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Spatial distribution of green peach aphid, *Myzus persicae* Sulzer and its parasitoid, *Aphelinus asychis* Walker in bell pepper under polyhouse conditions

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Abstract
Investigations were carried out during October 2017- March 2018 at the Experimental Farm of the Department of Entomology, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India in order to study the spatial distribution of *Myzus persicae* and its parasitoid, *Aphelinus asychis* Walker in bell pepper under poly house conditions. One month old bell pepper seedlings cultivar California wonder were planted in the field in the month of October, 2017. In the present study 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 ($\sigma^2=5.2646X^{1.335}$ for aphid and $\sigma^2 = 2.7871 X^{1.277}$ for parasitoid), Iwao's patchiness regression and optimum number of samples (N_{opt}) required to achieve the desired precision were calculated for different densities. Green peach aphid, *M. persicae* appeared in the 47th standard week (57.47aphids/ plant and 0.65 parasitoids / plant during 2017) and persisted upto 4th standard week (2.79 aphids/ plant and 0.15parasitoids / plant during 2018 is ongoing) and followed a negative binomial distribution. Optimum number of samples (N_{opt}) required varied with mean density as well as precision level. The present study will be useful for developing a sampling plan of *M. persicae* and its parasitoids, *A. asychis* in bell pepper for its monitoring and management.

Keywords: Spatial distribution, green peach aphid, parasitoid, sampling, index

Introduction
Bell pepper (*Capsicum annuum* L.) is one of the most important vegetable crops grown extensively in sub-temperate climate throughout the world. Growing of capsicum under polyhouse has been reported to give high yield of good quality produce [1]. The state of Himachal Pradesh is the leading supplier of high quality fresh fruits to the plains during summer and rainy seasons which bring lucrative returns to the farmers. Mid-hills of Himachal Pradesh bestowed with mild climate are best suited for off season cultivation of bell pepper. Many limiting factors have been identified in successful cultivation of capsicum, but, the share of insect pests is significant. Among different insect pests reported on this crop, *Myzus persicae* (Sulzer) (Aphididae: Hemiptera) is the most important causing great damage to the crop [2, 3]. The green peach aphid, *Myzus persicae* (Sulzer) (Aphididae: Hemiptera) is a cosmopolitan and polyphagous species reported to feed on more than five hundred host plants [4]. Both nymphs and adults suck the vital cell sap from various parts of the plant thereby inducing premature senescence. It also excretes honeydew on which sooty mould grows which inhibits the photosynthesis. In addition to direct losses, the aphid is also capable of transmitting more than one hundred and fifty viral diseases in different hosts particularly Solanaceous vegetables [5]. The pest is particularly notorious for insecticide resistance [6] and hence extremely difficult to control with insecticides. Under such circumstances biological control is an ecofriendly and sustainable option to manage this pest. *Aphelinus asychis* Walker is an important parasitoid found commonly associated with *M. persicae* on capsicum [7]. 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. Knowledge of spatial distribution is useful for designing efficient sampling programmes for population estimation, pest management and development of population models and assessment of levels of damage. Distribution pattern of an insect population is an important aspect as it represents the interaction between

individuals of the species and their habitat. Incorporation of the spatial distribution of a natural enemy in to the model improves our understanding about the synchrony between pest and natural enemy. The biological cause of aggregation is largely behavioural, but, highly unpredictable [8]. Many workers have studied in this direction by recording actual number of aphids on randomly selected plants [9-11]. The knowledge of spatial distribution is also important to understand the bioecology of the pest and its parasitoid to determine the sampling protocol for that species. Seasonal population fluctuation of *M. persicae* and *A. asychis* under polyhouse has been studied [7] but the information on spatial distribution is lacking. Therefore, the aim of the present study was to develop a sampling procedure suitable for population dynamics studies of the green peach aphid on bell pepper and its associated parasitoid to determine the within and between-plant distributions and temporal changes in spatial pattern of the aphid in capsicum ecosystem under polyhouse conditions.

Materials and Methods

Study Area

The present study was conducted at the Experimental Farm of the Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. The region falls between mid-hills and high-hills having sub-humid and sub-temperate climate. In the area, the winter season commences from October to March, summer season extends from April to June followed by the rainy season from July to September. Maximum precipitation occurs during the months from July to September. In the winter season precipitation as snow fall also occurs at the higher reaches (above 1000 m amsl) and rainfall in mid hills. Mean maximum and minimum temperature ranges between 0 °C and 35 °C.

Sampling:

Investigations were carried out during October 2017 to March 2018 at the Experimental Farm of the Department of Entomology of Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. One month old capsicum seedlings (cv. California wonder) were planted in the field in the month of September. The crop was raised by following all the recommended agronomic practices of the University except the application of insecticides. The aphid population was recorded as per method of Sachan and Srivastava [12]. Population of *M. persicae* was recorded at weekly intervals starting 15 days of transplanting on 3- leaf sample, one each from lower, middle and upper whorl from each plant and mean aphid population was counted. The population of *A. asychis* was recorded by counting the mummified aphids at weekly intervals on 3- leaf sample one each from lower, middle and upper whorl from each plant and mean parasitoid population was counted.

Data analysis

Indices of Spatial Distribution or Dispersion:

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 poison distribution was considered and the departure of the distribution from random to uniform or aggregated was tested by calculating the index of dispersion (I_D) which was further used to calculate z values as $I_D = (\sigma^2 / X)(n-1)$ where σ^2 = variance, X = mean, n= number of samples, $z= \sqrt{2I_D} - \sqrt{2v-1}$, where v= n-1

z-value between -1.96 and +1.96 confirms the random distribution, whereas, z-value less than-1.96 and more than + 1.96 verifies uniform and aggregated distribution, respectively [13]. The index of clumping or David -Moore index (IDM) was calculated as per David and Moore [14]:

IDM = σ^2 / X -1, σ^2 = variance and X = mean.

The value of IDM is zero for random distribution, less than zero for uniform and more than one 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) was also worked to verify the type of distribution [8]. 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, was calculated as under [15]:

$k= X^2/ (\sigma^2-X)$.

The relationship between variance and mean was worked out by fitting Taylor's power equation as $\sigma^2 = aX^b$ or $\log \sigma^2 = \log a + b \log X$. Where, a = sampling parameter, b = index of aggregation. The Iwao's patchiness regression [16] between mean crowding and mean density was calculated as under:

X2 = $\alpha + \beta X$, where, β referes to the coefficient of contiguousness. The distribution with α =0 and β= >1 corresponds to aggregated distribution and α =0 and β= 1 to random distribution, whereas α =0 and β=<1 corresponds to uniform distribution.

Optimum number of samples:

The optimum number of samples (N_{opt}) required to achieve the desired precision (desired standard error of mean) was calculated for different densities. Generally, a precision level (expressed as standard error of mean) of about 25 percent is desired, however, if the estimate is required to construct the life table a higher level of precision (10%) is desirable [15]. Hence, the N_{opt} was calculated for different densities at 10, 20 and 30% standard error by using the following formula:

$N_{opt} = (t/D)^2 a X^{b-2}$ where, t is the tabulated value of student's at p= 0.05, D is the desired precision/ standard error, X is the mean density and a and b are Taylor's regression coefficients.

Results and Discussion

Seasonal abundance of *M. persicae*

Data presented in Table 1 reveal that the first incidence of green peach aphid appeared on the bell pepper plants during the forty seventh standard week i.e. third week of November, 2017 with an average density of 57.47 aphids per plant and persisted throughout the cropping season with one peak (63.11 aphids/ plant) during the 48th standard week i.e. fourth week of November 2017. Thereafter, the population of the aphid declined and reached the minimum (2.79 aphids/plant) on fourth standard week i.e. fourth week of January, 2018. The present findings corroborate the findings of Nickolas *et al.* [17].

Spatial Distribution of *M. persicae*

It is evident from Table1 that the variance was higher than the mean density which indicated aggregated or negative binomial distribution for the aphids at all sampling dates. The mean variance ratio is the simplest and most fundamental index for determination of aggregation. The variance to the mean ratio (σ^2 / X) during was more than one, which showed a negative binomial distribution of the aphid. This ratio varied from 4.14 to 24.99 for different standard weeks. The z-values (2.71-15.61) were more than 1.96 in each case which confirmed aggregated or negative binomial spatial distribution and the null hypothesis for poison distribution was rejected. The David More Index (IDM) also confirmed the negative binomial distribution of the aphid. The Lloyd's mean crowding (X*) varied from 7.79 to 83.66 during for different standard weeks. The mean crowding to mean ratio (X*/X) fluctuated between 1.25 and 6.11 with maximum during 1st standard week which again verified the aggregated nature of the spatial distribution of the aphid. The patchiness regression fitted to the negative binomial was X* =10.30 +1.152X (r^2 = 0.957) and Taylor power equation was $\sigma^2 = 5.2646\ X^{1.335}$ (r^2 = 0.932) confirming the strong contaguous and dependence of variance on mean density. The present findings corroborate the findings of Singh *et al*. [18]. The contagious distribution of aphid has also been reported by Rai and Singh [19] on *Brassica* crops and Devi [20] on cole crops. The value of dispersion parameter 'k' was calculated for each sample which fluctuated from 0.19 to 3.97. The maximum value of 'k' was found in the 50th standard week i.e. second week of December, 2017. The parameter 'k' is a general reciprocal index of dispersion that also arises as the parameter of negative binomial. The present findings corroborate the results of Anscombe [9] and Akhtar *et al* [21].

Table 1: Spatial distribution of *M. persicae* in bell pepper under protected conditions

Standard Week	Population density and indices of dispersion							
	X	**σ^2**	**σ^2/X**	**k**	**z**	**IDM**	**X***	**X*/X**
47	57.47	1188.26	20.67	2.92	13.66	19.67	77.15	1.34
48	63.11	13.60.47	21.56	3.06	14.07	20.56	83.66	1.33
49	61.68	1294.66	20.98	3.08	13.81	19.99	81.67	1.32
50	57.89	900.79	15.56	3.97	11.03	14.56	72.45	1.25
51	51.52	919.94	17.85	3.05	12.25	16.85	68.38	1.33
52	27.68	691.80	24.99	1.15	15.63	23.99	51.67	1.87
1	4.68	116.89	24.95	0.19	15.61	23.95	28.64	6.11
2	4.89	20.27	4.14	1.56	2.71	3.14	8.04	1.64
3	5.11	39.82	7.79	0.75	6.01	6.79	11.90	2.33
4	2.79	16.77	6.01	0.56	4.52	5.01	7.79	2.79
Taylor's power equation	$\sigma^2 = 5.2646\ X^{1.335}$ (r^2 = 0.932)							
Iwao's regression	X* = 10.30+1.152 X (r^2 = 0.957)							

Optimum Number of Samples for *M. persicae* and *A. asychis*: Data contained in Table 2 and 4 reveal that the optimum number of samples required varied with the mean density and the precision level desired. At low densities, large sample size and at high densities small sample size are required for achieving same precision level. 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 are low, more number of samples are required to achieve the desired precision of the estimate. Whereas, in the middle of the season, when densities are high, even less number of samples will achieve the same level of precision. Similar relationship between optimum number of samples and population density and precision level has also been reported for alfafa weevil, *Hypera postica* (Gyllenhal) in Iran [22] and for *Eriosoma lanigerum* and *Aphilinus mali* on apple in India [18].

Table 2: Optimum number of samples of *M. persicae* at different densities and precisions

Density	Precision(D)		
	0.1	**0.20**	**0.30**
5	925.00	200.00	89.79
50	200.00	49.83	22.15
100	126.00	30.97	13.77
500	43.10	10.77	4.79
1000	26.90	6.73	2.99

Table 4: Optimum number of samples of *A. asychis* at different densities and precisions

Density	Precision(D)		
	0.1	**0.20**	**0.30**
0.5	2353.80	588.17	261.43
1	1426.04	356.47	158.44
3	644.43	160.41	71.30
5	445.43	110.50	49.12
10	269.85	63.37	29.94

Spatial distribution of *A. asychis*

It is evident from Table 3 that variance was higher than mean density which indicated aggregated or negative binomial distribution for the parasitoid at all sampling dates. The mean variance ratio (σ^2/X) was more than 1 which showed a negative binomial distribution of the parasitoid. The ratio varied from 1.25 to 5.39 during different standard weeks. The results of z-values showed variation from 0.72 to 8.15 for different standard weeks. In this study, all these values except on 3rd (0.72) and 4th standard week (-6.16) were more than 1.96 which confirmed aggregated of negative binomial spatial distribution and the null hypotheses for poison distribution was rejected. The David- Moore (IDM) also confirmed the negative bionomial distribution of the aphid. The Lloyd's mean crowding (X*) varied from 0.75 to 5.04 for different standard weeks. The mean crowding to mean ratio (X*/ X) fluctuated between 1.33 and 7.75. The maximum value of the mean ratio (X*/X) was 7.75 on 47th standard week of crop season. This verified aggregated nature of spatial distribution of the parasitoid. Taylor's power equation and patchiness regression were fitted to study the relationship between variance and mean and between mean crowding and mean, respectively. The patchiness regression fitted to the negative binomial X* = 1.089+1.826 X (r^2 = 0.370) and Taylor's power equation was $\sigma^2 = 2.7871\ X^{1.277}$ (r^2 =0.847) confirming the strong contaguous and dependence of variance on mean density. The value of dispersion 'k' fluctuated from 0.15 to 3.05. The maximum value of k (3.05) was found in the 3rd standarad week i.e. week of third week of January, 2018. The parameter is a general reciprocal index of dispersion that also arises in the parameter of negative binomial. The population of the parasitoid was low (0.15parasitoids/plant) during fourth week of January, 2018 and the corresponding z-value was -6.16 which indicated random distribution of the parasitoid. Similar to present findings Omkar *et al.* [23] reported that

Aphelinus asychis a parasitoids of *M. persicae* caused 2.3 to 38 percent parasitization of *M. persicae* on sweet pepper (*Capsicum annuum* L.) crops in greenhouses in Himachal Pradesh, India.

Table 3: Spatial distribution of *Aphelinus asychis* in bell pepper under protected conditions during 2017

Standard week	Population density and indices of dispersion							
	X	σ^2	σ^2/X	k	z	IDM	X*	X*/X
47	0.65	3.50	5.39	0.15	8.15	4.39	5.04	7.75
48	1.45	4.47	3.08	0.69	4.66	2.08	3.53	2.44
49	1.58	3.70	2.34	1.17	3.27	1.34	2.92	1.85
50	1.10	3.04	2.76	0.62	4.09	1.77	2.87	2.61
51	1.70	6.12	3.59	0.65	5.53	2.59	4.29	2.53
52	1.50	3.63	2.42	1.06	3.43	1.42	2.92	1.95
1	1.80	9.01	5.01	0.44	7.63	4.01	5.81	3.22
2	1.25	3.88	3.10	0.59	4.69	2.10	3.56	2.68
3	0.75	0.93	1.25	3.05	0.72	0.25	0.99	1.33
4	0.15	0.24	1.59	0.25	-6.16	0.59	0.75	4.98
Taylor's power equation	$\sigma^2 = 2.7871\ X^{1.277}$ (r^2 =0.847)							
Iwao's regression	X* = 1.089+1.826 X (r^2 = 0.370)							

Conclusion

Both *Myzus persicae* and its endoparasitoid, *Aphelinus asychis* followed negative binomial distribution on capsicum throughout the cropping season. 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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