Original Research Article

Seasonal spatial distribution of the mango fruit fly (*ceratitis cosyra*) in mango trees pruned to give three different pruning canopies in high density mango production in the South eastern Lowveld of Zimbabwe

Abstract

One of the major pest of economic importance and which restricts mango exports from infested production areas in the SADC region is the mango fruit fly (Ceratitis cosyra Walker). The effect of three pruning techniques, box/rectangle, spherical/round and the central leader, on assessing spatial distribution of fruit fly populations in high density mango production were investigated at Chiredzi Research station ($21^{0}01$'S, $31^{0}33$'E) from 2010 to 2013. Results showed a significant rise in the number of adult fly catches among pruning techniques as from July to December (p< 0.05). Traps baited with Malathion 25%WP with molasses as an attractant were used to trap the flies. Results from all treatments indicated a significant rise in mean adult fruit fly catches from the months of July up to December. It can be concluded that spatial distribution of the mango fruit fly is influenced by the fruiting and ripening patterns of mango.

Key word

High density, fruit fly, spatial distribution, adult catches, pruning techniques, mango

1.0 INTRODUCTION

The mango (*Mangifera indica*), originated in the Indo-Burma region where it grows in the wild forest, but is now grown throughout the tropics and in the sub tropics (1). It is sometimes called the 'king of fruits', by volume is the second largest tropical fruit crop in the world after bananas and fourth in total fruit after bananas, citrus and apples. It is native to north-eastern India and Burma. India, the main producer, accounts for 65 per cent of the world's mango crop, which is estimated at 16 million tonnes (2). Cultivation of mango has occurred for some 4000 years and the tree has great cultural and religious significance in some countries.

The mango is a densely-foliaged evergreen tree, some varieties of which grow to 20 m tall and live for 40 years or more. Once established, it serves as a useful windbreak, shade tree and ornamental, with attractive perfumed flowers. Its growth is marked by flushes of new bronze-pink leaves, three to five times a year. These turn green on reaching maturity. Flowers are produced on terminal panicles and occur during the early part of the dry season in the tropics and during spring in the warmer temperate regions. Fruit bearing is often biennial. The fruit is large, fleshy, delicious, drupe in size up to 20 cm long, yellow or red when ripe. Unripe fruits are used in pickles, chutneys, salads or consumed fresh. Ripe fruits are eaten raw as dessert, whole, or in fruit salads. They may also be frozen, dehydrated, canned or made into jellies, jams, juices and incorporated into yoghurts and iced confectionery. The mango is a good source of sugars, vitamins A and C and minerals. Production in the sub-tropics is however affected by pests and diseases. Of importance is the mango fruit fly (*Ceratitis cosyra* Walker) (3), (4), (5)

The mango fruit fly, *Ceratitis cosyra* (Walker), (4), (5) is also commonly known as the marula fruit fly, based on its common occurrence in these host plants (6), (7). Marula, (*sclerocarya caffra*) is a native African fruit related to mango and sometimes known locally as wild plum. This fly is a serious pest in smallholder and commercial mango across sub-Saharan Africa, where it is more destructive than the Natal fruit fly (*Ceratitis rosa* Karsch) (8), (9), (10), (11), (3), (12). Worldwide averages indicate that between 20 and 30% of the mango yield is lost due to fruit fly alone (13). Fruit fly of the genera have been widely reported as being economically important and infesting tropical fruits in Africa (14), (15). The fly's impact is growing along with the more widespread commercialisation of mango.

growing along with the more widespread commercialization of mango. Late maturing varieties of mango suffer most in sub-tropics (16), (1).

Body and wing colour is yellowish; sides and posterior of thorax prominently ringed with black spots, dorsum yellowish except for two tiny black spots centrally and two larger black spots near scutellum; scutellum with three wide, black stripes separated by narrow yellow stripes; wing length 4–6 mm, costal band and discal cross band joined. Adults are similar in size, coloration, and wing markings to medfly. The female fly oviposits into the mesocarp or pulp of the fruit just under the skin of the mango fruit (7). Affected fruits show oviposition punctures with dark stains (rotting) around them. The pulp is heavily mined and the mines contain many small white maggots (17). Prematurely ripening fruits fall off or bored mature fruits are often accompanied by fungi and bacteria which rot the fruit. Thus control measures are needed if marketable fruits are to be obtained (1).

One of the main aims of ecology is to understand the distribution and abundance of organisms (18). Knowledge of the distribution pattern in terms of an insect is very important because it is as a result of the interaction between individuals of the species and their habitat (19). Knowledge of this pattern allows a better understanding of the relationship between an insect and its environment and provides basic information for interpreting spatial dynamics, designing efficient sampling programs for population estimation and pest management (19), (20), (21), (22), and the development of population models (23). On the other hand, effective management of this fly on mango require a better understanding of the seasonal dynamics of the present species present in a locality. This ensures control measures are targeted at periods of population build up and or at the most vulnerable stage of the crop to achieve effective control (6).

In the south east dry areas of Zimbabwe, observation studies were conducted on an already established mango pruning trial over three seasons, with the view of monitoring the spatial distribution of the mango fruit fly over different periods of the mango fruiting and ripening cycle.. Observations revealed that there is a difference in susceptibility to attack by fruit fly basing on its spatial movement as influenced by different pruning techniques a farmer is likely to employ. Studies on different pruning techniques on susceptibilities in other countries (24) have found differences and therefore possible interpretations that there is an intrinsic benefit on different pruning techniques in the monitoring spatial distribution of the mango fruit fly. Control and management had always been by full cover spraying of broad spectrum pesticides but, this has broken down the ensuing desire in the instigation of this project. To date, no information is known about the distribution of the fruit fly, (*Ceratitis cosyra* Walker), a key pest of mango and many other fruits in the south eastern Lowveld of Zimbabwe. As such, the objective of this study was to ascertain the spatial distribution pattern of *Ceratitis cosyra* in the mango ecosystem through captures of adult flies using baits.

1.2 Methods and materials

1.2.1 Study site

The study was carried out at Chiredzi Research Station *(21^{0}01'S, 31^{0}33'E* 429 m above sea level*)* located in the southeastern lowveld (agro-ecological region 5) of Zimbabwe. It experiences temperatures ranging from 29 – 39^{0}C and can reach up to 42^{0}C and receive rainfall totals of 450-650 year round. Triangle PE1 series such as shallow sandy clay soils dominate (25).

1.2.2 Experimental procedure and treatments

The study was carried out on an already established 10 year old orchard with different pruning techniques and the cultivar was Haden. Treatments were laid in a randomized complete block design replicated 3 times. Trees were spaced at 5m between rows and 4m within rows and each plot was composed of three trees. Pruning techniques evaluated were Box, central leader (control) and round. Twenty seven trees were selected from an orchard of 60 trees. Baits were placed in the selected trees. Traps were suspended below the base of the canopy. Depending upon the dimensions of the tree, the distance from the ground to the base of the trap ranged from 90 cm-170 cm and distance from the outer edge of the canopy from 50 cm – 90 cm. Molasses was used as an attractant. Catches were set up at flowering stage until the crop was harvested. Daily catches were recorded per tree throughout the season. However due to degradability of chemicals used, trapping material was subject for renewal especially during the rainfall season. Traps were changed each morning after the rains and every week when there was no rain. Data was analysed using GENSTAT version 14. The data was subjected to one-way analysis of variance, and means separated at α=0.05 by least squared differences (LSD) (26). On average adult fruit fly catches, the data was transformed using arc-sine transformation after adding 0.5 to each value.

1.2.3 Monitoring of fruit fly adults and fruit damage

To study the seasonal movement of adult fruit fly in various canopies, monitoring was carried out from July 2010 to December 2013. In each plot, one bait trap was set up in the centre of the tree canopy and was hung 1.5 m above the ground in a shaded part of the plant. The bait traps consisted of transparent plastic bottles (capacity 1.5L) filled with 250 ml water. The bait consisted of 5 g of Malathion 25 % WP, 30 ml molasses diluted in one litre of water. On daily basis, a count of the flies captured over night was recorded. No chemical sprays were done throughout the study period. Recorded adult flies would be removed from the traps to give precedence for next day count. At harvest, fruits were inspected on damage inflicted by the fly. Harvesting was done three times a week at peak ripening period. Signs such as punctures, signs of rotting with some larvae were regarded in the inspection for damage. The fallen fruits from selected trees were included in the harvest while those from unselected trees were removed and destroyed to reduce fruit fly re-infestation inoculum. Total marketable and non-marketable yield was compiled for all treatmen

1.3 RESULTS

1.3.1 Spatial distribution of the adult fruit fly over seasons

The general trend of the distribution of the fruit fly across seasons indicate a rise in the total mean catches from 2011 to 2013 in all the pruning techniques (fig 1

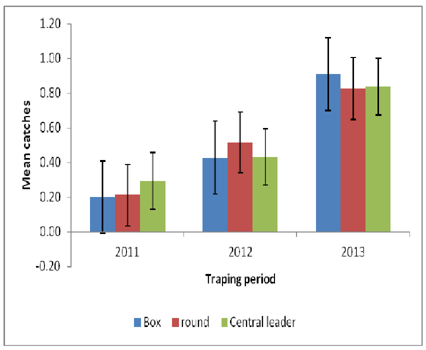

Fig. 1: Mean overall catches of Adult fruit fly distribution across seasons

However in 2011, the central leader recorded higher mean catches than all other treatments. In 2012 the round technique showed the highest which the central leader and box had almost the same number of catches. In 2013 the box technique had the highest while the central leader and the round were almost the same. There were no significant differences at p= 0.05 over the period from July to December for the three trapping seasons. It was also observed that mean catches dropped from July to September and started rising from September to December (fig 2).

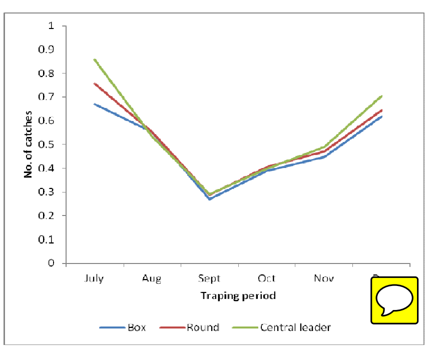

Fig. 2: Mean overall catches from July to December for 3 seasons

Yield

1.3.2 Effect of fruit fly damage on yield on box, round and central leader pruning techniques.

Despite the non significant relationship recorded on fruit fly catches among different pruning techniques over the study period, mango yield was however affected by the mango fruit fly. In 2011 the non marketable fruits were significantly high p<0.05 (fig 3). Damages ranged from 44-55% with round recording 55% damages. Round technique gave a total of 112.7 kg/tree in 2011 and dropped to 39 kg/tree in 2012.

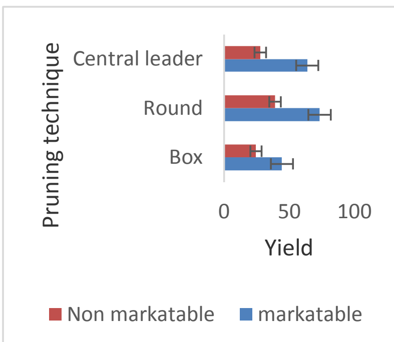

Fig. 3: Effect of fruit fly damage on yield on box, round and central leader pruning techniques in 2011.

In 2012 non markable yield was significantly lower p<0.05 (fig 4). It ranged between 18-20% of the total yield among treatments. The box technique recorded least damages. No significant yield results p<0.05 in 2013 were recorded among treatments.

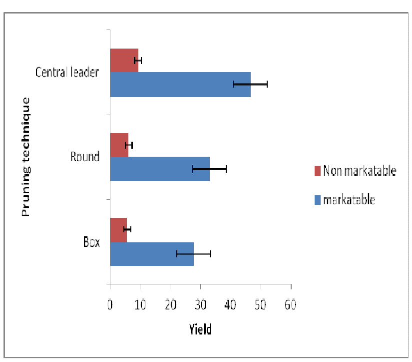

Fig. 4: Effect of fruit fly damage on yield on box, round and central leader pruning techniques in 2012.

No significant markatable yield differences were recorded among treatments. Percentage damage was significantly higher on the round technique which recorded 57 % over the 2013 season. Across the trapping seasons (Fig 5), no significant non markatable yield was recorded among treatments. Thirty five percent yield loss was recorded on the central leader while 44 % was recorded from the box and round techniques.

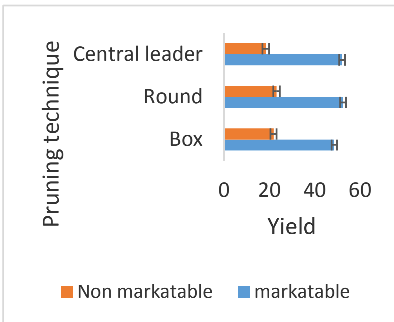

Fig. 5: Effect of fruit fly damage on yield on box, round and central leader pruning techniques across seasons.

1.4 DISCUSSION

Number of mean adult fruit fly catches increased in numbers in all treatments as well as throughout the trapping period from the months of November to December (Fig 2). The increase and distribution of the fruit fly coincided with the fruiting of both early and late maturing mango varieties as was observed by (15). In addition, the months of November to December are the wet periods in the south east agro-ecology, which is conducive for the population growth of C*eratitis cosyra* (29).

Production of mango is affected by *Ceratitis cosyra* (Diptera: *Tephritidae*). The earlier however cause large scale economic damage to the mango fruits (27). Fruit loses of up to 40% have been reported in some parts of Africa (28), (29), (30). The results from the study showed that the fly caused enormous damage (Fig 5) to mango fruits and can result in complete fruit loss if appropriate control measures are not taken (28), (7) in future. The high trap catches of the fly during the wet season was also corroborated by (29), (31) who observed an increase in trap catches for this pest shortly after the on-set of the fruiting cycle and the rain season.

Results also show an infestation gradient (Fig) that spread from the month of July to September and November to the month of December. This might mean that the number of catches among treatments was reduced during flower initiation (July –September) and increased during fruit setting and ripening period (November –December). This also concurred with the findings of (3) and (1), who observed that fruit bearing peaks of varieties result in an upward or downward trend of average mean catches of the fruit fly and also that damage by fruit fly can be severe and certain mango cultivars can totally be destroyed. Variations were also noticed on differernt treatments due to fruitng abilities after pruning. Number of fruititng bodies on mango depends on the mature branches that can bear fruits that season (32), (24). Usually pruned trees have less mature branches for that year. This concide well with (33) who observed that there is need to check the relationship between canopy size and fruiting. This also concurred with (15) who found out that the fly is attracted by either flowering or fruiting bodies on the plant.

The fruit fly population seem to be aggregated in the dense central leading method due to a thick canopy. The causes of this aggregation as declared by (34) and (38) might be due to active aggregation of the fruit fly such as behaviour whereby presence of each individual is influenced by sexual attraction, and reproductive biology influenced by the heterogeneity of the environment such as micro climate especially relative humudity and prefered part of the plant. Also (35) confirmed presence of prefered part of plant. Pertaining to behaviour, it can be explained that the fruit fly catches from all treatments baited with malathion/molasses combination, a highly potent attractant for the male and female flies of the *Ceratitis cosyra* specy (36), (37) and (35). Hence, the main reason they tend to aggreagate in the same situaition or habbitat might be sexual attraction or *Ceratitis cosyra* has a peak abundance at different times of the year.

The yield of mango was highly affected by fruit flies (Diptera: *Tephritidae*) as treatments recorded a non-marketable yield of 40% and above (fig. 5). During the 2012 season, the round technique recorded the highest number of damaged fruits caused by the fruit fly (Diptera: Tephritidae) (27). This was also reported by (28), (29), and (30) who found out that fruit loses of up to 40% have been reported in some parts of Africa. The results from the study showed that the fly therefore causes enormous damage to mango fruits and can result in complete fruit loss if appropriate control measures are not taken (28), (7). Damage may be more acute on mature fruits especially at the end of the ripening period as was reported by (1), that some mango varieties can be attacked severely either early or late in the season.

The observed levels of infestation in mango agree with earlier findings by (29), who reported high *Ceratitis cosyra* and *Bactrocera invadens* infestation is similarly acidic hosts. They suggested that *Ceratitis cosyra* and *Bactrocera invadens* might be adapted to a range of fruit characteristics. The guava (*Psidium guajava*) is a primary host for *B. invadens*, while *Annona spp.* and *Citrus spp*. are secondary hosts; and they will allow fruit fly population proliferation and trigger quick infestation in mango before the pick of the mango season (28). The growing of mangoes with other cultivated crops or near wild plants is a common practice in many farming communities in Zimbabwe; and will have implications on the control measures being developed. Also the high degree of aggregation of *Ceratitis cosyra* amongst all treatments indicates its potential coexistence with other trees species. This was corroborated by (39) who found out that other than mango, it is also associated with marula, guava and citrus. The attraction of the traps may lead to overestimating the size of local populations due to migration of insects attracted from adjacent areas (40) or there are probably other factors involved, including abiotic factors, which can have an influence upon the spatial distribution and that should be taken into account in future studies.

The effect several biotic and abiotic factors such temperature and humidity may be considered to have been the most important abiotic factors explaining population dynamics in insect species (41; 42). The role of temperature as a determinant of abundance in *Ceratitis cosyra* is mediated either directly or indirectly through its effects on rates of development, mortality, and fecundity. Rates of increase (or decrease) of individual populations are dependent upon the values of these parameters, and they in turn are determined by the multiple influences impinging upon the individuals from within the population's "life-system" (43).They tend to congregate in locations which provide shelter and food. These overwintering groups often form fairly stable populations because birth rate is zero, death rate is low, and movements are inhibited by low temperatures (44). They are usually restricted to patches of evergreen foliage such as citrus (44) and other "favourable" plants (45). They may become active enough to feed during the warmer hours of the days, but tend to return to the same sheltered foliage when temperatures fall.

1.5 CONCLUSION

In summary the results from this study showed that the mango fruit fly (*Ceratitis cosrya*) was the dominant fruit fly species in the mango ecosystem in the south eastern agro-ecology during the dry and wet season. The fly coincides with the main mango fruiting and ripening periods. Hence, control measures must be targeted at this pest during this period to forestall damage to the fruits. It is more dominant during end of the wet season by which time all early maturing mangoes will be harvested. Hence, the pest inflicts more damage on the late maturing mango cultivars. Farmers who cultivate late maturing cultivars must therefore adopt management strategies that are targeted at to the pest. Pruning is also one of the management options that can be used to manage the pest in high density production systems. Such pruned environment allow in light which is contrary to reproduction of the fly.

Disclaimer: - This manuscript was presented in the conference “11th Zimbabwe International Research” available link is “http://www.rcz.ac.zw/wp-content/plugins/download-attachments/includes/download.php?id=1381” date 16-17 February 2017.

1.6 RECOMMENDATION

Farmers should implement control measures for the management of the mango fruit fly prior to flower initiation to forestall damage to the fruits. Farmers who cultivate late maturing varieties should adopt management strategies that are targeted at the mango fruit fly (*ceratitis cosyra*).

REFERENCES

1. Manzungu, E, Rendell, C.H, Dirorimwe, W. (1991). Annual Report. Horticulture Research Inst
2. Johnson, P.R. and Robinson, D.R. (1997). An evaluation of mango (*Mangifera indica* L.) cultivars and their commercial suitability for the Kimberley. Department of Agriculture. 21/97 ISSN 1326-4168 Agdex 234/34
3. Rendell CH, Mwashayenyi E, Banga D J. 1995. The mango fruit fly: population and varietal susceptibility studies. Zimbabwe Science News 29: 12-14.

4. De Meyer M. 1998. Revision of the subgenus *Ceratitis* (*Ceratalaspis*) Hancock (Diptera: Tephritidae). Bulletin of Entomological Research 88: 257-290.
5. N'Guetta K. 1994. Inventory of insect fruit pests in northern Cote d'Ivoire. Symposium on tropical orchards, Montpellier, France, 30 August - 5 September, 1993. Fruits - Paris 49: 430- 431, 502-503.
6. Ekesi S and Billah, M.K (Eds.) (2009) A field guide to the management of economically Important Tephritid Fruit Flies in Africa. 2nd Edition. ISBN:92-9064-179-7 Pp.3-45
7. Lux, S.A, Ekesi S, Dimbi S, Mohamed S, Billah M.K (2003a). Mango infesting fruit flies in Africa-perspectives and limitation of biological approaches to their management. Pp 277-293.
8. Malio E. 1979. Observations on the mango fruit fly *Ceratitis cosyra* in the Coast Province, Kenya. Kenya Entomologist's Newsletter 19: 7.
9. Labuschagne T, Brink T, Steyn W.P, De Beer M.S. 1996. Fruit flies attacking mangoes -- their importance and post-harvest control. Yearbook South African Mango Growers' Association 16: 17-19.
10. Javaid I, 1979. Attack of mangoes in Zambia by the fruit fly *Pardalaspis cosyra*. Bulletin of African Insect Science 3: 17.
11. De Lima C.P.F and Javid I, 1979. Attack of mangoes in Zambia by the fruit fly *Pardalaspis cosyra*. Bulletin of African Insect Science 3: 17.
12. Lux S.A, Zenz N, Kimani S. 1998. The African fruit fly initiative: development, testing and dissemination of technologies for the control of fruit flies. ICIPE Annual Scientific Report 1998- 1999 7: 78-80.
13. Elson-Harris M. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. International Institute of Entomology, London. 601 pp.
14. Billah, M.K, Wilson D.D, Cobblah M.A, Lux S.A, Tumfo J.A (2006) Detection and preliminary survey of the invasive fruit fly, Bactrocera invadens (Diptera: Tephritidae) in Ghana . J.Gh. Sci.Assoc. 2(8):38-144
15. Mwatawala, M.W, De Meyer M, Makundi, R.H, Maerere, A.P (2009). Host range and distribution of fruit infesting pestiferous fruit flies (Diptera: Tephritidae) in selected areas of central Tanzania. Bull. Entomol. Res.,10: 1-13
16. Javaid I. 1986. Causes of damage to some wild mango fruit trees in Zambia. International Pest Control 28: 98-99.

17. Barnes, H.F. (1949). Gall Midges of Economic Importance, vol. vi.., Gall Midges of Miscellaneous Crops, pp.149-7. Crosby, Lockwood: London.
18. Andrewartha, H.G. and L.C. Birch. 1954. Distribution and abundance of animals. University of Chicago Press. Barnes, H.F. (1949). Gall Midges of Economic Importance, vol. vi.., Gall Midges of Miscellaneous Crops, pp.149-7. Crosby, Lockwood: London.
19. Sevacherian, V. and V.M. Stern. 1972. Spatial distribution patterns of Lygus bugs in California cotton fields. Environ. Entomol 21: 996-1001.
20. Taylor, L.R. 1984. Assessing and interpreting the spatial distribution of insect population. Annu. Rev. Entomol. 29: 321-358.
21. Binns, M.R. 1986. Behavioural dynamics and the negative binomial distribution. Oikos 47: 315-318.
22. Kuno, E. 1991. Sampling and analysis of insect populations. Annu. Rev. Entomol. 35: 285-304.
23. Croft, B.A. and S.C. Hoyt. 1983. Integrated management of insect pests of pome and stone fruits. Wiley, New York
24. Thorp, T.G. and Stowell, B. 2001: Effect of pruning height and selective limb removal on yield of large 'Hass' avocado trees. HortScience 36 (4): in press
25. Vincent V, Thomas RG, 1960. Agricultural Survey of Southern Rhodesia Part 1- Agro-Ecological Survey, Salisbury. Government Printers Pp1
26. SAS INSTITUTE 1987 .SAS/STAT guide for personal computers, version 6 edition. SAS Institute Inc., Cary, NC.
27. White IM, Elson-Harris M. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. International Institute of Entomology, London. 601 pp.
28. Billah MK (2007). ECOWAS fruit fly scoping study and regional action programme. Evaluation of the fruit fly problem in Ghana. A report on Ghana. 47pp.
29. Vayssieres J.F, Goergen G, Lokossou O, Dossa P, Akponon C (2005). A new Bactrocera species in Benin among mango fruit fly (Diptera: Tephritidae) species. Fruits 60: 1-9.
30. Nboyine J.A, Billah M.K, Afreh-Nuamah K (2012). Species range of fruit flies associated with mango from three agro-ecological zones in Ghana, J. Applic. Biosci., 52: 3696-3703

31. Vayssieres J.F, Sinzogan A, Korie S, Ouagoussoun I, Odjo A (2009). Effectiveness of spinosad bait sprays (GF-120) in controlling mango infesting fruit flies (Diptera: Tephritidae) in Benin. J. Econ. Entomol. 102(2): 515-521
32. Wünche, J.N. and A.N. Lakso 2000: Apple tree physiology – implications for orchard and tree management. Compact Fruit Tree 33 (3): 82-88.
33. Tustin, D.S. 2000: The evolution of central leader apple tree management in New Zealand. Compact Fruit Tree 23 (3): 83-92.
34. Southwood, T.R.E (1978) Ecological methods with particular reference to the study of insect populations. 2nd Ed. Chapman and Hall, London
35. Stonehouse J, Mahmood R, Poswal J, Mumford J, Baloch K.N, Chaudhary Z.M, Makhdum, A.H, Mustafa G and Hugget D (2002b). Farm assessments of fruit flies (Diptera: Tephritidae) in Pakistan: distribution, damage and control. Crop Protection 21:661-669
36. Chuah, C.H, Yong H.S, Goh, S.H (1997) Methly eugenol, a fruit fly attractant from the browning leaves of *Proiphys amboinensis* (Amaryllidaceae). Bio-Chemical Systematics and Ecol. 25 (5): 391-393
37. Stonehouse J, Afzal M, Zia Q, Mumford, J Poswal and Mahmood A (2002a). Single Killing point field assessment of bait and lure control of fruit fly (Diptera; Tephritidae) in Pakistan. Crop Prot. 21: 651-659
38. Wratten, S.D and Fry, G.L.A (1980) Field and Laboratory exercises in ecology. 1st published by Edward Arnold Ltd. London
39. De Meyer M., Robertson M. P., Mansell M. W., Ekesi S., Tsuruta K., Mwaiko W., Vayssières J. F., Peterson A. T. 2010. Ecological niche and potential geographic distribution of the invasive fruit fly *Bactrocera invadens* (Diptera, Tephritidae). Bull. Entomol. Res. 100: 35–48.
40. Jenkins, A.D, Epski, N.D, Kendra, P.E, Heath, R.R, Goenaga, R (2011) Food-based lure performance in 3 locations in Puerto Rico: attractiveness to Anastrepha suspense and A. oblique (Diptera: Tephritidae). - Fla. Entomol. 94: 186-194.
41. Duyck, P.F., David, P. and Quilici, S. (2004). A review of relationships between interspecific competition and invasions in fruit flies (Diptera: Tephritidae). Ecological Entomology 29 (5): 511–520.

42. Vayssières, J.F., Carel, Y., Coubes, M. and Duyck, P.F. (2008). Development of immature stages and comparative demography of two cucurbit-attacking fruit flies in

Reunion Island: Bactrocera cucurbitae and Dacus cilitus (Diptera: Tephritidae). Environmental Entomology 37 (2): 307–314.

43. Clark, L.R., Geier, P.W., Hughes, R.D., Morris, R.F. (1967). The ecology of insect populations in theory and practice. London: Methuen.

44. Monro, J. (1966). Population flushing with sexually sterile insects. Science 151: 1536-1538

45. Nishida, T. (1963). Zoogeographical and ecological studies of Dacus cucurbitaein India. Hawaii Agricultural Experimental Station Technical Bulletin 54: 28