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Full Length Article

Assessment of Spatial Variability and Mapping of Apricot Fruit Fly Infestation using Geographic Information System

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Abstract

The fruit fly is one of the most damaging economic insect pests of fruits and vegetables in the world including Gilgit-Baltistan, Pakistan. To develop an effective pest management strategy, information on the spatial variability and mapping of the fruit fly infestation level is crucial. In the current study, three districts of Gilgit-Baltistan were examined to assess the variability of fruit fly infestation in apricot orchards by using descriptive and geostatistical techniques. The results revealed that the infestation level was significantly different ($P < 0.05$) among the months and districts. The mean infestation (31.67, 23.21 and 22.34%) was high during August in all three districts. Based on the geostatistical technique, the respective semivariogram, thematic maps, histograms and trend analysis were prepared using Arc GIS (Geographic Information System) software (Arc Map 10.7) and inverse distance weight (IDW) interpolation method. The result showed that the ratios of the nugget to sill variance were 43.07, 32.90 and 87.50% in Gilgit, Hunza and Nagar districts, respectively and suggesting moderate to weak spatial variability. Furthermore, GIS maps, histograms, and trend analysis graphs also showed the spatial variability of fruit fly infestation. This study concluded that fruit flies were present in apricot orchards of all locations/districts throughout the crop seasons and the time window may be considered a critical one in the management of fruit flies.

Keywords: Apricot; Fruit fly; Infestation; GIS; IPM; Gilgit-Baltistan

Introduction

Fruit flies are members of the Diptera order and the Tephritidae family contains over 4,500 species. These fruit flies are polyphagous pests of numerous horticulture crops globally including Pakistan (Akram *et al*. 2023). Mangoes, peaches, guava, orange, banana, pumpkin, and bitter guard are the most commonly attacked soft-bodied fruits and vegetables. More than 70 species of *Bactrocera* genera (Tephritidae) are thought to constitute a major crop pest around the world (Jing *et al*. 2020). These pests, resulting in significant production losses are attacking fresh vegetables and fruits. Due to strong attack of fruit flies, the economic value of fruits and vegetables may eventually decrease. These pests adapt to various climate conditions and are most prevalent in tropical and subtropical regions of the world, resulting in significant economic losses with an increasing threat of spread into new areas (Clarke *et al*. 2005; Mishra *et al*. 2012; Saeed *et al*. 2022).

The researchers have extensively explored the phenology and population dynamics of fruit flies. However, the temperate areas have received less attention and rare studies in the northern and cold portions of current geographical distribution (Akram *et al*. 2023). Studies in temperate areas revealed that relatively low winter temperatures are the main factor regulating the insect population in these areas. Low winter temperatures have an impact on the phenology and population dynamics of these pests in cooler temperate areas of Europe (Papadopoulos *et al*. 2001; Gutierrez *et al*. 2016; Merkel *et al*. 2019).

Pakistan has abundant agricultural resources and earns billions of dollars from large and small crops including horticultural plants (PHDEB 2005). The oriental fruit fly (*B. dorsalis* Hendel), peach fruit fly, (*B. zonata* Saunders) and the melon fly (*B. cucurbitae* Coquillett) are the three species of fruit fly (Genus: *Bactrocera*) usually found in Pakistan. *B. zonata* is the most common pest in fruit orchards around the world. This pest attacks apples, peaches, guava, mango, citrus, apricot, fig and apple. Tomatoes, peppers and eggplants are among the vegetables that are most vulnerable to fruit flies (Khan and Naveed 2017; Qin *et al*. 2021). The Guava fruit fly (*B. correcta* Bezzi) was originally registered in Bihar, India in 1916 (Bezzi 1916) and is now widespread in most Southeast

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Asian countries including Pakistan, India, Nepal, and Sri Lanka (Drew and Raghu 2002).

In Pakistan, a loss of about 24% due to an infestation of *B. zonata* has been recorded in the Cucurbitaceae family. About 50–80% of the infestation is found in pears, peaches, apricots, figs and other fruits. This species is quickly becoming a very serious pest of citrus and other fruits and vegetables (Weems *et al*. 2012; Akram *et al.* 2023). It has been found in practically every region of Pakistan, from the Baluchistan and Sindh coasts to the northern parts of Punjab, and the slopes of the Islamabad and Peshawar basins. As a result, *B. zonata* is the dominating species with higher populations than the other two Bactrocerea species (*B. cucurbitaie* and *B. dorsalis*). Fruit fly of the cucurbit, *B. cucurbitaie* is a very rare species that do not pose severe harm to fruits. *B. dorsalis* infested a variety of fruits, including guava, citrus, mango, papaya and Jamun, *Syzygium cumini* (Ullah *et al*. 2015; Akram *et al*. 2023).

Fruit flies caused significant yield loss (30–100%), which is dependent on the fruit species and season (Patra *et al*. 2022). The management strategies such as cultivating fly-resistant genotypes, augmentation of biological control and pesticides, fruit begging field sanitation, and protein bait can help to control these fruit flies. The most efficient strategy for controlling fruit flies was field cleanliness (Reddy *et al.* 2020). To break the reproductive cycle and population increase of fruit flies, the growers must thoroughly bury all unharvested fruits or vegetables in the field (Klungness *et al*. 2005). This pest has been reported from all regions of Pakistan, and it was first registered in the Gilgit-Baltistan (GB) region in 2018 (Hussain *et al*. 2019). However, there has been no assessment regarding its levels of infestation and fruit damage since its first finding in the GB region of Pakistan. Apricot (*Prunus armeniaca* L.) is the most popular fruit of GB and is a major source of income for a sizable portion of small and medium-sized farmers. It is vulnerable to fruit flies which are significantly reducing the quality and causing substantial economic losses (Akram *et al.* 2023). Thus, the current study was carried out to determine the range of fruit fly damage and infection in the apricot orchards of selective districts of GB.

Materials and Methods

Assessing fruit fly infestations

The level of infestation of fruit flies in apricot in the selected three districts of GB (Gilgit, Hunza and Nagar) was investigated from June to September 2022. A comprehensive survey was conducted in three districts consisting of fifteen valleys (Fig. 1–2). Each valley is divided into three strata (Stata 1, 2 and 3). A total of forty-five strata, and from each stratum fifty fruits were randomly collected. The collected fruits were counted as healthy or infested/dropped apricot fruits and data were recorded for three months duration (June to august for District Gilgit while July to September for District Nagar and Hunza in the Year 2022). The percent infestation was calculated using the following formula as given by Kakar *et al.* (2014):

$$I\% = \frac{\text{NIF}}{\text{TNF}} \text{ x } 100$$

Where (I% = Infestation percentage, NIF= Number of infested fruits, TNF = Total Number of fruits).

Data analysis

An analysis of variance (ANOVA) was performed to determine the mean difference within the valley by using Statistical Package (Statistix 8.1) as used by Naheed *et al.* (2022).

Apricot fruit fly infestation: geostatistical analysis and spatial variability mapping

A database of selected districts comprised of X and Y coordinates in the study valleys was created. Afterwards, the shapefile of each District was opened in GIS software (Arch 10.4). Three fields X, Y, and Z were opened in the project. In X-field, X-coordinate, Y-field, and Y-coordinate were selected, whereas in the Z-field disease data was placed. Arc view spatial analyst “Interpolate grid option” was selected. On the output “grid specification dialogue”, the output grid extends chosen was the same as the District Gilgit, Nagar, and Hunza boundary, and the interpolation method employed was inverse distance weight (IDW) (Hussain *et al.* 2021a, b; Akram *et al.* 2023).

In geostatistics, the spatial variability of a variable was considered by a semivariogram function and the calculation of its role was stated based on the following equation as mention by Goovaerts (1998):

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}}$$

Where, Z(x0) is the interpolated value, n represents the total number of sample data values, xi is i th data value, hij is the separation distance between interpolated value and the sample data value, and β denotes the weighting power.

The spatial distribution of fruit fly species was characterized by a semivariogram function and the calculation of its function was expressed based on the following equation (Akram *et al.* 2023):

$$\text{r(h)} = 1/2\text{N(h)} \sum_{i=1}^{N(h)} [\text{Z(Xi)} - Z(xi + h)]^2$$

Where, Z(xi) and Z(xi +h) are the measured values of

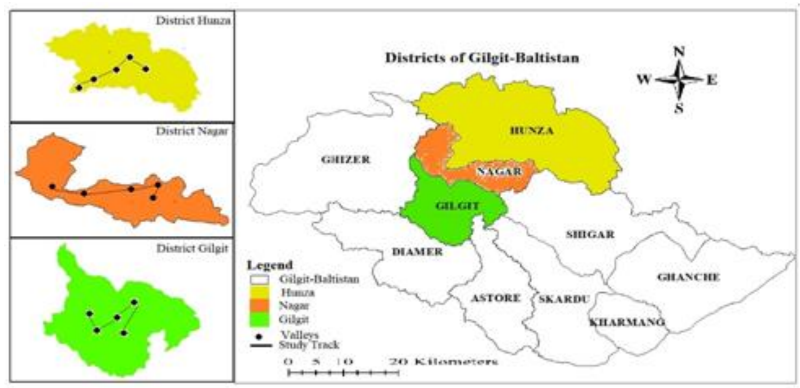

Fig. 1: Map of the district Gilgit-Baltistan

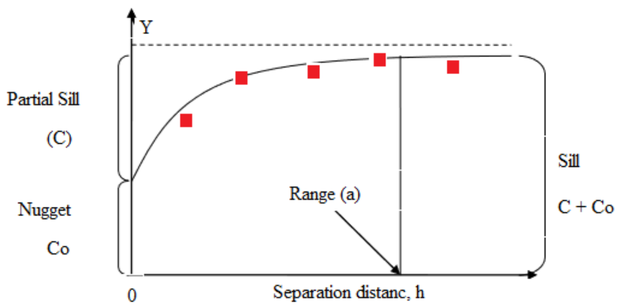

Fig. 2: Semivariogram: nugget, range and sill

the regionalized variable Z(xi) at the spatial positions xi and xi + h, respectively and r(h) is the semivariogram function. H is the spatial distance of the sample points, also known as the step size.

The function graph created with r(h) as the ordinate is known as the semivariogram function graph if h is the abscissa. The corresponding theoretical model and the model parameters was found by fitting the value of the r(h) coordinate. By examining the model's input parameters, the characteristics of spatial variability were determined and utilized spherical model (Vauclin *et al.* 1983).

0, h=0

$$r(h) = \{C_0 + C\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right), 0 \leq h \leq a$$

$$C_0 + \text{C, h} > a$$

$$\text{Spherical} = \gamma(h) = \left\{C_0 + C\left(\frac{3h}{2ac} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right) \quad \begin{matrix} 0 \leq h < a \\ h \geq a, \end{matrix}\right.$$

The spatial dependence (SDP) percentage was designed as described by Akram *et al.* (2023) and Hussain *et al.* (2021b) which gave the following expression:

$$\text{SDP Spherical\%} = \frac{\text{C1}}{\text{C0} + \text{C1}} \text{ x } 100$$

For the spherical semivariogram: SDP Spherical (%); ≤ 25% strong spatial dependence; 25% < SPD (%) ≤ 75% moderate spatial dependence and ≥75% weak spatial dependence.

Results

The level of fruit fly infestation on apricot fruits in fifteen valleys of three Districts of Gilgit-Baltistan (GB), Paksitan was evaluated. The data regarding fruit fly infestation in apricot fruit is given in Table 1. The results showed that there were significant variations in fruit fly infestation among months, valleys, and Districts. In District Gilgit, the fruit fly infestation range during different months was 15.00–27.33, 24.00–35.33 and 24.00–40.00% during June, July and August, respectively. In District Nagar, the fruit fly infestation ranges during different months were 11.00–17.60, 18.33–26.66 and 20.00–22.66% during July, August and September, respectively. In District Hunza, the fruit fly infestation ranges during different months were 10.00–18.33, 16.00–29.00 and 22.66–29.00% during July, August and September, respectively. The mean values of the data indicated that the highest infestation of fruit fly was during August in the Gilgit (31.67%) and Nagar (22.34%) district and 26.21% in the Hunza district during September.

Geostatistical analysis

The semi-variogram can indicate the spatial variability of the fruit fly infestation. Table 2 shows the semivariogram parameters of the spherical model applied to the current study data. The spatial dependence ranged from moderate (for the District Gilgit and Hunza) to weak (for the District Nagar). The District Gilgit data had an N/S ratio of 0.430, inferring moderate spatial dependence. This means that 43.07% of the total variation in fruit fly infestation can be explained by spatial variations while the remaining 56.93% was attributable to unexplained sources of variations. For District Hunza, N/S ratio of 0.329 was indicative that 67.1% of the total variation was spatial variation while 32.90% was due to other sources of variation. The spatial dependence was weak in the district of Nagar. In Fig. 3, both theoretical and empirical semivariogram models were presented for each District. In comparison to District Nagar (Fig. 3B), the semivariograms of the Districts Gilgit (Fig. 3A) and Hunza (Fig. 3C) showed a high degree of similarity. The

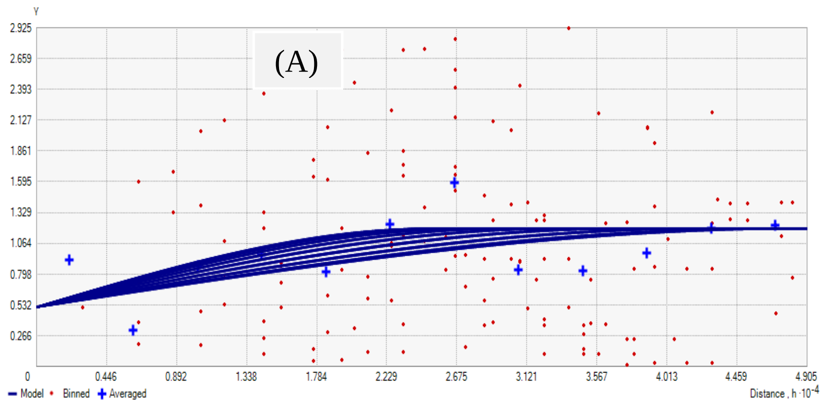

Fig. 3A: Experimental and theoretical semivariograms computed on data of fruit fly infestation in District Gilgit (Mode0.51307*Nugget + 0.67825*Spherical (49047,25056,120.9)

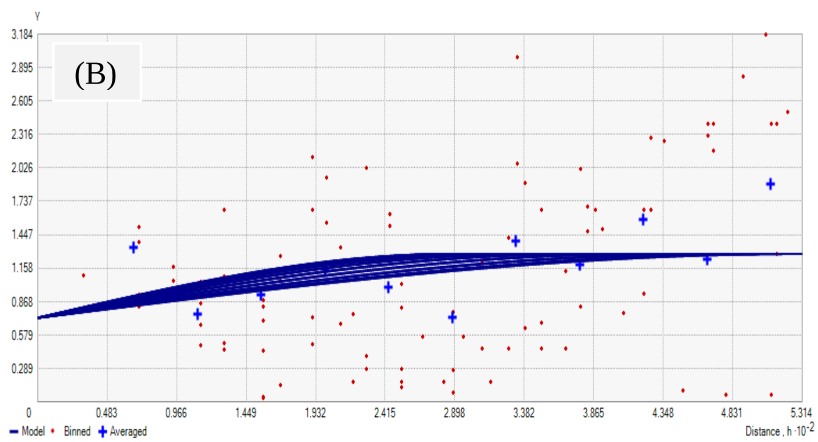

Fig. 3B: Experimental and theoretical semivariograms computed on data of fruit fly infestation in District Nagar (Model: 0.72766*Nugget + 0.55309*Spherical (531.39, 286.36, 130.6)

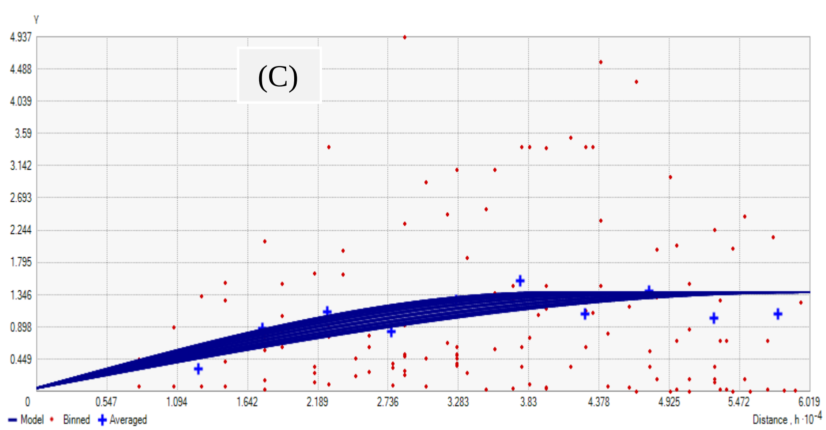

Fig. 3C: Experimental and theoretical semivariograms computed on data of fruit fly infestation in District Hunza (Model: 0.45403*Nugget + 1.3334*Spherical (60192, 40352, 93.5)

interpolation maps of apricot fruit fly infestation allowed us to visually understand the spatial distribution pattern in the study site expressed as in Fig. 4A–C. In the District Gilgit (Fig. 4A), the infestation ranged between 20.66 to 35.99%, indicating spatial distribution. A high infestation was observed in the central and eastern parts. In the District Hunza (Fig. 4B) North to the southern part of the area, the concentration of infestation was increased. More area is

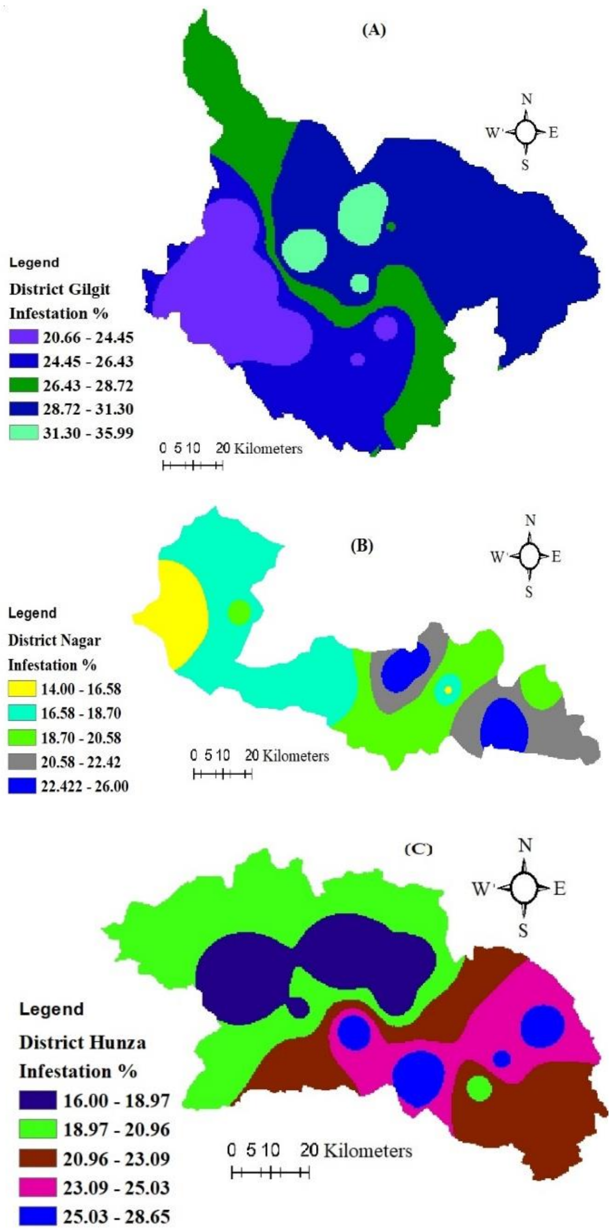

Fig. 4: Interpolated maps representing distribution patterns of fruit fly infestation in the study area (**A**) map of Distrcit Gilgit, (**B**) map of Distrcit Nagar and (**C**) map of District Hunza

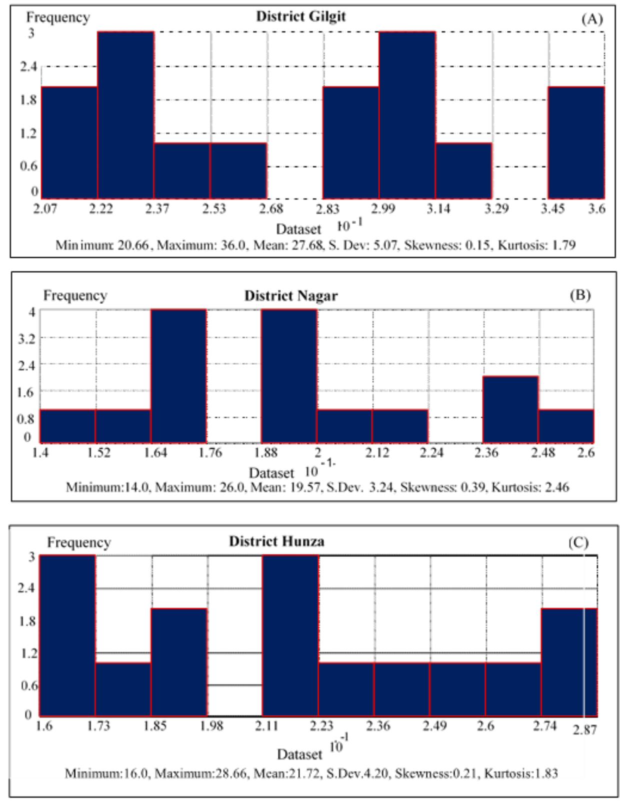

Fig. 5: Histograms of fruit fly infestation percentage used to understand the distribution of the dataset (**A**) Distrcit Gilgit, (**B**) District Nagar and (**C**) Distrcit Hunza

affected in the east to the southern part of the District Hunaz. Likewises, in the District Nagar (Fig. 4C), the blue shades indicate high infestation compared to the yellow shade and lied form south to west part.

The histogram of measured values (X-axis) of each variable and its frequency (Y-axis) with a distribution curve or bell curve showed that the data observed were normally distributed (Fig. 5). The mean ± SD (standard deviation) for the measured parameters were 27.68 ± 5.07 (Gilgit) (Fig. 5A), 21.72 ± 4.20 (Hunza) (Fig. 5C) and 19.57 ± 3.24 (Nagar) (Fig. 5B). Gilgit and Nagar were bimodal districts, whilst Hunza was unimodal.

The trend analysis revealed the fruit fly infestation trends in the study area (Fig. 6). In the graph, X axis represents the east direction, Y axis for north direction and Z axis indicates the magnitude of the measured value of each sample. The green curve indicates the change in the trend effect of the east-west trend and the blue curve is the change in the trend effect of the south-north direction. If simulating trends exist in a particular direction, and the line is straight, there is no global trend. Fruit fly infestation (%) from all three districts (Gilgit, Hunza and Nagar) showed a downward trend from east to west. The district Gilgit (Fig. 6A) showed trend of high to low, Nagar low to high (Fig. 6B) and Hunza low to high (Fig. 6C) then a low trend was found from north to south direction.

Discussion

Apricot (*P. armeniaca* L.) is a popular fruit of Gilgit-Baltistan (GB).and is vulnerable to fruit flies. Fruit flies are major threat to the fruit and vegetable industry in GB (Akram *et al.* 2023).

The effective planning regarding crop protection requires accurate and reliable assessment of the pest, in addition to the identification of causal agents. The spatial

Table 1: Percent fruit fly infestation in apricot orchards located in the valleys of selected Districts of Gilgit-Baltistan

District Gilgit	Valley	June	July	August
	Chilmish - Nomal	24.33 ± 4.16^{A}	30.66 ± 2.08^{AB}	35.66 ± 3.05^{A}
	Sultanabad- Guru	23.33 ± 6.65^{A}	30.33 ± 4.16^{ABC}	33.66 ± 3.05^{A}
	Danyore-Jalalabad	27.33 ± 5.50^{A}	35.33 ± 5.13^{A}	40.00 ± 3.00^{A}
	Gilgit City - Baseen	22.00 ± 2.64^{AB}	24.33 ± 3.05^{BC}	24.00 ± 5.00^{B}
	Bagrote	15.00 ± 2.00^{B}	24.00 ± 3.00^{C}	25.33 ± 5.13^{B}
	Mean, *LSD*	22.39, *3.91*	28.94, *2.86*	31.67, *3.49*
District Nagar	Valley	July	August	September
	Chalt	17.6 ± 64.16^{A}	26.66 ± 3.51^{A}	22.33 ± 4.16^{A}
	Jafarabad	16.6 ± 63.05^{AB}	25.66.16^{A}	22.66 ± 3.51^{A}
	Minapin	15.66 ± 5.03^{AB}	22.33 ± 4.16^{AB}	21.66 ± 4.04^{A}
	Shayar	11.33 ± 2.08^{B}	18.66 ± 2.51^{B}	22.00 ± 2.64^{A}
	Asqurdas	12.00 ± 2.00^{AB}	18.33 ± 33.05^{B}	20.00 ± 3.60^{A}
	Mean, *LSD*	14.67, *2.98*	22.34, *2.66*	21.74, *3.02*
District Hunza	Valley	July	August	September
	Nasirabad	17.33 ± 1.52^{A}	26.00 ± 4.35^{A}	27.33 ± 5.13^{A}
	Murtazabad	17.00 ± 4.35^{A}	26.33 ± 5.68^{A}	29.00 ± 6.24^{A}
	Aliabad	18.33 ± 3.05^{A}	29.00 ± 3.00^{A}	28.00 ± 4.58^{A}
	Attabad	10.00 ± 1.00^{B}	16.00 ± 3.00^{B}	24.00 ± 3.00^{B}
	Gulmit	16.33 ± 2.08^{A}	18.66 ± 3.21^{B}	22.66 ± 4.04^{B}
	Mean, *LSD*	15.81, *2.44*	23.21, *3.11*	26.21, *3.81*

The values represent the means of three replicates (mean ± standard deviation). The means with different letters in a column of each District are statistically significant at $P < 0.05$

Table 2: Geostatistical analysis for the Semivariogram parameters

District	Model	Range (m)	N (C_o)	PS (C)	S (C_o + C)	N/S ratio	SDI%	Spatial Class
Gilgit	Spherical	49046.5	0.513	0.678	1.191	0.430	43.07	Moderate
Hunza	Spherical	60191.18	0.454	1.333	1.378	0.329	32.90	Moderate
Nagar	Spherical	531.39	0.727	0.553	0.830	0.875	87.50	Weak

N: nugget; PS: partial sill; Sill; N/S ratio = [N/ (N + PS), SD: Spatial dependence

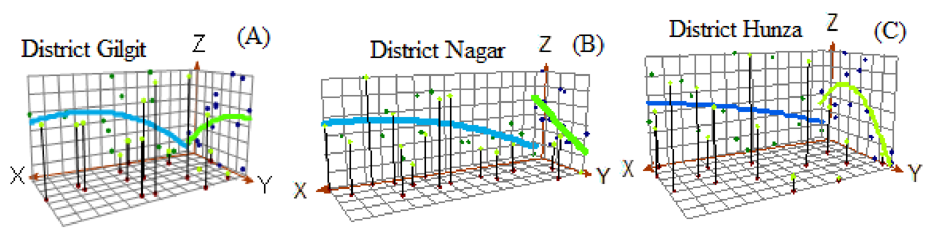

Fig. 6: Trend analysis of fruit fly infestation in the study area (**A**) Distrcit Gilgit, (**B**) District Nagar and (**C**) Distrcit Hunza

pattern of pest distribution in the field has recently gained more attention. Thus, a better understanding of the spatial distribution is key to the effective mapping of pest distribution, overall infestation level and optimization of control measures. In the current study, geostatistical methods were used to characterize spatial analysis of the infestation of fruit flies on apricot in three districts of GB, Pakistan.

The spatial analysis of pest distribution can help us to identify the hot spot area which may lead to highlighting risk factors to manage pest problems (Bivand *et al.* 2008; Hussain *et al.* 2021a, b). Our result indicated that fruit fly infestation is spatially distributed in the study area. This was further confirmed by the nugget/ sill ratio that fruit fly infestation (%) is spatially distributed in the area. The geostatistical techniques can be used to compute the degree, range, and spatial dependence patterns of pests over time (Rekah *et al.* 1999). The diseases, pests and soil nutrients that vary spatially suggest that structural features play a significant role in causing the high level of geographical variability brought on by random parts.

In the present study, a substantial variance in fruit fly infestation was found among Districts and valleys. The author asserted in a prior study that the highest population of Bactrocera species was observed in August (Mahmood and Mishkatullah 2007). According to Khan and Naveed (2017), ripening month fruits cause the greatest population of fruit flies. From August to September is an apricot fruit ripening month in the study area, which explains the high population dynamics. The highest population causes the highest apricot fruit infestation (Kakar *et al*. 2014; Akram *et al.* 2023). Fruit flies are brought on by things like unclean canopies, fruit that falls to the ground, and inconsistent watering, all of which offer them food and a place to live. Reddy *et al.* (2020) found that temperature, relative humidity, and rainfall all have a substantial positive correlation with the rate of fruit fly infestation. Afia (2007) studied the seasonal abundance of fruit flies in three successive seasons (2000–

2003) on a different host and found that there was abundant population throughout the season, except in winter months when fruit hosts were not available and cold conditions prevailed. Khan *et al.* (2020) reported that the annual temperature cycle in Gilgit-Baltistan province during July was the hottest month, with a mean monthly temperature of 27.20°C and a mean monthly maximum temperature of 40°C. The average relative humidity of the area is 47%, with a maximum of 56% in Gilgit and a minimum of 37% in Chilas (Khan *et al.* 2020). Duyck *et al.* (2004) reported that lower humidity levels between 30–50% have a significant effect on the survival of fruit fly species. An increase in temperature is the primary factor for the maximum fruit fly population, while low humidity also increases the number of fruit fly populations (Chen and Ye 2007). The humidity is significantly correlated with the population of fruit flies, but humidity and temperature are negatively correlated because when temperature increases, humidity decreases and vice versa (Mustafa *et al.* 2011). This study will assist in the development of IPM strategies for the management of the species and a reduction in the damage the species do to the agricultural products in the area. It will also make it easier to manage fruit flies in various valuable crops, particularly apricots.

Conclusion

The present study shows that geostatistical base mapping provides an opportunity to assess the spatial distribution of fruit fly infestation in the study area. This could facilitate the appropriate management of fruit flies, leading to higher quality and quantity of apricots and ensuring sustainable food security for marginalized apricot growers in the region. The results reveal considerable spatial variability in fruit fly infestation percentages in apricots, even within the districts. Fruit fly infestation in apricot orchards was highest in District Gilgit, followed by Hunza District. Similarly, the mean values of the data indicated that the highest infestation of fruit flies was 31.67 and 22.34% in Gilgit and Nagar Districts, respectively in August and 26.21% in Hunza District during September. This study will help apricot growers and relevant stakeholders make informed decisions for the management of fruit flies.

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Author Contributions

AH carried out research work, and data analysis, and reviewed the manuscript. WA wrote the original draft of the manuscript and carried out fieldwork and data collection. MM carried out fieldwork and data collection. AH helped in carrying out research work. WA improved and edited the final manuscript.

Conflict of Interest

The authors have declared no conflict of interest for this research work.

Data Availability

All the related data reported in the manuscript will be available as requested.

Ethics Approval

The authors declare that the research was following all ethical standard.

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