BioPublisher

Bioscience Methods 2014, Vol.5, No.3, 1-11
http://bm.biopublisher.ca

Research Article Open Access

Seasonal phenology of *Bactrocera invadens* (Drew, Tsuruta and White) and *Ceratitis cosyra* (Walker) (Diptera: Tephritidae) in Northern Ghana

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Bioscience Methods, 2014, Vol.5, No.3 doi: 10.5376/bm.2014.05.0003
Received: 05 Oct., 2014
Accepted: 18 Nov., 2014
Published: 02 Dec., 2014

Preferred citation for this article:
Badii et al., 2014, Seasonal phenology of *Bactrocera invadens* (Drew, Tsuruta and White) and *Ceratitis cosyra* (Walker) (Diptera: Tephritidae) in Northern Ghana, Bioscience Methods, Vol.5, No.3 1−11 (doi: 10.5376/bm.2014.05.0003)

Abstract Sustainable management of fruit flies in any given ecology requires proper understanding of the population dynamics of key species in relation to host availability and the influence of abiotic factors. Studies were conducted to determine the phonological patterns of *B. invadens* and *C. cosyra* in the northern savanna ecology of Ghana. Fruit samples from 12 main host plants were collected from multiple sites at regular intervals between October, 2011 and September, 2013. These were maintained for pupal and adult fly emergence, and the results compared with the seasons and whether parameters. The widespread variability and abundance of fruit species in the ecology ensured year-round breeding of *B. invadens* and *C. cosyra* with different seasonal population levels. Dynamics of emergence of the flies fluctuated at various levels in response to availability of the host fruits and the influence of weather factors. Regression analysis indicated that precipitation showed the strongest influence on the fly populations. Infestation of *B. invadens* was positively related with temperature, relative humidity (RH) and precipitation while *C. cosyra* infestation was negatively related with RH. These studies provide baseline information on the natural anundance and occurrence periods of the main hosts and their influence on tephritid population patterns in Ghana. This can be useful in the development of sustainable control programmes by way of developing forecasting models for IPM decision making, applying sanitary measures, male annihilation techniques and setting up bait stations at the best period before the cropping season.
Keywords Tephritid species; occurrence pattern; host plants; climatic factors; savanna ecology

Introduction

The horticultural industry in sub-Saharan Africa is confronted with several constraints including the incidence of pests and diseases (Norman, 2003). The fruit and vegetable production sector in particular is threatened with infestation by fruit fly pests (Lux et al., 2003). Tephritid fruit flies are considered to be of greatest concern owing to their extensive damage and economic losses to major fruit and vegetable crops, coupled with their quarantine status (White and Elson-Harris, 1992; Ishida et al., 2005; De Meyer et al., 2007). Economically important fruit fly pests in Africa belong to the genera *Bactrocera*, *Ceratitis*, *Dacus and Trirhithrum* (De Mayer et al., 2007). Most species of these genera are highly polyphagous, attacking several cultivated and wild fruits and vegetable crops (De Mayer et al., 2007). In Ghana, the earlier fruit flies observed to be of major concern were *C. capitata* (Wiedman) which attack citrus (Afreh-Nuamah, 1999), and *C. cosyra* (Walker) which attacked mango (Lux et al., 2003). However, the arrival of the African invader fly, *B. invadens* (Drew et al., 2005) has jeopardized the situation in the fruit and vegetable production sector (Lux et al., 2003; Vayssieres et al., 2005; Drew et al., 2005; Billah et al., 2006). In the northern part of Ghana in particular, production of major fruit and vegetable crops such as mango, water melons, tomato, peppers and the cucurbits has been severely hit with heavy losses from fruit fly attack.

Harrington et al. (1999) noted that plant susceptibility to insects depends on the phenological synchrony between the insect and the host plant. In turn, a suitable plant for the development of insect populations can often escape herbivory infestation and damage by its occurrence in time and space (Fahrig, 2003; Klapwijk and Lewis, 2008). This might be because the seasonal pattern of the insect may not coincide with the plant susceptible stage or period of occurrence (Messina and Jones, 1990). Knowledge about fruit fly species and their respective seasons of occurrence in relation to host plant phenology is crucial to understanding the population dynamics of these economically important insects (Souza-Filho et al., 2009). According to Messina and Jones (1990), fruit infestation by tephritid pests is influenced by its degree of maturation during the fruit fly oviposition period. Foraging differences can be observed as fruit flies make incursions into fruits of certain developmental stage. According to Dias and Vásquez (1993), such information can be obtained by collecting and incubating host fruits throughout their development or maturation periods. Papadopoulos et al. (2001) noted that in the tropics, the phenology and abundance of fruit flies is determined by environmental temperature, rainfall, relative humidity, and host fruit availability. These environmental variables show annual fluctuations within optimum levels and are therefore, much of limiting factors in population establishment and persistence of tephritid species (Lv et al., 2008).

The African invader fly, *B. invadens* and the mango fruit fly, *C. cosyra* have been considered the most economically important fruit fly pests in sub-saharan Africa (Lux et al., 2003) owing to their quarantine status and losses recorded in fruit and vegetable crops (STDF, 2009). The seasonal occurrence of these pests in relation to host phenology and abiotic factors in the sub-region is yet to be fully optimized. In fact, only few studies in Africa have examined the effect of host fruit and weather variability on population fluctuations of *B. invadens* and *C. cosyra* (Mwatawala et al., 2009; Vayssieres et al., 2009; N’diaye et al., 2012). N’diaye et al. (2012) found that the dynamics of emergence of tephritid species in mango orchards in the Niayes and the Thies Plateau of Senegal fluctuated in response to the occurrence and ripening periods of the main host plants. Fruit fly populations outside mango season was sustained at various levels by the diversity of fruit trees, changes in weather factors, lack of pest control and poor orchard care. Vayssieres et al. (2009) in a correlation study of fruit fly infestation of major mango cultivars reported that temperature, relative humidity and rainfall were the major factors influencing fruit fly populations in northern Benin. Mwatawala et al. (2009) observed that widespread variability and abundance of fruit species in certain localities of central Tanzania ensured year-round breeding of fruit fly pests.

At present, no known studies have been conducted in Ghana to monitor the seasonal occurrence and phonological patterns of these species through the host fruit collection and incubation approach. Preliminary trapping by Billah et al. (2006) in the forest ecology of Ghana revealed the presence of high populations of *B. invadens* and *C. cosyra* in mango orchards. Updated reports by Billah (2012) and Nboyine et al. (2012) in the savanna ecology of Ghana have confirmed that *B. invadens* and *C. cosyra* still remain the most dominant and damaging fruit fly species in northern Ghana. It was imperative to obtain baseline data on the seasonal occurrence pattern of fruit flies and the influence of host phenology and abiotic factors on the activity of these pests in the ecology. This would be helpful in developing and implementing management programmes for tephritid pests in the country. The present study determined the seasonal pattern of occurrence of *B. invadens* and *C. cosyra* as affected by availability of major hosts and abiotic parameters in the northern savanna ecology of Ghana. The primary goals were to monitor the seasonality of the pests, and establish the importance of the different host fruits for population development in relation to temperature, rainfall and relative humidity.

1 Materials and Methods

1.1 Fruit collection

To determine the seasonal phenology of *B. invadens* and *C. cosyra* in the savanna ecology of Ghana, fruit samples were collected from predetermined host plants in the area. Collections were made from multiple sites in the Northern, Upper West and Upper East regions of the country between October, 2011 and September, 2013. A total of five sampling localities were selected in each region for the collection programme (Table 1). Fruit species included in the study were those that proved to be the main hosts of *B. invadens* and *C. cosyra* based on previous survey records in the area (Nboyine et al., 2012). Details of the selected fruit species sampled for the study are shown in Table 2. Ripe, semi-ripe and mature fruits as well as fruits from underground as windfalls or senescence were collected.

Table 1 Sampling localities in northern Ghana with their agroecological zones from which fruit samples were collected for the study

Province/Region	Collection site	Agro-ecology
Northern	Tamale suburbs	Guinea savanna
	Salaga woodland	Guinea savanna
	Damongo forest	Guinea savanna
	Daboya valleys	Guinea savanna
	Gushie bushland	Guinea savanna
Upper West	Wa suburbs	Sudan savanna
	Wahabu forest	Sudan savanna
	Daffiama bushland	Sudan savanna
	Wechiaw woodland	Sudan savanna
	Babille bushland	Sudan savanna
Upper East	Bolga suburbs	Sudan savanna
	Sandema woodland	Sudan savanna
	Navrongo bushland	Sudan savanna
	Zebilla hills	Sahel savanna
	Bawku bushland	Sahel savanna

The number of fruits in a sample varied according to the species and their on-site abundance. Sampled fruits were placed in plastic bags with the appropriate labels. Each plastic bag was put inside a piece of synthetic mesh and placed in a plastic container. The ends of the synthetic mesh was pulled and tightened over the rim of the container, lifting the fruits off the bottom of the container. They were secured in this position by fitting the plastic lid of the container over the mesh. Elevating fruits over the bottom of the container avoids physical damage to fruits on the rough local roads. To ensure adequate ventilation, the middle portion of each lid was cut out and replaced by 10 x 15 cm piece of tight-weave synthetic mesh capable of retaining any emerged insects. During transportation of fruits from field to laboratory, the containers were covered with moistened cotton fabric to avoid excessive heating.

Table 2 List of the main hosts of *B. invadens* and *C. cosyra* in northern Ghana from which fruits were sampled for the study

Fruit species	Common name	Habitat	Total no. Samples
Mangifera indica L.	Mango	Cultivated	53
Sclerocarya birrea A. Rich.	Marula plum	Wild	19
Annona senegalensis Pers.	Sour sop	Wild	30
Terminalia catapa L.	Tropical almond	Wild	53
Diospyros mespiliformis A. DC.	Persimon	Wild	38
Ficus syncomosus L.	Syncomore fig	Wild	25
Ziziphus mucronata Willd.	Jujube	Wild	19
Sarcocepholus latifolium Smith. Bruce	African peach	Wild	71
Vitellaria paradoxa C.F. Gaertn	Sheanut	Wild	69
Capsicum anuum L.	Green pepper	Cultivated	32
Icacina senegalensis Juss.	Icacina, false yam	Wild	59
Ximenia americana L.	Albarillo	Wild	41

1.2 Fruit incubation

In the laboratory, fruits in each sample were counted and weighed before being placed in incubation units. An incubation unit consisted of a 1.5-litre rectangular plastic container with 0.5 cm ellipsoid holes cut into the bottom. An ellipsoid-shaped hole (but not circular) prevented fruits from clogging the holes during incubation while at the same time allowing mature larvae of fruit flies to fall through after they had exited the host fruit. The lid of the container was cut open at 1.0 x 0.5 cm on the middle and covered with a synthetic mesh. The container with holes was covered with the lid and nested into a second container (without holes at the bottom). A layer of sterilized sand was placed at the bottom of the second container to serve as pupation medium for the exiting larvae in addition to soaking up fruit juice.

The incubation units were arranged on metal shelves, the legs of which were placed in a water-filled container, thus helping to supplement humidity while simultaneously acting as a effective barrier to strange insects. Each fruit sample was maintained for a minimum period of 4 weeks at 25±3 ℃ and 60±10% RH. The 4-week holding period encompassed the period of larval pupation, and most fruits were shrunken and dry by the end of the period (Copeland et al., 2002). During the holding period, fruit samples were kept moist by spraying with fine mist of water as needed, but spraying was avoided on fruits samples that were prone to mouldiness. Under drier conditions, large containers were filled with water and placed around the corners of the rearing room to help maintain a relatively high humidity.

1.3 Insect monitoring

Each incubation unit was checked daily for the presence of puparia, which were picked up using a pair of soft forceps or by gently sifting. The puparia recovered were handled based on the procedure of Mwatawala et al. (2009) for adult fly emergence. These were counted before being placed in petri dishes with moistened filter paper. The petri dishes containing the puparia were placed in small ventilated transparent rectangular plexiglas (perpex) used as rearing cages. These were held at 26-28 ℃ and 60-70% RH, a condition adequate for preventing pupal water loss while minimizing development of moulds. The puparia were held in the cages for 5 to 7 days for the emergence of adult flies. Emerged adults were monitored following the procedure described by White and Elson-Harris (1992) and N'diaye et al. (2012). Emerging flies were maintained for 3 days during which full adult development and body coloration were attained to enhance identification. The flies were killed (by freezing) and the number from each fruit species recorded in a data sheet.

1.4 Meteorological data

Meteorological data on mean monthly precipitation, air temperature and relative humidity for the study period were obtained from the various Meteorological Units under the Savanna Agricultural Research Institute (SARI), Ghana. The meteorological stations for the Guinea savanna, Sudan savanna and Sahel savanna zones were located in Nyankpala (Northern Region), Wa (Upper West Region) and Manga (Upper East Region), respectively.

1.5 Data analysis

Fruit infestation data were processed using Microsoft Excel and XL Stat for the analysis of variance and mean comparisons. Infestation level (number of flies per unit weight of fruit) was determined according to the procedures given by Copeland et al. (2002). The ANOVAs for fruit species in relation to emergence of *B. invadens* and *C. cosyra* took particular account of various sampling seasons (months) and the weather parameters (precipitation, air temperature and relative humidity). Relationship between fly emergence and weather variables was tested using multiple linear regression analysis following the procedure of Yonow et al. (2004) to look at the changes in fruit fly abundance across host fruits, seasons and climatic factors.

2 Results

2.1 Host infestations

The infestation data for the 12 main host reservoirs of *B. invadens* and *C. cosyra* indicated that infestation level varied significantly with type of fruit ($P < 0.001$). Mean number of *B. invadens* per kg fruit was highest in sheanut, followed by African peach, tropical almond, persimmon, icacina and mango. Albarillo and jujube recorded the lowest infestation for *B. invadens* while the rest of the fruit species recorded moderate infestations with significant variations among them. On the other hand, mean number of *C. cosyra* was highest in African peach, followed by albarillo, jujube and icacina with significant differences among them. Mango and sour sop recorded the lowest number of *C. cosyra* per unit weight of fruit. It general, fruit species that suffered heavy infestation by *C. cosyra* were slightly infested by *B. invadens*, and vice versa (Table 3).

Table 3 Infestation data for the main hosts of *B. invadens* and *C. cosyra* in northern Ghana

Fruit species	Avg. no. fruits /sample	No. *B. invadens*/kg fruit*	No. *C. cosyra*/kg fruit*
Mango	4.0	60.1 ±3.0 d	11.5 ±1.7 a
Marula plum	25.5	51.3 ±2.8 c	47.7 ±3.0 d
Soursop	19.8	45.2 ±3.1 b	24.2 ±2.6 b
Tropical almond	30.6	65.5 ±4.4 e	85.4 ±10.0 f
Persimmon	59.4	65.0 ±6.8 e	36.3 ±2.9.1 c
Syncomore fig	35.0	42.5 ±1.4 b	72.4 ±7.2 e
Jujube	177.5	37.4 ±2.0 a	122.0 ±11.1 h
African peach	18.5	70.7 ±9.6 f	143.0 ±19.0 i
Shea nut	23.7	80.1±11.0 g	90.6 ±12.1 f
Green pepper	20.7	47.8 ±2.4 bc	32.4 ±2.7 c
Icacina	35.5	64.4 ±4.4 e	111.7 ±15.8 g
Albarillo	167.0	35.6 ±2.0 a	128.8 ±12.0 h

Note: * Mean number ±standard error. Means with same letters within columns are not significantly different at p = 0.05

2.2 Seasonal fluctuations

Suitable hosts were available throughout the year for both *B. invadens* and *C. cosyra*. Figure 1 shows the seasonal trends of occurrence and infestation levels of the 12 main host species recorded in the area. Green peppers were available during both dry and wet seasons

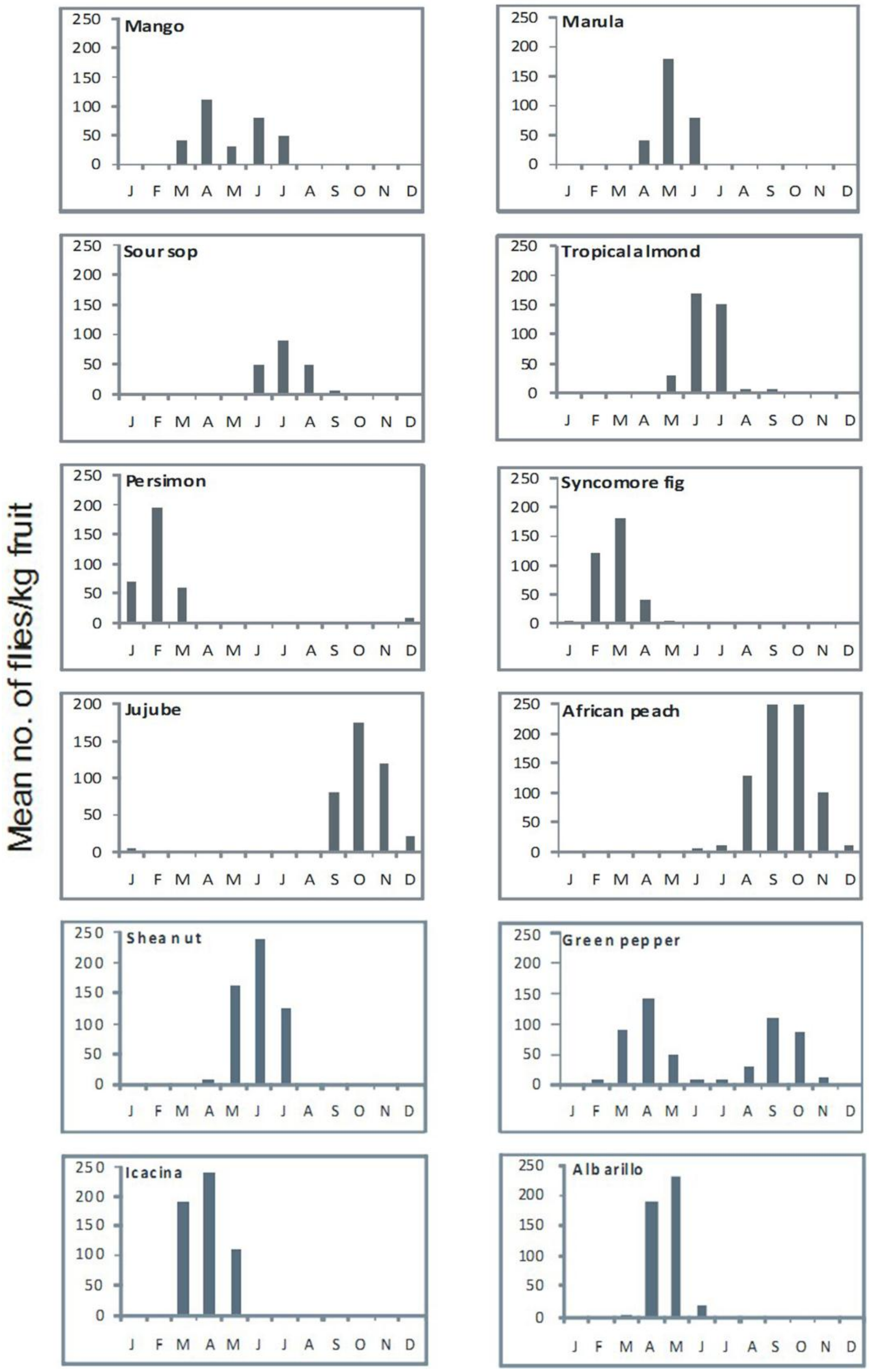

Figure 1 Seasonal trends in infestations by *B. invadens* and *C. cosyra* (pooled data) in12 main host plants in northern Ghana

under irrigated and rainfed conditions. During the major dry season (December-March), persimmons and syncomore figs dominated the wild fruit flora with infestation peak reaching 200 flies per kg fruit. During the early dry season (April-June), the host flora was succeeded by both cultivated and wild species dominated by mango, icacina, albarillo, marula plum, tropical almond and sheanut. The peak infestation of these species occured in alternation over the months with each fruit species recording not less than 100 flies per kg fruit at the peak fruiting period. The mango season stretched from mid March to early July with peak infestation in April and June for the early and late season mangoes, respectively. These fruit species were widely distributed in the ecology, providing fertile breeding grounds for the resurgence of both *B. invadens* and *C. cosyra*. Moreover, the occurrence of other wild fruits such as syncomore figs and sour sops generally overlaped the early rainy season, serving as important survival niches especially through the prolonged spells in parts of May and June.

The mid season period, which stretched from July to September, was dominated by tropical almonds, peaches and sour sops, with some patches of late mangoes, sheanut and albarillos. Tropical almonds and peaches appeared to be the major reservoir hosts for the flies during this period. The major peach season began in August and extends through the end of the year. This species proved to be the most abundant, persistent and widely distributed hosts in the ecology accounting for the highest populations of *B. invadens* and *C. cosyra* during September and October. Wild jujube also becomes available as alternative reserviours for the flies from September until the end of December during which time syncomore figs and persimmons begin their re-apperance as suitable hosts for the flies through the drier periods of the new year.

The results obtained relating to the emergence of the fruit fly species from the main hosts compared as a function of the study regions and seasons are shown in Figure 2. It was observed that fruit fly infestation was generally highest in the Northern region and lowest in the Upper East Region while the Upper West Region experienced moderate infestation. In all regions, emergence of both fruit fly species was at the lowest level at the beginning of the year, but this assumed a sharp increase after February, reaching a peak around August. Thereafter, tephritid emergence dropped steadily to very low level by December. During the first four months, rate of emergence of *C. cosyra* was found to be higher than that of *B. invadens*, but the reverse occurred from April until August when *C. cosyra* becomes dominant again for the rest of the season.

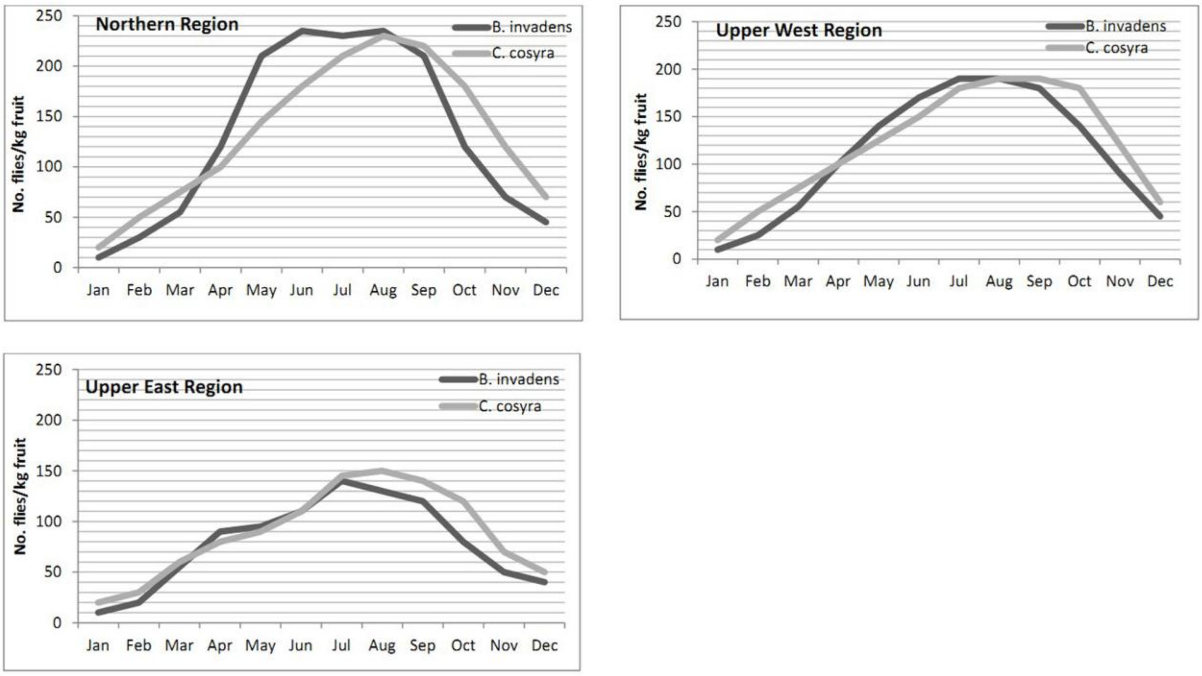

Figure 2 Emergence dynamics of *B. invadens* and *C. cosyra* from the 12 main hosts (pooled data) in relation to the study regions

2.3 Effect of abiotic factors

The relationship between the climatic factors and fruit fly population dynamics is shown in Figure 3. Tephritid populations were generally regulated by changes in rainfall, temperature and relative humidity. The fly species generally appeared at low numbers at the start of the rainy season, became more abundant at the peak of the rains and drastically declined at the end of the rains. Between the months of January and March, low precipitation coincided with minimum relative humidity with increasing air temperature. During this period, average infestation levels of both *B. invadens* and *C. cosyra* were as low as 10.0 and 20.0 flies per kg fruit, respectively. However, as precipitation increased from 50 mm in April to the peak of about 240 mm in September, there was a consistent increase in relative humidity (from 45.5 to 59.0 %) with a decrease in air temperature (from 34.9 to 29.8 ℃). This conditions greatly favoured tephritid populations, with infestation levels of *B. invadens* and *C. cosyra* increasing to the peak of about 186 and 210 flies per kg fruit, respectively. However, as average precipitation assumed its sharp drop between October and December, there was a corresponding decrease in relative humidity with some fluctuations in average air temperature. During this period, tephritid numbers dropped steadily to their lowest levels.

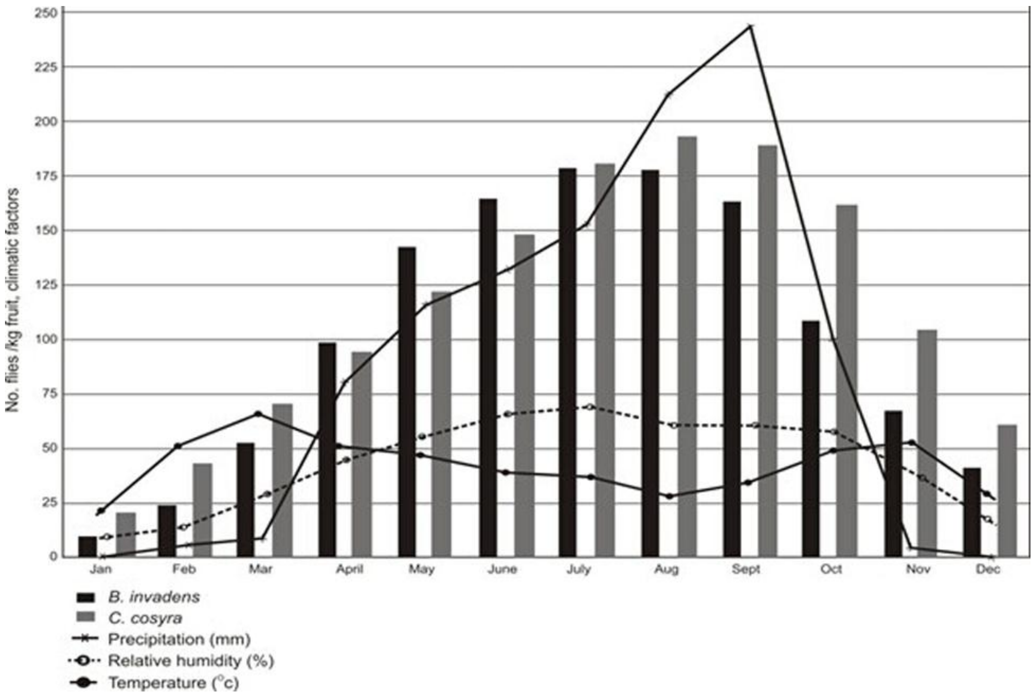

Figure 3 Relationship between climatic factors and infestation levels of *B. invadens* and *C. cosyra* on the 12 main host plants (pooled data)

Table 4 shows the results of the regression analysis of counts of *B. invadens* and *C. cosyra*. Regression between the climatic factors and infestation levels of the fly species indicated that temperature, mean relative humidity and rainfall all had positive relationship (r^2 =0.58) with *B. invadens* numbers. As described previously, these parameters increased during the fruiting season of many host plants. At the onset of the first effective rains in April, and with a considerable increase in relative humidity, the population of *B. invadens* rapidly resurged and became widely predominant from April to July. The first effective rain at 50 mm probably led to a very rapid increase in the population of *B. invadens* to a level higher than *C. cosyra* until August (Figure 3). Moreover, the high season x mean relative humidity interactions showed that as fly populations declined towards the late season, the mean relative humidity begun to decrease. Thus, temperature and rainfall had positive relationship (r^2 = 0.60) with the upsurge of *C. cosyra* population upsurge while relative humidity had negative correlation (r^2 = 1.98). For both fruit fly species, only rainfall showed positive relationship (r^2 = 0.77) with total average infestation levels (Table 4).

Table 4 Regression analysis of counts of *B. invadens* and *C. cosyra* with climatic factors

Covariates	Likelihood ratio chi-square (p<0.05)		
	B. invadens	*C. cosyra*	Both species
Month (12-lev. factor)	57.34	206.13	63.30
Max. Temp	(+) 11.00	ns	(−) 30.06
Min. Temp.	(+) 0.64	(+) 71.06	(−) 34.12
Mean-RH	(+) 31.00	(−) 46.00	(−) 130.00
Rainfall	(+) 601.23	(+) 12.05	(+) 110.68
Month x Max. Temp.	(−) 398.50	ns	(−) 113.40
Month x Min. Temp.	(−) 59.07	ns	(−) 245.95
Month x Mean RH	ns	(−) 329.90	(+) 143.05
Month x Rainfall	ns	ns	(−) 105.25
Max. Temp. x Min. Temp.	ns	ns	(+) 11.20
Max. Temp. x Mean RH	ns	ns	(+) 105.99
Max. Temp. x Rainfall	ns	ns	ns
Min. Temp. x Mean RH	ns	ns	(+) 86.60
Min. Temp. x Rainfall	ns	ns	(−) 111.87
Mean RH x Rainfall	(−) 540.48	ns	ns

Note: (+) or (−) indicates the sign of the regression coefficients. ns = not significant at p = 0.05

3 Discussion

The results of this study have shown that suitable hosts are available all-year-round for *B. invadens* and *C. cosyra* in the savanna ecology of Ghana. From the sampling of the major and economically important fruits species, it was evident that this host range provided suitable reservoir for the fruit flies throughout the full year cycle but with fluctuating importance, depending on the fruit availability. Non-commercial fruits such as African peach, sheanut, tropical almond, jujube and albarillo played a key role in bridging the period between the fruiting season of mango and other cultivated crops. The mechanisms behind the decline of incidence and infestation rate of *B. invadens* and *C. cosyra* as the rains subsided could either be due to the absence of suitable hosts or unfavourableness of available fruits for oviposition. Mwatawala et al. (2006) showed that *B. invadens* populations increase from the onset of the short rains period onwards to reach a maximum at the long rains period. This observed patterns need to be confirmed through continuous sampling over successive years prior to any control programme.

The relationship between the start of the rainy season, and the increase of *B. invadens* with heavy fruit infestation, was observed on mango in Benin (Vayssie`res et al., 2005). The period of short rains was followed by a shorter period of drier conditions (but with high relative humidity) in February-March, to be followed by a period of higher rainfall during a more extended period (long rains season). The average temperature remained high but gradually decreased during the long rains. This season was the main fruiting season for tropical almond, sheanut, marula plum and albarillo. Populations of *B. invadens* remain high during this period but seem to infest mainly sheanut and tropical almond, as well as other non-commercial fruits that were available around that time. When temperature and rainfall decrease during the dry season, the populations of *B. invadens* also decrease dramatically (Mwatawala et al., 2006), but viable populations can be maintained in noncommercial hosts, such as persimmon, jujube and figs, till the next short rains period. Host availability for *C. cosyra* seemed a little more ambiguous from the analysis. It was unclear what the predominant hosts are for this species in the dry season since only sporadic records were obtained from icacina and persimons during that period.

Bactrocera invadens is currently considered as one of the major tephritid pest in Africa. Its polyphagous nature, predominance in certain hosts and rapid spread throughout Africa (Drew et al., 2005) makes it a devastating pest. Local farmers have indicated that there is a huge impact of this fruit fly on their fruit production (Yaya Toure´ and Temiognage, 2007).

Besides being an important pest, it also seems to have an impact on the indigenous fruit fly fauna in commercial fruit produce. Although pre-invasion data are generally lacking, there is some indication that the pest could have an impact on the presence of major indigenous pests, such as C. *cosyra*. Duyck et al. (2007) indicated that K-selected tephritid species could be better invaders, and through interspecific competition, decrease the number and niches of pre-established species. *Bactrocera* species appeared to have K-selected traits and to dominate representatives of the genus *Ceratitis*, as in a case study in La Re ́union (Lv et al., 2008). It is not unlikely that similar trends can be observed on mainland Africa in environments such as northern Ghana.

The study further demonstrated a distinct seasonal pattern in the population fluctuations of *C. cosyra* in the ecology. Infestation rate for this pest was relatively low during the early and mid rains period, increased in June, reaches high levels in July and peaks in August. Larval activity becomes low at end of November, during which period, the fly survives as a larva inside host fruits which either remain on the trees or fall to the ground. Though the mortality of larvae and pupae during winter may be very high, proportion of the population survives and yields a small number of adults in spring (Papadopoulos et al. 2000). Although not detected by fruit sampling or trapping, these adults appear in December and a proportion of them may live until the end of February (Papadopoulos et al., 2001). Reproduction is thus, possible during the early rains when host conditions become favourable giving rise to the following generation.

The influence of abiotic factors is closely related with fly abundance (Vera et al., 2002; Duyck et al., 2006) and on their population dynamics (Amice and Sales, 1997). With *B. invadens*, temperature (min–max), RH and rainfall all had positive relationship with infestation rate. Among them, daily rainfall was the factor showing the strongest positive correlation with *B. invadens* populations. The population dynamics of *B. invadens* in northern Ghana appeared very similar to those of *B. cucurbitae* in Benin (Vayssieres et al., 2005) and *B. dorsalis* in Asia (Chen et al. (2006). Han et al. (2011) underlined that the monthly rain days are the strongest one among all the climatic factors. Similar studies with abiotic factors were carried out on *B. dorsalis*, *B. zonata* and *B. correcta* in India (Sarada et al., 2001). They showed a positive correlation for *B. dorsalis* populations captured partly at periods of high RH, but also with the onset of the rains. Shukla and Prasad (1985) however, observed a negative correlation between the populations of *B. dorsalis* captured and temperature, and maximum RH. According to Agarwal and Kumar (1999), *B. zonata* populations have positive correlation with temperature and rainfall in India. With *C. cosyra* in northern Ghana, minimum temperature and rainfall had positive relationships with infestation level. Vayssieres et al. (2009) recorded the similar positive correlation of *C. cosyra* with minimum temperature and RH on mango and guava. Positive relationship with minimum temperatures was also recorded in India on the oriental fruit fly, *B. dorsalis* (Kannan and Venugopala, 2006) and guava fruit fly, *B. correcta* (Jalaluddin et al., 2001).

These results suggest that climatic factors such as temperature, RH and rainfall play an important role in regulating populations of *B. invadens* and *C. cosyra*. Rainfall makes the soil moist and thus provides some favourable conditions for eclosion of adults from their puparia. The first important rains, and increasing relative humidity are important factors favouring the sudden outbreak of *B. invadens* especially as it coincides with the fruiting seasons of the major host plants. Other reasons could be proposed such as the quasi-absence of natural enemies and the polyphagous status of this formidable invasive species. It could be proposed that the three main factors involved in population dynamics are the reduced availability of fruits (due to trees bearing in alternate seasons), the fruit sampling method, and the impact, albeit to a lesser extent, of incubating fruits. Further research is needed to estimate their respective importance. These findings generally imply that programs that aim at suppressing of fruit fly populations could focus on the hosts with high infestation rates with respect to particular fruit fly species. In export situations, fruits with a higher incidence of fruit flies become a major concern because of strong quarantine regulations imposed by importing countries. Non-commercial hosts with high incidence and infestation rates, and found in the vicinity of commercial orchards, should be removed to reduce the alternative reservoirs of fruit fly population build up in between crop peaks. In addition, any suppression of pest population should be conducted at the start of the growing season in order to curb the population peaks.

Acknowledgements

The authors are thankful to the Research Technicians who assisted in the field and laboratory work. The Ghana National Fruit Fly Management Committee (GNFFMC), and the Ghana Education Trust Fund (GETFUND) provided logistical and financial suport, respectively to the research.

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