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Research Article

Spatial distribution of *Aphidius matricariae* (Haliday) and *Myzus persicae* (Sulzer) in bell pepper under polyhouse conditions

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ABSTRACT: The spatial distribution of *Aphidius matricariae* and *Myzus persicae* was studied in bell pepper under polyhouse conditions. In the present study, *M. persicae* and its parasitoid, *A. matricariae* populations followed negative binomial distribution throughout the season. The variance to mean ratio (σ^2/X), mean crowding (X*), ratio of mean crowding to mean (X*/X), 'k' of negative binomial, Taylor's power equation for *M. persicae* and *A. matricariae* were $\sigma^2 = 6.97X^{1.531}$ ($R^2 = 0.931$), and $\sigma^2 = 4.29X^{1.282}$ ($R^2 = 0.90$) during 2018-2019, respectively. Iwao's patchiness regression was $X^* = 45.12 + 1.333X$ ($R^2 = 0.853$), and $X^* = 5.406 + 1.195X$ ($R^2 = 0.767$) during 2018-2019, respectively. Optimum number of samples required for the green peach aphid, *M. persicae* and *A. matricariae* were 261.1 and 474 at 20% precision level. The present study will be useful for developing a sampling plan of *M. persicae* and its parasitoid, *A. matricariae* in bell pepper for its monitoring and management.

KEY WORDS: *Aphidius matricariae,* green peach aphid, parasitoid, spatial distribution

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INTRODUCTION

Capsicum (*Capsicum annuum* L.), popularly known as bell pepper, is one of the important vegetable crops grown throughout the world. Mid-hills of Himachal Pradesh, bestowed with mild climate are best suited for off season cultivation of capsicum under protected conditions, which provides stable and favourable microclimate for pests to limit the success of this crop production system (Sood, 2010). Although capsicum provides lucrative returns to the farmers, yet, there are some constraints in its cultivation and among them the share of insect-pests is significant. Among different insect pests attacking bell pepper crop, the green peach aphid, *Myzus persicae* (Sulzer); cotton whitefly, *Bemisia tabaci* (Gennadius); greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), thrips, *Scirtothrips dorsalis* (Hood); fruit borer, *Helicoverpa armigera* (Hubner), tobacco cutworm, *Spodoptera litura* (Fabricus) and mite, *Polyphagotarsonemus latus* (Banks) are the important ones (Kaur and Sangha, 2016; Moreau and Isman, 2012). The green peach aphid, *M. persicae* (Hemiptera: Aphididae) is a cosmopolitan, polyphagous and important pest of bell pepper. The aphid transmits more than one hundred and fifty viral diseases in different hosts particularly solanaceous vegetables (Castle and Berger, 1993; Syller, 1994). Rapid population increase, wide host range and high insecticide resistance make this pest more difficult to control (Blackman and Eastop, 1985; Yano, 2003; Ralec, *et al.,* 2010). For the management of *M. persicae,* farmers mostly rely on the insecticides. Indiscriminate use of insecticides, however, results in insecticide resistance, pest resurgence, secondary pest outbreak, pesticide residues, besides killing the natural enemies (Van Emden, *et al.,* 2014). Thus, there is a need to develop ecofriendly alternative management strategies to control this pest. Biological control is considered as a viable option in integrated pest management programmes, where in use of chemicals is minimized, or selective insecticides are preferred (Hoy, 1993).

Aphidius matricariae, a polyphagous parasitoid, which probably originated in northern India or Pakistan, parasitizes about 40 aphid species (Stary, *et al.,* 1975) including *M. persicae*. Before developing a biological control programme for the pest or to predict the natural biological control of the pest by the parasitoid, it is important to develop an effective sampling plan for the pest as well as the parasitoid. Spatial distribution is one of the most important properties of insect populations that determine the behavioural response of the individuals to their habitat (Young and Young, 1998; Southwood and Henderson, 2000). Knowledge on the spatial distribution of pest species provides the useful information for its monitoring in the field and to develop an effective sampling plan for the pest as well as the parasitoid and lays the foundation for decision making in IPM programmes (Feng and Nowierski, 1993; Binns, *et al.,* 2000; Khaing, *et al.,* 2002). Spatial distributions of insect populations, however, may vary in space and in time depending upon the behaviour of population and environment (Debouzie and Thioulouse, 1986; Moradi-Vajargah, *et al.,* 2011). Taylor's power law and Iwao's patchiness regression are the simple but robust models to describe the stable relationships between the sample mean and variance (Bisseleua, *et al.,* 2011). So, studies have been carried out on spatial distribution of the pest, *M. persicae* and the parasitoid, *A. matricariae* in bell pepper ecosystem, which will be helpful in developing a bio-intensive strategy for the management of this aphid.

MATERIALS AND METHODS

Bell pepper (*Capsicum annuum* L.) was raised at the Experimental Farm of Department of Entomology of the Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India (altitude 1275 m amsl; 31.28°N latitude and 76.94°E longitude) by following all the recommended package of practices (Annonymous, 2014) except the application of insecticides. Population density of *M. persicae* and its parasitoid, *A. matricariae* was recorded as per method of Sachan and Shrivastava (1972) at weekly interval on 50 randomly selected plants starting from 15 days after transplanting until final harvest. For this purpose, three leaves; one each from lower, middle and upper portion of the plant were selected. Data thus obtained were used to calculate percent parasitism and indices of dispersion of the aphid and the parasitoid.

Spatial Distribution

Spatial distribution of *M. persicae* and its parasitoid, *A. matricariae* was studied by calculating different indices of spatial distribution or dispersion as under:

Indices of Spatial Distribution or Dispersion

Variance to Mean Ratio

Variance to mean ratio is the simplest approach to measure dispersion and for this mean population density (X) and variance (σ^2) of the aphid and the parasitoid was calculated for each sampling date using standard statistical procedure. The ratio between variance and mean density was calculated by dividing variance by the mean (σ^2/X). This ratio is one for poison or random distribution, less than one for uniform distribution and more than one for aggregated or negative binomial distribution. A null hypothesis that the aphid or the parasitoid follows poisson distribution was considered and the departure of the distribution from random to uniform or aggregated was tested by calculating the index of distribution (I_D) which is further used to calculate z-values as under:

$$I_D = \frac{\sigma^2}{X} \times (n-1)$$

$$z = \sqrt{2I_D} - \sqrt{2v-1}$$

Where, σ^2 = variance, X = mean, n = number of samples, v = n-1.

Z-value between -1.96 and +1.96 confirms the random distribution, whereas, z-values less than -1.96 and more than +1.96 verifies uniform and aggregated distribution, respectively (Patil and Stiteler, 1973).

David-Moore index (IDM)

The index of clumping or David-Moore index (IDM) was calculated as per David and Moore (1954).

$$IDM = \frac{\sigma^2}{X} - 1$$

Where, σ^2 = variance and X = mean.

The value of IDM is zero for random distribution, less than zero for uniform and more than zero for aggregated distribution. Mean crowding (X*) which explains the possible effect of competition and mutual interference among individuals was calculated as:

$$X^* = X + IDM.$$

Lloyd's mean crowding index (X*/X) worked to verify the type of distribution (Lloyd, 2017). The value of (X*/X) is 1, <1 and >1 for random, uniform and aggregated distribution, respectively. The 'k' of negative binomial, often referred to as the parameter of dispersion and calculated as under (Southwood and Henderson, 2000):

$$k = \frac{X^2}{\sigma^2 - X}$$

Relationship between Variance and Mean

The relationship between variance and mean was worked out by fitting Taylor's power law as:

$\sigma^2 = aX^b$ or $\log \sigma^2 = \log a + b \log X$

Where a = sampling parameter, b = index of aggregation.

Iwao's Patchiness Regression

The Iwao's patchiness regression (Iwao, 1972) between mean crowding and mean density was calculated as under:

$X^* = \alpha + \beta X$

Where, β refers to the coefficient of contiguousness.

The distribution with $\beta > 1$, $\beta = 1$ or $\beta < 1$ corresponds to aggregated, random or uniform distribution, respectively.

Optimum number of samples

The optimum number of samples (N_{opt}) required for achieving desired precision was calculated for different densities. Generally, a precision level (expressed as standard error of mean) of about 25% is desired, however, if the estimate is required to construct the life table a higher level of precision (10%) is desirable (Southwood and Henderson, 2000). Hence, the N_{opt} was calculated for different densities at 10, 20 and 30% standard error by using the following formula:

$N_{opt} = (t/D)^2 \, aX^{b-2}$

Where, t is the tabulated value at p = 0.05, D is the desired precision, X is the mean density and 'a' and 'b' are Taylor's regression coefficients.

RESULTS

Spatial distribution of *M. persicae* on bell pepper

The aphid appeared on the crop during 41st standard week and persisted throughout the cropping season with peak (263.35 aphids/plant) during 48th standard week of 2018 (Table 1). The variance (σ^2) was higher than the mean density (X) for all the sampling dates indicating an aggregated or negative binomial distribution for the green peach aphid throughout the crop growing period. The variance to mean ratio (σ^2/X) varied from 3.16 to 239.58 during 2018-2019 for different sampling dates. In each case, the variance to mean ratio (σ^2/X) was more than one, exhibiting a negative binomial distribution of the aphid. The index of dispersion I_D and z-values were calculated to determine the departure of the distribution from random to poisson. Z-values varied from 7.75 to 143.38 for different sampling dates. Since, all these values were more than 1.96, the null hypothesis that the aphid follows poisson distribution was rejected with confirmation of aggregated or negative binomial distribution. The David Moore Index (IDM) also confirmed the negative binomial distribution of the aphid. The Lloyd's mean crowding (X*) varied from 3.54 to 415.87 for different sampling dates. The mean crowding to mean ratio (X*/X) ranged from 2.57 to 18.18 which again verified the aggregated nature of the spatial distribution of the aphid (Table 1). The Taylor's power equation was $\sigma^2 = 6.97X^{1.531}$ ($R^2 = 0.93$) (Fig. 1a) and patchiness regression fitted to the negative binomial was X* = 45.12 + 1.33X ($R^2 = 0.85$) (Fig. 1b) confirming the strong contiguous and dependence of variance on mean density. The value of dispersion parameter 'k' was calculated for each sample. It fluctuated from 0.06 to 3.50. The maximum value (3.50) of 'k' was found in the 52nd standard week i.e. 4th week of December, 2018. The parameter 'k' is a general reciprocal index of dispersion that also arises as the parameter of negative binomial.

Spatial distribution of *Aphidius matricariae* parasitizing *M. persicae* on bell pepper during 2018-2019

The aphid mummies due to *A. matricariae* parasitism appeared during the 46th standard week and persisted throughout the season with peak during the 1st standard week i.e. 1st week of January, 2019 (Table 2). The variance (σ^2) was higher than the mean density (X) for all the sampling dates indicating an aggregated or negative binomial distribution of the parasitoid throughout the crop growing period. The variance to mean ratio (σ^2/X) was more than one exhibiting a negative binomial distribution for different sampling dates. The parasitoid activity started during 46th standard week i.e. 2nd week of November, 2018 with mean density of 0.38 parasitized aphids per leaf accounting for 0.42% parasitisation of *M. persicae.* The parasitoid density increased and attained the peak (19.70 parasitized aphids/leaf) during 1st standard week i.e. 1st week of January, 2019 and thereafter, the population of the parasitoid declined. The parasitoid's main activity period was 1st and 2nd standard week (X = 15.82-19.70) with spatial distribution of aggregated one (z =17.87-26.28; IDM = 6.87-12.36; σ^2 = 124.48-263.19; k = 2.30-1.59; X* = 22.69-32.06; X*/X = 1.43-1.63). The Taylor's power equation was $\sigma^2 = 4.29X^{1.282}$ ($R^2 = 0.90$) (Fig. 2a) and patchiness regression fitted to the negative binomial was X* = 5.406 + 1.195X ($R^2 = 0.767$) (Fig. 2b).

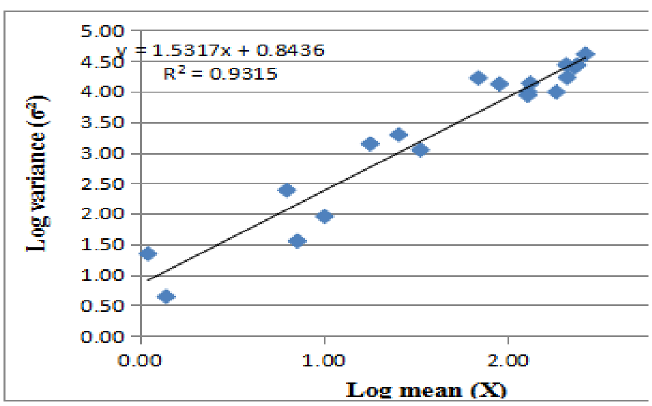
Optimum number of samples of *M. persicae* and *A. matricariae*

Data presented in Tables 3 and 4 revealed that the optimum number of samples required varied with the mean density and the desired precision level for the aphid and its parasitoid. At low density, (eg. 10, and 1 in case of *M. persicae,* and *A. matricariae*, respectively), large sample size (eg. 261.1 and 474 for *M. persicae* and *A. matricariae*) is

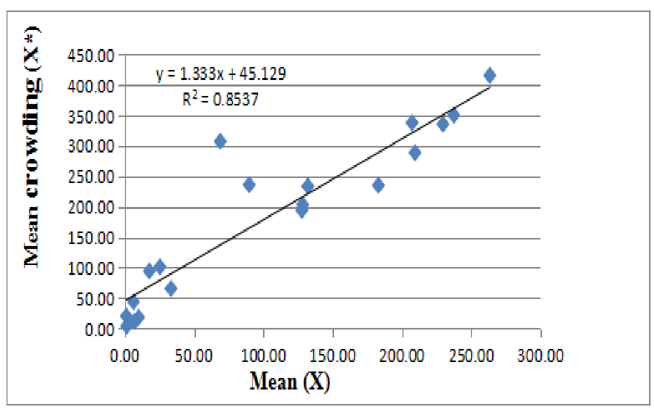
Table 1. Spatial distribution of *M. persicae* on bell pepper under polyhouse condition during 2018-2019

Standard Week	Population density and indices of dispersion							
	X	σ2	σ2/X	K	Z	IDM	X*	X*/X
41	1.10	21.89	19.90	0.06	34.31	18.90	20.00	18.18
42	6.26	239.71	38.29	0.17	51.41	37.29	43.55	6.96
43	17.78	1376.54	77.42	0.23	77.26	76.42	94.20	5.30
44	25.40	1944.20	76.54	0.34	76.76	75.54	100.94	3.97
45	68.92	16511.71	239.58	0.29	143.38	238.58	307.50	4.46
46	89.71	13216.32	147.33	0.61	110.31	146.33	236.03	2.63
47	132.03	13561.06	102.71	1.30	90.48	101.71	233.74	1.77
48	263.35	40430.22	153.52	1.73	112.81	152.52	415.87	1.58
49	207.31	27334.03	131.85	1.58	103.82	130.85	338.16	1.63
50	229.50	24618.00	107.27	2.16	92.68	106.27	335.77	1.46
51	209.45	16800.06	80.21	2.64	78.81	79.21	288.66	1.38
52	182.95	9741.46	53.25	3.50	62.39	52.25	235.19	1.29
1	237.36	27122.69	114.27	2.10	95.97	113.27	350.63	1.48
2	128.32	9774.47	76.17	1.71	76.55	75.17	203.49	1.59
3	127.78	8586.49	67.20	1.93	71.30	66.20	193.98	1.52
4	33.34	1100.07	33.00	1.04	47.02	32.00	65.34	1.96
5	10.04	89.71	8.94	1.27	19.74	7.94	17.98	1.79
6	7.14	35.43	4.96	1.80	12.20	3.96	11.10	1.55
7	1.38	4.36	3.16	0.64	7.75	2.16	3.54	2.57
Taylor's power equation					**$\sigma^2 = 6.97X^{1.531}$ ($R^2 = 0.93$)**			
Iwao's Regression					**$X^* = 45.12 + 1.33X$ ($R^2 = 0.85$)**			

X mean density, σ^2 variance, k parameter of dispersion, z-z value, IDM David Moore Index, X* mean crowding



a) power equation for *M. persicae*



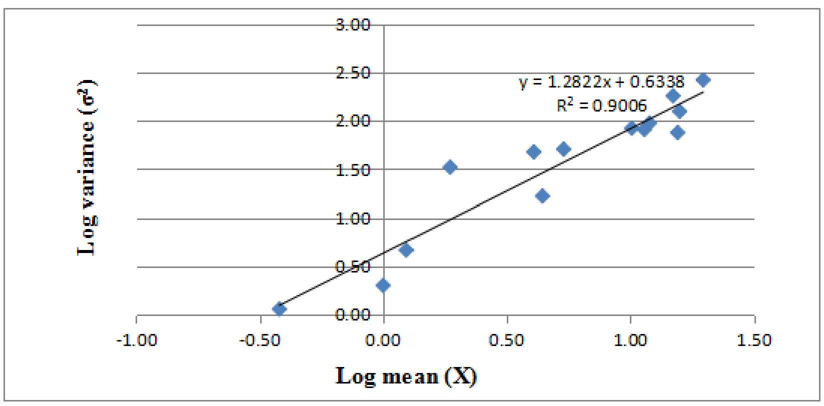
b) Iwao's patchiness regression

Fig. 1. Linear regression equation for *M. persicae*

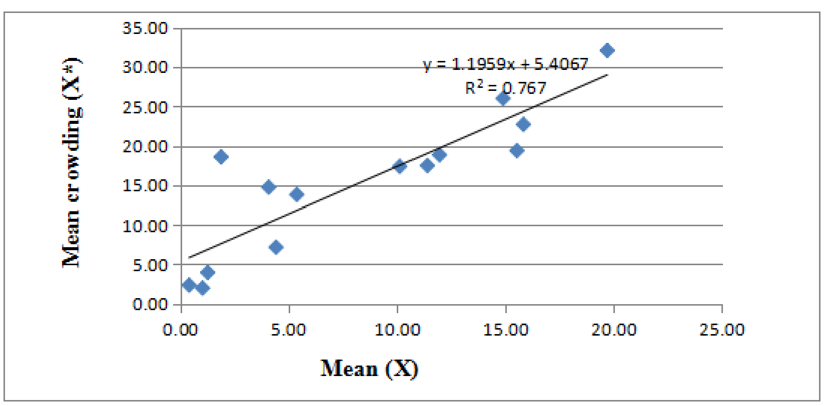
Table 2. Spatial distribution of *A. matricariae* parasitizing *M. persicae* on bell pepper during 2018-2019

Standard Week	Population density and indices of dispersion								
	X	Parasitiza-tion (X)	σ^2	σ^2/X	K	Z	IDM	X*	X*/X
46	0.38	0.42	1.14	3.00	0.19	7.23	2.00	2.38	6.25
47	1.86	1.41	32.94	17.71	0.11	31.76	16.71	18.57	9.98
48	5.36	2.04	50.64	9.45	0.63	20.53	8.45	13.81	2.58
49	4.06	1.96	47.40	11.68	0.38	23.93	10.68	14.74	3.63
50	14.88	6.48	180.11	12.10	1.34	24.54	11.10	25.98	1.75
51	10.12	4.83	83.41	8.24	1.40	18.52	7.24	17.36	1.72
52	11.94	6.53	94.22	7.89	1.73	17.91	6.89	18.83	1.58
1	19.70	8.30	263.19	13.36	1.59	26.28	12.36	32.06	1.63
2	15.82	12.33	124.48	7.87	2.30	17.87	6.87	22.69	1.43
3	15.52	12.15	75.15	4.84	4.04	11.88	3.84	19.36	1.25
4	11.38	34.13	80.73	7.09	1.87	16.47	6.09	17.47	1.54
5	4.40	43.82	16.61	3.78	1.59	9.34	2.78	7.18	1.63
6	1.24	17.37	4.64	3.74	0.45	9.24	2.74	3.98	3.21
7	1.00	72.46	2.00	2.00	1.00	4.10	1.00	2.00	2.00
Taylor's power equation	**$\sigma^2 = 4.29X^{1.282}$ (R^2 = 0.90)**								
Iwao's Regression	**X* = 5.406 + 1.195X (R^2 = 0.767)**								

X mean density, σ^2 variance, k parameter of dispersion, z-z value, IDM David Moore Index, X* mean crowding



Taylor power equation



b) Iwao's patchiness regression

Fig. 2. Linear regression for *A. matricariae* during 2018-2019

Table 3. Optimum number of samples of *M. persicae* at different densities and precision levels

Density (X)	Precision (D)		
	0.1	0.2	0.3
10	1044.4	261.1	116.0
100	354.7	88.7	39.4
250	230.8	57.7	25.6
500	166.7	41.7	18.5
1000	120.5	30.1	13.4

Table 4. Optimum number of samples of *A. matricariae* at different densities and precision levels

Density (X)	Precision (D)		
	0.1	0.2	0.3
1	1896.1	474.0	210.7
5	597.0	149.3	66.3
10	363.0	90.7	40.3
15	271.3	67.8	30.1
20	220.7	55.2	24.5

required for achieving precision level of 0.2. It can, therefore, be concluded that during the beginning and towards the end of the season when the mean densities of the aphid and the parasitoid were low, more number of samples would be required to achieve the desired precision of the estimate. Whereas, in the middle of the season, when densities of the aphid and the parasitoids were high, even less number of samples would achieve the same level of precision.

DISCUSSION

In the present study, the green peach aphid, *M. persicae* followed negative binomial distribution or aggregated distribution and various indices of dispersion confirmed the aggregated distribution of the green peach aphid. The green peach aphid, *M. persicae* followed a aggregate or negative binomial distribution in bell pepper under protected conditions in Himachal Pradesh and the various indices of dispersion such as mean (X), mean crowding (X*), 'k' of negative binomial, Taylor's power equation, Iwao's patchiness regression and the David Moore index also confirmed the negative binomial distribution for the green peach aphid (Verma, *et al.,* 2018). There was a good linear relationship between mean crowding and the population mean of potato aphid, *M. euphorbiae* in potato (Walker, *et al.,* 1984). The woolly apple aphid, *Eriosoma lanigerum* also followed aggregate distribution, which was confirmed by negative binomial parameter k, Taylor's power law and Iwao's regression technique (Asante, *et al.,* 1983; Singh, *et al.,* 2016). The *A. gossypii* parasitism by Aphidiid wasps was highest during January to February and the spatial distribution exhibited aggregate distribution on *Hibiscus rosa-chinensis* (Rajabpour and Yarahmadi, 2012). The spatial distribution of *Aphidius colemani*, *A. matricariae*, *Diaretella rapae*, *Praon staryi* and *Praon volucre* parasitizing *M. persicae* on tobacco was recorded and observed the negative binomial distribution. The percentage of mummification reached almost 61% at the end of the cropping period (Kavallieratos, *et al.,* 2005). The *A. asychis,* a parasitoid of *M. persicae* caused 2.3 to 38% parasitisation of *M. persicae* on sweet pepper in greenhouses of Himachal Pradesh (Gavkare, *et al.,* 2013).

The optimum number of samples required varied with the mean density and the desired precision level. At low densities, large sample size and at high densities small sample size are required for achieving same precision level.

During the beginning and towards the end of the season when the mean densities of the aphid and the parasitoid are low, more number of samples are required to achieve the desired precision of the estimate. In case of woolly apple aphid, *E. lanigerum* and its parasitoid, *A. mali,* reports states that 10, 20 and 30% level of precision required (Singh, *et al.,* 2016) and for green peach aphid, *M. persicae* and its parasitoid, *A. asychis* at 10, 20 and 30% level of precision required for densities of 5, 50, 100, 500 and 1000 and 1, 3, 5 and 10 for aphid and parasitoid, respectively (Verma, *et al.,* 2018).

CONCLUSION

Both *M. persicae* and its endoparasitoid, *A. matricariae* followed negative binomial distribution on capsicum throughout the cropping season. The appropriate number of samples required was directly proportional to the precision level and inversely proportional to the population density. Present findings will be useful in developing an effective sampling plan for the pest and the parasitoid and also to develop this parasitoid oriented IPM for the pest.

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COMPETING INTEREST

There is no conflict of interest statement among the authors.

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