs artificially introduced into stage one fruit do not survive, perhaps due to the chemical composition of the substrate. In stage one, the pulp of fruit contains a high concentration of tannins, there is a lack of free water, and starch concentrations are high. As the fruit ripens tannins

and starch break down and more water becomes available. The peel also softens enabling females to successfully oviposit. Changes in the pulp allow eggs to hatch and larvae to develop in ripening fruit beyond green stage one.

In response to the question posed to EFSA by the European Commission on whether the commercial import of fruits of *Musa* (bananas and plantains) could provide a potential pathway for the introduction of *B. dorsalis* and other non-EU Tephritidae, for which *Musa* fruits are a host, the EFSA Panel on Plant Health concludes no.

Reports of *B. dorsalis* infesting and developing on green bananas in Cabo Verde do not detail the precise stage when oviposition occurred in the fruits. Whilst taking part in the Working group, hearing experts, including those who originally took the photographs in Cabo Verde, reviewed the photographic evidence, and concluded that the fruit was beyond mature green stage one.

The Panel went on to consider whether bananas and/or plantains carried in passenger baggage entering the EU could provide a potential pathway for the introduction of *B. dorsalis* and other non-EU Tephritidae, for which *Musa* fruits are a host. Bananas and plantains grown for domestic consumption may be harvested at ripening stages later than stage one in some countries. Even if harvested at stage one, bananas remain potentially exposed to fruit flies whilst ripening beyond stage one. *Musa* fruits maturing beyond stage one become potential hosts for 12 species of non-EU Tephritidae and whilst ripening, oviposition and further development of immature life stages is possible in the fruit. Passengers are allowed to carry small amounts of some plant products, including fruits, with them when travelling to the EU. It is therefore possible that unknowingly infested *Musa* fruit could be carried in luggage by international travellers arriving into the EU.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

1.1.1. Background

Bactrocera dorsalis (Hendel) is a polyphagous fruit fly of the family Tephritidae. It is not known to occur in the EU and it is regulated as a Union Quarantine Pest i.e. it is included in the annexes of Commission Implementing Regulation (EU) 2019/2072. The pest is polyphagous and has a strong dispersal power. Banana (*Musa* sp.) is known to be a host for *B. dorsalis*.

Fruits of *Musa* sp. are included into Annex XI, part C of Implementing Regulation (EU) 2019/2072; therefore, a phytosanitary certificate is not required for the introduction into the Union territory.

In trade, fresh fruits of *Musa* sp. are divided into plantains (eaten after cooking, CN code 0803 10 10) and dessert bananas (eaten raw, CN code 0803 90 10). The vast majority of bananas imported into the EU belong to the (dessert banana) variety *Cavendish*. They are harvested in an unripe stage and transported under cool conditions to the country of destination in order to delay ripening.

In August 2019, the Commission was made aware of research showing that in Cabo Verde *Cavendish* bananas of different ripening stages are infested by tephritid fruit flies, including *Bactrocera dorsalis*. Although the exact stages in which the bananas were infested have not been recorded by the researchers (pers. comm.), it is important to clarify whether import of bananas is a potential pathway for non-EU Tephritidae.

1.1.2. Terms of Reference

EFSA is requested to deliver an opinion whether the importation of fruits of banana (*Musa* sp.) into the EU constitutes a potential pathway for the introduction of *B. dorsalis* and other non-EU Tephritidae for which *Musa* sp. is a host. In this opinion, EFSA shall put particular emphasis on the importation of green Cavendish bananas, but other varieties of dessert bananas and plantains should be considered as well. In order to reach that conclusion, EFSA shall take also into account all relevant scientific and technical information, including data collected in Cabo Verde and made available to the Commission, as well the available information on best practices and common practices in use in harvest, storage and transport of fruits of *Musa* sp. before they enter the Union territory.

1.2. Interpretation of the Terms of Reference

Following clarification of some aspects of the Terms of Reference (ToR) from the requestor, the EFSA Panel on Plant Health (hereafter Panel) interpreted the ToR as a request to provide an opinion as to whether the commercial trade in cultivated varieties of *Musa*, either unripe banana ('green banana') or unripe plantain fruits, imported by the EU from third countries provides a potential pathway for the entry of *B. dorsalis,* an EU priority pest (EC 2019/1702) or other non-EU Tephritidae for which *Musa* is listed as a host. Although the ToR explicitly refers to green banana, i.e. unripe fruits, following the clarification, the Panel expanded the remit of the opinion to consider whether ripe bananas carried in passenger baggage could be a potential pathway. The risk elements describing likelihood of establishment, spread and impact were not within the scope of this opinion.

To inform the opinion particular attention is needed on the best practices and common practices used in the banana export industry, in particular with regard to the growing, harvest, storage and transport of fruits of *Musa* before they enter the Union territory.

The Panel adopted a pest categorisation of non-EU Tephritidae in 2019 (EFSA PLH Panel, 2020), which concluded that of 4,765 species regarded as non-EU Tephritidae, 257 species satisfy the necessary criteria assessed by EFSA such that they can be considered as potential quarantine pests for the EU. The reader is referred to that document for information on the identity, biology, detection and identification, establishment, spread and impacts of non-EU Tephritidae. In general, information provided in the pest categorisation is not repeated here, but may appear for ease of reference.

1.2.1. Additional information

Additional information was delivered to EFSA from research carried out at the Universidade dos Açores (Annex II to the Terms of references), which includes six individual documents:

i) Power point presentation authored by Dr David João Horta Lopes titled: '*Bactrocera dorsalis* (ex-invadens) Hendel (Diptera: Tephritidae) uma nova ameaça para as culturas fruticolas' 49 slides in pdf, dated as March 2019 in Portuguese.
ii) Power point presentation authored by Dr David João Horta Lopes titled: '*Bactrocera dorsalis* (ex-invadens) Hendel (Diptera: Tephritidae) uma enorme ameaça para as culturas fruticolas'. Presented for Frui Fly Protec, 49 slides in pdf, November 2019 in Portuguese (Figure 1a,b).
iii) Book titled 'A mosca do Mediterraneo no grupo central do Arquipelago dos Açores' edited by Pimentel R, Lopes D, Cabrera R and Dantas L (100 pages in pdf). In Portuguese.
iv) Conference poster in pdf titled: 'The presence of *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) in the Cape Verde Archipelago' authored by Horta Lopes DJ, Pimentel R, Cabrera Perez R, Balde A. One page in English.
v) Abstract to the 'Third FAO–IAEA International Conference on Area-wide Management of Insect' 2016 titled 'The presence of *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) in the Verde Archipelago' authored by Horta Lopes D, Pimentel R, Cabrera Perez R, Balde A. One page PDF in English.
vi) PDF titled damage_on_bananas_*Bactrocera_dorsalis*, which includes six slides of the power point presentation with pictures. Authors are not mentioned on this document or the date. Captions below the pictures are in English.

Figure 1 shows three of the images of *B. dorsalis* oviposition marks on banana taken in Cabo Verde and provided to the European Commission. Figure 1c is an image from the poster (iv. in list above) and labelled in the poster as 'Detail of the postures of *Bactrocera dorsalis*, in green and ripe banana'.

Figure 1: Damage of *Bactrocera dorsalis* on bananas in Santiago Island, Cabo Verde, courtesy of Raimundo Cabrera Perez from the University of La Laguna, Canary Islands, Spain

2. Data and methodologies

2.1. Data

The Web of Science, Google Scholar, Scopus, PubMed bibliographic databases were accessed during a literature search (see Section 2.2). Relevant papers were reviewed, and further references and information were obtained from experts, as well as from citations within the references and grey literature. For this opinion, the following additional data were searched:

- Eurostat (https://ec.europa.eu/eurostat/data/database). Data on the EU import of banana (CN 0803 9010) and plantains (CN 0803 1010). These data were obtained in June 2020 EUROSTAT (Statistical Office of the European Communities) for the period Jan 2012–Dec 2019.
- Statista (https://www.statista.com/). Data platform on market analysis, trade, industry and consumer data.
- FAOSTAT (http://www.fao.org/faostat/en/#data). Database of food and agriculture data for over 245 countries/territories and regional groupings.
- Europhyt (https://ec.europa.eu/food/plant/plant_health_biosecurity/europhyt_en). Database for pest-specific notifications on interceptions and outbreaks.
- CABI (https://www.cabi.org/). Crop protection compendium for information on crop pest. Acquisition of *Musa* datasheets.
- EPPO Global Database (https://gd.eppo.int/). Pest-specific information produced or collected by EPPO. The database is constantly being updated by the EPPO Secretariat.

- ProMusa (http://www.promusa.org/) a network of people promoting scientific discussions on bananas with the International Society for Horticultural Science (ISHS); aims to share the latest research developments and encourage collaborations. Search term "Tephritidae" retuned zero hits.
- MusaLit (http://www.musalit.org/about.php) a bibliographic database containing 17,915 references on bananas. A PDF is freely available for 51% of the references.
- EFSA Tephritidae database (EFSA PLH Panel, 2020). Between May 2018 and November 2019 EFSA, in collaboration with the University of Thessaly Tasking grant holder (GP/EFSA/ALPHA/2017/02 Lot3 GA1), compiled information on non-EU Tephritidae into a database. The information supported the Pest categorisation of non-EU Tephritidae and is published as Appendices A–J (EFSA PLH Panel, 2020, Supporting information). The appendices list more than 5,000 species of Tephritidae. For many of the species detailed information such as nomenclature; host plants: cultivated or wild and distribution was retrieved.

2.2. Methodologies

2.2.1. Literature search on harvesting

Recognising that timing of harvest was likely to be a critical feature in this opinion, a literature search specifically regarding the harvest of *Musa* was conducted at the beginning of this study (June 2020) using the Web of Science bibliographic search engine. Search terms and combinations of search terms are shown with the number of resulting hits in Table 1 regarding banana harvesting and also in Appendices A–C (English, French, Spanish, key words, respectively).

Table 1: Literature search regarding harvest date/ripeness

Search	Search terms/combination	Hits in Web of Science
1	Banana	58,212
2	*Musa*	35,723
3	Plantain	8,099
4	1 or 2 or 3	65,520
5	Harvest	680,302
6	Pick	140,933
7	5 or 6	811,132
8	4 and 7	10,103
9	Fruit	1,175,923
10	Ripe*	163,261
11	9 and 10	73,869
12	8 and 11	1,074
13	Restrict to papers published since 1990	710

The titles of 710 papers were downloaded into Endnote and reviewed. Titles of relevance were selected, and PDFs obtained for 225 papers which were further examined for relevant information.

2.2.2. Literature search on oviposition

A detailed literature search was conducted in Web of Science bibliographic database to check available information regarding banana infestation by Tephritidae fruit flies, banana ripening stage and viability of egg/larval stages. The 'advanced search' mode was applied to narrow the search to specific criteria. Specifically, the field tag 'TS (topic) = term' was used which finds records of publications containing the searched terms in any Topic field. Keywords/terms used included "banana" (also searched by the terms "Musa" and "plantain"), "Tephritidae" (also searched by the term "fruit flies"), "*Bactrocera*", "infestation", "fruit ripeness", "oviposition", "pre-harvest" and "passenger baggage" or "passenger luggage" The same terms were also searched in other languages (French, Spanish). All possible combinations of the aforementioned terms with a logical explanation were also searched (Appendices A–C). Some additional references were retrieved in Portuguese language.

3. The banana and plantain industry

This section has eight main subsections. The first (3.1) provides context for this opinion and describes world production of bananas and plantains with reference to detailed appendices showing national production area and exports. Subsequent subsections provide information on the growth and development of *Musa* plants (3.2); information on the range of cultivated *Musa* varieties (3.3) and invertebrate pests and pest management (3.4). Later subsections describe industry practices with regard to the harvest, storage and transport of fruits of *Musa* before they enter the Union territory, as requested by the ToR (1.1.2).

3.1. A global perspective of banana and plantain production

FAO data indicate that in 2018 bananas were grown in over 130 countries with a total harvested area in excess of 6.1 million ha (Appendix D). The area of banana production has grown substantially since 1993, when 3.6 million ha of banana was harvested. The increase in banana production has been driven by population growth in low- and middle-income countries with major banana producing countries such as Brazil, China, India and the Philippines also being major consumers. Between 2000 and 2015, the harvested area in India and China almost doubled and yields increased by 48 and 83%, respectively (FAO, 2020). Globally, between 2014 and 2018, the mean annual production of bananas was 115.7 million tonnes (Appendix E). Approximately 85% of world banana production is consumed in local or regional markets whilst around 15% of world production is exported; North America, Europe and Japan are the primary export markets (Ploetz and Evans, 2015). An increased awareness of the health benefits from eating bananas has driven banana consumption in Europe and North America and banana is the most consumed tropical fruit in the world (Hailu et al., 2013).

The global harvested area of plantains and cooking bananas in 2018 was 5.6 million ha with four of the top five producing countries in Africa (Appendix D). The mean annual global production of plantain from 2014 to 2018 was 38.3 million tonnes, the vast majority being consumed in the countries of production. Less than 2.3% of world plantain production is exported (Appendix F).

3.2. *Musa* plant characteristics, growing needs and crop phenology

Sections 3.2–3.8 describe *Musa* fruit production focussing on commercial cropping practices in areas that export to the EU. The focus is on banana production although many processes also apply to plantains (Figure 3). The *Musa* plant is a monocotyledonous evergreen perennial herb, growing 2.0–9.0 m tall. The 'trunk' or apparent stem, technically a pseudostem, consists of tightly packed, thickened and elongated leaf sheaths that develop from suckers that grow from the underground rhizome to develop into a pseudostem close to the parent plant (Robinson and Galán Saúco, 2010). The pseudostem supports 6–20 leaves; leaves can be ~ 2.7 m long and 0.7 m wide (Figure 2a,b). A banana terminology is available at the end of this opinion (p. 84).

3.2.1. Plant growth

The optimum temperature for growth is 27°C; the maximum 38°C. In sites of major banana production, temperature does not fall below 15°C for long. Thus, banana production is concentrated in tropical or near tropical regions where temperatures range between 15°C and 38°C (Hailu et al., 2013). Rainfall is also important; bananas grow best in areas with an annual precipitation of ~ 2,000 mm (De Buck and Swennen, 2016). They can also grow in areas with a mean rainfall of at least 100 mm per month and where any dry season does not exceed 3 months (Morton, 1987). Stable temperatures in the tropics mean that banana harvesting is often calendar based and occurs 9–16 weeks after flowering. In subtropical areas, this period may extend up to 28 weeks after flowering. The economics of banana production are such that commercial production is possible outdoors, e.g. in South Africa and at its ecological limits in and around parts of the southern Mediterranean (e.g. in Cyprus, Greece (Crete) and Spain (Andalusia, mostly Granada and Malaga)). Outside of the tropics commercial production of bananas can also take place in greenhouses e.g. in South Africa, Tunisia, Turkey, Korea and Argentina (OECD, 2009). Approximately 3,000 ha of banana are grown in greenhouses in the Canary Islands (Spain), largely to protect them from winds (OECD, 2009). A small amount of banana production also occurs in greenhouses in Iceland where geothermal technology is used to provide heating (Lund et al., 2011). Production in subtropical areas can be used to meet market needs when tropical hurricanes or typhoons destroy production in tropical regions (R. Swennen, pers. comm., 11/9/20).

3.2.2. Flowering and harvest

In a commercial plantation, planting density is around 2,000 plants per ha. One bunch of flowers is produced per pseudostem and 30–60 plants are likely to be flowering per ha per week although there is a degree of seasonality that correlates with rainfall and not with temperature. Figure 4 indicates year-round weekly production of bananas in the Canary Islands.

In the tropics, flowers may begin to develop 6 months after a new sucker forms its first leaf although 8–9 months is more common. Appendix G provides a detailed description of the growth stages of banana and plantains. In a commercial plantation, one plant with its ratoon can produce three bunches in 2 years (R. Swennen, pers. comm., 11/9/20).

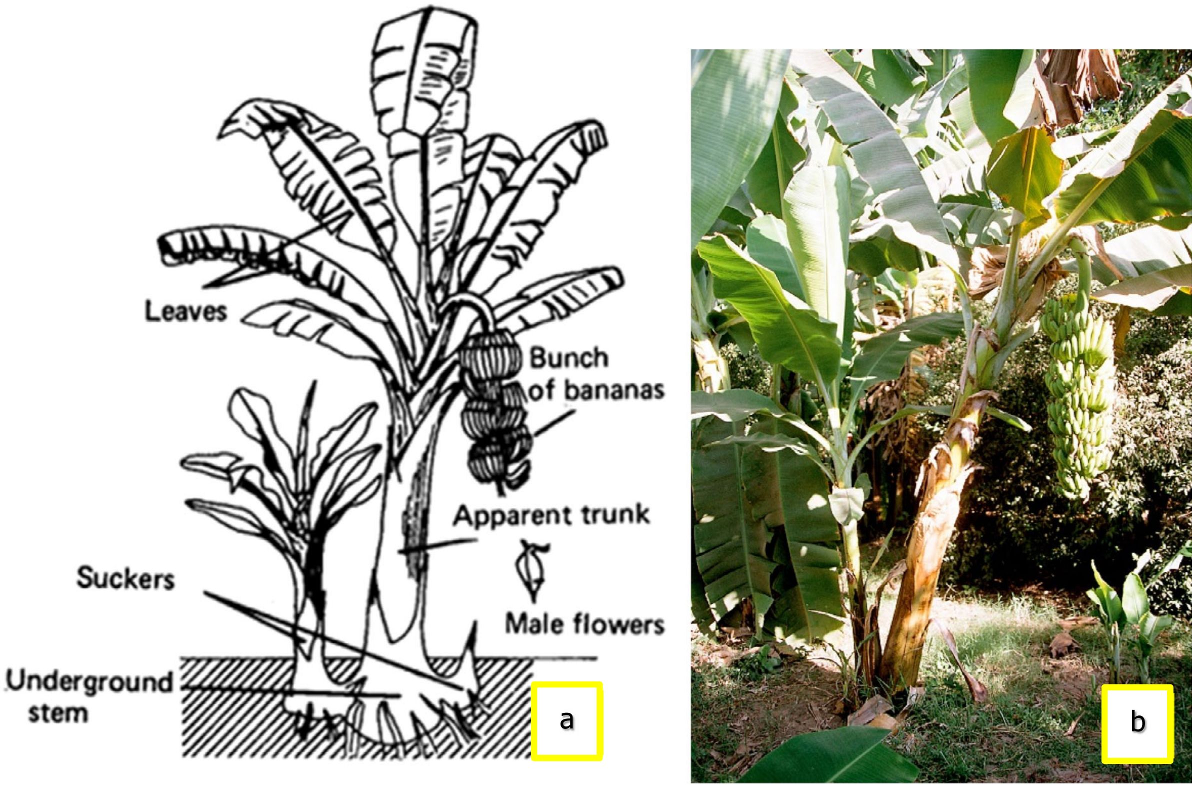
Due to the variation in flowering date within a plantation, growers typically tie coloured ribbons onto plants to mark the date of flowering. Plants flowering in the same week will have the same coloured ribbons and will later be harvested together. At any one time a plantation will have four or five different coloured ribbons in use on plants at different stages of flowering. As the bunch elongates during flowering, the bracts roll back to first reveal clusters of female flowers whose ovaries ripen to form the fruit. Continued elongation of the bunch leads to neutral flowers, then further elongation results in non-functional male flowers lacking pollen.

Flowers on the tips of the fruit are removed 2–3 weeks after flowering. Leaving dehydrated flowers on banana tips reduces the fruit quality. Edible bananas are vegetatively parthenocarpic, meaning that they develop a mass of edible pulp without pollination (Robinson and Galán Saúco, 2010). Within a bunch, fruits are curved. Clusters of fruits grow as 'hands'; individual fruits within a hand are called 'fingers'. After the development of 10 hands on a bunch, the lower hands are cut off the bunch, the remaining fruits become larger and there is more uniform development of the fruit within the remaining hands. Plants have the potential to flower and produce fruit on the bunch for 4 months, but farmers only allow plants to flower for 2 weeks.

Two to 3 weeks after flowering bunches can be covered with insecticide-impregnated plastic bags to protect the young fruit from bruising, sun scald, bleaching and from infestation of pests such as thrips and bats (see Section 3.4). The temperature inside bags is 2–3°C higher than ambient which speeds the growth of fruit. Bags are not sealed so they do not entirely prevent fruit from being attacked by pests. Rather than use coloured ribbons, farmers can use colour-coded bags based on the date each bunch is covered (J. Golding, pers. comm., 13/7/20). There is no bagging of fruit in Cabo Verde partly because the temperature inside bags would be too high and the fruit would spoil (D. Horta-Lopes, pers. comm., 24/6/20).

Typically, banana exporters to the EU expect to harvest approximately 40 bunches per ha per week (R. Swennen, pers. comm., 12/10/20). Fruit bunches develop faster during the wet season. There is variation in the rate of forming suckers ('ratoons') between cultivars and between seasons so the time between successive crops also varies.

After harvest, the aerial parts (leaves, pseudostem and fruit stalk) are cut down. Replanting of a production field takes place after 7–10 years because ratoons grow on top of the previous sucker and subsequently the roots including underground stems are gradually exposed. The plant starts to weaken giving smaller bunches with a slower rate of development.



'Underground stem' = rhizome; 'apparent trunk' = pseudostem; 'Sucker' = ratoon.

Figure 2: Banana plant (*Musa*): a) Annotated drawing (Food and Agriculture Organization of the United Nations. Reproduced with permission), b) photograph (Wikimedia Commons)

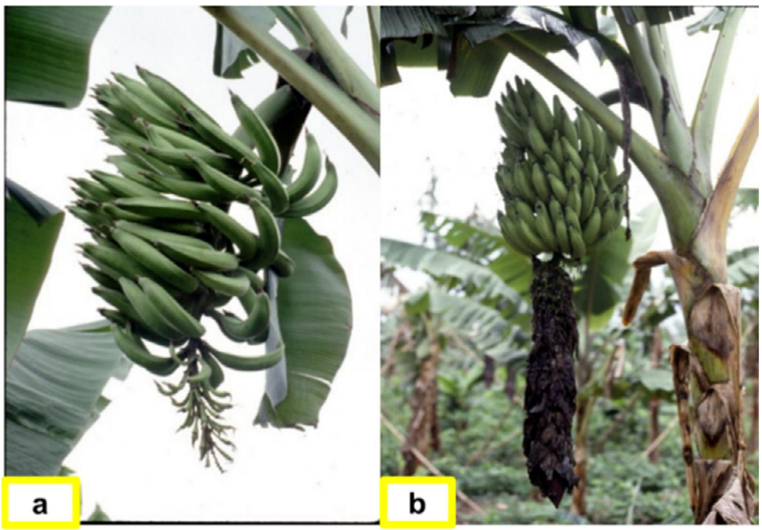


Figure 3: Plantains: a) mature bunch of a False Horn plantain; b) mature bunch of a French plantain (courtesy of Rony Swennen from the Katholieke Universiteit Leuven (Belgium) and IITA, International Institute of Tropical Agriculture (Tanzania))

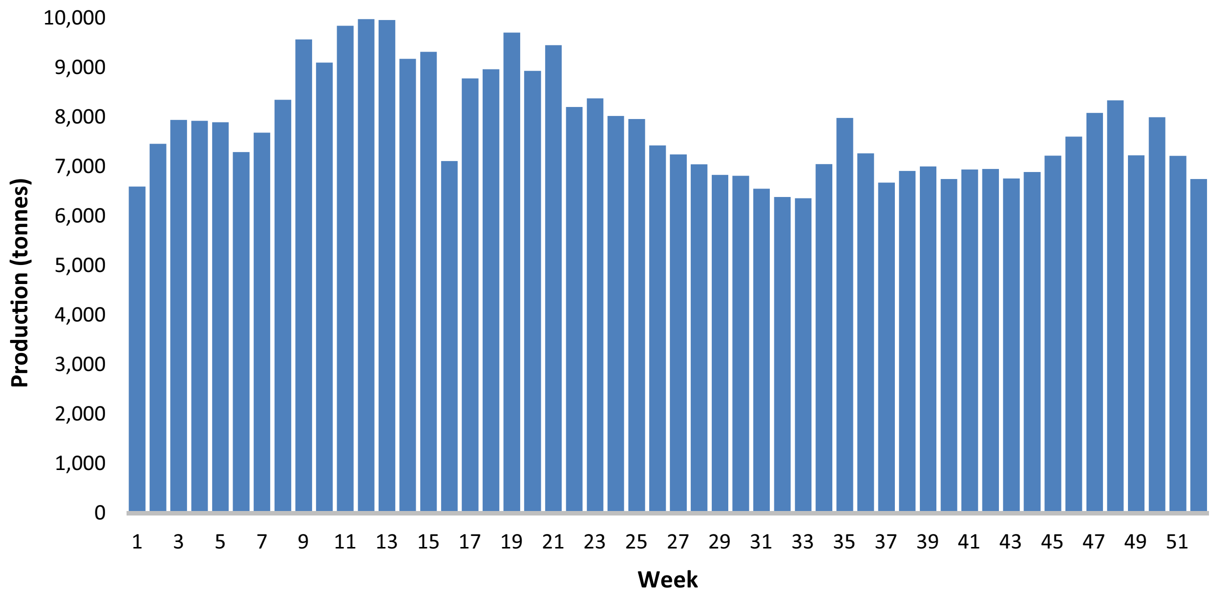


Figure 4: Weekly production of banana in the Canary Islands (2019) indicating production is all year round; peak production is from late February to March (weeks 9–13) (ASPROCAN, 2020)

3.3. Banana and plantain cultivated varieties

As requested in the ToR, this opinion puts particular emphasis on the importation of green Cavendish bananas whilst recognising that other varieties of dessert bananas and plantains are to be considered as well.

Musa has been cultivated for hundreds of years. The centre of diversity for cultivated *Musa* being South-East Asia and the western Pacific (Robinson and Galán Saúco, 2010). Modern edible cultivars are classified into groups according to polyploidy (the number of sets of chromosomes they contain), and the species from which the chromosomes derive. The vast majority of cultivars are derived from crosses between *Musa acuminata*, providing the A genome, and *M. balbisiana*, providing the B genome (Nelson et al., 2006). Simmonds and Shepherd (1955) classified cultivars into groups according to ploidy and the proportion of features they have based on 15 morphological characteristics, each a diagnostic feature to discriminate between *M. acuminata* and *M. balbisiana* (Robinson and Galán Saúco, 2010). Since first published, the Simmonds and Shepherd (1955) classification system has been refined by other authors and Vezina (2019) advocates further revisions.

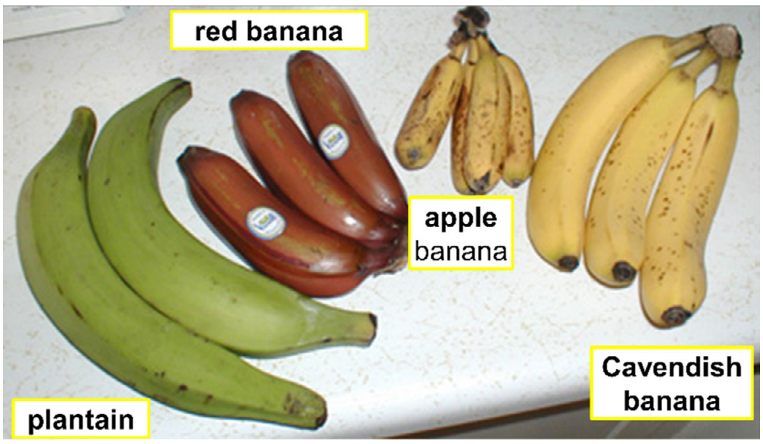


Figure 5: Examples of different types of *Musa* fruit (By User TimothyPilgrim on en.wikipedia - Taken by Timothy Pilgrim., CC BY-SA 3.0)

Due to the long history of hybridisation, banana taxonomists agree that no single scientific name can be given to all edible bananas. Instead, it is accepted by banana taxonomists that banana cultivars should be referred to using the genus *Musa* followed by a code denoting the genome group and ploidy level, followed by the subgroup name (if any) then by the popular name of the cultivar (Robinson and Galán Saúco, 2010). Due to a lack of information from Borneo and Indonesia where there are many undocumented *Musa* varieties, the precise number of *Musa* cultivars in the world is unknown. Approximately 130 have been recognised and Robinson and Galán Saúco (2010) reported that there could be between 200 and 500 with the greatest number in Papua New Guinea, followed by the Philippines, Malaysia and India. For brevity in this opinion, we use the term *Musa* and cultivar name without further details when referring to commercial bananas and plantains. If wild plants of *Musa* are also included, we use *Musa* spp.

Cultivars derived from *M. acuminata* are more likely to be used as dessert bananas, while those derived from *M. balbisiana* and hybrids of the two are usually plantains or cooking bananas (Figure 5). There are also cultivars that have resulted from crosses with *M. schizocarpa*, providing the S genome, and *M. textilis*, the T genome. *M. acuminata* hybridises with any of these three species (B, S or T). Hence, the four species used for banana cultivation have been combined to generate a wide diversity of diploid and triploid cultivars with diverse genetic make-ups such as AA, AB, AS, AT, AAA, AAB, ABB, AAS to AAT. There are few cultivated bananas composed of S and T genomes (Sardos et al., 2016) and tetraploid clones are very rare (Robinson and Galán Saúco, 2010). Within each of the genome groups, cultivars are classified into subgroups which correspond to groups of varieties clonally derived from each other after a single sexual event. The triploid subgroups AAA (which includes the important Cavendish dessert banana) and AAB (African plantains) are especially important for food security in Africa. For example, Karamura et al. (1998) estimated that 30 million people subsisted on *Musa* fruit as the principal source of dietary carbohydrate in Eastern and Southern Africa. Several important diploid cultivars are grown in South-East Asia and the Melanesia region (Sardos et al., 2016).

Through breeding, several different banana varieties are available worldwide, with well-known agronomic characteristics and organoleptic properties such as colour, size, texture, sweetness and flavour. The Cavendish subgroup of varieties (AAA) supply 95% of international trade in bananas, the best-known being 'Grand(e) Nain(e)', 'Williams', 'Valery', 'Robusta', 'Poyo' and 'Dwarf Cavendish'. The name Dwarf Cavendish refers to height of the growing banana plant, not the length of the fruit. Cv. Gros Michel was previously the leading international cultivar, but production has dropped due to its susceptibility to Fusarium wilt disease. AA cv. Pisang Mas, also known as 'Bocadillo' is important in SE Asia and in South America (OECD, 2009). Dwarf Brazilian bananas 'Santa Catarina Prata' (*Musa* AAB subgroup) is a non-Cavendish group cultivar that is marketed from Brazil and Hawaii mainly within USA but also internationally (Wall, 2007).

Figure 6: Harvested Cavendish banana bunch (courtesy of Rony Swennen from the Katholieke Universiteit Leuven (Belgium) and IITA, International Institute of Tropical Agriculture (Tanzania))

As noted, the Cavendish (Figure 6) group of cultivars dominates international trade in bananas; such trade is operated mainly by multinational corporations. Nevertheless, other varieties are traded internationally into niche markets, such as 'Bungulan' (*Musa acuminata*, AAA group), which is grown organically in the Philippines for export to Japan (Esguerra et al., 2017).

Regarding plantains, Tchango Tchango et al. (1999a) described research in Cameroon on 'French Clair', 'Batard' and 'Big Ebanga' for potential export to Europe. High grade plantain 'False Horn' is exported to Europe and North America from Africa (Tchango Tchango et al., 1999b).

ProMusa[1] has created a checklist of banana cultivar names based on available literature. Table 2 provides examples of banana and plantain cultivars in polyploid groups of *Musa* (based on Robinson and Galán Saúco, 2010).

Table 2: *Musa* groups and examples of cultivars with accompanying notes

Group name	Subgroup name	Example cultivar	Comments
Musa AA	Sucrier	'Pisang Mas'	Most important banana cultivar in Malaysia.
	Lakatan	'Lakatan'	Found in the Philippines and Malaysia.
Musa AAA	Gros Michel	'Gros Michel'	Until the late 1950s this was the primary cultivar traded internationally until plantations in Central America succumbed to *Fusarium oxysporum* f. sp. *cubense* race 1.
Musa AAA	Cavendish	'Dwarf Cavendish'	One of the most commonly planted varieties in the Cavendish group
	Cavendish	'Lacatan'	Limited commercial importance; only in Jamaica and West Indies.

[1] http://www.promusa.org/tiki-index.php?page=Banana+cultivar+checklist

Group name	Subgroup name	Example cultivar	Comments
	Cavendish	'Williams'	One of the most commonly planted varieties in the Cavendish group
	Cavendish	'Robusta'	
	Cavendish	'Valery'	
	Cavendish	'Grand Nain'/ 'Grande 'Naine'	One of the most popular varieties in commercial plantations
	Cavendish	'Masak Hijau'	Popular in Southeast Asia and the West Indies.
	Red	'Red'	Widely distributed but not commercially important. Grown in home gardens for domestic consumption.
	Green Red		Widely distributed but not commercially important. Grown in home gardens for domestic consumption.
	East African Highland Banana (EAHB)	'Lujugira'	Used to produce beer and for cooking in East African highlands
Musa AB	–	'Ney Poovan'	Grown in India but not commercially important.
Musa AAB	Plantain	'False Horn'	Plantain imported to EU
	Dessert banana	'Mysore'	70% of banana production in India is Mysore, but little grown elsewhere.
	–	'Thap Maeo'	Recommended by EMBRAPA in Brazil
	–	'Pome'	Common in southern India, of minor importance in Hawaii and Australia where it is known as Lady Finger. Common in Brazil
Musa ABB	–	'Pisang Awak'[(a)]	Most common cultivar in Thailand, eaten fresh or cooked.
Musa BB	–	'Abuhon'	An early maturing cultivar in the Philippines.
Musa BBB	–	'Saba'	Important in the Philippines. Cooked before being eaten.

(a): 'Pisang Awak' was reclassified as AABB by Pillay et al. (2006).

Although yellow cultivars of banana are the most familiar in Europe, elsewhere in the world ripe bananas can be brown, green, purple, red or silver (Figure 5), depending on cultivar (Toma et al., 2018) with pulp (flesh) being either white, cream, yellow, yellow-orange or orange (Nelson et al., 2006). Table 3 provides data regarding production of major *Musa* cultivars by world regions.

Table 3: Distribution of world production of banana and plantains by use and cultivar group (based on Lescot, 2013)

Production region	Percentage of world production				
	Cavendish[(a)]	Highland + others[(b)]	Gros Michel + others[(a)]	Plantain AAB[(b)]	Sum
Asia	27.9394	7.8211	10.0956	1.6119	47.4680
South America	9.2430	0.2957	2.8894	3.8700	16.2982
East Africa	1.5829	12.4373	0.8382	0.9938	15.8522
West and Central Africa	1.7455	0.7683	0.3672	6.5909	9.4719
Central America	5.3328	0.0564	0.0590	0.5717	6.0199
Caribbean	0.9057	0.3050	0.1562	0.7437	2.1106
North Africa and Middle East	1.4680	0.0071	0.0530	–	1.5282
Oceania	0.3442	0.3880	0.1894	0.0009	0.9226
Europe	0.3202	0.0007	0.0008	0.0001	0.3218
North America	0.0058	0.0007	0.0001	–	0.0066
Sum	48.8877	22.0804	14.6489	14.3830	100

(a): Dessert bananas.
(b): Cooking.

3.4. Major arthropod banana pests and in-field management practices

A variety of insect pests infest banana plantations in all tropical regions and especially in Africa, significantly reducing yields and affecting banana production (Gold and Gemmill, 1993; Pinese and Piper, 1994). The major insect pests of banana plantations feed on the rhizome and pseudostem (Gold et al., 2002). The most important of them include the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), the banana pseudostem borer *Odoiporus longicollis* (Olivier) and the silky cane weevil *Metamasius hemipterus sericeus* (Olivier). Larvae of these species feed throughout the rhizome and true stem resulting in plant collapse and destruction of the entire crop (Gold et al., 2002). Larvae of moths such as *Opogona glycyphaga* Meyrick, *O. sacchari* Bojer and *Tirathaba rufivena* (Walker) (Lepidoptera: Tineidae) feed on senescing flowers and decaying plant material (Nelson et al., 2006). Larvae of the scab moth, *Nacoleia octasema* (Meyrick) (Lepidoptera: Crambidae), feed on young banana fruit prohibiting normal development and causing fruit distortion. Other moths that are regarded as pests in localised areas include the Pacific fruit-piercing moth *Eudocima* (Othreis) *fullonia* (Clerck) and the sugarcane bud moth *Decadarchis flavistriata* Walsingham (Nelson et al., 2006). Adult *E. fullonia* feed on ripening fruit causing punctures and premature ripening while larvae of *D. flavistriata* feed on decaying flowers and cause fruit scarring.

Other insect pests that infest banana fruit are thrips such as the banana rust thrips *Chaetanaphothrips signipennis* (Bagnall) and the banana flower thrips *Thrips hawaiiensis* (Morgan) (Thysanoptera: Thripidae) causing fruit spotting, reddish rusty and silver grey discoloration on the fingers, as well as the banana fruit scarring beetle *Colaspis hypochlora* Lefevre (Coleoptera: Chrysomelidae) causing extensive scarring on the fruit peel (Gold et al., 2002). Insect pests of rather limited concern to producers are the banana skipper, *Erionota thrax* (L.) (Lepidoptera: Hesperiidae) and caterpillars (*Caligo* spp., *Opsiphanes* spp. and *Antichloris* spp.) that can cause extensive defoliation. Sucking arthropods such as aphids and mites may stress the plant, affect the photosynthetic capacity and prolong the fruit filling period. Outbreaks of aphids may result in sooty mould development on fruit. In addition, the banana aphid *Pentalonia nigronervosa* Coquerel (Hemiptera: Aphididae) is the vector of a serious viral disease, the banana bunchy top disease (Varma and Capoor, 1958; Magnaye, 1979; Dale, 1987). Mite infestation is usually limited on the leaves, although during colony outbreaks, infestation may appear on bunches and affect fruit development (Pinese and Piper, 1994). Mite infestation is usually more pronounced when other stressors such as drought or weevil damage coexist (Gold et al., 2002).

The susceptibility of cultivated *Musa* to insect pest infestations exhibits high variation among different clones and genome groups (Pavis and Minost, 1992). For example, plantains are more susceptible to banana weevil infestation than other clonal groups, while AB and ABB groups are the most resistant ones to banana weevil (Kiggundu et al., 1999).

Fruit flies (Tephritidae) are generally not regarded as major pests in commercial banana or plantain production. For example, text books and reviews such as Pinese and Piper (1994), Gold et al. (2002), Gowen (2012) and Anonymous (2020) do not refer to Tephritidae as pests of bananas or plantains. Also, the website ProMusa (see Section 2.1) does not report any Tephritidae species within its list of common pests.

Although Tephritidae are generally not regarded as significant pests of economic importance for *Musa*, several fruit flies, e.g. *Ceratitis capitata* (Wiedemann), *Bactrocera musae* (Tryon), *B. dorsalis*, *B. kandiensis* Drew and Hancock and *B. tryoni* can infest ripe *Musa* fruit (Pinese, 1999; Ekanayake et al., 2002; Shimelash et al., 2008; Rutikanga et al., 2015). This is because females of most banana-infesting tephritids oviposit in ripe and overripe fruit well after the fruit has been harvested for commercial purposes. Nonetheless, *B. musae* females are reported to infest unripe fruit of a wild species of banana, *Musa banksii* native to New Guinea and Australia (Vijaysegaran, 1997; Ekesi et al., 2016). However, both Vijaysegaran (1997) and Ekesi et al. (2016) provide no information regarding the exact ripening stage when infestation in the wild species occurs, or whether larval development can be completed. In addition, no information exists regarding whether *B. musae* can oviposit in unripe commercial banana or plantain cultivars, or whether larval development can be completed if eggs are oviposited at stage one of fruit development. In Australia, bananas from Queensland, where both *B. tryoni* and *B. musae* occur, can be transported to other states but only when green stage one, recognising that this phenological stage is not a host for the fruit flies (J. Golding, pers. comm., 13/7/20). Female *B. musae* can oviposit in healthy fruit and deposit eggs in the flesh of the fruit just below the skin (Ekesi et al., 2016). Oviposition attempts in rough areas of the fruit peel, as well as in cracks or in fruit already infested by other insects have also been observed (Heimoana et al., 1997). Oviposition stings of all fruit fly species (see Section 4) are visible on the fruit peel of several hosts resembling black spots which decrease the fruit commercial value. Larvae develop within the fruit pulp, feeding on the tissues and leave the fruit to pupate in the soil. Damage due to larval feeding and development include secondary microbial infestations and rot and may also cause premature ripening and abortion in a wide variety of fruit hosts (Stephenson, 1981; Sallabanks and Courtney, 1992).

General pest management practices of banana cultivation include (a) crop rotation and fallowing, (b) field sanitation/removal of crop residues, (c) use of healthy plant propagules (suckers, ratoons) when replanting new banana stands/fields, (d) paring/removal of the outer part of the rhizome (against weevils), (e) weeding/deleafing/desuckering to reduce shelters and (f) trapping with commercial traps or using crop-residues traps (harvested rhizomes/pseudostems) against weevils and moths.

Biological control methods include the use of endemic and imported natural enemies (predators and parasitoids), entomopathogenic nematodes and fungi, as well as endophytes. Elimination of flowers after fruit formation or insecticide injections into emerging inflorescence are practiced against pests that feed on flowers (thrips, moths). Chemical control using neonicotinoids, pyrethroids, cyclodienes, organophosphates and carbamate insecticides is applied during planting procedures (dipping of suckers) and against several pests throughout the growing season. Also, covering banana bunches with a bag (bagging of bunches) impregnated with insecticides is usually applied against thrips. Bagging also protects the fruit from bats and birds.

Banana harvesting at 'ripening stage one' (hard green bananas) is standard industry practice and ensures that fruit is removed from the field before becoming susceptible to fruit fly infestation (Gold et al., 2002) although the primary reason for harvesting at stage one is to maximise green life (see Section 3.6.1). Other management practices against fruit flies aim at the synchronised development, ripening and harvest of banana bunches. Adequate plantation strategies prevent the asynchronous or mixed ripe bunches that may act as breeding sites of fruit flies. In Papua New Guinea harvesting bananas at early stage is a common practice to avoid infestation from fruit flies (Sar et al., 2001). Also, Malaysia uses the same practice as a quarantine treatment before exporting bananas to Japan (Sar et al., 2001). Usually, no insecticide applications are necessary or practiced against fruit flies.

3.5. Harvesting

The Von Loesecke ripening scale (Von Loesecke, 1950) is used to classify bananas into one of seven classes based on peel colour (Figure 7a). A similar colour scale can also be used to describe the maturity of plantain, e.g. 'Corne 1' (Dongo et al., 2011; Figure 7b). A range of additional examples of the colour scale can be found on the internet (e.g. see Soltani et al., 2011).

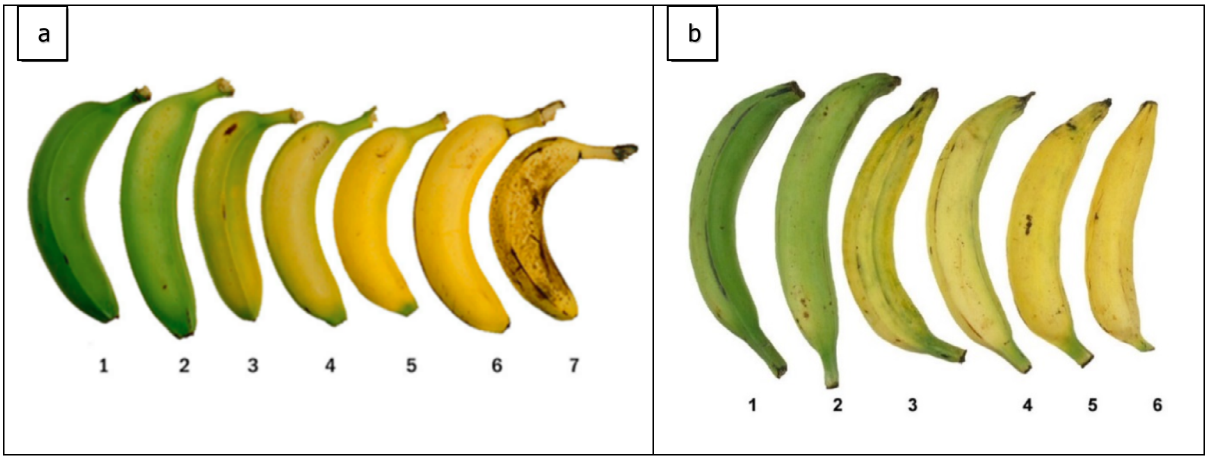


Figure 7: Ripening scales of a) banana and b) plantains. Harvesting for exporting strictly takes place at stage 1 (green), while for local consumption, more advanced ripening stages are considered. Copyright © 2014 Regents of the University of California. Used by permission

3.5.1. Harvesting stage

Bananas need to be harvested at the optimum stage of maturity during fruit growth and development in order to assure the best final quality of the fruit and a sufficient shelf-life for marketing

(Kheng et al., 2012). The date of harvest will depend mostly on the target market and the duration of the required postharvest life. Choosing the optimum harvest date allows producers to minimise the risk of ripening during export and to maximise fruit size (Tixier et al., 2010). The harvest of commercial bananas occurs when the fruit has sufficiently developed but has not begun to ripen (Cordenunsi-Lysenko et al., 2019). Bananas to be marketed locally can be harvested at a more advanced ripening stage than those which are to be exported. Bananas targeted for export are harvested green (stage one) at less than 75% maturity, also called 'three-quarters round', i.e. fruit having ridges but with convex planes between them (Robinson and Galán Saúco, 2010); bananas for local domestic markets are generally still harvested whilst at green stage one, but slightly later, at 90% of full maturity (Hailu et al., 2013; Appendix G). The EFSA PLH Panel distinguishes mature fruit (ready for harvest) from ripe fruit (ready to eat).

Of particular relevance in informing an opinion as to whether the import of bananas or plantains to the EU provides a pathway for Tephritidae, is the well-documented industry practice of harvesting *Musa* fruit for export at the stage one, green mature step of fruit development. The significance of harvesting at this stage will be examined further in Section 4 which reports on studies of Tephritidae oviposition in *Musa* fruit.

3.5.1.1. Colour of fruit peel

Literature reports a range of methods that are, or have been, used to determine when bananas and plantains should be harvested. Fruit maturity has been based on colour for many years and represents an assessment of chlorophyll content of the peel (Acharya et al., 2013). Banana peel contains 50–100 μg/100 g fresh weight chlorophyll which gives green colour, 5–7 μg/100 g fresh weight xanthophyll, which provides yellow colour, and 1.5–3.5 μg/100 g fresh weight carotene, giving an orange colour (Singh et al., 2011). Colour hue of fruit peel is frequently used to assess the physiological maturity of various fruits, including banana. In general, colour is assessed and categorised by human eye but this can be biased. Oliveira et al. (2017) recommended that digital image analysis should be used for the evaluation of the hue of fruit peel when fruit presents non-uniform coloration but there is no evidence that this has become industry practice in relation to banana or plantain harvesting.

3.5.1.2. Weeks since flowering began

A common method of deciding when to harvest bananas is to consider a predetermined number of weeks after anthesis (the start of flowering) (Ahmad et al., 2001). The time between anthesis and harvest varies by cultivar and location. In Ecuador (a major supplier to EU), bananas are typically harvested 12 weeks after flowering during the wet season when warm humid conditions promote fast growth and development; in the dry season, harvesting takes place 14 weeks after flowering (Ambuko et al., 2013). In Malaysia, the banana cv. Rastali is harvested 11 or 12 weeks after first emergence of flower for export to India; fruit harvested in week 12 are sweeter than those harvested in week 11 but have a shorter green life (see Section 3.6.1) (Kheng et al., 2012). In India, cv. Red (Musa AAA group) has an optimal harvest time 15 weeks after first emergence of flowers (Lekshmi et al., 2008). Working with Cavendish cv. Grande Naine, Bonnet et al. (2013) distinguished immature green, early mature green and late mature green corresponding to ~ 40, 60 or 90 days after flowering. Early green bananas are not able to respond to ethylene ripening so harvesting at this time is not appropriate (Mbéguié-A-Mbéguié et al., 2007). If cv. Valery is harvested 95 days after flowering the green life is 28 days at 13.5°C, but harvesting 102 days after flowering can reduce green life by 3 days. Given the time taken for transport to Europe, this reduces shelf-life and marketability, hence harvesting at the right time to maximise green life is commercially very important (Brat et al., 2020).

3.5.1.3. Fruit diameter

An alternative method to 'weeks since flowering began' for harvesting bananas is to measure the diameter of individual fruit, but this is impractical with tall varieties. Nevertheless, the harvest indicator most used in the French West Indies and all commercial plantations in Latin America is fruit diameter, measured at the midpoint of the middle banana in the fourth hand on the bunch. Measuring fruit diameter works well under normal and stable growing conditions. However, when conditions are cooler or drier than normal, or if the plant is stressed (e.g. by disease), fruit that have reached the appropriate harvest diameter may not be in the right physiological state resulting in a shorter green life than expected based on diameter alone (Jullien et al., 2008). Marin et al. (1996) reported that banana harvesting date has been based on either making a direct measure of fruit characteristics, such as the diameter of a finger on a bunch, or more simply the fruit age in number of weeks after flowering for many years. Cavendish bananas (AAA) are required to have a minimum diameter of 32 mm before being suitable for harvest and export, while 'Goldfinger' (AAAB) can be harvested at 36–39 mm (Brat et al., 2020).

Typically, producers will harvest when bananas reach the 'three-quarters full' stage of development. Judging what is 'three-quarters full' is based on the farmer's experience. However, industry practice is generally not to use a more complex procedure such as to measure skin hardness or measure the sugar or starch content of fruit. Nevertheless, growers are very cautious during harvest and avoid harvesting any precociously ripening fruit. Indeed, just a single ripening stage 2 banana can spoil the whole package of transported bananas due to ethylene production (R. Swennen, pers. comm., 11/9/20).

A combination of fruit diameter and the time interval since flowering is still used by many growers to determine when to harvest. Nevertheless, temperature variations during the flowering period can still lead to variable fruit quality.

For export bananas, the ideal physiological age for harvest corresponds to the time when fruit will have a green life of around 25 days, measured at 20°C, which is the maximum recorded duration of banana packing and shipping stages before artificial ripening (Bugaud and Lassoudière, 2005).

3.5.1.4. Temperature accumulation

Physiological age, which can indicate a suitable harvest date, can be determined based on temperature accumulation, or thermal sum, above a threshold and is measured in degree days. To ensure a green life of not less than 25 days at 98% RH, the recommended thermal sum for Cavendish bananas is 900 degree days (DD) above a threshold of 14°C after flowering (Ganry and Chillet, 2008; Umber et al., 2011). In Guadeloupe 'Grande Naine' is harvested 90 days after flowering, corresponding to approximately 900 DD above a threshold of 14°C (Mbéguié-A-Mbéguié et al., 2007). Working in Martinique on the non-Cavendish cv. Figue Rose Naine (Musa AAA group) a pink banana, for export to Europe, Tixier et al. (2010) calculated the optimum harvest time was 548 DD above a threshold of 19.8°C which gave a green life of 25 days. Bananas harvested at 900 DD (threshold 14°C) reach a marketable diameter and have a green life of approximately 30 days at 20°C (Jullien et al., 2008). Umber et al. (2011) showed a strong linear relationship between thermal sum and the number of days between flowering and harvest above specific thresholds for two cultivars (F916 and F918) grown in Martinique and being developed for potential export markets. The authors also showed a strong linear relationship between green life and thermal sum. For cv. F916, a green life of 25 days was achieved by accumulating 680 DD above a threshold of 17°C. For F918, a green life of 25 days was reached at 970 DD above a threshold of 13.9°C. If being sold locally, banana can be harvested later because the green life need not be so long (Castelan et al., 2012).

Setting harvest date to optimise green life based on thermal sum is more accurate than when estimating it only on the basis of fruit diameter (Turner and Rippon, 1973; Jullien et al., 2008) or of the fruit age in number of weeks (Ahmad et al., 2001). However, in practice harvest date is still largely determined by measuring the diameter of fruit and the thermal sum is only used as a limit not to be exceeded to avoid the likelihood that the fruit will ripen during sea transport, thus bunches are harvested earlier than 900 DD if the diameter of fruit reaches the required value.

3.5.1.5. Plantains

Regarding plantains, harvesting date and maturity of fruit will depend on the target market. Plantains for export are harvested earlier than those bound for local markets. As is the case of dessert bananas, peel colour strongly determines when plantains are harvested, although time interval since flowering and the swell and shape of fingers is also taken into account (Tchango Tchango et al., 1999b). For export to Europe by ship from Cameroon, Tchango Tchango et al. (1999a) recommended harvesting plantain cv. Bâtard 68–75 days, cv. Big Ebanga 71–78 days, and cv. French Clair 79 days after flower emergence, but all still at stage one (green mature). If the fruits are harvested when too mature, they can split during handling, especially if they have recently been irrigated or exposed to rain (Hailu et al., 2013).

3.5.2. Harvesting technique

Bananas and plantains are harvested by hand in bunches. Two people are required to harvest each bunch. One person partially cuts the pseudostem half way up to allow the bunch to lower onto the shoulder of a second person who is below the bunch and who receives the bunch onto a cushioned pad on their shoulder (Figure 8b), such an approach is designed to protect the bunch from mechanical or pressure damage (OECD, 2009). Fruit bunches are handled very carefully to avoid mechanical damage because damage such as crushing causes the fruit to produce and release ethylene which triggers the ripening process (Chillet and de Bellaire, 2002). Bunches are transported to the 'packing shed' on padded trailers or on an overhead cable system. Protective plastic sheets (formas) are placed between hands to prevent hands rubbing against each other during transport to the packing shed. Like bananas, plantains for export are harvested, handled and transported carefully to avoid mechanical damage and to preserve the quality of the fruit (Tchango Tchango et al., 1999a,b). Figure 8 illustrates the steps followed in banana production, packing and trading.

Figure 8: (a-k). Banana production: a) plantation of Cavendish banana; b) harvest; c) production site with banana bunches waiting to be packed; d) removal of bananas from the stem (dehanding); e and f) washing bananas in water; g) labelling; h) quality control; i) packing; j) loading for transport; k) ripening room at destination. (Pictures a,c,d,e,f,g,h,i courtesy of Rony Swennen (Katholieke Universiteit Leuven (Belgium) and IITA, International Institute of Tropical Agriculture (Tanzania)), picture b) a courtesy of John Golding (NSW Department of Primary Industries, Australia), pictures j and k – Source: Food and Agriculture Organization of the United Nations. Reproduced with permission

3.6. Post-harvest processes

Export bananas are subjected to a series of post-harvest processes that start at the packing house, with cleaning, sorting and grading of the hands, and finish when stimulated to ripen at destination just prior to retail. The whole process can be divided in two periods. The first period is from harvest until bananas reach the destination country and covers the 'green life' (see below). During this period, controlled conditions should ensure that bananas do not mature beyond the mature green stage. Upon arrival at destination markets, the second period includes fruit exposure to controlled conditions leading to fruit maturation and transport to retail stores.

3.6.1. Green life

It is commercially desirable for fruit of *Musa* cultivars to have a prolonged green life enabling them to be transported and stored before the fruit begins to ripen. The green life can be prolonged by (i) good preharvest management, (ii) harvesting at the early stage of fruit maturity and (iii) transporting at low temperature in a controlled atmosphere. To avoid premature ripening during shipment any delay between harvesting and loading the fruit into the refrigerated space should be avoided. The cooling process must also be as rapid as possible (preferably within 24 h after harvesting) (Cargo Handbook, 2020).

During the green life period, the respiration rate and ethylene production by fruit is almost undetectable (Brat et al., 2020). Li and Huang (1988) reported 0.20 nL g^{-1} h^{-1} of ethylene was detected in green harvested banana during the pre-climacteric period and this level remained nearly constant up to the onset of ripening.

3.6.2. De-handing

After harvest bunches are carefully transported to a packhouse where they are de-handed (FAO, 2018a). The process of de-handing consists of the separation of hands and removal of the stalk of the banana. This is done with a de-handing knife that is curved to fit the crown of the banana or plantain (Figure 8d).

3.6.3. Washing

Washing banana hands and clusters in chlorine-water solution to clean the fruit and staunch the latex exudate after they are cut from the bunch was a standard industry practice in the 20th Century (Armstrong, 1983). Nowadays, FAO (2018a) report that hands are washed in clean water (Figure 8e, f) to remove dirt from the surface of the banana and latex from the cut surface of the crown. If latex is abundant, it may be necessary to wash bananas in two tanks – washing in the first tank to remove dirt, followed by delatexing in a solution containing 1 percent alum (Figure 8e).

Kader (2020) reports that hot water treatments, such as 5 min in 50°C water, and/or fungicide treatment to control crown rot may be applied to bananas as a post-harvest control method against pathogenic fungi which would spoil the fruit.

3.6.4. Picking and sorting

At this stage, grading staff must reject i) any single host fruit, or any hand or cluster which contains a fruit whose flesh is not hard or is flexible, or which is not green or shows any yellow coloration other than sun bleaching, and ii) any host fruit with preharvest cracks, splits, punctures or other breaks of the skin which penetrate through to the flesh.

The reason of removing these fruits is that such bananas would release ethylene which would trigger the ripening of other (undamaged) bananas, a phenomenon that should be avoided during transport (see below). High quality export green bananas are sorted to eliminate all defects. Aberrant or damaged bananas showing insect scars, decay, ant burns, sunburn, cracks/splits, fused fingers, point scars and precocious ripening are referred as 'culled' bananas or 'faults' and are discarded at the packing houses (Armstrong, 2001). Precocious ripening is a physiological abnormality characterised by the advanced ripening of one or more fingers on a hand or a bunch of green bananas, when still attached to the plant (before harvest) (Nelson et al., 2006; Robinson and Galán Saúco, 2010). It is observed more often in some banana cultivars, such as 'Brazilian', than others (Armstrong, 2001). Picking and sorting of fruit that do not meet export quality standards is crucial because damaged fruit would increase respiration and ethylene production, leading to rapid deterioration of fruit quality (FAO, 2018a).

3.6.5. Post-harvest losses

At the farm level, post-harvest losses in banana result from small fruits (unsuitable for marketing), sun burn, harvesting injury and cracks and cankers. At wholesale markets, losses result from physiological dryness, physical damage and pressed and crushed fruits and over ripening; losses at the retail level result from physically damaged fruit and over ripened fruit (Nayak et al., 2018).

3.7. Transport of fresh fruit of *Musa* to EU

Banana and plantains for export are boxed and transported from packing houses to a harbour in temperature-controlled trucks. Enclosing banana or plantain in sealed polyethylene bags in boxes (Figure 8i) reduces water loss, lowers O_2 and increases CO_2 concentration, extending the green life by reducing the rate of respiration and inhibiting ethylene synthesis (Mangaraj and Goswami, 2009). At the harbour, boxes delivered by trucks are consolidated into pallets that are loaded directly inside a refrigerated/temperature-controlled cargo ship for bulk transport.

Alternatively, boxes at the packing house can be loaded directly into temperature-controlled containers, known as 'reefers' (short for refrigerated containers), for transport via road to the harbour where they are directly loaded for transport onto a container ship (Arduino and Parola, 2010).

Harvesting takes place in the morning and by early afternoon, the harvest is boxed and in transit (R. Swennen, pers. comm., 11/9/20).

Good bulk packaging is essential in maintaining the quality of bananas during transport and subsequent handling. The basic functions of bulk packaging are to provide adequate protection to the bananas, to contain convenient quantities of bananas, and to facilitate their transportation, handling and distribution. Rigid plastic stackable containers are highly recommended for the bulk packaging of bananas since they provide adequate protection against compression damage (FAO, 2018a).

During long distance transport, bananas must be kept in the pre-climacteric state, so that ripening can later be induced artificially in the 'ripening rooms' (See Section 3.8). Therefore, packed bananas and plantains are shipped to the EU in conditions of controlled atmosphere; a system where the fruit is stored in a sealed and temperature-controlled managed environment with lower oxygen and higher carbon dioxide concentrations compared to normal air (e.g. low oxygen concentrations of 2.5% O_2) and high relative humidity (90–95%; J. Golding, pers. comm., 13/7/20). The low temperature (13–14°C; Bugaud et al., 2006) and oxygen concentration slow metabolism lowering the respiration rate and blocking the production of ethylene. This in turn slows the metabolism of banana peel de-greening and the conversion of starch to sugar. Therefore, this is a very efficient method to extend the shelf-life of harvested bananas (Ahmad et al., 2006; Zhang et al., 2010), which should remain at stage one until reaching the ripening rooms in the EU. If cooling is interrupted during transport and temperature rises, bananas will begin to metabolise faster and may begin the process of ripening such that on arrival in the EU the consignment arrives in a poor quality. Jedermann et al. (2015) report that this occurs to a 'low percentage of containers'. Should this happen, the detection at the port of entry of one single yellow banana in a single box in a single container could mean that the whole container is rejected (R. Swennen, pers. comm, 11/9/20). As an additional insurance to avoid early ripening should temperatures rise in containers, bananas can be packed with sachets of potassium permanganate ($KMnO_4$) which would absorb ethylene and delay ripening (de Souza Prill et al., 2012).

Transport to the EU from the Caribbean usually takes between 10 and 15 days (Bugaud et al., 2007) but can take up to 18–19 days (Bugaud et al., 2006). Bananas from the Canary Islands reach EU mainland (mostly Spain) in just 3 days (R. Swennen, pers. comm., 11/8/20). This allows Canarian farmers to wait longer to harvest, until round – not pentagon shaped but still ripening stage 1 (R. Swennen, pers. comm. 11/9/20).

Five multinational companies dominate the international trade in bananas (Chiquita, Delmonte, Dole, Fyffes and Naboa, the Ecuadorian international banana company) largely exporting to the EU from Ecuador and Colombia. The companies are each vertically integrated, meaning that they control small and independent growers as well as owning large plantations for production in South America, the Caribbean Islands and other banana-producing regions. They also own or rent specialised refrigerated cargo container ships for exporting their bananas (Dodo, 2014). Vertical integration is partly driven by the need to synchronise production and transport when there is continuous production and flow of produce. Vertical integration also allows an operator to control the quality of service in the transport of perishable products (Casson, 1986). Similarly, in the Canary Islands ASPROCAN (Asociación de Organizaciones de Productores de Plátanos de Canarias), which integrates all banana farmers in the archipelago, takes care of transport. In the Caribbean and parts of Ecuador, there is some export production from small independent growers (Arduino and Parola, 2010).

3.7.1. Storage and ripening of fresh *Musa*

Upon arrival at the port of destination in the EU, stage one green bananas are stored in modified atmospheric rooms. Bananas can be kept at +13.2°C for up to approximately 28 days in regular packs and up to 40 days in 'Banavac' packaging. This consists of polyethylene bags 0.4 mm thick, in which the CO_2 content is raised to 5% and the O_2 content is reduced to 2% ('modified atmosphere'). This slowing respiration and extends green life; ethylene produced by the fruit is absorbed by adding potassium permanganate, as used during transport (De Souza Prill et al., 2012).

Just prior to marketing bananas are treated with ethylene (Ahmad et al., 2006) to trigger ripening. Once ripening begins, it is an irreversible process leading banana peel to change colour from green to yellow, with brown spots appearing at the end of ripening (Diezma et al., 2016). According to Kader (2020), most commercial cultivars of bananas require exposure to 100–150 ppm of ethylene for 24–48 h at 15–20°C and 90–95% relative humidity to induce uniform ripening. CO_2 concentration should be kept below 1% to avoid its effect on delaying ethylene action. Use of a forced-air system in ripening rooms assures more uniform cooling or warming of bananas and more uniform ethylene concentration throughout the ripening room. In the EU, palletised banana boxes are mostly ripened in pressurised ripening rooms (Figure 8k). This process, called 'the ripening cycle', takes 4–7 days, with a ripening cycle of 5 days being the most common cycle (Madrid, 2011). Fruit colour changes during ripening. Chlorophyll (which provides green colour) degrades allowing carotenoids (which provide yellow colour) to become more visible. A change in luminosity of banana peel takes place simultaneously, with luminosity increasing as colour changes from green to yellow (stages 2–5). Then luminosity decreases as peel darkens e.g. at stage 7 (Borges et al., 2019). During peel colour change, the pulp becomes softer and sweeter as the ratio of the sugar to starch increases (Toma et al., 2018). The pulp to peel ratio, total soluble extract and total acid and peel dry matter content increase considerably, while pulp firmness, pH and pulp dry matter content decrease. These changes, which may differ between genotypes or *Musa* subgroups (Ngoh Newilah et al., 2010), contribute to the appearance, desirable sweetness and eating quality of the ripened banana (Adao and Glória, 2005; Ngoh Newilah et al., 2010; Cordenunsi-Lysenko et al., 2019). Similar changes take place during ripening of plantain (Agoreyo et al., 2003).

In some cultivars such as cv. 925 (a non-Cavendish type), the peel of mature and ripened banana fruit can split 3–6 days after ripening if stored in saturated humid conditions. Such peel splitting is a major physiological disorder affecting post-harvest banana quality. Cavendish cultivars (e.g. 'Grande Naine') are not susceptible to this type of splitting (Brat et al., 2016).[2] Splits in ripened banana would allow fruit flies to easily access the pulp in which to oviposit. However, because such splitting occurs after ripening at destination markets, this physiological disorder does not facilitate the entry of non-EU Tephritidae into the EU.

3.8. EU imports of bananas and plantains

Bananas are grown in tropical and subtropical countries. Details of world production and of exports from producers are provided in Appendix C for banana and Appendix D for plantain and cooking bananas. Global exports of bananas, excluding plantain, reached a new record high of an estimated 21 million tonnes in 2019, an increase of 10.2 percent compared with 2018 (FAO, 2020).

Between 2012 and 2019 the EU imported bananas from over 50 countries (Appendix E) although three countries Ecuador, Colombia and Costa Rica usually provide more than 70% of bananas imported annually by the EU (Figure 9).

Between 2012 and 2019, the EU imported plantains from over 40 countries (Appendix F). Two countries dominate the provision of plantains to the EU, Ecuador and Colombia, which provide more than 90% of imported plantains. Together with Ecuador and Colombia, Guatemala, Uganda and the Dominican Republic make up the top five suppliers of plantains to the EU (Figure 10).

[2] Splitting of the banana peel after ripening can sometimes occur in Cavendish type bananas. But this only occurs post-harvest, transport and ripening. It does not happen in the field. If it does the fruit would not be harvested or packed. Post-harvest splitting can occur with Cavendish types at certain times of the year, but this is long after harvest when the fruit had been ripened in the EU. Therefore, no chance of fruit fly infestation (J. Golding, pers. comm., 4/1/2021).

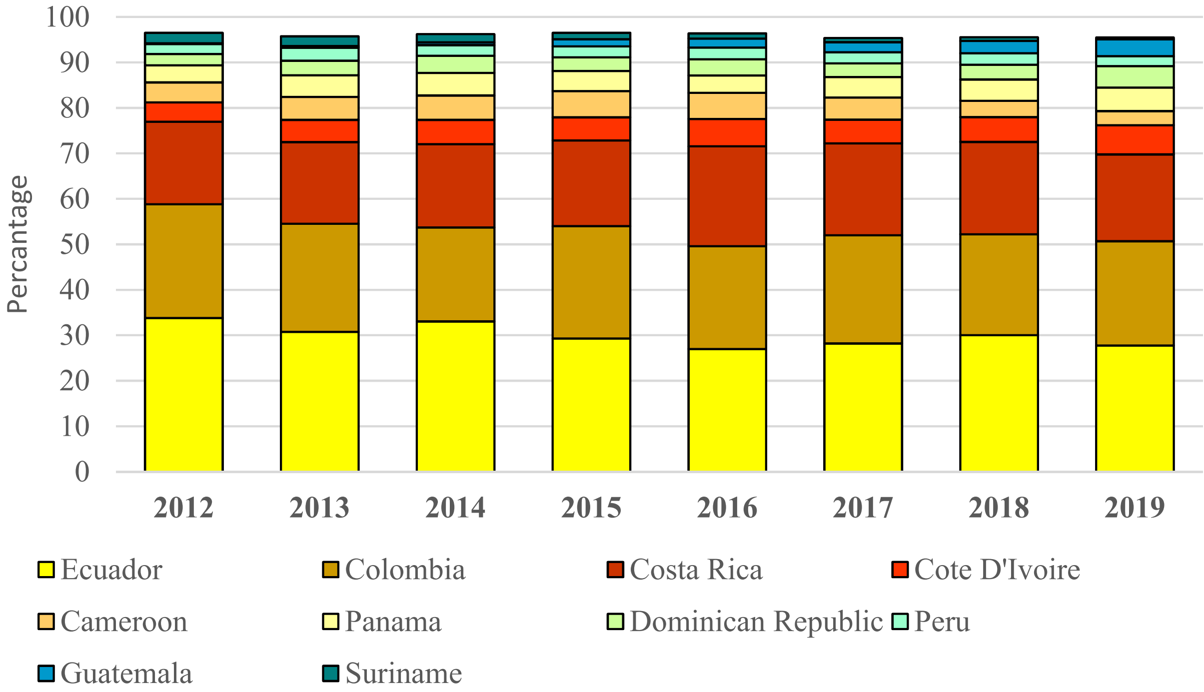


Figure 9: Percentage of EU 27 imports of dessert banana (CN 0803 9010) from top 10 third country producers 2012–1019 (Source: Eurostat)

Non-EU Tephritidae which can infest ripening bananas do not occur in Ecuador, Colombia or Costa Rica, the three main suppliers of banana to the EU (see Section 4).

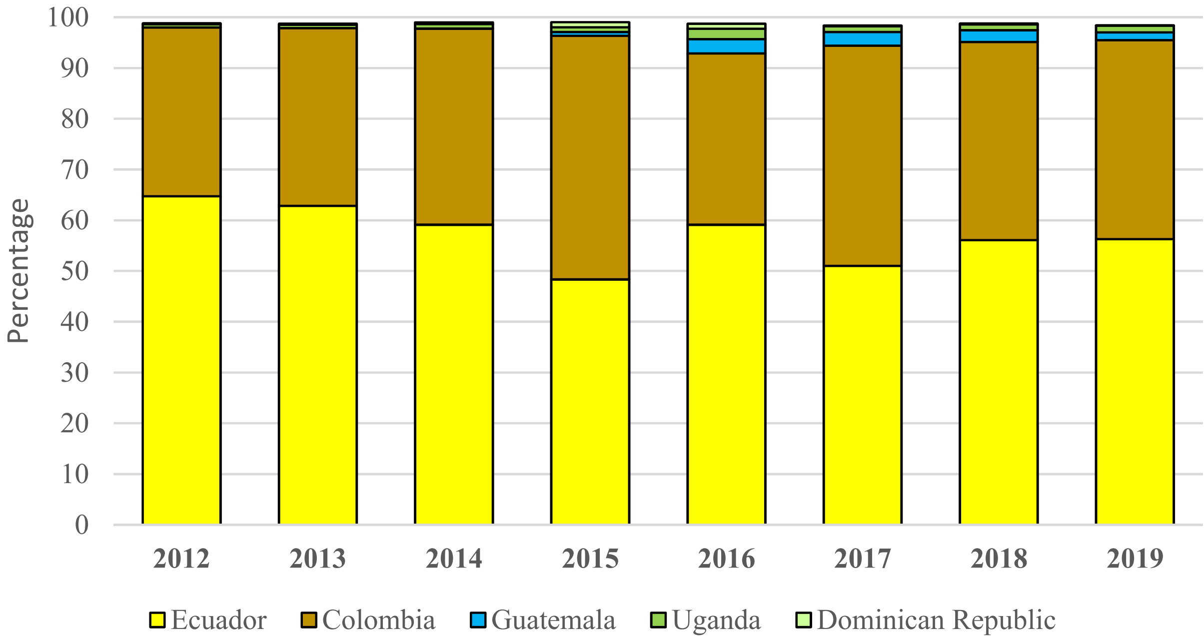


Figure 10: Percentage of EU 27 imports of fresh plantain (CN 0803 1010) from top five-third country producers 2012–1019 (Source: Eurostat)

4. Tephritidae

4.1. Identification of pest species and host relations

The Tephritidae (true fruit flies) is the most species-rich family of Diptera, with more than 5,000 described species, 500 genera, six subfamilies (Tachiniscinae, Blepharoneurinae, Phytalmyiinae, Trypetinae, Dacinae and Tephritinae) and many undescribed species distributed worldwide (Uchôa, 2012; EFSA PLH Panel, 2020). Several species of the major genera *Anastrepha*, *Bactrocera*, *Ceratitis*, *Dacus*, *Rhagoletis* and *Zeugodacus* are notorious pests of high economic importance for a wide variety of fruit and culinary vegetables. Nevertheless, only a limited number of species within the genus *Bactrocera* and *Ceratitis* can infest ripe banana or plantains (see Section 4.2).

Fruit maturity and ripeness level play a significant role on the host or non-host status for many polyphagous Tephritidae. As such, fruits become hosts only when they reach a particular stage of development. For example, when Cavendish bananas are green (stage one) they are not a suitable host for *C. capitata* (Mediterranean fruit fly) (Umeya and Yamamoto, 1971; Anonymous, 1996). *C. capitata* is a quarantine pest of major concern to the USA (Collier and Manoukis, 2017) yet green bananas have been imported into the United States for many decades from regions in Central and South America where *C. capitata* occurs. Japan does not consider green bananas a host for either *C. capitata* or *B. dorsalis* and allows importation of bananas from Central and South America, where *C. capitata* is wide spread, as well as Southeast Asia and Hawaii, where both species of Tephritidae occur, with the restriction that all fruit arriving must be green with no appearance of ripening (Anonymous, 1996).

When Tephritidae are recorded from an unusual host fruit, i.e. from the fruit of plants on which they are not commonly recorded, it is usually because of abnormal premature ripening as a result of physical damage to the fruit (Hancock et al., 2000). A well-documented example is that of *Dirioxa pornia* (Walker), which occurs in Eastern Australia, New Zealand and some Pacific islands, and it is often retrieved from decaying fruits. *D. pornia* females oviposit and larvae can conclude development in a wide range of ripe, overripe and fallen or damaged fruit (Hancock et al., 1998; Hancock, 2015; Baker and Crisp, 2016). ISPM 37 (FAO, 2018b) recognises that host status of a fruit may change over time because of changes in conditions and that it is important to record the stage of fruit maturity when assessing the host status of fruit to fruit flies.

4.2. Non-EU Tephritidae known as pests of ripening *Musa*

The 12 non-EU Tephritidae species that are reported to infest ripening *Musa* spp., at phenological stage 82 and beyond (Appendix G) (corresponding to stages beyond green mature stage one of the Von Loesecke ripening scale) and their geographic distributions are given in Table 4. Most of them (11 species) belong to the genus *Bactrocera* (Diptera: Tephritidae: Dacinae), which includes major pests of fruits mostly found in the tropics and subtropics of Asia, the Pacific and Oceania (Hancock et al., 2000; Plant-Health-Australia, 2016). Also, a non-EU Tephritid that has been found to infest ripe banana, is the marula fruit fly, *Ceratitis cosyra* (Walker) (Diptera: Tephritidae: Dacinae).

- *Bactrocera dorsalis* (Hendel), the oriental fruit fly, is highly polyphagous and the most widespread fruit fly, which from the ancestral territories of South East Asia has invaded and is currently present in South East Asia, most of Sub-Sahara Africa, and in tropical islands of the Pacific Ocean, including French Polynesia and Hawaii (White and Elson-Harris, 1992, EPPO, online). The international spread of *B. dorsalis* in several tropical countries has caused impediments to fruit production due to the additional management practices that are now required and the quarantine restrictions on fruit trading. Fruits of mango, cashew, tropical almond and banana are among its preferred hosts (Rwomushana et al., 2008; Goergen et al., 2011; Cugala et al., 2014).
- *Bactrocera musae* (Tryon), the banana fruit fly, is a pest of ripe bananas grown in north Queensland (Australia) the Torres Strait, Papua New Guinea and nearby islands. *B. musae* is primarily a pest of cultivated bananas and plantains and of the native/wild banana, *Musa banksii*, (Vijaysegaran, 1997; Hancock et al., 2000). Whether *B. musae* oviposits in commercial bananas and/or is able to complete development during the mature green ripening stage one is not known (Tenakanai, 1997; Vagalo et al., 1997). No more recent information regarding infestation of ripening stage one bananas by *B. musae* has been found. Considering the

importance of banana as a trade commodity, this lack of records can be interpreted as an inability to oviposit during green stage one.

- *Bactrocera tryoni* (Froggatt), the Queensland fruit fly, is also a pest of bananas grown in north Queensland (Australia) the Torres Strait, Papua New Guinea and nearby islands. It has an extensive host range and females oviposit in ripe or ripening banana fruit (Gold et al., 2002).
- *Bactrocera frauenfeldi* (Schiner), the mango fruit fly, is a major pest in Papua New Guinea, mostly infesting native tropical fruits and nuts (Drew and Romig, 1997; Plant-Health-Australia, 2016). Banana is recorded as a rare/secondary host species of *B. frauenfeldi,* which however cannot be infested during mature green ripening stage one (Hancock et al., 2000; Plant-Health-Australia, 2016).
- *Bactrocera jarvisi* (Tryon) is capable of infesting ripening bananas (Drew and Romig 1997). Geographic distribution available in Table 4.
- *Bactrocera bryoniae* (Tryon) is a major pest for plants of the family Cucurbitaceae and Passifloraceae. It can also infest bananas at advanced ripening stage (past harvesting and trading ripening stage) (Hancock et al., 2000). Geographic distribution available in Table 4.
- *Bactrocera kraussi* (Hardy) is a polyphagous fruit fly mostly infesting plants of the families Rutaceae, Rosaceae, Myrtaceae and Musaceae, although no records exist regarding infestation of banana fruit during the mature green stage one (Hancock et al., 2000). Geographic distribution available in Table 4.
- *Bactrocera neohumeralis* (Hardy) is an extremely polyphagous species (Appendix J) with banana included in its host range, although no information exists regarding its potential to complete development in mature green (stage one) bananas (Hancock et al., 2000). Geographic distribution available in Table 4.
- *Ceratitis cosyra* (Walker), the marula fruit fly, has a limited range of host plants that include banana (DeMeyer, 1998). It is the major fruit fly pest of mangoes in Kenya (Malio, 1979), Zambia (Javaid, 1986), Zimbabwe (Rendell et al., 1995) and some areas of South Africa (Labuschagne et al., 1996). Conversely, in Côte d'Ivoire it has been recorded as a major pest of guava (N'Guetta, 1994). Cugala et al. (2014) have sampled field infested bananas ('Dwarf Cavendish') by *C. cosyra*, during 2010–2011 in Kenya. Infestation levels were very low (2, 7, 9 and 12 adults emerged from four samples of 649–881 bananas) and adults were recovered from ripe, precociously ripe and cracked/split bananas. However, *C. cosyra* is not included in the catalogues of banana infesting fruit flies of Africa (De Meyer et al., 2002) and has not been recorded to infest banana during an extensive fruit sampling in Kenya during 2006 (Copeland et al., 2006) (Figure 11).

Table 4: Distribution of non-EU Tephritidae species that can infest ripening *Musa* fruits

#	Species	Distribution
1	*Bactrocera dorsalis* (Hendel) Oriental fruit fly	Throughout most of sub-Saharan Africa, across the Indian subcontinent to China, throughout the South-east Asian Indo/Malay Archipelago as far east as New Guinea, the islands of the South Pacific and Hawaii, Philippines and Palau, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mauritania, Mayotte, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Sierra Leone, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe, USA (Hawaii), Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Christmas Is., East Timor, India, Indonesia (Irian Jaya, Java, Kalimantan, Nusa Tenggara, Sulawesi, Sumatra), Laos, Malaysia, Myanmar, Nepal, Oman, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, United Arab Emirates, Vietnam, French Polynesia, Nauru, Northern Mariana Is. Palau, Papua New Guinea

#	Species	Distribution
2	*Bactrocera musae* (Tryon) Banana fruit fly	Papua New Guinea, Australia (Queensland, Torres Strait Islands), Bismarck Archipelagos, Solomon Islands
3	*Bactrocera frauenfeldi* (Schiner) Mango fruit fly	Australia (Queensland), Federal States of Micronesia, Indonesia (West Papua), Kiribati, Marshall Islands, Nauru, Northern Mariana Islands, Palau, Papua New Guinea, Solomon Islands
4	*Bactrocera tryoni* (Froggatt) Queensland fruit fly	Australia (Queensland to Victoria, Eastern New South Wales, Northern Territory), New Guinea, French Polynesia, New Caledonia, Austral and Society Is.
5	*Bactrocera facialis* (Coquillett)	Tonga
6	*Bactrocera kandiensis* Drew and Hancock	Sri Lanka
7	*Bactrocera bryoniae* (Tryon)	Papua New Guinea, Australia (Western Australia, Northern Territory, Queensland) and Bismarck Archipelagos
8	*Bactrocera neohumeralis* (Hardy) Lesser Queensland fruit fly	Papua New Guinea, Australia (Qld., NSW) New Caledonia
9	*Bactrocera kraussi* (Hardy) Krauss's fruit fly	Australia (Torres Strait islands, northeast Queensland as far as Townsville)
10	*Bactrocera jarvisi* (Tryon) Jarvis' fruit fly	Northern Australia from Broome, Western Australia to eastern Arnhem Land, Northern Territory and northwest Queensland, Torres Strait islands and eastern Australia from Cape York to the Sydney district, New South Wales
11	*Bactrocera kirki* (Froggatt)	South Pacific: Austral Islands, Niue, American and Western Samoa, Tahiti, Tonga, Fiji, French Polynesia, Wallis and Futuna Islands
12	*Ceratitis cosyra* (Walker)	Present in all sub-Saharan African countries in which suitable hosts are grown: Tanzania, South Africa, Madagascar, Congo (DR), Ivory Coast, Guinea, Kenya, Malawi, Mali, Mozambique, Nigeria, Senegal, Sierra Leone, Togo, Zimbabwe, Zambia, Gabon, Burundi, Central African Republic, Benin, Ethiopia, Namibia, Sudan, Cameroon, Ghana, Burkina Faso, Uganda, Botswana, Angola

4.3. Uncertainty of banana as a host for fruit flies

Besides the 12 fruit fly species listed in Table 4, there are other genera and species of Tephritidae that have been reported as pests of banana within the literature, although upon closer investigation such literature is erroneous and may result from misidentification of species or from a misinterpretation of primary literature. For example, *Ceratitis rosa* Karsch, and *C. quilicii* De Meyer et al., 2015 have been reported to infest ripe Cavendish varieties of banana and the uncultivated *Musa nana* (Copeland et al., 2006; Cugala et al., 2014; De Meyer et al., 2002). However, *C. rosa* is a pest of the banana passion fruit (*Passiflora tarminiana*) and this may have caused a misidentification of banana as a host (Duyck et al., 2008). Also, Copeland et al. (2006) reported banana as a host of *C. rosa* in the introductory part of their paper but no infestation was recorded in bananas when fruit was sampled in Kenya. Cugala et al. (2014) also reported banana as a host for *C. quilicii.* However, no other records exist regarding banana infestation by these species and the same authors did not include *Musa* as a host of this pest when they later reported a case study in Uganda (Rwomushana and Tanga, 2016).

Zeugodacus cucurbitae (Coquillett) (melon fly) has been reported to infest Cavendish banana 'Chinese' and 'Blue Field' banana (Ekesi et al., 2016). *Z. cucurbitae* can be reared and is able to infest non-cucurbit hosts such as Solanaceae, but very low infestation rates/incidents have been reported. A thorough fruit sampling of various potential hosts including banana in Tanzania and a review of the literature regarding its geographic distribution and host range in Africa, resulted in the characterisation of *Musa* as a non-host for *Z. cucurbitae* (Mwatawala et al., 2010; De Meyer et al., 2015).

In conclusion, a detailed bibliographic investigation led to the characterisation of bananas and plantains as non-hosts of *C. rosa*, *C. quilicii* and *Z. cucurbitae* (Harris et al., 1986; Copeland et al., 2006; Duyck et al., 2008; Mwatawala et al., 2010; Ali et al., 2013; Fadlelmula and Mohammed Ali, 2014).

4.4. Polyphagous Tephritidae that occur in countries which are major suppliers of *Musa* to the EU

As noted in Section 3.8 above, the vast majority of imported bananas to EU are produced in countries of the Central and South America such as Ecuador, Colombia, Costa Rica and Panama, as well as in African countries such as Cote d'Ivoire, Cameroon, Ghana and Angola. Some quantities are also imported from Asia, particularly from the Philippines and India (Table 5, based on details in Appendix H). Non-EU Tephritidae which are reported to infest ripening bananas (Table 5) are not known to occur in Ecuador, Colombia or Costa Rica, which are the three major banana exporters to the EU. Tephritid fruit flies that are native in Central and South American countries, where more than 88% of EU imported bananas are produced, mostly belong to the genus *Anastrepha*. Although *Anastrepha* spp. includes polyphagous species with major economic importance, such as *A. ludens* (Loew), *A. striata* Schiner, *A. obliqua* (Macquart) and *A. fraterculus* (Wiedemann), no infestation of *Musa* by these fruit flies has ever been recorded (P. Liedo pers. comm. 28 July 2020, and our thorough literature review). Native Tephritidae in African and Asian countries exporting banana to the EU include, among others, *B. dorsalis* (Oriental fruit fly), *B. frauenfeldi* (the mango fruit fly) and *C. cosyra* (the marula fruit fly) which are reported as pests of banana but all of them are only able to infest ripe fruit, well beyond ripening stage one (Rwomushana et al., 2008; Goergen et al., 2011). Quantities of banana imports from Africa reached approximately 11% of total imports during 2012–2019 and from Asia 0.008% for the same period (Table 5).

Table 5: Major banana-exporting countries to EU and percentage of share in total EU banana imports. The number of Tephritidae species that are native to each country and the species that can infest *Musa* are shown

Banana exporter	Mean percentage of imports in EU (2012–2019) ± SE[(1)]	Number of native Tephritidae fruit flies	Pests of ripe *Musa*
Ecuador	29.978 ± 0.87	97	
Colombia	23.214 ± 0.50	128	
Costa Rica	19.354 ± 0.49	115	
Côte D'Ivoire	5.325 ± 0.23	55	*B. dorsalis* *C. cosyra*
Cameroon	4.735 ± 0.35	122	*B. dorsalis* *B. frauenfeldi* *C. cosyra*
Panama	4.509 ± 0.18	107	
Dominican Republic	3.380 ± 0.23	13	
Peru	2.439 ± 0.08	211	
Guatemala	1.662 ± 0.44	70	
Suriname	1.362 ± 0.24	9	
Mexico	1.096 ± 0.17	259	
Ghana	0.823 ± 0.08	63	*B. dorsalis* *C. cosyra*
Belize	0.781 ± 0.03	16	
Nicaragua	0.670 ± 0.25	16	
Brazil	0.399 ± 0.11	288	
Honduras	0.217 ± 0.04	13	
Angola	0.023 ± 0.01	43	*B. dorsalis* *C. cosyra*
Turkey	0.012 ± 0.00	120	
Philippines	0.007 ± 0.00	176	*B. dorsalis*
USA (Hawaii)*	0.004 ± 0.00	287	*B. dorsalis*
Albania	0.003 ± 0.00	31	

Banana exporter	Mean percentage of imports in EU (2012–2019) ± SE(1)	Number of native Tephritidae fruit flies	Pests of ripe *Musa*
Uganda	0.002 ± 0.00	183	*B. dorsalis* *C. cosyra*
Madagascar	0.001 ± 0.00	74	*B. dorsalis* *C. cosyra*
India	0.001 ± 0.00	301	*B. dorsalis*

(1): Mean percentages of all major banana exporters sum 99.995%.

*: *Bactrocera dorsalis* is only present in Hawaii, the largest Cavendish producer in US for local consumption. Florida follows Hawaii in production levels (Thai and cooking-Bluggoe bananas) and is the major production state in the USA (Evans and Ballen, 2012).

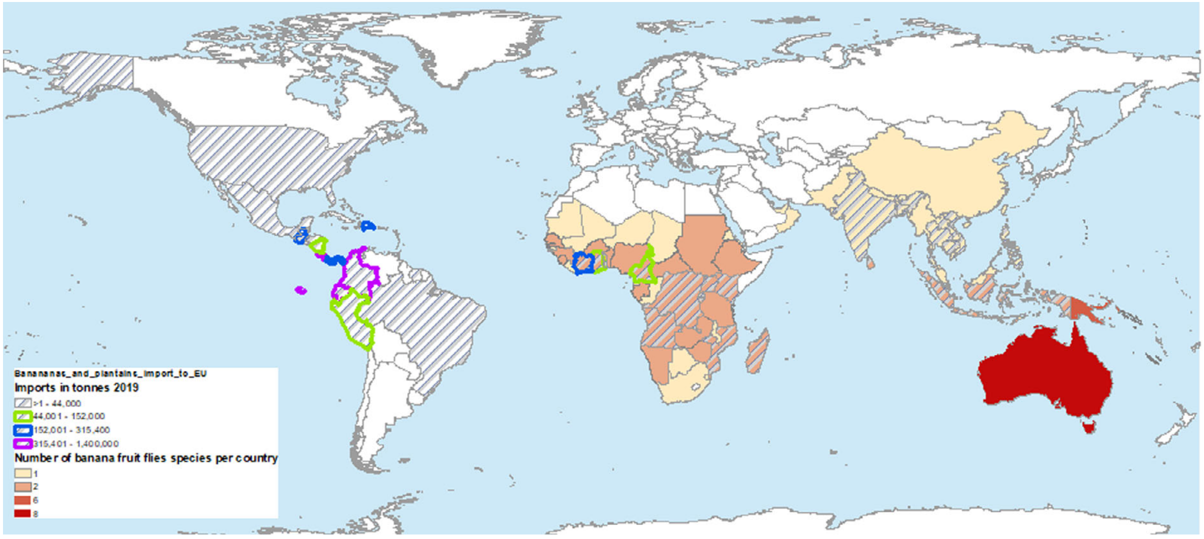


Figure 11: Distribution of non-EU Tephritidae utilising *Musa* spp. as a host. Solid colours (cream to red) indicate 1–12 species; white = 0. Grey diagonal lines indicate countries exporting bananas and/or plantains to EU. The lime green, blue and violet borders of countries indicate magnitude of *Musa* exports. Tephritidae occurrence based on Table 4 in 4.2; Import data from Appendices F and G

Figure 11 gives the number of tephritid species that can infest *Musa* spp. in countries around the world. Such species occur in Africa, Asia and Oceania. In contrast the vast majority of EU imports of banana and plantains come from South and Central America where there are no Tephritidae that infest fruit of *Musa.* Of note, the highest diversity of Tephritidae that infest bananas or plantains is in SE Asia and Australia, the same region where *Musa* spp. originate. Of potential significance is the presence of non-EU Tephritidae fruit flies (*B. dorsalis, B. frauenfeldi, C. cosyra*) in Côte d' Ivoire (marked with blue border), Ghana and Cameroon (each marked with a lime green border) that provided approximately 10% of bananas imported into the EU in 2019.

4.5. Population densities of Tephritidae fruit flies in banana plantations – fruit sampling in the field and in cull dumps

Wild populations of *C. capitata,* and other tephritids appear to be abundant in banana plantations as indicated by extensive adult trapping in Hawaii (Back and Pemberton, 1916). Also, *B. dorsalis* and *Z. cucurbitae* were trapped both in banana plantations and in 'cull dumps' in Puna District and Oahu, Hawaii (Armstrong, 2001).

The first report of infestation by Tephritidae fruit flies on healthy bananas was in 1907 by French, who successfully obtained adult fruit flies from naturally infested green bananas in Queensland, Australia. However, his findings were later questioned by Severin and Hartung (1912) and by Back and Pemberton (1916) who only managed to rear *C. capitata* from ripe bananas. Other reported field infestations of *Musa* from *C. capitata* refer to the 'Popoulou and 'Moa' cultivars of plantains, sampled at a backyard in Hawaii, where they were traditionally grown only for local consumption (Back and Pemberton, 1916). Both varieties are characterised by short, thick fruit with relatively thin skin. Infestation occurred when fruit was fully ripe and yellow (cv. Popoulou) or the peel was cracked and the pulp exposed (cv. Moa). Oviposition punctures on the peel of cv. 'Moa' were mostly empty and when eggs were deposited within the peel no larvae emerged (Back and Pemberton, 1916).

Despite the presence of gravid *C. capitata* females in the field, precocious ripe and other 'culled' bananas (> 5,500 fruit), which were picked and discarded in Hawaiian packing sheds, before exported to mainland US, did not yield any adults (Back and Pemberton, 1916). *B. dorsalis* adults emerged from culled bananas of the 'Brazilian dwarf', 'Valery', 'Williams' and 'Brazilian' cultivars, collected in cull dumps of Oahu, Kaneohe and Waimanalo, Hawaii, which were punctured or cracked leaving the flesh/pulp exposed (Armstrong, 1983, 2001). No infestation from *C. capitata* or *Z. cucurbitae* was recorded in culled bananas of any kind (cut, split, precocious ripe etc.), while infestation from *B. dorsalis* was only reported when the damage of the fruit left the pulp exposed (Armstrong, 2001).

Extensive sampling of healthy bananas in Hawaiian plantations, belonging to different ripening stages and of several cultivars ('Valery', 'William's', 'ice-cream', 'Manila hemp' *M. textilis* and 'Borabora' or 'Polapola' *M. fehi*) resulted in zero records of infestation by fruit flies (Back and Pemberton, 1916; Armstrong, 1983). Extensive fruit sampling of several fruit hosts, including ripe bananas of unknown varieties, in a wide geographic region of Kenya, showed banana infestation from *B. dorsalis* (Rwomushana et al., 2008). Later, Cugala et al. (2014) performed extensive sampling of Cavendish dwarf bananas of different ripening stages in Kenya and recorded infestation from *B. dorsalis* when sampled bananas were past ripening stage one (Figure 12a). The number of emerging adults of *B. dorsalis* increased as the ripening stage of bananas proceeded (Figure 12b).

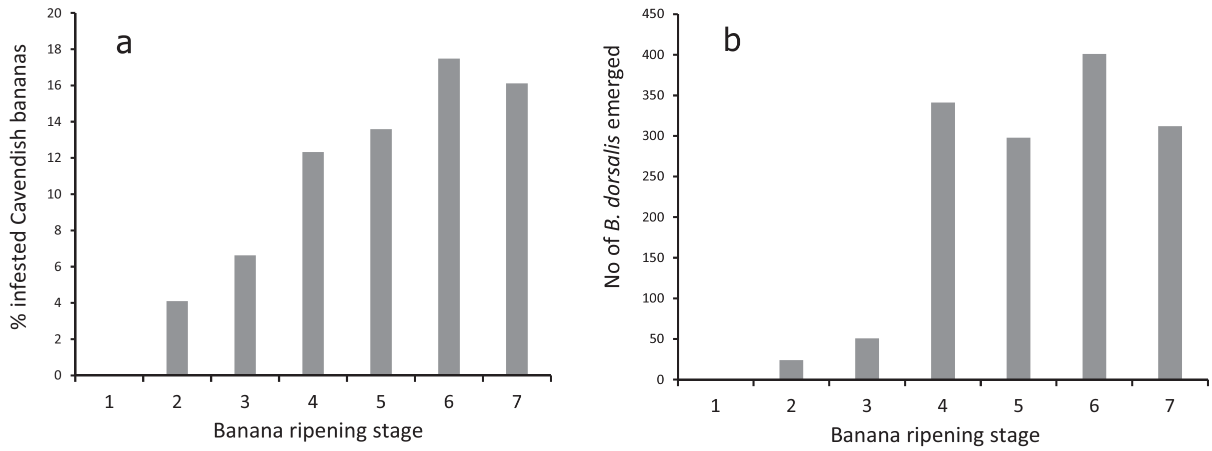


Figure 12: a) Percentage of field infested bananas (Cavendish dwarf cultivar) from *Bactrocera dorsalis* for different ripening stages. b) Adults of *Bactrocera dorsalis* emerging from field infested bananas (Cavendish dwarf cultivar) of different ripening stages. Bananas were sampled in commercial plantations and gardens of Kenya during 2010–2011 (Cugala et al., 2014 modified)

4.6. Peel hardness and fruit flies

Field infestation tests indicated that mature green bananas were not susceptible to *C. capitata* infestation for up to 1 week past the scheduled harvest date when attached to the plant or within 24 h after harvest (Severin and Hartung, 1912; Back and Pemberton, 1916).

Although *A. ludens* has been reported to oviposit larger egg clutches in hard fruits in laboratory trials (Díaz-Fleischer and Aluja, 2003), generally fruit firmness is considered as inversely proportional to fruit fly oviposition. Indeed, in avocado infestation rate increased with decreasing fruit firmness. Also, skin puncture resistance was an important deterrent to oviposition, as fruit with a patch of skin removed produced more flies than intact fruit (Follett, 2009). In this study, avocado fruit was observed to be potentially infested within 1 day after harvest, suggesting that fruit should be transferred to fruit fly-proof containers as they are harvested to minimise the risk of attack. Although risk of infestation is negatively correlated with fruit firmness, even some hard fruit may become infested. Therefore, fruit firmness cannot be used alone as an indicator to ensure fruit fly-free 'Sharwil' avocados. Measuring fruit firmness may be a useful component of a multiple component systems approach as an additional safeguard to reduce risk of infestation (Follett, 2009).

4.7. Semi-field and field trials

Several semi-field and field trials have been conducted since the early 1900s to assess the host status of banana for Tephritidae fruit flies (Severin and Hartung, 1912; Back and Pemberton, 1916; Armstrong, 1983, 2001; Cugala et al., 2014). From 1911 to 1912, Severin and Hartung performed semi-field trials in Hawaii and managed to obtain a few *C. capitata* adults from ripe Cavendish bananas cv. Chinese. During their trials, entire green banana bunches were exposed to a wild population of *C. capitata* in a citrus orchard, for 8 days. Within this period, the ripening of bananas on the bunch was advancing and wild females were able to infest the fruit. Low infestation levels were also recorded when semi-ripe and overripe bananas were likewise hung on lemon trees and exposed to wild *C. capitata* females (Severin and Hartung, 1912). Armstrong (2001) tested the natural infestation rates of cv. Brazilian dwarf (green and ripe bananas) from *C. capitata* and *B. dorsalis*, by hanging banana bunches for 24 h in coffee plantations in Hawaii. Although adult trapping indicated large numbers of adult tephritids being present in the coffee plantation, no infestation was recorded by either of the two tephritids in mature green stage one bananas. A small number of progeny was recovered though from ripe banana bunches (Armstrong, 2001).

A few years later (1913–1914) than the field experiments by Severin and Hartung (1912), extensive field trials in Hawaii were performed by Back and Pemberton (1916) emphasising on ripening stage one, mature green bananas that were attached to the plant. First, using large field cages, 20 'Chinese' banana plants bearing 14 bunches and approximately 1,000 fruits were exposed to female *C. capitata* for 3 months, and no infestation was recorded, regardless of the ripening stage of the fruit (Back and Pemberton, 1916). In more confined conditions, entire banana bunches (ripening stage one) were again exposed to female *C. capitata* for 48 h and were then inspected for oviposition punctures. Only 5.93% of the fruit showed oviposition attempts (punctures) and only two of them were deep enough to sustain eggs. One of the two punctures had a single egg which did not hatch. All the punctures were subsequently sealed by sap exudations. The same scientific group performed infestation tests, using *C. capitata*, on mature green banana bunches of Hawaiian commercial orchards, which were stamped by the inspectors and granted for harvest and shipment to San Francisco, US (Back and Pemberton, 1916). Selected bunches were caged with gravid females for 10 days after reaching mature green stage. Every 2 days bananas were cut and inspected for oviposition punctures, deposited eggs and larval development. Oviposition punctures were recorded in a small percentage of bananas and eggs were deposited in very few of these oviposition attempts. Some of the eggs hatched but no larvae survived regardless of the ripening stage of the fruit (Table 6) (Back and Pemberton, 1916).

Table 6: Data from field experiments performed by Back and Pemberton (1916) in commercial banana plantations of Hawaii. Bananas at ripening stage one, while remaining on the tree, were caged with gravid *Ceratitis capitata* females for a period of 8 days

Days after ripening stage one	Bananas exposed to females	Bananas with punctures	Total oviposition punctures	Number of punctures bearing eggs	Number of total eggs deposited	Number of eggs hatched	Number of alive larvae
0–2	505	9	14	1	5	5	0
2–4	238	42	159	3	Several	Several	0
4–6	202	46	126	2	Several	3	0
6–8	200	15	26	0	0	0	0

Similar infestation tests were performed much later, in 'Valery', 'Williams' 'Brazilian' and 'Brazilian dwarf' banana plantations of Hawaii to determine whether *C. capitata* or *B. dorsalis* would oviposit into green bananas of a bunch still attached or hung to the plant (Armstrong, 1983, 2001). During these trials, entire banana bunches were exposed for 24 h or 48h to 500, 1,000 or 2,000 gravid females corresponding to marginal high population densities in the field and extreme artificial infestation pressures. Although a high amount of oviposition punctures was recorded from both tephritids in tested bananas, no *C. capitata* or *B. dorsalis* were recovered when detached bunches were exposed at harvest date, or one week after harvest date to 500 gravid females. Severe infestation pressure of 1,000 gravid female *C. capitata* or *B. dorsalis* lead to the recovery of a low amount of *C. capitata* progeny and to zero infestation from *B. dorsalis*, which demonstrated the non-host status of 'Brazilian dwarf' cultivar for the two tephritids (Armstrong, 2001). Also, attached to the plant bunches of 'Valery', 'Williams' and 'Brazilian' cultivars which were exposed to 2,000 gravid females of *C. capitata* and *B. dorsalis* for 48 h had empty oviposition punctures (Armstrong, 1983). Fewer and empty oviposition punctures had been previously recorded by Umeya and Yamamoto (1971) in cvs. Gros Michel and Valery still attached on the plant. Darkening and hardening of the peel around oviposition punctures which probably led to egg encapsulation was observed in both green and semiripe/ripe bananas (Armstrong, 1983).

In a more recent study performed in Kenya and Mozambique, *B. dorsalis* gravid females (100, 500 and 1,000 individuals) were enclosed for 24 h with whole 'Dwarf Cavendish' banana plants, carrying a bunch with 80–100 fingers during different ripening stages (1, 2 and 6) or with a mature (stage 6) bunch bearing precociously ripe fingers. The number of oviposition stings recorded on the fruit increased with increasing female densities within the field cage on both ripening stage one fruit and on precociously ripe bananas (Figure 13). Mature and precociously ripe bananas had more oviposition stings than mature green ones (ripening stage 1) (Figure 13a). Regardless of the amount of oviposition stings, no adult emergence was observed from ripening stage one bananas. The number of emerging adults from precociously ripe bananas increased with high oviposition pressure inside the field cage (Figure 13b). In the same study, exposure of whole banana plants during ripening stages 1, 2 and 6 to 500 gravid *B. dorsalis* females for 24 h in Mozambique, resulted in more than 300 oviposition stings per bunch regardless of the ripening stage of the banana bunch (Figure 14a). However, no adults emerged from bananas infested at ripening stages 1 and 2 and less than 10 adults per bunch emerged when infested bananas were at mature yellow ripening stage 6 (Figure 14b) (Cugala et al., 2014).

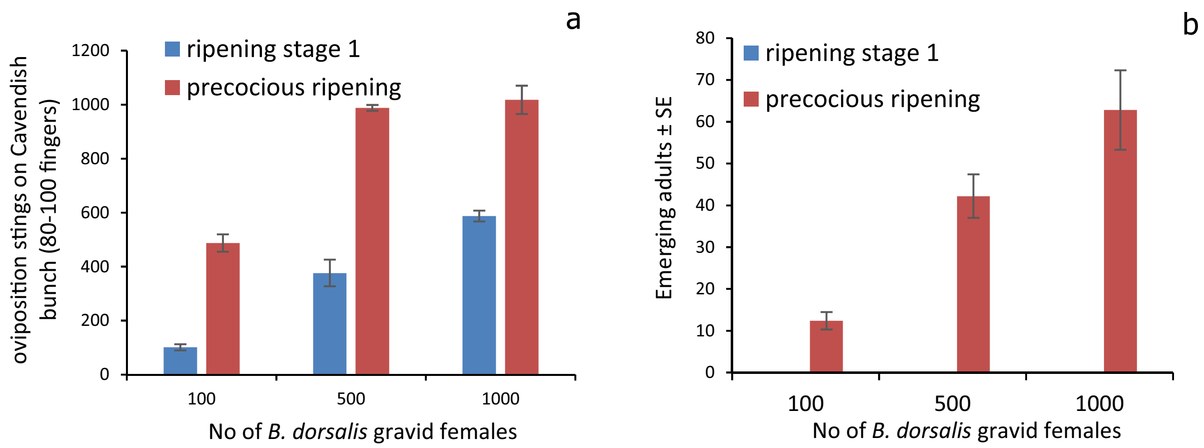


Figure 13: Number of oviposition stings a) and emerging adults b) on Cavendish dwarf banana bunches during artificial infestation with *Bactrocera dorsalis* in field cages. Different infestation pressures were tested by caging banana plants with 100, 500 or 1,000 gravid females. Bunches during ripening stage one (blue bars) and mature bunches (red bars) with precociously ripe fruit were tested. Experiments were performed in Kenya during 2010–2011 (Cugala et al., 2014)

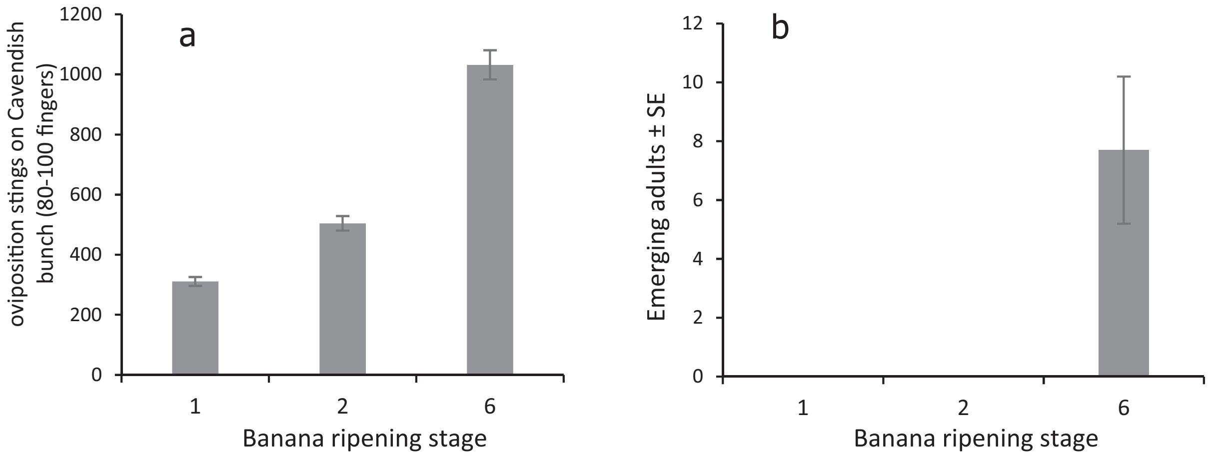


Figure 14: Number of oviposition stings a) and emerging adults b) from Cavendish dwarf banana bunches that were artificially infested from *Bactrocera dorsalis* in field cages. Banana plants during ripening stage one, 2 and 6 were caged with 500 gravid females. Experiments were performed in Mozambique during 2010–2011 (Cugala et al., 2014)

Last, Back and Pemberton (1916) tested the viability of artificially implanted eggs from *C. capitata* in the peel of bananas (ripening stage one) still attached to the trees, as well as the larval development. Almost 41.5% of the total amount of eggs implanted hatched and first instar larvae were alive and active 2 days post eclosion. However, 9 days after egg implanting, all larvae were dead without having reached the pulp of the fruit. During these trials, extensive sap flow was noted when the incisions on the fruit were made, which prevented artificial implanting of eggs in the peel. Later, Umeya and Yamamoto (1971) performed tests in Costa Rica and similarly showed that *C. capitata* and *B. dorsalis* larvae could not survive development in ripening stage one of 'Gros Michel' and 'Valery' banana cultivars.

Based on the study by Severin and Hartung (1912) and regardless of the fact that the two authors were unable to draw safe conclusions regarding banana infestation in natural field conditions, imports of 'Gros Michel' and 'Valery' banana cultivars were permitted from Hawaii in Japan without quarantine treatment for *C. capitata*.

4.8. Laboratory trials

Severin and Hartung (1912) managed to rear *C. capitata* only in ripe cv. Chinese and 'Brazilian' banana cultivars during laboratory trials. Rearing of *C. capitata* was unsuccessful when females were urged to oviposit in green bananas. In that case, eggs were deposited on the surface of banana peel indicating inability to drill with their ovipositor the hard skin of green bananas. Eggs laid on the surface of bananas are susceptible to dehydration and either not hatch, or if larval hatching occurs, first instar larvae are unable to burrow into the fruit and survive. Back and Pemberton (1916) recorded a 40% infestation of the same cultivars when green bananas were offered to female medflies for 48 h, one day after harvest. Nevertheless, no adults emerged. Armstrong (2001) recorded the oviposition punctures and eggs deposited by *C. capitata* and *B. dorsalis* in green 'Brazilian dwarf' bananas, exposed immediately after harvest, as well as 1, 2 and 3 days after harvest to 5, 15 or 25 gravid females per banana/finger. Both tephritid species were able to penetrate the peel and oviposit in green cv. Brazilian dwarf bananas. *C. capitata* produced more oviposition punctures and oviposited more eggs than *B. dorsalis* adjusting for time after harvest. Increased infestation pressure resulted in more oviposition punctures but the host suitability of 'Brazilian dwarf' bananas did not increase over time after harvest for the two tephritid species. A low percentage of adults were recovered from *C. capita*-infested fruit but no adult *B. dorsalis* were recovered (Armstrong, 2001). A few years before, Armstrong (1983) had shown that healthy mature green Cavendish bananas (cvs. Brazilian, Valery and Williams) could not be naturally or artificially infested from *C. capitata*, *B. cucurbitae* or *B. dorsalis*.

Artificial implanting of eggs in different parts of green 'Chinese' bananas (peel, pulp, flower scar) led to only 0.44% of adult emergence, and these adults developed from eggs deposited directly in the pulp of the fruit (Severin and Hartung, 1912). In the same study, 69% of artificially implanted eggs in the peel of green 'Chinese' bananas were able to hatch but all larvae died almost instantly, probably due to high concentration of tannins. A similar observation was made when first instar larvae were implanted in the pulp of green bananas by removing the flower scar. Moreover, when 20 third instar larvae were individually implanted, 50% managed to pupate, 10% left the fruit to pupate but died and 40% pupated inside the bananas. Adversely, 42% of artificially implanted eggs in ripe bananas gave adults (Severin and Hartung, 1912), while only 1.1% of bananas (past-ripening-stage-1) that were offered to female medflies for 1 day gave adults (Back and Pemberton, 1916).

More recent laboratory trials testing infestation rates of banana from *B. dorsalis* resulted in high percentages of pupation and adult emergence during choice and no-choice tests (Rwomushana et al., 2008). However, bananas used in these experiments were of fully ripe yellow stage. In conclusion, laboratory trials indicated that rearing *C. capitata* and *B. dorsalis* in green bananas was unsuccessful.

4.8.1. Oviposition and egg hatch in fruit of *Musa*

Oviposition attempts of females on unripe bananas are usually unsuccessful due to several reasons. First, females find it challenging to overcome mechanical difficulties and penetrate the hard peel of the fruit with their ovipositor. Second, even when the female succeeds to rapture the epidermis of the fruit, sap exuding from the oviposition puncture forces her away from her position before depositing the eggs (Back and Pemberton, 1916). This probably explains the increased number of oviposition punctures that contain no eggs when infestation attempts are performed on fruit attached to the tree. In the case that bananas are harvested and then offered to female Tephritids for oviposition, less empty oviposition punctures are observed, as most of the sap is drained or altered due to ripening process forming a more suitable environment for the eggs.

4.8.2. Immature survival and development in fruit of *Musa* and adult emergence

Egg and larval survival are greatly affected by the chemical composition of the fruit. Green bananas are rich in tannins and their concentration decreases as the fruit ripens and becomes edible. When ripening stage one bananas are harvested (12–16 days prior normal ripening in the field in Hawaiian climatic conditions), the peel is surcharged with sap laden with tannins that flows as soon as a scratch or an oviposition puncture occurs. A high percentage of eggs and hatched larvae are killed due to the toxic effects of tannins, especially when they are deposited in the peel (Back and Pemberton, 1916). Indeed, only seven adults emerged per bunch from more than a thousand oviposition stings per bunch from *B. dorsalis* on ripe bananas attached on the plant, (Cugala et al., 2014). In the case that bananas are harvested and then offered to female Tephritids for oviposition, larval survival is higher, and more individuals manage to reach the adult stage. The chemical composition and sap levels of bananas at ripening stage one, are quickly altered due to the ripening procedure that accelerates after harvest (Back and Pemberton, 1916).

Among the management strategies applied for the control of tephritid pests in fruit production industry, non-host stage of maturity and early harvesting have been practiced empirically for many decades as alternative approaches to quarantine treatment. Non-host fruits for a given pest are defined as those that cannot be attacked or infested at any stage of growth or maturity (Armstrong and Jang, 1997). Nevertheless, several fruits that are vulnerable to infestation by tephritids when fully ripe, may have a non-host stage of maturity (Armstrong and Jang, 1997; Aluja and Mangan, 2008). Certain fruits such as papaya, sapodilla and banana seem to possess a non-host maturity stage (Harvest index 2 for papaya, ripening stage one for banana), and harvesting during this non-host stage may secure the acquisition of healthy fruit that do not need any quarantine treatment to reach the market (Vijaysegaran, 1997). In practice, papaya var. Eksotica is free of fruit fly infestation when harvested at ripening stage 2 and Malaysian producers have been following this practice since 1988 for harvesting and exporting papaya to US (Vijaysegaran, 1997). Similarly, since 1996, Japan does not consider green bananas a host for either *C. capitata* or *B. dorsalis* and allows imports from Central and South America, Southeast Asia (including Malaysia), and Hawaii without demanding postharvest quarantine treatment given that all fruits arriving are at ripening stage one with no appearance of any further ripening (Vijaysegaran, 1997; Armstrong, 2001).

Collaborative research between Kenya and Mozambique showed that mature green 'Cavendish dwarf' bananas are not hosts of *B. dorsalis*, although ripe, yellow fruits were (Cugala et al., 2014). On this basis, a prohibition of banana exports from Mozambique to South Africa was removed (Dohino et al., 2017).

4.8.3. Artificial rearing of Tephritidae fruit flies using banana

Artificial substrates for Tephritidae fruit flies used in mass rearing facilities as well as in small-scale rearing laboratories of academic departments are mainly based on the use of protein hydrolysate adult diets to promote egg production and on low cost, nutritious larval diets (Walker et al., 1997). Alternative laboratory rearing techniques for small-scale operations and for newly introduced wild populations include the pulp of available fruits such as pawpaw, breadfruit and banana. Ripe and overripe bananas are commonly used either as entire fruits or as ingredients in diets, for the artificial rearing of several fruit flies such as *Anastrepha* spp., *B. tryoni, Bactrocera psidii* (Froggatt), *B. curvipennis* (Froggatt) and *C. capitata*, regardless of whether they are considered pests of banana (Walker et al., 1997). In other words, some of these species can be reared in the laboratory using ripe and overripe bananas although in the wild they do not infest unripe banana fruit.

5. Passenger baggage

The movement of people and the plant material they carry with them whilst travelling provides opportunities for non-native plant pests to spread internationally. For instance, airline passengers can inadvertently carry plant pests on their clothes and baggage (Sheridan, 1989) and travellers can be considered as providing potential pathways for infested fruit (EC DG SANTE 2018, section 4.3 Fruit and vegetables). The transport of infested fruits is considered the most probable way for *B. dorsalis* and *Bactrocera zonata* (Saunders) dispersion to uninfested areas (EPPO, 2005, 2010).

McCullough et al. (2006) analysing 725,000 interceptions of pests of quarantine significance (2,340 species in total), over 17 years (1984–2000), at US ports of entry and border crossings revealed that 62% were in baggage carried by travellers, 30% were associated with cargo and 7% concerned plant propagating material. Most of the interceptions were at airports (73%), followed by the Mexico–US border crossing (13%) and marine ports (9%). Of the interceptions in baggage, 50% were with fruit, 29% with 'plant parts', this includes ornamental plants and some propagating material, 11% with seeds, 6% with cut flowers and 4% with other categories, including bulbs, soil and wooden items. Of relevance to this opinion, fruit was the most common commodity associated with insect and mite interceptions on baggage and almost half of all pests intercepted in baggage came from confiscated fruit.

Border inspections in New Zealand in the late 1990s showed that 0.6% of all passengers carried nursery stock (defined as propagating material other than seeds) in their baggage, whilst 1.9% of all passengers carried plant seeds, either deliberately or as a contaminant in their luggage (Williams et al., 2000). Between 2005 and 2007, the USA Department of Homeland Security conducted random inspections of passenger baggage to determine the proportion of passengers carrying plant quarantine materials, i.e. any plants or plant parts that are prohibited from entering the United States (Meissner et al., 2009). The results indicated that 1.4 million, 3.75% of all 'visitor groups' (groups travelling with a single customs declaration) arriving in the USA each year were carrying plant quarantine materials. A baggage survey of 6,816 passengers entering New Zealand at international airports demonstrated that 3% of these travellers carried food items including fruits (MPI, 2013).

Inspectors checking airline baggage in the USA noted that the most commonly infested and intercepted commodity was fruit and that the most commonly intercepted insects were Diptera (including Tephritidae) and Homoptera hemipterans (Liebhold et al., 2006). According to Meurisse et al. (2019), Diptera rank second, after Sternorrhyncha hemipterans, in the list of the most frequent insect orders unintentionally transported in passenger baggage. Indeed, Li et al. (2010), who analysed pathways for non-native fruit flies (i.e. Tephritidae) into southern China, found that the risk of introducing fruit flies with passengers was high when compared to that of introducing fruit flies with fruit imported by sea. Likewise, Joomaye and Price (1999), who studied the pathways for the arrival of non-native Tephritidae into Mauritius, rated illicit movement of fruits and vegetables coming from untreated areas and carried by airline passengers as the highest risk pathway for fruit fly introductions. Similarly, the introduction of non-native fruit flies via passenger baggage into the EU cannot be excluded.

The plant health regime in the EU allows travellers to bring small quantities of plants and plants products, such as fruit, into the EU without the need of a phytosanitary certificate, if the plants or plant products are part of their personal luggage and if not used for professional or commercial purposes (Article 75 of 2016/2031). Fruit in passengers' luggage was seen as a possible route of entry for the *B. dorsalis* specimens detected in Italy (Nugnes et al., 2018) and for *Bactrocera* spp. in Austria (Egartner et al., 2019).

5.1. Direct passenger flights into the EU

Appendix K provides examples of direct passenger flights from countries where non-EU Tephritidae from the genus *Bactrocera* and *C. cosyra* (Table 5) which can infest ripe *Musa* fruit occur, especially from those with large banana and/or plantain production (Appendices D–F). The flights, and consequently the number of passengers travelling from those countries to the EU, represent a potential pathway for non-EU Tephritidae if passengers carry banana or plantains at a ripening stage potentially susceptible to be infested by fruit flies.

5.2. Macaronesia

As pointed out in the ToR, one of the reasons that triggered the Commission to ask EFSA to clarify whether import of bananas is a potential pathway for non-EU Tephritidae was the report showing that Cavendish bananas of different ripening stages were infested by tephritid fruit flies, including *B. dorsalis*, in Cabo Verde. The archipelago of Cabo Verde is part of a wider biogeographic region, the Macaronesia, which includes the Canary Islands and the archipelagos of the Azores and Madeira (Figure 15). In terms of EU phytosanitary regulations, the Canary Islands are treated as outside of the EU territory, whilst Madeira and the Azores are not (EU 2019/2072). This section comments on the threat of non-EU Tephritidae entering the EU via banana that come from these islands, which belong to the same biogeographic region.

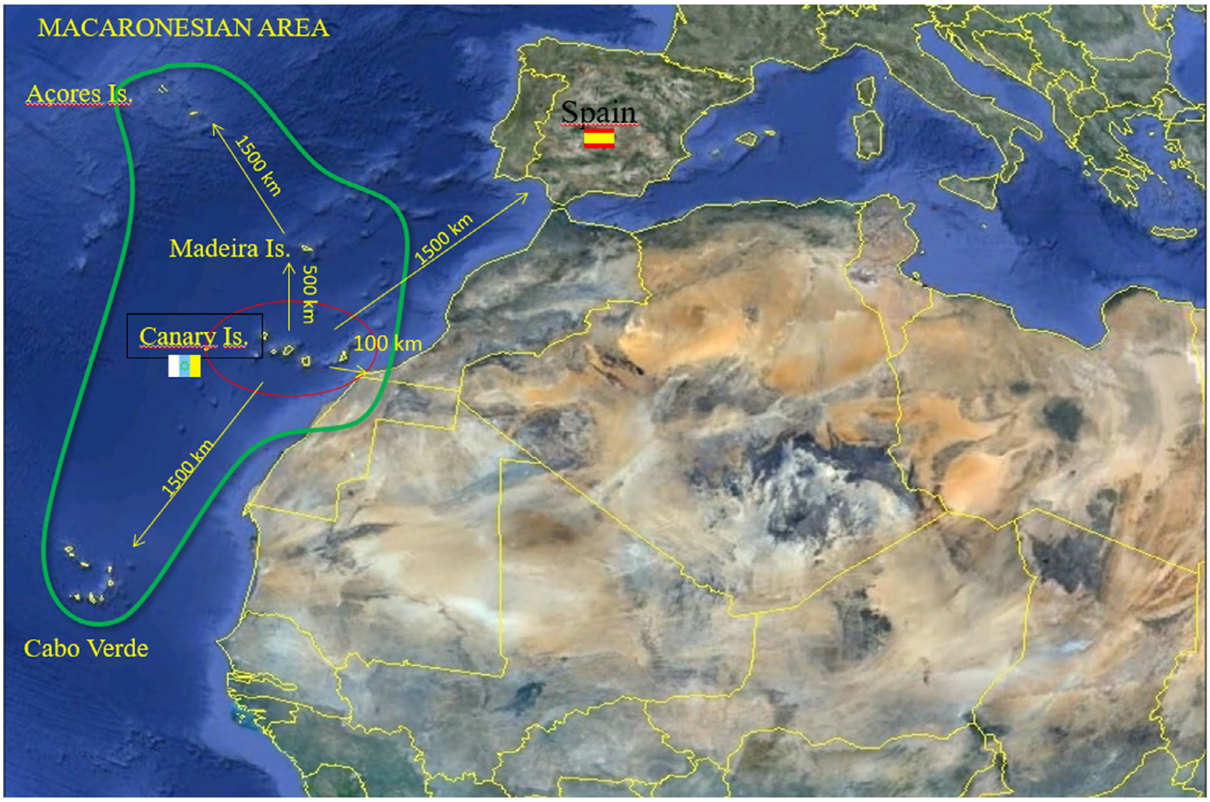


Figure 15: Map of the Macaronesia region (Google Earth, courtesy of Raimundo Cabrera Perez and Antonio Gonzalez Hernandez)

Biogeographical regions can be defined as regional species pools shaped by stochastic, ecological and evolutionary processes (Ricklefs, 2008) that act as dynamic entities in space and time (Noguera-Urbano, 2016). As a result, these regions can be defined based on the species found in them. All the archipelagos in the Macaronesian region have a volcanic origin, most probably the product of different geological hotspots, and never were part of a continent. As a consequence, native flora and fauna reached the islands via long-distance dispersal. With the exception of the Canary Islands, the other archipelagos in the region remained uninhabited until the arrival of European colonisers in the XV century. The subsequent colonisation of all these territories brought dramatic changes to the islands, including the felling of forest trees, the clearing of vegetation and the introduction of foreign plants and animals. In spite of many recent legislative initiatives aimed at protecting the islands indigenous habitats from new invading species, human-driven changes continue nowadays and this may facilitate dispersal of species occurring in one island to others and, eventually to EU mainland. Just as an example, first direct commercial flights from the Canary Islands to Cabo Verde started in 2012. In 4 years (2012–2016), more than 36,000 travellers used these flights (Tournews, 2016), with the inherent risk of passenger baggage accidentally introduced alien species (see Section 5). If similar to US (Meissner et al., 2009) and New Zealand (MPI, 2013) about 3% of these travellers carried in their baggage plant quarantine materials, about 135 plant quarantine materials from Cabo Verde could have entered the Canary Islands annually. Because these territories are part of the same biogeographic region, the establishment of potential invasive species inadvertedly infesting those quarantine materials, like fruit flies, could be easier. The Canary Islands but also Madeira and Azores could therefore work as a stepping stone on the way of these invasive species to EU mainland. According to the Government of the Canary Islands, this archipelago received around 15 million travellers annually in the period 2016–2019 (Turismo de Islas Canarias, 2020).

6. Conclusions

In response to the question posed to EFSA by the European Commission on whether the commercial import of fruits of *Musa* (bananas and plantains) could provide a potential pathway for the introduction of *B. dorsalis* and other non-EU Tephritidae, for which *Musa* fruits are a host, the EFSA Plant Health Panel answers:

- No. The commercial import of *Musa* fruit (bananas and plantains) does not provide a plausible pathway. This is based on a review of the evidence which shows:
    - i) Mature green stage one bananas and plantains are not a host for oviposition and further immature development of Tephritidae, and
    - ii) industry practices ensure that only mature green stage one bananas and plantains are exported to the EU.

Following some clarification with the requestor, the EFSA Plant Health Panel expanded the remit of the opinion to consider whether bananas and/or plantains carried in passenger baggage entering the EU could provide a potential pathway for the introduction of *B. dorsalis* and other non-EU Tephritidae, for which *Musa* fruits are a host. To this second issue, the EFSA Plant Health Panel answers:

- Yes. Bananas and/or plantains carried in passenger baggage, e.g. on flights originating in countries where *Musa* fruit are produced, and where non-EU Tephritidae which can utilise ripening *Musa* fruit as hosts occur, do provide a plausible pathway. This is based on a review of the evidence which shows:
    - i) bananas and plantains for domestic consumption in those countries may be harvested at ripening stages later than stage one,
    - ii) *Musa* fruit at ripening stages 2 and higher are suitable hosts for oviposition and further development of immature life stages of species of the family Tephritidae, and
    - iii) there is evidence that approximately 3% of international passengers carry plant material in their baggage, a proportion of which can be fruit, including *Musa*.

During the last decade, adults of the non-EU Tephritidae *B. dorsalis* have been detected in traps set in different EU MS (Austria, France, Italy) at locations close to international markets and/or airports (EUROPHYT/TRACES accessed 27/11/2020; EPPO Global Database). These findings have been related to separate entries of larvae in infested fruit rather than to established populations of this fruit fly (Nugnes et al., 2018; Egartner et al., 2019; EPPO Global Database).

B. dorsalis is one of the most commonly intercepted non-EU Tephritidae in the EU (EFSA PLH Panel, 2020; EUROPHYT). Such interceptions relate to fruit other than *Musa* (EU 2019/2072). Therefore, detections of 'outbreaks' of *B. dorsalis* in the EU cannot be attributed to commercial trade of *Musa* fruits.

7. Uncertainties

- The reports of *B. dorsalis* infesting and developing on green bananas in Cabo Verde (See Section 1.2.1) do not detail the precise stage when oviposition occurred in the fruits. Hearing experts who reviewed the photographic evidence concluded that the fruit was beyond mature green stage one.
- No reports or data from other sources support the report from Cabo Verde or elsewhere.
- Harvesting of banana for local consumption in Cabo Verde can occur at ripening stage 2 or 3; it is not local practice to protect bunches using bags. As such, hanging bunches may have been considered green stage one as they had not been harvested when in fact, they were beyond stage one and were therefore susceptible to infestation by *B. dorsalis*.
- Although all commercial bananas for export to the EU are harvested at stage one, passengers might carry banana or plantains at a ripening stage potentially susceptible to be infested by fruit flies. There is uncertainty as to how significant this is as a pathway.
- *B. dorsalis* continues to spread in Africa and multiple pathways exist for its entry into the EU.

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Abbreviations

EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization
IPPC	International Plant Protection Convention
ISPM	International Standards for Phytosanitary Measures
MS	Member State
PLH	EFSA Panel on Plant Health
PZ	Protected Zone
TFEU	Treaty on the Functioning of the European Union
ToR	Terms of Reference

Glossary

Control (of a pest)	Suppression, containment or eradication of a pest population (FAO, 2018c)
Entry (of a pest)	Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled (FAO, 2018c)
Eradication (of a pest)	Application of phytosanitary measures to eliminate a pest from an area (FAO, 2018c)
Establishment (of a pest)	Perpetuation, for the foreseeable future, of a pest within an area after entry (FAO, 2018c)
Greenhouse	A walk-in, static, closed place of crop production with a usually translucent outer shell, which allows controlled exchange of material and energy with the surroundings and prevents release of plant protection products (PPPs) into the environment
Impact (of a pest)	The impact of the pest on the crop output and quality and on the environment in the occupied spatial units
Introduction (of a pest)	The entry of a pest resulting in its establishment (FAO, 2018c)
Measures	Control (of a pest) is defined in ISPM 5 (FAO 2018c) as 'Suppression, containment or eradication of a pest population'. Control measures are measures that have a direct effect on pest abundance. Supporting measures are organisational measures or procedures to support the choice of appropriate Risk Reduction Options that do not directly affect pest abundance
Pathway	Any means that allows the entry or spread of a pest (FAO, 2018c)
Phytosanitary measures	Any legislation, regulation or official procedure having the purpose to prevent the introduction or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests (FAO, 2018c)
Protected zones (PZ)	A Protected zone is an area recognised at EU level to be free from a harmful organism, which is established in one or more other parts of the Union

Quarantine pest	A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (FAO, 2018c)
Regulated non-quarantine pest	A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (FAO, 2018c)
Risk reduction option (RRO)	A measure acting on pest introduction and/or pest spread and/or the magnitude of the biological impact of the pest should the pest be present. A RRO may become a phytosanitary measure, action or procedure according to the decision of the risk manager
Spread (of a pest)	Expansion of the geographical distribution of a pest within an area (FAO, 2018c)

Banana terminology

Bunch/cluster	a group of fingers (bananas) separated from a hand but remaining joined by sections of Crown (12–20 flowers per cluster)
Crown	group of fingers, attached by the stalk by a common stem section
Finger	individual fruit, commonly called a banana
Green life (GL)	The time between harvest and initiation of natural ripening, the beginning of the climacteric response. GL is expressed in number of days. It represents storage life
Hand	A cluster of fingers (5–6)
Mature fruit	suitable for harvesting
Precocious ripening	Advanced ripening of one or more fruits on a bunch of green fruit attached to the plant
Ripe fruit	suitable for eating

Appendix A – Literature search regarding banana infestation by Tephritidae fruit flies using keywords in English (accessed on 8/10/2020)

Search	Search terms/combination	Hits in Web of Science
1	Banana or Musa or plantain	19,440
2	Tephritidae	6,817
3	Fruit flies	4,857
4	Bactrocera	2,571
5	1 and 2	30
6	1 and 3	20
7	Infestation	34,841
8	1 and 2 and 7	9
9	1 and 3 and 7	4
10	Fruit ripeness	183
11	1 and 10	69
12	1 and 7 and 10	2
13	Oviposition	21,611
14	Pre-harvest or preharvest	5,645
15	Passenger baggage or passenger luggage	46
16	1 and 14	60
17	1 and 2 and 13	6
18	1 and 3 and 13	11
19	1 and 13 and 14	0
20	1 and 7 and 14	0
21	1 and 15	0
22	2 or 3 and 15	1
23	4 and 15	0

Appendix B – Literature search regarding banana infestation by Tephritidae fruit flies using keywords in French (accessed on 13/10/2020)

Search	Search terms/combination	Hits in Web of Science
1	Banane or Musa	5,313
2	Tephritidae	6,819
3	Mouches des fruits	0
4	Bactrocera	2,572
5	1 and 2	8
6	Infestation	34,850
7	1 and 2 and 6	4
8	1 and 3 and 6	0
9	Maturation des fruits	0
10	1 and 9	0
11	1 and 6 and 9	0
12	Ponte	909
13	Pre-recolte	0
14	1 and 13	0
15	1 and 2 and 12	0
16	1 and 3 and 12	0
17	1 and 12 and 13	0
18	1 and 6 and 13	0

Appendix C – Literature search regarding banana infestation by Tephritidae fruit flies using keywords in Spanish (accessed on 13/10/2020)

Search	Search terms/combination	Hits in Web of Science
1	Platano or Musa	5,340
2	Tephritidae	6,819
3	Moscas de fruta	0
4	Bactrocera	2,572
5	1 and 2	8
6	Infestacion	6
7	1 and 2 and 6	0
8	1 and 3 and 6	0
9	Madurez or maduracion	20
10	1 and 9	0
11	1 and 6 and 9	0
12	Oviposicion	1
13	Antes de cosecha	0
14	1 and 13	0
15	1 and 2 and 12	0
16	1 and 3 and 12	0
17	1 and 12 and 13	0
18	1 and 6 and 13	0

Appendix D – Banana and plantain harvested area

2018 harvested area of bananas and plantains (plantains includes cooking bananas)[(a)] (ha) FAOSTAT.

Countries ranked by sum of banana and plantain area.

	Country	Bananas	Plantains	Sum	Ratio banana: plantain	
1	D.R. Congo	82,854	1,087,894	1,170,748	0.08	:1
2	Uganda	127,614	885,567	1,013,181	0.14	:1
3	India	884,000		884,000	–	
4	Tanzania	490,701	293,763	784,464	1.67	:1
5	Philippines	484,247	263,642	747,889	1.84	:1
6	Colombia	131,260	406,639	537,899	0.32	:1
7	Côte d’Ivoire	8,878	514,836	523,714	0.02	:1
8	Nigeria	–	502,087	502,087	–	
9	Rwanda	464,321	–	464,321	–	
10	Brazil	449,284	–	449,284	–	
11	Cameroon	85,616	303,036	388,652	0.28	:1
12	China	383,216	–	383,216	–	
13	Ghana	7,731	372,441	380,172	0.02	:1
14	China, mainland	367,768	–	367,768	–	
15	Ecuador	161,583	100,603	262,186	1.61	:1
16	Burundi	208,603	–	208,603	–	
17	Peru	8,107	162,971	171,078	0.05	:1
18	Guinea	41,119	94,177	135,296	0.44	:1
19	Viet Nam	128,508	–	128,508	–	
20	Angola	123,017	–	123,017	–	
21	Indonesia	120,408	–	120,408	–	
22	Haiti	60,811	36,754	97,565	1.65	:1
23	Guatemala	80,754	13,283	94,037	6.08	:1
24	Myanmar	–	89,912	89,912	–	:1
25	Cuba	22,289	61,546	83,835	0.36	:1
26	Papua New Guinea	81,532	–	81,532	–	
27	Venezuela	31,770	48,996	80,766	0.65	:1
28	Mexico	78,533	–	78,533	–	
29	Mozambique	77,395	–	77,395	–	
30	Thailand	77,028	–	77,028	–	
31	Dominican Republic	28,020	48,244	76,264	0.58	:1
32	Kenya	72,748	2,711	75,459	26.83	:1
33	Madagascar	73,035	–	73,035	–	
34	Bolivia	20,155	40,958	61,113	0.49	:1
35	Gabon	2,296	56,246	58,542	0.04	:1
36	Costa Rica	47,750	10,000	57,750	4.78	:1
37	Sri Lanka	–	57,549	57,549	–	:1
38	Ethiopia	55,729	–	55,729	–	
39	Sudan	51,373		51,373	–	
40	Malawi	14,008	35,776	49,784	0.39	:1
41	Bangladesh	49,123		49,123	–	
42	Central African Republic	18,064	30,886	48,950	0.58	:1
43	Liberia	13,198	22,770	35,968	0.58	:1
44	Cambodia	31,185		31,185	–	

	Country	Bananas	Plantains	Sum	Ratio banana: plantain	
45	Malaysia	31,183		31,183	–	
46	Pakistan	30,031		30,031	–	
47	Egypt	29,892		29,892	–	
48	Laos	23,120		23,120	–	
49	Honduras	13,770	8,004	21,774	1.72	:1
50	Congo	12,214	9,251	21,465	1.32	:1
51	Panama	7,184	13,737	20,921	0.52	:1
52	Guinea-Bissau	697	17,945	18,642	0.04	:1
53	Nepal	15,765		15,765	–	
54	Taiwan	15,448		15,448	–	
55	Nicaragua	1,680	13,090	14,770	0.13	:1
56	Equatorial Guinea	6,508	7,908	14,416	0.82	:1
57	Zimbabwe	13,433		13,433	–	
58	Australia	12,477		12,477	–	
59	Jamaica	8,884	2,548	11,432	3.49	:1
60	Yemen	9,377		9,377	–	
61	Spain	9,092		9,092	–	
62	Guyana	1,321	7,643	8,964	0.17	:1
63	Morocco	8,412		8,412	–	
64	Argentina	8,336		8,336	–	
65	Sierra Leone		8,259	8,259	–	
66	Paraguay	8,172		8,172	–	
67	Comoros	8,114		8,114	–	
68	Turkey	7,616		7,616	–	
69	South Africa	7,482		7,482	–	
70	St Vincent and the Grenadines	6,016	146	6,162	41.21	:1
71	Mali	6,032		6,032	–	
72	Martinique	5,291	692	5,983	7.65	:1
73	Puerto Rico	1,324	3,552	4,876	0.37	:1
74	Benin	4,679		4,679	–	
75	Dominica	3,856	753	4,609	5.12	:1
76	Iran	4,506		4,506	–	
77	Samoa	4,480		4,480	–	
78	El Salvador	1,900	2,012	3,912	0.94	:1
79	Guadeloupe	2,750	420	3,170	6.55	:1
80	Israel	2,850		2,850	–	
81	Belize	2,471	316	2,787	7.82	:1
82	Trinidad and Tobago	1,069	1,470	2,539	0.73	:1
83	Lebanon	2,321		2,321	–	
84	Suriname	1,730	483	2,213	3.58	:1
85	Togo	2,097		2,097	–	
86	Réunion	2,077		2,077	–	
87	Vanuatu	1,810		1,810	–	
88	Jordan	1,732		1,732	–	
89	Kiribati	1,615		1,615	–	
90	Oman	1,560		1,560	–	
91	French Guyana	800	440	1,240	1.82	:1
92	Somalia	1,226		1,226	–	
93	Senegal	1,187		1,187	–	

	Country	Bananas	Plantains	Sum	Ratio banana: plantain	
94	Eswatini	1,151		1,151	–	
95	Saint Lucia	737	362	1,099	2.04	:1
96	Portugal	1,041		1,041	–	
97	Micronesia	383	596	979	0.64	:1
98	Tonga	528	245	773	2.16	:1
99	Grenada	695	23	718	30.22	:1
100	Wallis and Futuna Islands	677		677	–	
101	Fiji	489	154	643	3.18	:1
102	Brunei Darussalam	624		624	–	
103	New Caledonia	394	110	504	3.58	:1
104	Mauritius	492		492	–	
105	Bahamas	425	28	453	15.18	:1
106	American Samoa	363		363	–	
107	Cayman Islands	285		285	–	
108	Cabo Verde	275		275	–	
109	Sao Tome and Principe	263		263	–	
110	United States of America	261		261	–	
111	Cyprus	205		205	–	
112	Barbados	184		184	–	
113	Timor-Leste	156		156	–	
114	Solomon Islands	150		150	–	
115	Zambia	148		148	–	
116	Palestine	138		138	–	
117	Seychelles	99		99	–	
118	Bahrain	84		84	–	
119	Greece	84		84	–	
120	Montserrat	63		63	–	
121	British Virgin Islands	54		54	–	
122	Antigua and Barbuda	43		43	–	
123	Niue	40		40	–	
124	French Polynesia	27		27	–	
125	Bermuda	21		21	–	
126	Japan	17		17	–	
127	Algeria	16		16	–	
128	Guam	15		15	–	
129	Italy	14		14	–	
130	Maldives	12		12	–	
131	United Arab Emirates	11		11	–	
132	Cook Islands	8		8	–	
133	Tokelau	5		5	–	
134	Syrian Arab Republic	4		4	–	
	Sum	6,111,899	5,643,474	11,755,373	1.08	:1

(a): CPC ver.2.1 Expanded for agriculture (crops, livestock and derived products) and correspondences to FAOSTAT commodity list (fcl) Last updated 21 January 2017. Available online: http://www.fao.org/fileadmin/templates/ess/classifications/Correspondence_CPCtoFCL.xlsx

Appendix E – World banana production and export

Mean annual production and export of bananas 2014–2018. Source: FAOSTAT (accessed 18/9/2020)

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Part A: Major EU sources			
Ecuador	6,653,620	6,152,029	92.5
Guatemala	3,821,088	2,231,608	58.4
Colombia	3,618,500	1,748,352	48.3
Costa Rica	2,450,912	2,303,575	94.0
Cameroon	1,157,328	266,123	23.0
Dominican Republic	1,141,393	255,957	22.4
Côte d'Ivoire	377,875	351,910	93.1
Panama	319,543	271,940	85.1
Peru	220,921	197,587	89.4
Suriname	63,760	54,733	85.8
Part B: Other exporting countries			
Philippines	5,912,417	2,271,792	38.4
Honduras	692,451	644,980	93.1
Mexico	2,276,265	472,993	20.8
Mozambique	577,750	118,780	20.6
Bolivia	294,147	115,275	39.2
Nicaragua	93,380	98,953	106
India	29,873,110	90,486	0.3
Belize	87,209	89,541	102.7
Ghana	88,980	68,378	76.8
Brazil	6,755,065	66,619	1
Pakistan	128,788	51,614	40.1
Viet Nam	1,975,108	51,072	2.6
Paraguay	72,094	34,646	48.1
Thailand	1,113,626	31,610	2.8
Lebanon	69,252	29,559	42.7
Malaysia	331,039	23,984	7.2
Yemen	118,781	20,233	17
Ethiopia	502,061	11,909	2.4
China (excluding Taiwan)	11,150,120	11,058	0.1
Laos	801,917	10,940	1.4
South Africa	396,472	8,412	2.1
Eswatini	6,572	6,440	98
Tanzania	3,432,106	5,795	0.2
Indonesia	7,558,564	5,763	0.1
Sudan	919,069	5,693	0.6
St Vincent and the Grenadines	59,358	2,885	4.9
Taiwan	308,756	2,403	0.8
Sri Lanka	62,549	1,585	2.5
Zimbabwe	104,026	1,525	1.5
Burundi	1,125,103	910	0.1
Angola	3,703,174	863	< 0.1
Cambodia	143,038	847	0.6

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Uganda	546,218	757	0.1
Dominica	25,268	457	1.8
Somalia	21,325	120	0.6
Jordan	39,887	98	0.2
Australia	329,528	82	< 0.1
Egypt	1,313,130	81	< 0.1
Venezuela	474,681	71	< 0.1
Jamaica	59,258	71	0.1
Madagascar	373,153	61	< 0.1
Zambia	667	46	6.9
Guam	353	42	11.9
Bangladesh	792,619	41	< 0.1
Haiti	269,401	31	< 0.1
Kenya	1,414,342	30	< 0.1
Morocco	332,961	30	< 0.1
Togo	25,576	20	0.1
Congo	309,484	16	< 0.1
Samoa	22,179	14	0.1
Turkey	339,263	12	< 0.1
Fiji	4,737	10	0.2
Central African Republic	84,730	8	< 0.1
Guinea	225,961	7	< 0.1
Guyana	14,332	7	< 0.1
Senegal	33,923	6	< 0.1
Trinidad and Tobago	3,159	5	0.2
Rwanda	2,474,821	4	< 0.1
Nepal	236,157	4	< 0.1
Gabon	18,423	4	< 0.1
Tonga	779	4	0.5
Cuba	260,646	3	< 0.1
Equatorial Guinea	30,149	3	< 0.1
Japan	59	3	5.1
Bermuda	326	2	0.6
Martinique (France)	188,808	Note a	–
Guadeloupe (France)	64,006	Note a	–
United States of America	28,354	Note b	–
Réunion (France)	10,235	Note a	–
French Guiana (France)	8,520	Note a	–
Part C: Non-exporting producers			
Papua New Guinea	1,319,947	–	
Malawi	425,889	–	
Argentina	174,693	–	
Mali	168,059	–	
Liberia	137,664	–	
Iran	130,451	–	
Israel	127,575	–	
Congo	82,823	–	

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Puerto Rico	75,029	–	
Comoros	46,856	—	
Benin	20,800	–	
Sao Tome and Principe	20,274	–	
Oman	17,600	–	
Vanuatu	16,461	–	
El Salvador	15,969	–	
Cabo Verde	10,240	–	
Bahamas	9,801	–	
Guinea-Bissau	8,558	–	
Mauritius	8,101	–	
Kiribati	7,845	–	
Saint Lucia	7,304	–	
Wallis and Futuna Islands	7,018	–	
Palestine	3,116	–	
Bhutan	2,667	–	
Grenada	2,406	–	
Micronesia (Federated States)	2,036	–	
Seychelles	1,983	–	
New Caledonia	1,750	–	
Brunei Darussalam	1,486	–	
Barbados	1,008	–	
Bahrain	984	–	
American Samoa	838	–	
Maldives	577	–	
Timor-Leste	534	–	
British Virgin Islands	467	–	
Algeria	316	–	
Solomon Islands	312	–	
Tuvalu	289	–	
Antigua and Barbuda	264	–	
Cayman Islands	216	–	
United Arab Emirates	200	–	
French Polynesia	199	–	
Montserrat	196	–	
Syrian Arab Republic	154	–	
Niue	80	–	
Cook Islands	30	–	
Tokelau	16	–	
Part D: EU banana production and export (Note c)			
Spain (mainly Canary Is)	392,701	93,018	23.7
France (French Guiana, Guadeloupe, Martinique and Reunion)	1,431,361	269,276	18.8
Portugal (mainly Madeira and Azores)	24,958	8,588	34.4

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Cyprus	6,060	146	2.4
Greece	2,558	–	–
Italy	345	–	–
Global sum	115,653,769	18,564,535	16.1

(a): FAO does not report exports from French Guiana, Guadeloupe, Martinique or Reunion but includes them as exports from France.
(b): Exports not shown for USA due to high volume of re-export.
(c): For EU members, exports includes intra-EU trade.

Appendix F – World plantain production and export

Mean annual production and export of plantain 2014–2018. Source: FAOSTAT (code 'plantain and other') Accessed 18/9/2020

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Part A: Major EU sources			
Ecuador	692,593	209,620	30.3
Colombia	3,584,410	111,950	3.1
Guatemala	305,223	214,689	70.3
Uganda	3,959,195	2,143	0.1
Dominican Republic	993,449	141,585	14.3
Part B: Other exporting producers			
Philippines	3,167,101	50,546	1.6
Nicaragua	181,199	41,306	22.8
Côte d'Ivoire	1,794,722	18,827	1.0
Sri Lanka	655,286	17,029	2.6
Panama	142,413	5,099	3.6
Costa Rica	107,000	4,405	4.1
El Salvador	40,440	2,685	6.6
Bolivia	461,127	1,496	0.3
Venezuela	563,769	1,460	0.3
Ghana	3,981,113	697	< 0.1
Saint Vincent and the Grenadines	3,946	630	16.0
Honduras	101,194	615	0.6
France (French Guiana, Guadeloupe, Martinique)	Note a	552	–
Saint Lucia	1,246	367	29.4
Dominica	5,585	297	5.3
Tanzania	576,971	136	< 0.1
Nigeria	3,047,850	119	< 0.1
Cameroon	3,923,375	25	< 0.1
Peru	2,104,224	24	< 0.1
Jamaica	43,441	18	< 0.1
Malawi	375,980	16	< 0.1
Tonga	2,428	13	0.5
Grenada	198	10	5.2
Kenya	32,449	6	< 0.1
Guinea	485,736	5	< 0.1
Fiji	4,269	4	0.1
Dem Republic Congo	4,797,016	4	< 0.1
Suriname	19,380	1	< 0.1
Martinique (France)	15,316	Note a	–
Guadeloupe (France)	4,372	Note a	–
French Guiana (France)	2,882	Note a	–
Part C: Non-exporting producers			
Myanmar	1,132,454	–	
Gabon	270,361	–	
Haiti	240,601	–	
Central African Republic	87,104	–	
Puerto Rico	78,366	–	

Producing country	Mean annual production (tonnes)	Mean annual exports (tonnes)	% exported
Congo	77,395	–	
Guinea-Bissau	54,597	–	
Liberia	49,058	–	
Sierra Leone	44,519	–	
Equatorial Guinea	39,833	–	
Sao Tome and Principe	39,796	–	
Guyana	10,476	–	
Belize	5,666	–	
Trinidad and Tobago	5,120	–	
Micronesia (Federated States of)	307	–	
New Caledonia	208	–	
Bahamas	202	–	
Cayman Islands	22	–	
Sum world	38,312,983	826,379	2.2%

Note: FAO does not report production for France but categorises exports from French Guiana, Guadeloupe and Martinique as exports from France.

Appendix G – Phenological growth stages and BBCH identification keys of edible Musaceae

Meier U (ed.), 2001. Growth stages of mono- and dicotyledonous plants. 2nd Edition. BBCH Monograph. Federal Biological Research Centre for Agriculture and Forestry

Principal stage	2 digit code	Description
0: Sprouting or emergence	00	Recently planted material, plants from tissue cultures and rhizomes, without visible growth
1: Leaf development	10	Formation of first leaf of planted rhizome
2: Sucker formation	21	First sucker with visible leaf
3: Pseudostem elongation	35	The pseudostem reaches 50% of its typical thickness and length according to the genome or clone
4: Leaf development of the sucker (sword sucker)	40	Subphase of dependent growth: the sucker becomes visible and develops the leaf shoot
5: Emergence of inflorescence	50	The development of new normal leaves has been terminated and the flower bract emergence
6: Flowering	60	Emergence of the flower protected by the last bract leaf (1st sterile bract)
7: Development of the fruit	70	At least 50% of the fingers show an upwards curvature and the fruits (fingers) begin to fill
	72	The fingers of the hands show the characteristic curvature of the fruit (upwards and almost parallel to the axis or rachis)
	73	From the first two hands up to 30% of the hands have reached the maximum thickness of the fruit
	74	Up to 40% of the hands have reached the maximum thickness of the fruit
	75	Up to 50% of the hands have reached the maximum thickness of the fruit
	76	Up to 60% of the hands have reached the maximum thickness of the fruit
	77	Up to 70% of the hands have reached the maximum thickness of the fruit
	78	Up to 80% of the hands have reached the maximum thickness of the fruit
	79	All hands have reached the maximum thickness of the fruit and no hand shows a loss of weight
8: Ripening of the fruit	80	Ripening starts when the fruit has reached the maximum thickness, begins to lose weight and shows changes of the colour by which the degrees of maturity are defined
Harvest stage	81	Degree of maturity 1: green. Normal colour of the fresh fruit
	82	Degree of maturity 2: tinge of yellow. First modification of colour during the ripening cycle
Acceptable retail stage	83	Degree of maturity 3: more green than yellow
Acceptable retail stage	84	Degree of maturity 4: more yellow than green
Acceptable retail stage	85	Degree of maturity 5: tinge of green
Acceptable retail stage	86	Degree of maturity 6: all yellow
Acceptable retail stage	87	Degree of maturity 7: yellow with brown specks. Fruit is completely ripe, has the best flavour and a high nutritive value
	88	Degree of maturity 8: 20–50% of surface discoloured brown or spoiled
	89	Degree of maturity 9: More than 50% of the surface of the fruits is discoloured brown and spoiled

Principal stage	2 digit code	Description
9: Senescence and death	90	More than 50% of the surface of the fruits are discoloured brown
	91	The leaves the plant shows have died off acropetally and the male flowers have withered, are necrotic and/or have fallen off
	93	Total rot and necrosis of the fruits
	95	Degeneration (necrosis) of the flower
	97	The sheaths enclosed in the pseudostem become brittle which indicates the beginning of necrosis of the pseudostem. The pseudostem turns to be brown
	98	Total decomposition of the tissues and fall down of the pseudostem

Appendix H – EU Imports of fresh banana (CN 0803 9010) from third country producers

Source: Eurostat (Accessed 12/7/2020) Units: Hundreds of kg

Banana producer	2012	2013	2014	2015	2016	2017	2018	2019
Ecuador	12,122,263	11,690,659	13,338,572	12,256,661	11,868,903	13,472,872	14,959,846	13,635,839
Colombia	8,960,714	9,035,686	8,355,078	10,337,024	9,947,243	11,374,918	11,065,557	11,274,803
Costa Rica	6,515,606	6,818,497	7,395,792	7,873,579	9,661,481	9,662,548	10,124,876	9,382,476
Cote d'Ivoire	1,520,479	1,867,181	2,150,412	2,133,247	2,649,229	2,475,832	2,698,405	3,147,059
Cameroon	1,577,078	1,911,701	2,164,278	2,415,833	2,521,332	2,341,152	1,790,921	1,520,090
Panama	1,345,379	1,803,703	2,015,443	1,835,268	1,695,201	2,139,456	2,333,948	2,546,131
Dominican Republic	903,054	1,217,398	1,516,267	1,264,080	1,563,354	1,452,893	1,616,659	2,310,478
Peru	782,793	1,091,927	939,852	1,007,778	1,137,248	1,154,921	1,258,009	1,079,558
Guatemala	52,150	136,557	250,423	651,930	857,829	1,056,486	1,356,639	1,834,899
Suriname	831,256	809,559	725,928	585,834	497,384	442,652	400,033	191,457
Mexico	200,468	539,702	707,830	630,089	516,368	558,382	348,614	239,117
Ghana	375,657	321,637	269,068	224,515	264,235	351,050	456,086	606,290
Belize	292,603	328,951	321,900	347,987	278,722	314,582	375,147	440,054
Nicaragua				93,260	322,806	785,136	754,077	613,592
Brazil	301,488	345,369	180,094	113,394	149,090	26,845	59,662	104,890
Honduras	53,234	62,251	43,670	43,885	66,271	166,045	194,618	158,316
Angola					108	4,583	37,169	48,878
Turkey	15,220	15,922	4,242	23	202	0	211	
Philippines	9,967	2,599	753	212	537	9,398	122	152
United States	233			11,527		0	0	
Albania	1,062	4,107	210	2,973		0	698	
Uganda	701	799	856	1,154	903	942	1,045	1,213
Madagascar			45	2,018	445	520	0	586
India	235	276	431	309	478	396	494	370
Curacao		2,465				0	0	
Burundi	341	373	371	334	348	36	137	91
Mozambique		404	210			0	1108	222
Haiti					1537			
Argentina	1215					0	0	

Banana producer	2012	2013	2014	2015	2016	2017	2018	2019
China	701					0	0	
Thailand	89	101	89	75	63	82	86	109
South Africa			406			0	0	234
Egypt	464		1			0	147	
Sri Lanka	28	30	100	121	51	43	40	41
Bermuda			420	1				
Senegal			71	183		0	0	
Morocco			19	225	1	0	0	
Rwanda	22	5	5	4		119	34	29
Bangladesh		196		4	2	0	5	
Tunisia			203			0	0	
Chile			201			0	0	
Bolivia	192					0	0	0
Viet Nam				0	186	0	0	2
Lebanon					170	0	0	
Indonesia						0	11	15
Togo					2	1	1	5
Kenya	1	1	1	1	2	0	1	
Cambodia	0	0	4	0		1	0	
Dominica	1	1						
Guinea	2							
French Polynesia					0	0	2	

Appendix I – EU imports of fresh plantains* (CN 0803 1010) from third country producers (2012–2019)

Source: Eurostat Units: Hundreds of kg

Plantain producer	2012	2013	2014	2015	2016	2017	2018	2019
Ecuador	353,318	363,653	356,275	327,611	303,209	258,148	317,896	355,520
Colombia	181,405	202,745	232,660	325,333	173,138	219,473	221,103	247,505
Guatemala			157	5,170	14,575	13,643	13,075	9,948
Uganda	3,560	3,683	5,417	6,140	10,394	5,629	6,354	8,307
Dominican Republic	954	1,336	1,866	6,949	5,091	879	1,174	472
Ghana	2,270	1,912	2,299	2,184	1,041	1,546	1,408	1,625
Dominica	2,063	3,196	1,766	627	454	890	21	505
Sri Lanka	163	149	262	463	646	951	1,454	1,958
Panama	411	1,145			1,323	1,961	0	
Rwanda	272	258	9	47	9	868	1,610	1,538
Cote d'Ivoire	88	53	103	858	880	72	124	2,154
Philippines	4		176	982	292	194	243	320
Costa Rica	82	195	401	161	406	258	221	446
Cameroon	195	168	228	186	192	143	156	163
Mozambique	1					0	903	443
Thailand	97	95	102	283	149	205	196	180
Mexico			0			515	292	56
Nicaragua				407	40	110		218
Madagascar			85	84	530	0	0	
Peru	649	3	3	1	1	2	5	2
Vietnam	107	60	67	74	46	45	62	97
China			490			0	0	
Bangladesh		1	4	88	173	80	67	38
Cambodia	39	50	76	21	17	45	35	42
Laos	0		3	51	81	66	70	46
Honduras	1	65			67	116		
India	4	8	6	17	24	23	26	88
Suriname	77	22	4	3	4	12	6	47
Kenya	16	2	85	18		1	5	11
Burundi	5	0	6	19	14			

Plantain producer	2012	2013	2014	2015	2016	2017	2018	2019
Togo		1	3	4	2	2	9	17
Brazil	0	0	23			0	1	3
Egypt				8		0	0	
Malaysia	0					0	8	
United States						0	0	6
Nigeria				2		2	1	
Dem Republic Congo						0	2	2
Pakistan		0		1		0	3	
Tunisia				3			0	
Angola						1	1	
Haiti						1	1	
Tanzania						0	2	
Bolivia						0	1	
French Polynesia					0	0	1	0

Note that Cabo Verde is not a source of plantains for EU.
*: Plantains includes cooking bananas.

Appendix J – Host plants of *Bactrocera* and *Ceratitis* that can infest ripening *Musa*

#	Species	Hosts	References
1	*Bactrocera dorsalis* Oriental fruit fly	Polyphagous fly: mango (*Mangifera indica*, Anacardiaceae), guava (*Psidium guajava*, Myrtaceae), avocado (*Persea americana*, Lauraceae), citrus (*Citrus* sp., Rutaceae), apple (*Malus domestica*, Rosaceae), papaya (*Carica papaya*, Caricaceae), pawpaw (*Asimina triloba*, Annonaceae), cashew (*Anacardium occidentale*, Anacardiaceae), **banana (*Musa*, Musaceae)**, bell peppers (*Capsicum annuum*, Solanaceae), chilli (*Capsicum frutescens*, Solanaceae), tomato (*Solanum lycopersicum*, Solanaceae), aubergine (*Solanum melongena*, Solanaceae), arabica and robusta coffee (*Coffea arabica, C. canephora*, Rubiaceae), cocoa (*Theobroma cacao*, Malvaceae), clove (*Syzygium aromaticum*, Myrtaceae), carambola (*Averrhoa carambola,* Oxalidaceae), cherimoya (*Annona cherimola*, Annonaceae), cucumbers/melons/pumpkins (*Cucumis sativus, C. melo*, *Cucurbita maxima, C. pepo, Citrullus colocynthis, C. lanatus,* Cucurbitaceae), persimmon (*Diospyros kaki*, Ebenaceae), loquat, (*Eriobotrya japonica*, Rosaceae), passion fruit (*Passiflora edulis*, Passifloraceae), common bean (*Phaseolus vulgaris*, Fabaceae), breadfruit (*Artocarpus altilis*, Moraceae), black pepper (*Piper nigrum*, Piperaceae), apricot (*Prunus armeniaca*, Rosaceae), peach (*Prunus persica*, Rosaceae) sweet and sour cherry (*Prunus avium, P. cerasus*, Rosaceae), plum (*Prunus domestica*, Rosaceae), pomegranate (*Punica granatum*, Punicaceae) pear (*Pyrus communis, P. pyrifolia*, Rosaceae), jujube (*Ziziphos jujuba, Z. mauritiana*, Rhamnaceae). Several other species of Agavaceae, Alangiaceae, Amaryllidaceae, Anacardiaceae (*Mangifera foetida, M. odorata, M. caesia*), Annonaceae (*Annona muricata, A. glabra, A. macroprophyllata, A. montana, A. reticulate, A. senegalensis, A. squamosal, Cananga odorata*), Arecaceae, Apocynaceae, Boraginaceae, Burseraceae, Cactaceae, Capparaceae, Caprifoliaceae, Caricaceae, Chrysobalanaceae, Clusiaceae (*Garcinia mangostana*), Combretaceae, Convolvulaceae, Dilleniaceae, Dracaenaceae, Elaeocarpaceae, Ebenaceae, Euphorbiaceae, Fabaceae, Fagaceae, Flacourtiaceae, Hanguanaceae, Irvingiaceae, Lamiaceae, Lauraceae, Lecythidaceae, Loganiaceae, Malpighiaceae, Meliaceae (*Sandoricum indicum*), Menispermaceae, Moraceae (*Ficus* sp.), Myristicaceae, Myrtaceae (*Eugenia javanica*), Olacaceae, Oleaceae, Oxalidaceae, Polygalaceae, Primulaceae, Rhizophoraceae, Rubiaceaae, Rutaceae, Sapindaceae, Sapotaceae (*Manikara zapota*), Strychnaceae, Tiliaceae, Ulmaceae, Vitaceae, Zinziberaceae	Sar et al. (2000), Plant-Health-Australia (2016), White (2006), Schutze et al. (2015), Drew et al. (2005), Tan and Lee (1982), Allwood et al. (1999), Drew and Romig (2016), Simbiken et al. (2006), CABI datasheet

#	Species	Hosts	References
2	*Bactrocera musae* Banana fruit fly	Major pest of native banana (*Musa banksii*, Musaceae). Pest of **plantain (*Musa* x *paradisiaca*, Musaceae) and wild banana (*Musa acuminata*)** although not known if oviposition can take place during ripening stage one. Other hosts: guava (*Psidium guajava*, Myrtaceae), papaya (*Carica papaya*, Caricaceae), pawpaw (*Asimina triloba*, Annonaceae), hog plum (*Ximenia americana*, Olacaceae), chilli (*Capsicum annuum*, Solanaceae), tomato (*Solanum lycopersicum*, Solanaceae) Reared from: papaya (*Carica papaya*, Caricaceae); **bananas (*Musa acuminata, M. banksii, M. paradisiaca,* Musaceae)**; guava (*Psidium guajava*, Myrtaceae); passion fruit (*Passiflora edulis*, Passifloraceae); mandarin orange (*Citrus reticulata*, Rutaceae); tomato (*Solanum lycopersicum*, Solanaceae)	Hamaceck (1997), Tenakanai (1997), Vijaysegaran (1997), Sar et al. (2000), Plant-Health-Australia (2016), EPPO (online) Drew and Romig (2001), Drew et al. (2011), Hancock et al. (2000)
3	*Bactrocera frauenfeldi* Mango fruit fly	Polyphagous fly: cashew (*Anacardium occidentale*, Anacardiaceae), mango (*Mangifera indica*, *M. minor*, Anacardiaceae), ambarella (*Spondias dulcis*, Anacardiaceae), *Annona glabra*, *A. muricata*, *A. reticulata, A. squamosa* (Annonaceae), betel nut (*Areca catechu*, Arecaceae), papaya (*Carica papaya*, Caricaceae), mangosteen (*Garcinia* x *mangostana*, Clusiaceae), Indian almond (*Terminalia catappa*, *T. arenicola,* Combretaceae), Okari nut (*Terminalia kaernbachii*, Combretaceae), Singapore almond (*Terminalia catappa*, Combretaceae), avocado (*Persea Americana*, Lauraceae), Tahitian chestnut (*Inocarpus fagifer,* Leguminosae), Barbados cherry/acerola (*Malpighia glabra*, Malpighiaceae), breadfruit (*Artocarpus altilis*, *A. heterophyllus*, *A. mariannensis,* Moraceae), **banana, (Musa x paradisiaca, Musaceae)**, Suriname cherry (*Eugenia uniflora*, Myrtaceae), guava (*Psidium guajava*, *P. cattleianum*, Myrtaceae), bell fruits (*Syzygium aqueum, S. jambos, S. malaccense, S. samarangense*, Myrtaceae), carambola (*Averrhoa carambola*, Oxalidaceae), passion fruit (*Passiflora edulis*, Passifloraceae), citrus fruit (*Citrus aurantium, C. japonica, C. maxima, Citrus x microcarpa, C. paradisi, C. reticulata, C. sinensis*, *C. limon*, *Clymenia polyandra,* Rutaceae), Fijian longan (*Pometia pinnata*, Sapindaceae), star apple (*Chrysophyllum cainito*, Sapotaceae), sapotes (*Manilkara zapota, M. kauki, Pouteria caimito, P. campechiana*, Sapotaceae), bell pepper (*Capsicum annuum*, Solanaceae), white sapote (*Casimiroa edulis,* Rutaceae), mabolo (*Diospyros blancoi*, Ebenaceae), round kumquat (*Fortunella japonica*, Rutaceae)	Tenakanai (1997), Sar et al. (2000), EPPO (online), White and Evenhuis (1999), Leblanc et al. (2013), Allwood and Leblanc (1997), Drew and Romig (2001), Leblanc et al. (2001), Australian handbook (2016)
4	*Bactrocera tryoni* Queensland fruit fly	Polyphagous fly: pineapple guava (*Acca sellowiana,* Myrtaceae), kiwifruit (*Actinidia deliciosa*, Actinidiaceae), cashew (*Anacardium occidentale*, Anacardiaceae), cherimoya (*Annona*	Hancock et al. (2000), EPPO (online), Leblanc et al. (2013), Cameron et al. (2009), Drew

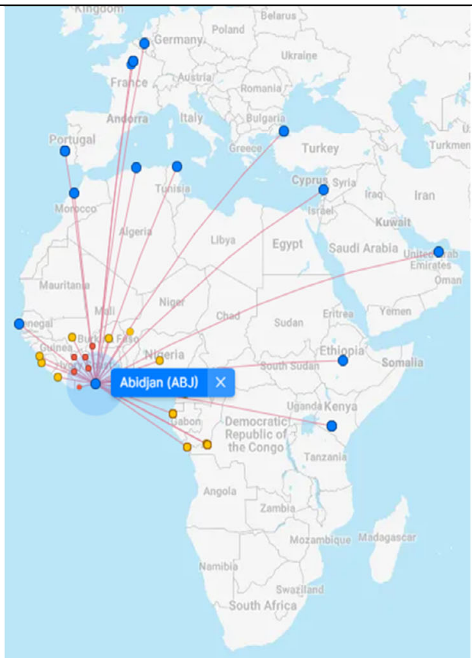
#	Species	Hosts	References
		cherimola, Annonaceae), breadfruit (*Artocarpus altilis*, Moraceae), carambola (*Averrhoa carambola*, Oxalidaceae), ylang-ylang (*Cananga odorata*, Annonaceae), bell pepper (*Capsicum annuum*, Solanaceae), chilli (*Capsicum frutescens*, Solanaceae), papaya (*Carica papaya*, Caricaceae), citrus fruit (*Citrus aurantium, C. aurantiifolia, C. jambhiri, C. limetta, C. limon, C. maxima, C. medica, C. paradisi, C. reticulata, C. sinensis*, Rutaceae), arabica coffee (*Coffea arabica*, Rubiaceae), melons (*Cucumis* sp., Cucurbitaceae), pumpkin (*Cucurbita moschata,* Cucurbitaceae), quince (*Cydonia oblonga*, Rosaceae), mabolo and persimmons (*Diospyros blancoi*, *D. kaki, D. virginiana*, Ebenaceae), durian (*Durio zibethinus*, Bombacaceae), loquat (*Eriobotrya japonica*, Rosaceae), Surinam cherry (*Eugenia uniflora*, Myrtaceae), strawberry (*Fragaria ananassa*, Rosaceae), walnut (*Juglans regia*, Juglandaceae), lichi (*Litchi chinensis*, Sapindaceae), mango *(Mangifera indica*, Anacardiaceae), apple (*Malus domestica*, Rosaceae), European olive (*Olea europea*, Oleaceae), passion fruit (*Passiflora edulis*, Passifloraceae), avocado (*Persea americana*, Lauraceae), date-palm (*Phoenix dactylifera*, Arecaceae), star gooseberry (*Phyllanthus acidus*, Euphorbiaceae), Cape gooseberry (*Physalis peruviana*, Solanaceae), Fijian longan (*Pometia pinnata*, Sapindaceae), apricot (*Prunus armeniaca*, Rosaceae), peach (*Prunus persica*, Rosaceae) sweet cherry (*Prunus avium,* Rosaceae), plum (*Prunus domestica*, Rosaceae), guava (*Psidium guajava*, Myrtaceae), pomegranate (*Punica granatum*, Punicaceae), pear (*Pyrus communis, P. pyrifolia*, Rosaceae), blackberry (*Rubus fruticosus*, Rosaceae), loganberry (*Rubus loganobaccus*, Rosaceae), boysenberry (*Rubus ursinus*, Rosaceae), tomato (*Solanum lycopersicum*, Solanaceae), aubergine (*Solanum melongena*, Solanaceae), ambarella (*Spondias dulcis*, Anacardiaceae), bell fruits (*Syzygium aqueum, S. jambos, S. malaccense, S. samarangense*, *S. cumini, S. forte*, *S. paniculatum*, Myrtaceae), blueberry (*Vaccinium corymbosum*, Ericaceae), grape (*Vitis vinifera*, Vitaceae), jujube (*Ziziphos jujuba, Z. mauritiana*, Rhamnaceae). Pest of **plantain**, **dwarf banana, lady finger banana and sugar banana (*Musa* x *paradisiaca*, Musaceae**), although no evidence that oviposition can take place during ripening stage one. Several other species of Anacardiaceae (*Spondias mombin, S. purpurea*), Annonaceae (*Annona glabra, A. muricata, A. reticulate, A. squamosal, Rollinia mucosa, R. pulchrinervis*), Apocynaceae (*Thevetia peruviana*), Arecaceae, Cactaceae, Clusiaceae, Combretaceae (*Terminalia arenicola,*	(1989), Purea et al. (1997), CABI datasheet

#	Species	Hosts	References
		T. catappa), Cucurbitaceae (*Trichosanthes cucumerina*), Flacourtiaceae, Liliaceae, Malpighiaceae, Malvaceae (*Gossypium hirsutum*), Meliaceae (Santoricum koetjape), Moraceae, Myrtaceae (*Eugenia brasiliensis, Psidium cattleianum, P. guineense*), Oxalidaceae (*Averrhoa bilimbi*), Passifloraceae, Rosaceae (*Prunus cerasifera, P. salicina*), Rutaceae (*Fortunella japonica*, *Aegle marmelos*, *Clausena lansium*), Sapindaceae, Sapotaceae (*Pouteria caimito, P. campechiana, P. sapota, Chrysophyllum cainito, Manikara zapota, Synsepalum dulcificum*), Solanaceae (*Solanum laciniatum, S. seaforthianum, S. torvum*), Tiliaceae, Vitaceae (*Vitis labrusca*)	
5	*Bactrocera facialis*	Cashew (*Anacardium occidentale*, Anacardiaceae), mango (*Mangifera indica*, Anacardiaceae), *Annona muricata* (Annonaceae), papaya (*Carica papaya*, Caricaceae), Singapore almond (*Terminalia catappa*, Combretaceae), avocado (*Persea americana,* Lauraceae), breadfruit (*Artocarpus altilis*, Moraceae), **plantain (Musa x paradisiaca, Musaceae)**, Surinam cherry (*Eugenia uniflora*, Myrtaceae), guava (*Psidium guajava*, Myrtaceae), rose apple (*Syzygium jambos*, Myrtaceae), passion fruits (*Passiflora edulis, P. foetida, P. Quadrangularis*, Passifloraceae), citrus (*Citrus aurantium, C. maxima, C. paradisi, C. reticulata, C. sinensis, C. limon*, Rutaceae), star apple (*Chrysophyllum cainito*, Sapotaceae), sapote (*Manilkara zapota,* Sapotaceae), bell pepper (*Capsicum annuum*, Solanaceae), chilli (*Capsicum frutescens*, Solanaceae), tomato (*Solanum lyycopersicum*, Solanaceae), *Solanum melongena* (Solanaceae), *Inocarpus fagifer* (Fabaceae), Fijian longan (*Pometia pinnata*, Sapindaceae), peach (*Prunus persica*, Rosaceae), bell fruit (*Syzygium malaccense,* Myrtaceae).	EPPO (online), Leblanc et al. (2013), Allwood and Leblanc (1997), Drew and Hancock (2000)
6	*Bactrocera kandiensis*	Cashew (*Anacardium occidentale*, Anacardiaceae), mango (*Mangifera indica*, Anacardiaceae), papaya (*Carica papaya*, Caricaceae), avocado (*Persea americana,* Lauraceae), guava (*Psidium guajava*, Myrtaceae), *Solanum melongena* (Solanaceae), ambarella (*Spondias dulcis*, Anacardiaceae), bell fruits (*Syzygium aromaticum*, *S. jambos*, Myrtaceae), *Annona glabra* (Annonaceae), citrus (*Citrus maxima, C. paradisi, Citrofortunella microcarpa*, Rutaceae), carambola (*Averrhoa carambola*, Oxalidaceae), **banana (Sinhalese: Embul, Alu Kehel, Anamalu, Embun, Rathambala and Sini cultivars**), jackfruit (*Artocarpus heterophyllus*, Moraceae), Ceylon breadfruit (*Artocarpus nobilis*, Moraceae), *Areca catechu* (Arecaceae), wild guava tree (*Careya arborea*, Ericaceae), Indian star apple (*Chrysophyllum roxburghii*, Sapotaceae), false mangosteen (*Garcinia xanthochymus*, Cluciaceae), Sri Lanka wild mango (*Mangifera zeylanica*,	EPPO (online), Leblanc et al. (2018), Kapoor (2002), Drew and Hancock (1994, 1996), Win et al. (2014), Ekanayake et al. (2002), USDA Database

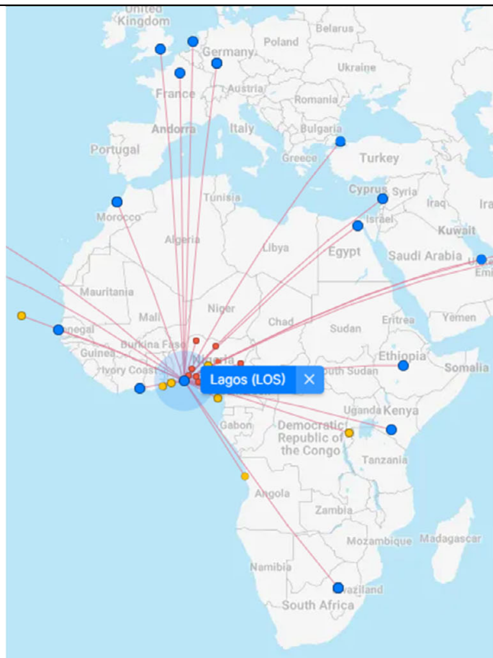
#	Species	Hosts	References
		Anacardiaceae), Cattley guava (*Psidium cattleianum*, Myrtaceae), pomegranate (*Punica granatum*, Lythraceae), *Spondias pinnata* (Anacardiaceae), sea almond (*Terminalia catappa*, Combreataceae)	
7	*Bactrocera bryoniae*	Striped cucumber (*Diplocyclos palmatus* = *Bryonopsis laciniosa*; misidentification, Cucurbitaceae), *Bryonopsis affinis* (Cucurbitaceae), *Mukia maderaspatana* (Cucurbitaceae), *Zehneria cunninghamii* (Cucurbitaceae), strychnine berry (*Strychnos lucida*, Loganiaceae), **banana (*Musa* x *paradisiaca*, Musaceae),** stinking and corky passion fruit (*Passiflora foetida*, *P. suberosa*, Passifloraceae), dip birds eye and Tabasco chilli (*Capsicum frutescens*, *C. annuum*, Solanaceae), tomato (*Solanum lycopersicum*, Solanaceae)	Hardy (1951), Hancock et al. (2000), Leblanc and Putoa (2000), Sar et al. (2000), Drew and Romig (2016), Leblanc et al. (2001), Drew et al. (2011)
8	*Bactrocera neohumeralis* Lesser Queensland fruit fly	Polyphagous fly: major hosts include species of the genus *Terminalia* such as brown damson *T. arenicola*, pacific almond *T. catappa*, Mueller's damson *T. muelleri*, damson *T. sericocarpa* *T. platyphylla*, *T. aridicola* and *T. subacroptera* (Combretaceae), acerola (*Malpighia emarginata*, Malpighiaceae), Brazilian cherry (*Eugenia uniflora*, Myrtaceae), cherry guava (*Psidium cattleianum*, Myrtaceae), guava (*Psidium guajava*, Myrtaceae), moderate hosts are lolly berry (*Salacia chinensis*, Hippocrateaceae) and coffee (*Coffea Arabica*, Rubiaceae). Can infest **banana (*Musa* x *paradisiaca*, Musaceae**), although no evidence that oviposition can take place during ripening stage one. Record of one specimen from native banana *Musa banksii*. Several other species of Anacardiaceae, Annonaceae, Apocynaceae, Arecaceae, Baselaceae, Cactaceae, Capparaceae, Caricaceae, Celastraceae, Chrysobalanaceae, Clusiaceae, Combretaceae, Davidsoniaceae, Ebenacaeae, Elaeocarpaceae, Euphorbiaceae, Flacourtiaceae, Hippocrataceae, Lauraceae, Lecythidaceae, Leeaceae, Malpighiaceae, Melostomataceae, Meliaceae, Moraceae, Myrtaceae, Olacaceae, Oleaceae, Oxalidaceae, Passifloraceae, Pipperaceae, Rhamnaceae, Rhizophoraceae, Rosaceae, Rubiaceae, Rutaceae, Santalaceae, Sapindaceae, Sapotaceae, Smilacaceae, Solanaceae, Verbenaceae, Vitaceae	Sar et al. (2001), Hardy (1951), Hancock et al. (2000)
9	*Bactrocera kraussi* Krauss's fruit fly	Polyphagous fly: major hosts include guava (*Psidium guajava*, Myrtaceae), cassowary pine (*Acmena graveolens*, Myrtaceae) and plum boxwood (*Niemeyera prunifera*, Sapotaceae). Can infest **banana (*Musa* x *paradisiaca*, Musaceae**), although no evidence that oviposition can take place during ripening stage one. Several other species of Agavaceae, Anacardiaceae, Annonaceae, Apocynaceae, Clusiaceae, Combretaceae, Cunoniaceae,	Hancock et al. (2000)

#	Species	Hosts	References
		Davidsoniaceae, Elaeocarpaceae, Euphorbiaceae, Flacourtiaceae, Icacinaceae, Lauraceae, Lecythidaceae, Loganiaceae, Malpighiaceae, Menispermaceae, Moraceae, Myrtaceae, Oleaceae, Oxalidaceae, Passifloraceae, Rosaceae, Rubiaceae, Rutaceae, Sapindaceae, Sapotaceae, Solanaceae, Thymeliaceae	
10	*Bactrocera jarvisi* Jarvis' fruit fly	Polyphagous fly: major hosts include mango (*Mangifera indica*, Anacardiaceae), guava (*Psidium guajava*, Myrtaceae), peach and **banana (*Musa* x *paradisiaca*, Musaceae**) Several other species of Anacardiaceae, Annonaceae, Arecaceae, Cactaceae, Caricaceae, Celastraceae, Chrysobalanaceae, Clusiaceae, Combretaceae, Curcubitaceae, Ebenaceae, Elaeocarpaceae, Lauraceae, Lecythidaceae, Malpighiaceae, Meliaceae, Moraceae, Musaceae, Myrtaceae, Oleaceae, Oxalidaceae, Passifloraceae, Punicaceae, Rosaceae, Rubiaceae, Rutaceae, Sapindaceae, Sapotaceae, Solanaceae	Drew and Romig (1997), Vijaysegaran (1997), Hancock et al. (2000), EPPO (online)
11	*Bactrocera kirki*	Polyphagous fly: major hosts include mango (*Mangifera indica*, Anacardiaceae), guava (*Psidium guajava*, Myrtaceae), apricot (*Prunus armeniaca*, Rosaceae), banana (*Musa* x *paradisiaca*, Musaceae), peach (*Prunus persica*, Rosaceae), pear (*Pyrus communis*, Rosaceae) and persimmon (*Diospyros kaki*, Ebenaceae)	White and Elson-Harris (1992), Vijaysegaran (1997), EPPO (online)
12	*Ceratitis cosyra* Marula fruit fly	Polyphagous fly: marula plum (*Sclerocarya birrea*), mango (*Mangifera indica*, Anacardiaceae), guava (*Psidium guajava*, Myrtaceae), citrus, early peaches (*Prunus persica,* Rosaceae), avocado (*Persea americana,* Lauraceae) and wild hosts belonging to a wide range of families	De Meyer et al. (2002), Copeland et al. (2006)

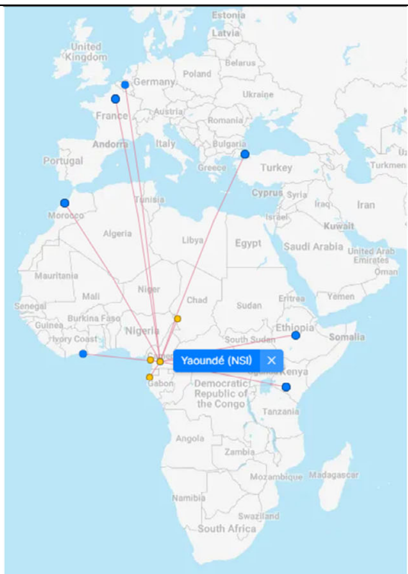
Appendix K – Examples of direct passenger flights from countries that are significant producers of banana or/and plantains and where *Bactrocera dorsalis* is present (printscreen from the website: https://www.flightconnections.com/)



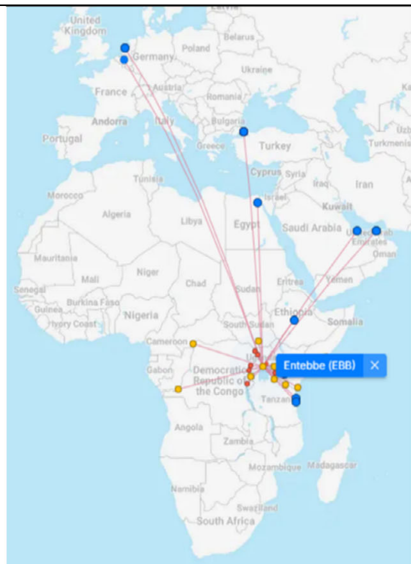
a) Côte d' Ivoire: 4th highest world supplier and highest supplier from Africa of bananas to EU in 2019; also important source of plantains.



b) Ghana: Principle African source of plantains and 3rd source of bananas to EU in 2019)



c) Cameroon: 2nd largest African source of bananas to EU in 2019; major plantain producer.



d) Uganda: 4th highest supplier of plantains/ cooking bananas to EU in 2019, major African producer.

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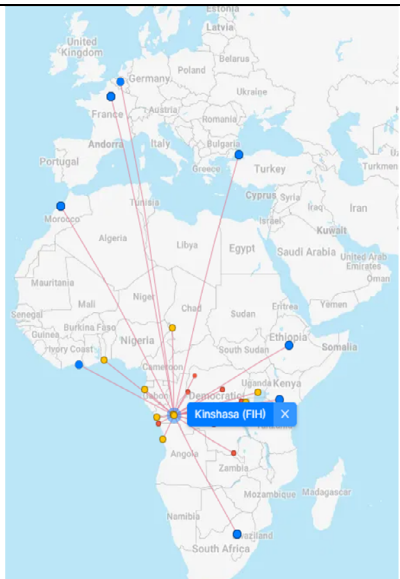
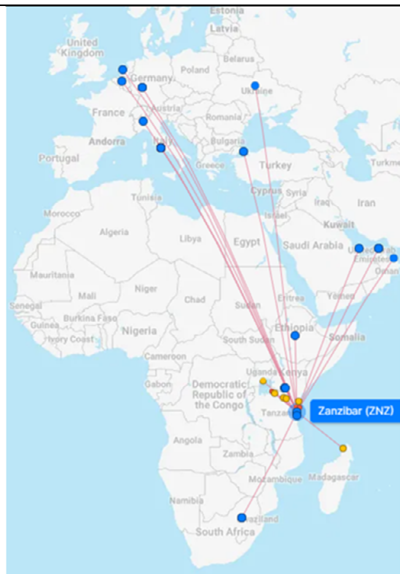
<td>

e) Democratic Republic of Congo: Largest world plantain producer.</td>
<td>

f) Tanzania: Major banana and plantain producer.</td>
</tr>
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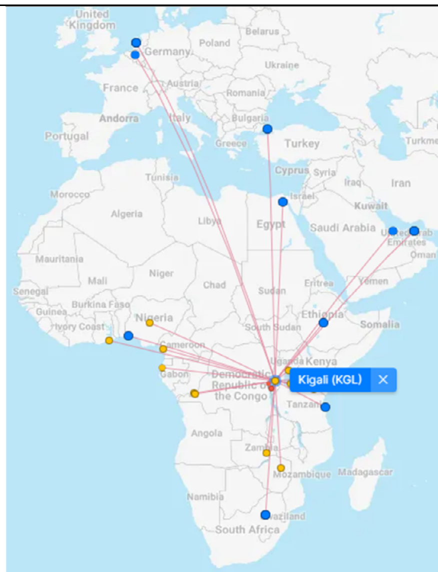
<td>

g) China: 2nd world banana producer *B. dorsalis* occurs in different regions</td>
<td>

h) Rwanda: major African banana producer.</td>
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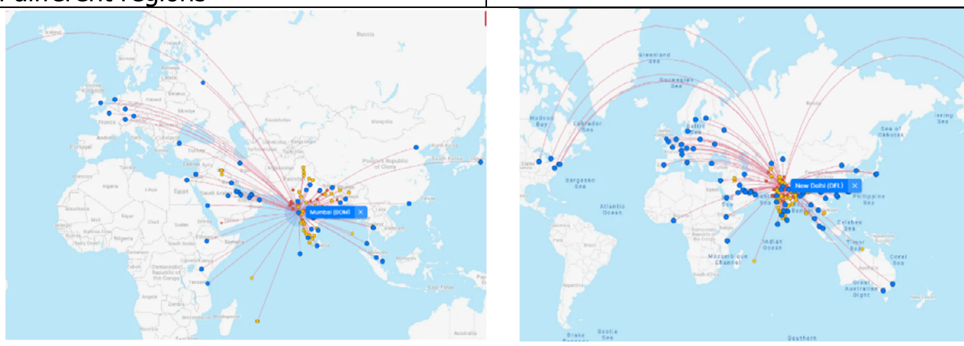
<td colspan="2">

i) India: very important banana producer (1st and 3rd world producer in terms of mean annual production in 2014-2018 and harvested area in 2018 respectively)</td>
</tr>
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