Chapter 8
Taxonomic Keys to Economic Fruit Flies (Diptera: Tephritidae) of the Sudan

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Abstract Fruit flies (Diptera: Tephritidae) are among the main constraints that limit the horticultural production in Sudan. The country has an enormous potential for horticultural production, over its wide range of climatic conditions and diverse ecosystems, but is threatened by an invasion of exotic fruit flies over its borders, due to weak interception and quarantine procedures. Thus, the correct identification of the pest is the first step in a management strategy for fruit flies. This study was carried out in order to produce identification keys for the economic fruit flies found in the Sudan. Intensive searching in the data of the National Insect Collection was carried out to ascertain the taxonomic status of the family Tephritidae (the true fruit flies) and its species of economic importance, among families of the order Diptera (the true flies). Specimens of fruit flies were identified morphologically at the National Insect Collection Unit at the Agricultural Research Corporation (ARC) and Faculty of Agriculture Biology Laboratory. The morphological identification of African tephritid fruit flies largely depends on the use of classical single-entry (dichotomous) keys. Taxonomic keys for the family Tephritidae and its genera were prepared, following the fruit fly taxonomic keys of White and Harris (Fruit flies of economic significance: their identification and bionomics. CAB International, Wallingford, 601 pp, 1992), De Meyer and Copeland (Taxonomic notes on the Afrotropical subgenera *Ceratitis* (*Acroptromma*) Bezzi and C. (Holpolophomiya) Bezzi (Diptera: Tephritide). Cimbebasia 17:77–84, 2001), and Billah (2005). As a result, six taxonomic keys for fruit flies were prepared: an introductory key to the family Tephritidae; and a key to the economic genera of Tephritidae, including *Ceratitis* spp., *Dacus* spp., *Bactrocera* spp. and *Carpomya* spp. from Sudan.

Keywords Fruit flies · Diptera · Tephritidae · Taxonomic key

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8.1 Introduction

Fruit flies of the family Tephritidae are among the most destructive agricultural pests in the world (De Meyer and Copeland 2001). Because of their widespread, agricultural impact and rapid expansion, tephritid fruit flies are the subject of quarantine and control efforts, worldwide (White and Elson Harris, 1992). There are about 450 genera and more than 4300 described species within Tephritidae, making it one of the largest families within the order Diptera.

Anastrepha Schiner, *Bactrocera* Macquart, *Ceratitis* MacLeay, *Dacus* Fabritius and *Rhagoletis* Loew are the most economically important genera, because many of their species are frugivorous. They infest almost every cultivated area and have wide bio-climatic adaptation potential (Bateman 1972). Thus, with the increasing movement of people and produce, they have the potential to invade other territories.

Sudan has enormous potential for horticultural productions over its wide range of climatic conditions and diverse ecosystems (Mahmoud 2011), but fruit flies are the main limiting constraints. More than 39 fruit fly species have been sampled in the Insect Museum of the Agricultural Research Corporation since early nineteenth century. Studies from 2008 to 2017 reported 19 species. The situation regarding fruit flies became exacerbated after the invasion of the country by the alien invasive species *Bactrocera dorsalis* in 2005 and by *B. zonata* in 2012. Competitive displacement between *B. dorsalis* and species of the genus *Ceratitis* MacLeay was noted, and was later reported between *B. zonata* and *B. dorsalis*, mainly on mango and guava. Fruit flies are reported as being the main insect pests that cause severe losses to fruit production, exceeding 80% for guava and 30–50% for the Abu Samaka mango variety, from 2005 to 2008 (Gesmalla et al. 2014). According to El Tahir and Taha Yousif (2004), in addition to the already existing problem of indigenous species in Sudan – *Ceratitis capitata*, *C. cosyra*, *Dacus vertebratus* and *D. ciliatus* – the country is threatened by invasions of many exotic pests.

Sidahmed et al. (2014), reported in their assessment of farmers' knowledge of fruit flies and their management, that only 12% of the interviewed farmers had high experience of fruit flies, and that 52% had received extension services and information about plant protection. 43% of the respondents use methyl eugenol to control fruit fly, with only 17% applying the correct dose. Several 'training of trainers' programmes (TOT) were held for plant protection directorate members, teaching staff, and extension and plant quarantine officers. In 2006, the International Center of Insect Physiology and Ecology held one TOT at the Agricultural Research Corporation, Wad Medani. More than 15 PhD and 25 MSc degrees were awarded by several Sudanese universities on various topics regarding basic studies or applied control of fruit flies. However, there is still a need for capacity building efforts to combat fruit flies, especially in taxonomy (Mahmoud et al. 2019).

The family Tephritidae has a history that is complicated by revisions in classification and taxonomy. Its taxonomic status has been repeatedly revised and positions of related groups have undergone complicated changes (White and Elson Harris 1992). Thus, there is a need to develop unified taxonomic keys to help in identifying flies easily so as to facilitate their control since an appropriate identification is one of the major tools in integrated pest management.

This study was carried out in order to create taxonomic keys for the economic fruit flies found in the Sudan in order to facilitate their identification by entomology students and researchers.

8.2 Materials and Methods

Intensive searching in the data of the National Insect Collection was done to ascertain the taxonomic status of the family Tephritidae (the true fruit flies) and of species of economic importance among the families of the order Diptera (the true flies).

Specimens of fruit flies were identified morphologically at the National Insect Collection Unit, at the Agricultural Research Corporation (ARC), and at Faculty of Agriculture Biology Laboratory.

The morphological identification of tephritid fruit flies largely depends on the use of classical single-entry (dichotomous) keys. Taxonomic keys for the family Tephritidae and its genera were prepared following the fruit fly taxonomic keys of White and Elson Harris (1992), De Meyer and Copeland (2001), White (2006) and Billah (2005). The species accounts include basic nomenclature details referring to White (2006). The keys, to the level of genera, were revised by Dr. De Meyer, The Royal Museum of Central Africa, Belgium.

Species groups were named by the type species name, with an initial letter as established by White (2006). Besides collecting fruit flies from orchards, four types of male lures (para-pheromones) were used: Cue lure (CUE) for *Bactrocera* and *Dacus* spp.; methyl eugenol (ME) for *Bactrocera* spp.; and terpinyl acetate (TA) and Trimedlure (TM) for *Ceratitis* spp. After transporting the captured flies to the laboratory, they were examined in taxonomic studies. A stereo binocular, a camel-hair brush, forceps, brushes and Petri dishes were used for this purpose.

8.3 Results and Discussion

Diptera represents one of the largest insect orders, comprising 43 families arranged in 300 genera that include about 700 species. Among these families, Tephritidae (the true fruit flies) is regarded as one of the largest families. The Tephritidae comprise 45 species, arranged in 21 genera; *Bactrocera* Macquart, *Carpomya* Costa, *Carpophthoromyia* Austen, *Celidodacus* Hendel, *Ceratitis* MacLeay, *Chelyophora* Rondani, *Coelotrypes* Bezzi, *Dacus* Fabricius, *Elaphomyia* saunders, *Ensina* Robineau-Desvoidy, *Euribia* Hendel, *Isoconia* Munro, *Leucotaeniella* Bezzi, *Myiopardalis* Bezzi, *Paroxyna* Hendel, *Platensina* Enderlein, *Rhabdochaeta* de Meijere, *Sphenella* Kützing, *Sphenicomyia* Bezzi, *Tephrella* Marston Bates, *Trupanea* Schrank and *Zeugodacus* Hendel.

The first three genera constitute the most concerning fruit flies that attack economically important fruit trees and vegetables. The most disastrous species are:

1. *Bactroceradorsalis* Hendel
2. *B. zonata* Saunders
3. *B. oleae* Rossi
4. *Ceratitis capitata* Wiedemann
5. *C. cosyra* Walker
6. *C. quinaria* Bezzi
7. *C. anonae* Graham
8. *Carpomya incompleta* Becker
9. *Dacus ciliatus* Loew
10. *D. frontalis* Becker
11. *D. bivittatus* Bigot
12. *D. vertebratus* Bezzi
13. *Zeugodacus cucurbitae* Coquillett

Six taxonomic keys of fruit flies were prepared during this study: an introductory key to the family Tephritidae; a key to the economic genera of Tephritidae found in the Sudan; and keys to *Ceratitis* spp., *Dacus* spp., *Bactrocera* spp. and *Carpomya* spp. in Sudan. These keys were compiled with reference to the efforts of White and Harris (1992), De Meyer and Copeland (2001), White (2006) and Billah (2005) who prepared reports on the taxonomic status of various fruit fly groups. They were prepared based on the distinctive characteristics of the economically harmful fruit flies. In these keys, there is an opposition of two traits and grading to others, until reaching the target group.

8.3.1 An Introductory Key to Family Tephritidae

1. Vein Sc abruptly bent forward at nearly 90° at the 3rd subcostal break. Dorsal side of vein R_1 with setulae. Wing is patterned by coloured bands. Wing basal cell cup with an acute extension.

TEPHRITIDAE

- Vein Sc not abruptly bent forward. Dorsal setulae on vein R_1 and frontal setae are absent; there is no any wing patterning and wing cell cup without an acute extension.

Non-Tephritidae

8.3.2 Key to Genera of Tephritidae of Economic Importance in Sudan

1. Wing cell cup is very narrow with very long extension. The 3rd segment of antennae is at least 3 times as long as broad. Head and thorax with reduced chaetotaxy; lacking ocellar, postocellar, dorsocentral and katepisternal setae.
   2

   Wing cell cup is broader than half depth of cell bm. Abdominal tergites are 5 with a pair of slightly depressed areas or ceromata.
   3

2. Abdomen with all tergites fused into a single plate with smooth transverse lines along boundaries. There is no overlapping in sclerites.
   DACUS

- Abdomen with all tergites separate with overlapping sclerites.
  BACTROCERA

3. Scutellum is usually convex and patterned with yellow and black areas. Head with 2 pairs of frontal setae.
   4

   Scutellum is concave and not patterned with yellow and black areas
   Non-target genus

4. Head without or with very small ocellar setae. Cell cup extension is about one-third as long as vein $A_1 + CuA_2$.
   CAPPARIMYIA

   Head with longer ocellar setae similar in length and strength to orbital setae. Cell cup extension is longer about half as long as $A_1 + CuA_2$.
   5

5. Scutellum with yellow areas, wing with pre-apical cross band on dm-cu which is isolated from the rest of the wing pattern. Basal cells of wing (c, br, bm and cup) with spot and fleck-shaped marks giving a reticulate appearance.
   CERATITIS

   Scutellum is flat, convex and patterned with yellow and black areas. Cell cup extension is short. Head with 3-4 pairs of frontal setae. Ocellar setae are very small, only as long as distance between anterior and posterior ocelli.
   CARPOMYA

8.3.3 *Key to* **Ceratitis** *Species of Economic Importance in Sudan*

1. Scutellum with yellow areas meeting margin, such that each apical scutellar is based in or adjacent to a yellow stripe

   2

   Scutellum with small black areas. Male mid tibia without stout setae arranged in such a way as to give a feathered appearance

   Ceratitis* (*Certalaspis*) *quinaria

2. Wing with apex of vein M not covered by diagonal coloured band. Yellow wavy band runs across base of scutellum. Male anterior pair of orbital setae is black with a sharp end to spatulate section.

   C.* (*Ceratitis*) *capitata

   Vein M may not be covered by diagonal coloured band. Yellow wavy band on scutellum not on across base. Male anterior orbital setae are not sharp to spatulate.

   3

3. Yellow band runs down to apex of scutellum dividing it to 3 dark spots. Wing banding brown to black, with a small break in costal band between costal break and R_1 or across R_1.

   4

   Wing banding more yellowish with no break in costal band. Scutellum also with 3 dark spots.

   5

4. Male with thick feathering on both mid femur and tibia along most of inner edge of femur with no gap in feathering.

   C.* (*Ceratitis*) *anonae

   Male with thick feathering restricted only to mid tibia.

   Non-target species

5. Scutum predominately yellow or pale brown with pattern of brown to black spots. Fore femur yellow on both sides. Postpronotal spot relatively big with an anterior seta. Costal band continuous.

   C.* (*Certalaspis*) *cosyra

8.3.4 *Key to* **Bactrocera** *Species of Economic Importance in the Sudan*

1. Scutellum with or without yellow areas, preapical crossband absent or not isolated. Basal cells of wing with consistent colour and no reticulate appearance.
2

Wing without a distinct costal band; cell sc often yellow, and apex of vein R_{4+5} with a brown spot. Scutellum with a triangular black mark.
3

2. Scutum with high degree of variations, from dark brown to black. Postpronotal lobe yellow. Scutellum yellow except a narrow black band at the base. Aggression of microtrichia in cell br. All femora yellow and tibiae dark with hind tibiae darker. Abdominal tergites 3-5 with black T-shape mark. Anatergite and katatergite both yellow. Males with pectin.
Bactrocera* (*Bactrocera) dorsalis* = *B. invadens

\- Scutum with both lateral and medial yellow stripes. Scutellum with 2 marginal setae. Wing with cross vein dm-cu covered by infuscate area which is separate from other parts of the wing pattern.
Zegodacus* (*Bactrocera*) *cucurbitae* = *B.* (*Zeugodacus*) *cucurbitae

3. Scutum and abdomen are pale orange-brown to red-brown. Scutum with only lateral yellow stripes. Presence of anterior supra-alar setae, prescutellar acrostichal setae. All the femora yellow, fore tibiae dark and hind tibiae with lighter middle part. No conspicuous black T-shape mark on abdomen.
B.* (*Bactrocera*) *zonata

\- Scutum without any yellow or orange stripes, although specimens with a distinct black area on the scutum may be red brown laterally, giving the appearance of lateral stripes. Area of wing close to apex with a dense patch of microtrichia.
B.* (*Daculus*) *oleae

8.3.5 *Key to* **Dacus** *Species of Economic Importance in the Sudan*

1. Scutum with lateral and/or medial yellow or orange stripes.
2

Scutum without any yellow or orange stripes.
3

2. Wing with very broad costal bands which extends below R_{4+5}, almost reaching vein M. postpronotal lobe pale at top and brown down.

Dacus* (*Dacus*) *bivittatus

Wing without such a broad costal band; combined depth of cells r_1 and r_{2+3} at r-m crossvein about equal to half-length of the r-m crossvein.

4

3. Both anatergite and katatergite with some yellow marking.

5

Yellow marking confined to only anatergite and katatergite brown.

6

4. General body colour orange-brown. Posterolateral area of thorax with a diagonal yellow stripe below the scutellum which extends across both katatergite, in front of the halter base, and anatergite.

D.* (*Dacus*) *punctatifrons

General body colour black. Posterolateral area of thorax with a yellow spot in front of the halter base which is confined to katatergite.

Non-target species

5. Yellow spot in anatergite separated from scutellum by its own diameter. Mid-femur yellow or orange, almost apical half slightly darker than basal half. Narrow costal band, with a small apical spot at tip. Two dark spots on lower scutum and a 3rd one on upper end which extends to a line. Abdominal tergite 3 with 2 dark spots on each side.

D.*(*Didacus*) *ciliatus

Postpronotal area of thorax with a diagonal yellow stripe below scutellum which extends across both katatergite and anatergite; stripe only separated from the scutellum by about $1/3$ of its length.

6

6. Yellow spot in posterolateral not confined to katatergite, but extends across both katatergite and anatergite forming stripe. Yellow stripe separated from scutellum only by $1/3$ of its length. All femora yellow in basal half and orange in apical one.

D.*(*Didacus*) *vertebratus

A predominately orange species. Basal parts of scutum with 2 black rounded spots on either sides of abdominal tergite 3. Most parts of anatergite covered by a yellow stripe. Apical half of mid femur darkened; no darkening in fore and hind femora. Apical spot of costal band extends more than $1/2$ way between veins R_{4+5} and M. Anterior supra-alar and prescutellar acrostichal setae present.

D.* (*Didacus*) *frontalis

8.3.6 *Key to* Carpomya *Species of Economic Importance in the Sudan*

1. Scutum consistently reddish-yellow. Scutellum regularly pale yellow. Wing with 3 slight cross-bands; without an apical cross-band.
Carpomya* (*Trypeta*) *incompleta
Scutum and scutellum bright yellow with black patches. Wing with 4 distinct cross-bands; apical cross-band joined to pre-apical one.
Carpomya* (*Myiopardalis*) *pardalina

8.4 Conclusion

The six taxonomic keys to fruit flies of economic importance in Sudan herein provided will facilitate their identification for students and researchers of Entomology and related disciplines. The taxonomic keys of the family Tephritidae, economic families, genera and species are recommended to be used in identifying fruit flies. Since taxonomy is a dynamic field in which names of different groups usually change and follow the species. Work in taxonomic keys on economic fruit flies should be continued to facilitate the identification process, which is the first step for fruit fly management.

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