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Local host fruiting pattern and climate variations impact on fruit fly (*Bactrocera dorsalis*) population trends: A regional fruit fly population tracker for management options

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ABSTRACT

Oriental fruit flies, *Bactrocera dorsalis* being highly polyphagous, mobile and relatively long lived (~3 months), the efficacy of area-wide management programs is mainly influenced by field fruit fly population levels. A study was conducted to understand the seasonal abundance and host shift pattern of *B. dorsalis,* a major pest of mango, *Mangifera indica* L. in relation to climatic factors and host fruit availability as it is known to survive on both wild and cultivated fruits. The fruit fly population attained high levels in the months of March-July due to the availability of main host (mango) as well as supporting host fruits (guava, sapota, rose apple, wild fig, singapore cherry, sour cherry, karonda, star fruit) and the population was less during November- January. Correlation analysis showed that the fruit fly trap catch was significantly negatively correlated with relative humidity (r =-0.87, RH I; r = -0.63, RH II), whereas it was significantly positively correlated with maximum temperature (r = 0.89), host fruit availability (r = 0.89) and fallen fruits (r = 0.80). The statistically significant values (P =0.01, 0.05) revealed that the occurrence of pest incidence is mainly due to its host availability and prevailing climatic factors. Therefore, the management of fruit fly *B. dorsalis* has to be promoted from the month of February onwards to realize maximum benefit of management strategies.

Key words: *Bactrocera dorsalis,* Climatic determinants, Host shift, Potential hosts

Oriental fruit fly [*Bactrocera dorsalis* (Hendel)] (Diptera: Tephritidae) is a frugivorus pest of worldwide importance and causes tremendous economic losses to farmers worldwide. Because of its polyphagous nature, it is almost exclusively associated with a wide range of fruits (>250 hosts) (Li and Ye 2000), predominantly of tropical wet forest origin encompassing both wild and cultivated fruit hosts with strong adaptability to various climates using the mosaic of host crops available locally (Clarke *et al*. 2001, Leblanc *et al*. 2001, Raghu *et al*. 2000, Drew 1987, Zalucki*et al*. 1984).

In India, it is a major pest on mango causing huge losses up to 30% (Verghese *et al*. 2002). Host-fruit availability and abundance of cultivated fruits were recognized as crucial factors for the existence of *B. dorsalis* (Kamala Jayanthi and Verghese 2011, McPheron and Steck 1996). The presence of high fecundity, high dispersion ability and the ability to survive on broader host range under a wide variety of climatic conditions results in successful survival of *B. dorsalis* (Aketarawong *et al*. 2007, Sakai *et al*. 2001). The success of currently advocated area wide fruit fly management programs mainly depend on the field fruit fly population levels which in turn depends on the local climate and availability of host fruits. The comprehensive information on the regional fruit fly-host interaction in relation to local abiotic variables is not available. Therefore, it is imperative to study the influence of local climatic determinants and host shift pattern of *B. dorsalis* to track its seasonal abundance for planning climate resilient management strategies well in advance.

MATERIALS AND METHODS

Field experiments were carried out in the experimental orchards of ICAR-Indian Institute of Horticultural Research (IIHR), Bangalore (12°58'N; 77°35'E), India from March 2012 to March 2013. The experimental orchards of IIHR include 263 ha with varied cultivated crops along with wild fruiting trees with regular fruit fly, *B. dorsalis* menace. The experimental orchards comprised different fruit crops (Table 1) along with their plant phenology (flowering, fruiting) were monitored regularly at weekly intervals.

Sampling was performed at weekly intervals from March 2012 to March 2013 as mentioned earlier. During each sampling, two collectors walked through the study

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Table 1 Local fruiting hosts monitored during the study period

Common name	Scientific name (Family)
Mango	*Mangifera indica* L. (Anacardiaceae)
Sapota	*Manilkara zapota* (L.) P Royen (Sapotaceae)
Star fruit	*Averrhoa carambola* L. (Oxalidaceae)
Passion fruit	*Passiflorae dulis* Sims (Passifloraceae)
Singapore cherry	*Muntingia calabura* L. (Tiliaceae)
Wild fig	*Ficus racemosa* L. (Moraceae)
Tropical almond	*Terminalia catappa* L. (Combretaceae)
Mulberry	*Morus indica* L. (Moraceae)
Chakota	*Citrus maxima* Merr. (Rutaceae)
Egg fruit	*Pouteria campechinana* Baehni (Sapotaceae)
Pomegranate	*Punica granatum* L. (Lythraceae)
Banyan fruit	*Ficus bengalensis* L. (Moraceae)
Kokum	*Garcinia indica* Choicy (Clusiaceae)
Sour cherry	*Prunus cerasus* L. (Rosaceae)
Loquat	*Eriobotrya japonica* (Thunb.) Lindl (Rosaceae)
Cashew	*Anacardium occidentale* L. (Anacardiaceae)
Rose apple	*Syzygium malaccense* (L.) Merr. & L.M. Perry (Myrtaceae)
Guava	*Psidium guajava* L. (Myrtaceae)
Karonda	*Carissa carandas* L. (Apocyanaceae)
Amla	*Emblica officinalis* Gaertn (Phyllanthaceae)

area (2.5 ha), and the host plant fruiting phenology of the selected hosts (proportion of host fruits available, *Hf*) was visually scored on 0-100 scale individually depending upon the host fruit availability. Simultaneously, each host plant was checked for fallen fruits and the same were collected from the ground. Samples of fallen fruits from individual fruit crops were brought to laboratory and the observations, viz. number of fallen fruits availability (*Ff*), weight of fallen fruits (*Fw* in grams) were recorded for each host. The collected fallen fruits were placed in individual plastic containers (21 cm diameter, 25 cm height) separately above the sterilized soil layer (5 cm), covered with white muslin cloth and kept for 2–3 weeks (until fruit fly larvae left fruits and pupated). Puparia were then extracted from containers and kept in separate petri-dishes (90 mm, Tarsons, India) until they emerged. Adult fruit flies were kept alive for approximately 1 week until they matured, then killed and mounted for further observation and identification. The H_{index} (Host specificity) of *B.dorsalis* was calculated using the formula $H_{index} = (S_F - 1)/(S_T - 1)$ (Novotny *et al.* 2005). Where, H_{index} represented host specificity (number of potential hosts available for *B.dorsalis); S_F represented number of taxa fed by B.dorsalis;* S_T represented number of hosts locally available pool of potential hosts.

The males of *B. dorsalis* responded to methyl eugenol traps. As the trap catches are good indicators of fruit fly population, fruit flies were trapped from the study area using methyl eugenol bottle traps. A total of 20 traps were placed all over the study area randomly for fruit fly monitoring. The traps were placed on fruit trees at a height of 2 m above the ground. These traps were made from used plastic mineral water bottles that measured 20 cm in length and 8 cm in diameter and consisted of plywood blocks of 2 cm^3 impregnated with methyl-eugenol and dichlorvos (in 1:1 ratio as killing agent). Traps were prepared by opening square holes (vents) of 2 cm^2 on four sides just below the shoulder of the bottle(i.e. 1/3rd from top). The holes were made by slitting along three sides of a square (i.e. two on the sides and one along the bottom) using a hot penknife. The cuts given in this manner enabled the slit to be lifted as a hood to form a 'rain guard'. In addition, four random holes of 3-4 mm diameter were punched at the bottom with warm needles to allow drainage of rainwater that may have accumulated in the bottle. The impregnated plywood blocks were suspended inside the bottle in such a way that they were hanging vertically along the vents, by making a hole on the cap and passing a thread through it. Recharging of the blocks was done for every 20 days with methyl-eugenol and dichlorvos (Kamala Jayanthi and Verghese 2011). Weekly monitoring of erected traps was carried out and the fruit flies trapped were brought to laboratory for further counting and identification.

The concurrent weather data on weekly basis was collected from the meteorological section of the Institute that was proximal to the study orchard and the weekly means of the weather parameters, viz. relative humidity (%), wind speed (km/h), maximum temperature (^oC), minimum temperature (^oC) and rainfall (mm) were also calculated.

The mean monthly trap capture data along with its corresponding host plant phenology and weather data were subjected to correlation along with linear and nonlinear analysis using trap catch, host plant phenology and weather data (Little and Hills 1979).

RESULTS AND DISCUSSION

Local host fruiting and fruit fly survival

Out of 20 fruiting hosts monitored regularly through fallen fruit sampling, only 10 hosts recorded fruit fly infestation and found to be supporting the *B. dorsalis* survival. Accordingly the H_{index} (Host specificity) of *B. dorsalis* was calculated as 0.5 (where $H_{index} \geq 0.5$ represents polyphagy).

The main local fruiting hosts that supported the fruit fly population during different parts of year are mango, tropical almond (*T. catappa*), guava (*P. guajava*), sapota (*M. zapota*), rose apple (*S. malaccense*), wild fig (*F. racemosa*), singapore cherry (*M. calabura*), sour cherry (*P. cerasus*), karonda (*C. carandas*), star fruit (*A. carambola*) (Fig 1). The fallen fruit sampling in other hosts, viz. passion fruit (*P. edulis*), mulberry (*M. indica*), chakota (*C. maxima*), pomegranate (*P. granatum*), banyan (*F. bengalensis*), kokum (*G. indica*), loquat (*E. japonica*), cashew (*A. occidentale*), egg fruit (*P. campechiana*), amla (*E. officinalis*) did not yield any fruit flies confirming *B. dorsalis* is not utilizing

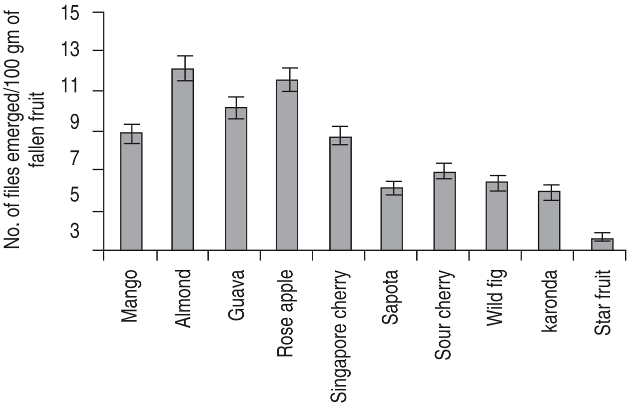

Fig 1 Fruit fly emergence from fallen fruits of different hosts supporting *B. dorsalis* survival.

these hosts for its survival in this region.

The trap data exhibited significant positive correlation with host fruit availability-*Hf* (*r* = 0.89) and fallen fruits-*Ff* (*r*=0.80) supporting the breeding of *B. dorsalis* in fallen fruits (Table 2). The per cent variability in the trap catch due to *Ff* and *Hf* could be explained to the tune of 65% and 81% independently through linear regression (y = 9.80+0.68Ff, R_2=0.65, *F*= 15.09, *P*<0.004; y =-19.45+5.42*Hf*, R_2=0.81, *F*=33.31, *P*<0.001) respectively. Together, both these variables, viz. host fruit availability and fallen fruits could explain the variability in the trap catch to the tune of 96% (y = -15.96+3.95*Hf*+0.39*Ff*, R_2=0.96, *F*= 90.02, *P*<0.0001).

Among the host plants that supported the *B. dorsalis* survival, the tropical almond, *T. catappa*, a common avenue tree in the study area supported the fruit fly population during the months of February - May. Significant positive correlations were observed between fruit fly trap catch and host plant phenology variables, viz. flowering (*r*=0.63), fruit availability (*r*=0.75), fallen fruits (*r*=0.90), fly emergence from fallen fruits (*r*= 0.80) in *T. catappa*. The guava supported the fruit fly population during the months of May – August with significant positive correlation between trap catch and fruit availability (*r* = 0.63). The *B. dorsalis* population survived on sapota during the months of March, May, July-September, November, January and February and the trap catch data exhibited significant positive correlation with host fruit availability (*r*=0.66). During the months of May and June, the *B. dorsalis* also survived on rose apple, and the trap catch data exhibited significant positive correlation with flowering (*r*=0.69), fruit availability (*r*=0.87), fallen fruits (*r*=0.86) and fly emergence from fallen fruits (*r*=0.61). The wild fig supported the fruit fly population during the months, viz. May-July and September–December and the fallen fruits of *F. racemosa* exhibited significant positive correlation (*r* = 0.67) with fruit fly trap catch. During the months of April to July, *B. dorsalis* also survived on singapore cherry with trap catch showing significant positive correlation with *M. calabura* flowering (*r* = 0.80) and fruit availability (*r*=0.68). The sour cherry supported the fruit fly population during the months of May, July–October and significant positive correlation was noticed for fruit fly trap catch with fruit availability (*r*=0.62) and fallen fruits (*r*=0.64). The karonda recorded fruit fly survival during the months from May–Aug and the variables fruit availability (*r*=0.93), fallen fruits (*r*=0.57) and fly emergence from fallen fruits (*r*=0.80) exhibited significant positive correlation with trap catch. The star fruit (*A. carambola*) supported the fruit fly population during the month of January and flowering (*r*=0.71) exhibited significant positive correlation with trap catch.

Table 2 Correlation of *B.dorsalis* trap catch with the biotic/abiotic parameters

Variables	Trap catch	Host fruit availability (*Hf*-%)	Fallen fruits availability (*Ff*-No)	Fallen fruits biomass (g)
Trap catch		0.74*	0.81**	0.65*
Flies emerged from fallen fruits (No)	0.89**			
Max Temp (ºC)	0.82**			
RH-1	-0.87**			
RH II	-0.63*			

* Significant @ *P*=0.05%; **significant @*P*=0.01%

The overall location specific host fruiting phenology calender was developed showing the *B. dorsalis* survival in supporting host crops round the year. The *B. dorsalis* population levels were higher between the months of March-July due to the abundance of host fruits, viz. tropical almond, guava, sapota, rose apple, karonda, singapore cherry *M. calabura* in addition to its main host, mango. Among the several hosts that helped fruit fly survival, the hosts that supported > 5 months are sour cherry (5 months), almond (5 months), wild fig (7 months) and sapota (8 months). Among the other hosts, tropical almond (*r* = 0.98) served as a potential host in the months of March-April, where as the hosts, viz. guava (*r* = 0.73), sapota (*r* =0.99), rose apple (*r* =0.99), singapore cherry (*r* =0.66), wild fig (*r* =0.99) and sour cherry (*r* = 0.99) were found to be supporting hosts in the months of May-July despite the presence of main host, mango. Whereas its population level exhibited a down trend during August-November and was found to be at the lowest level during December. In spite of the availability of supporting hosts, viz. star fruit and sapota during the months of December - February, the fruit fly activity was found to be low (Fig 2).

Local climate and fruit fly survival

Correlation of *B. dorsalis* trap data with its local weather parameters (Table 2) showed significant positive correlation with maximum temperature (*r*=0.82), whereas it showed significant negative correlation with relative humidity (RH) of both at morning hours-RH I (7:30 AM) (*r*= -0.87) and evening hours-RH-II (1:30 PM) (*r*=-0.63) respectively. The variability in the trap catch due to these climate variables can be explained to the tune of 70% (y= $7.52_{(\text{Max. temp.})}$+195.9), 76% (y=$-2.5_{(\text{RHI})}$+219.19) and 40%

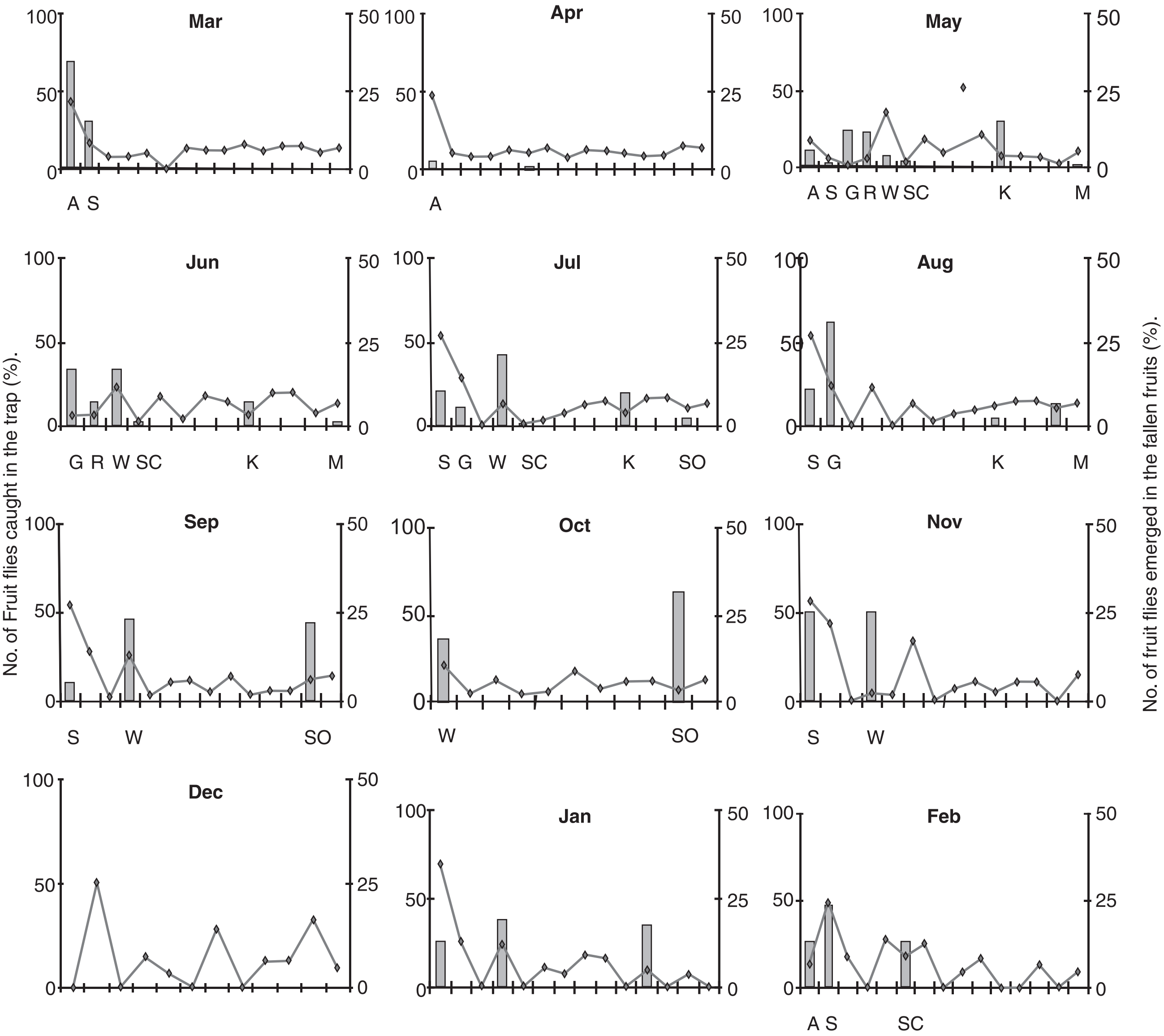

Fig 2 Temporal variation in *B. dorsalis* population with respect to host fruit availability during different months during 2012-13 at Bengaluru, India. No. of flies emerged; —♦— Trap catch. A: Almond, S: S: Sapota, G: Guava, R: Rose apple, W: Wild fig, K: Karonda, M- Mango, SO: Sour cherry, SC: Singapore cherry and SF: Star fruit.

$(y=1.38_{(RHII)}+95.58)$ respectively by maximum temperature, RH I and RH II through linear regression (Fig 3). All these variables together could explain the variability in the fruit fly trap catch to the tune of 89% ($y = 37.82+ 4.09_{Max.\ temp\ (x3)} -1.72_{RH\ I\ (x4)} +0.02_{RH\ II\ (x5)}$; $F= 15.49$, $P<0.001$, $R^2= 0.89$).Further, the *B. dorsalis* population levels exhibited a down trend during December may be attributed to low temperatures prevailed during this period.

Combined influence of local fruiting hosts and climate on B.dorsalis

Local fruiting hosts along with climate variables found

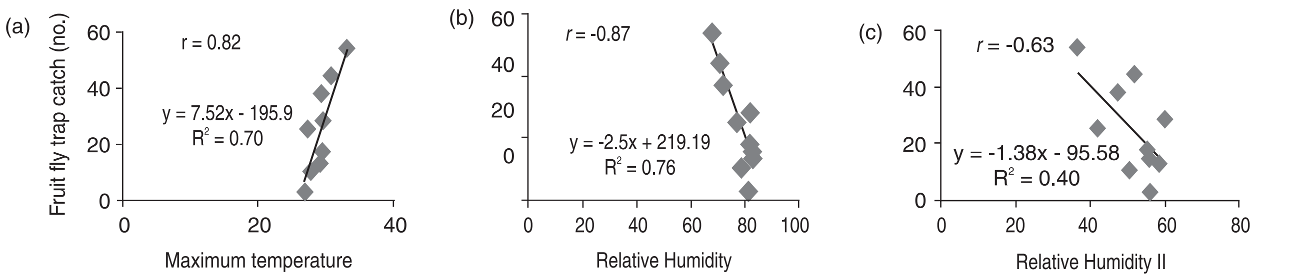

Fig 3 Relationship between the weather parameters with Trap catch of *B. dorsalis* (a) maximum temperature (b) Relative Humidity I and (c) Relative Humidity II.

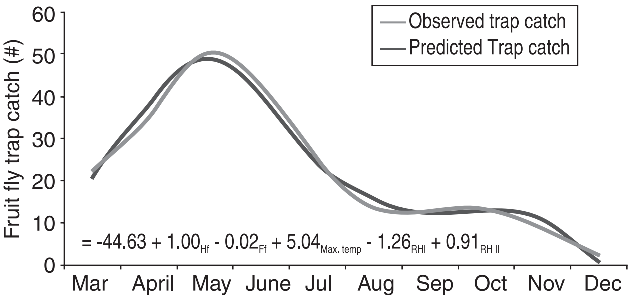

Fig 4 Prediction of fruit fly catch using host plant phenology and weather parameters.

to be crucial for supporting fruit fly population levels in a given area. A multiple regression analysis performed considering the host phenology factors, viz. host fruit availability, fallen fruit availability and abiotic factors, viz. maximum temperature, RH could predict the fruit fly trap catch to the tune of 98% ($y = -44.63 + 1.00_{Hf} - 0.02_{Ff} + 5.04_{Max.\ temp} - 1.26_{RH\ I} + 0.91_{RH\ II}$ (F= 57.49, P<0.001), R^2= 0.98 (Fig 4).

Regional pest management strategies provide both strategic and statutory framework for efficient and effective management of pests in a particular region. This is all the more important in case of polyphagous pests like *B. dorsalis* where area wide management approach is being progressively advocated globally for effective and sustainable fruit fly management (Stonehouse *et al*. 2005). Nevertheless, area wide pest management programmes are logistically complex and managerially intensive involving both technical and non-technical issues to ensure success (http://www-pub.iaea.org/mtcd/meetings/announcements.asp). The technical issues, viz. population dynamics of target pest, survival during off season, influence of abiotic factors are the corner stone tools to design a successful regional fruit fly management program and the present study encourages in this direction to develop regional fruit fly survival calendar in relation to local climate and host fruit availability.

In the present study, out of 20 fruiting hosts monitored regularly through fallen fruit sampling, only 10 hosts were found supporting the *B. dorsalis* survival with H_{index} 0.5 indicating a balanced and selective host utilization of this polyphagous fruit fly. The fruiting hosts, viz. *T. catappa*, *P. guajava*, *S. malaccense*, *M. calabura, M. zapota*, *P. cerasus*, *F. racemosa*, *C. carandas* and *A. carambola* supported clearly the survival of *B. dorsalis* in particular months indicating the specific host utilization nature (herbivore guilds) of this polyphagous pest. Thus defining herbivore guilds on temporal scale for a particular region will help to understand the host plant – herbivore interactions. Mapping of such potential regional herbivore guilds in the form of farmer friendly calendars serve as an indicator for fruit fly population levels in that area and specifies the point in time at which the control measures should be initiated.

The trap data exhibited significant positive correlation with host fruit availability as well as fallen fruit availability indicating the availability of host fruits on the tree as well as on ground (fallen fruits) is the main reason for *B. dorsalis* survival. Similar results were also reported from earlier studies where host fruit availability contributed to *B. dorsalis* survival (Kamala Jayanthi and Verghese 2011). In Kunming region of China, *B. dorsalis* population showed a peak in the months of June- July due to presence of hosts like mango, peach and guava fruits (Hui and Jian-Hong 2005). Further, the local weather variables, viz. minimum temperature and RH exhibited significant influence on trap catch. Inspite of host fruit availability, the absence of *B. dorsalis* during December may be attributed to low temperatures prevailed during this period. The studies of Singh and Mann (2003) in *B. dorsalis* at Punjab and Raghuvanshi *et al*. (2012) in *B. cucurbitae* at Varanasi revealed that the adult fruit fly population was drastically low in December to February months due to mild temperature.

The present study provides the basic information on seasonal abundance and host shift pattern of *B. dorsalis*. The statistically significant values revealed that the occurrence of fruit fly incidence is mainly due to host availability and prevailing climatic factors. Further, combining the local host fruit availability along with local weather variables could predict the fruit fly populations to the tune of 97% indicating these variables play crucial role in determining the fruit fly population levels in a particular region. Thus, the population fluctuation of *B. dorsalis* is highly influenced by prevailing ecological conditions comprising host fruit availability and abiotic variables. The peak population was observed in the month of April-June coinciding with the preferred host, *M. indica* fruiting. However, the initial population build up was noticed during the months of Feb-March on several hosts, viz. *T.catappa*, *M. zapota* and *M. calabura*. Thereby the efficient management of *B. dorsalis* has to be promoted in the month of February onwards itself for successful and efficient control during main host (*M. indica*) fruiting.

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