



Research Article

Spatial distribution of cabbage aphid, *Brevicoryne brassicae* (L.) and its parasitoid, *Diaeretiella rapae* (Mc Intosh) under sub-temperate conditions of Himachal Pradesh, India

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ABSTRACT: Cabbage aphid, *Brevicoryne brassicae* (L.) (Aphididae: Hemiptera) is one of the most serious pest of cauliflower throughout the world. Knowledge of spatial distribution is important for developing an effective sampling plan and ultimately for IPM strategies for a given pest. In the present study spatial distribution of *B. brassicae* and its parasitoid, *Diaeretiella rapae* (Mc Intosh) (Braconidae: Hymenoptera) was studied on cauliflower (*Brassica oleracea* var *botrytis*) under sub-temperate conditions of India during 2017. Both *B. brassicae* and *D. rapae* assumed activity in the fourth week of January and remained active till May end with peak activity during fourth week of March, 2017. Dispersion indices like variance to mean ratio (σ^2/X), David-Moore index ($IDM = \sigma^2/X-1$), mean crowding (X^*), Lloyd's mean crowding index (X^*/X) and 'k' of negative binomial indicated that both the aphid and the parasitoid followed negative binomial distribution throughout the cropping season, Taylor's power equation was $\sigma^2 = 1.7013X^{0.5314}$ for *B. brassicae* and $\sigma^2 = 2.2057X^{1.4467}$ for *D. rapae*, while Iwao's patchiness regression equation was $X^* = 32.0099 + 1.7947X$ and $X^* = -2.0678 + 2.2746X$ for *B. brassicae* and *D. rapae*, respectively. Optimum number of samples required varied with the mean density and the desired precision level for both the aphid and the parasitoid.

KEY WORDS: *Brevicoryne brassicae*, *Diaeretiella rapae*, dispersion, parasitoid, spatial distribution

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INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis*) is one of the most important crops grown in Himachal Pradesh for table as well as seed production within an area of 5.31 thousand hectares with annual production of 124.33 thousand tonnes (Anonymous, 2017). Cauliflower production in the state is hampered due to the attack of various insect-pests of which cabbage aphid, *Brevicoryne brassicae* (L.), cabbage butterfly, *Pieris brassicae* L., diamondback moth, *Plutella xylostella* L. and painted bug, *Bagrada cruciferarum* Kirkaldy are the important ones (Bhatia, 1986; Bhatia and Gupta, 2003; Kumar *et al.*, 2014; Meghana *et al.*, 2018). The damage caused to cauliflower by *B. brassicae* is both direct and indirect. The symptoms of direct injury are loss of plant vigour and stunted growth, while, indirect injury includes excretion of honey dew by aphids and development of sooty mould which hinders the photosynthetic process. According to Khan *et al.* (2015) cabbage aphid causes 35-75 per cent yield losses. Cabbage aphid also acts as the vector for viruses causing blackening spot in cauliflower, cauliflower mosaic and cabbage viruses A and B (Kaul, 1998). Estimating the pest densities is basic

requirement for any research programme in relation to insect ecology and/or pest management. The accurate estimate of the population density depends upon the reliable sampling programme. Sampling programme includes proper sampling time, sampling unit, and optimum number and for this, the knowledge of spatial distribution of the species is crucial. The biological cause of aggregation is mostly behavioural, but is highly unpredictable (Lloyd, 1967). Therefore, the knowledge of spatial distribution is also important to understand the bio-ecology of the pest and to determine the sampling protocol for that species.

An important role is played by natural enemies in the suppression of aphids, diamondback moth and cabbage butterfly. Because of the varied extent of parasitization of cabbage aphid in the field as reported in the earlier studies, it is important to study the distribution pattern of the parasitoid in the field. Seasonal population fluctuation of *B. brassicae* has been studied (Verma *et al.*, 2008) but the information regarding the spatial distribution of *B. brassicae* vis-a-vis its parasitoid, *D. rapae* on cauliflower conditions is lacking. The present study was therefore, aimed at to study the seasonal

interaction and spatial distribution of cabbage aphid and its parasitoid, *D. rapae* to develop reliable sampling programme as a tool for effective management strategy against this pest.

MATERIALS AND METHODS

Sampling

One-month old cabbage seedlings were transplanted in the field. The crop was raised as per recommended package of practices of vegetable crops, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (Anonymous, 2014) except the application of insecticides. The aphid population was recorded as per method of Sachan and Shrivastava (1972). Population of *B. brassicae* was recorded after 15 days of transplanting at weekly intervals on 3-leaf sample; one each from lower, middle and upper whorl from each plant.

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 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 follows poison 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 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 -values less than -1.96 and more than +1.96 verifies uniform and aggregated distribution respectively (Patil and Stiteler, 1974). The index clumping or David-Moore index (IDM) was calculated as per David and Moore (David and Moore, 1954):

$$IDM = \sigma^2/X - 1, \sigma^2 = \text{variance and } X = \text{mean.}$$

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 worked to verify the type of distribution (Lloyd, 1967). 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 (Southwood and Henderson, 2000):

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

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 (Iwao, 1972) between mean crowding and mean density was calculated as under:

$X^* = \alpha + \beta X$, where, β refers to the coefficient of contiguity. The distribution with $\alpha = 0$ and $\beta > 1$ corresponds to aggregated distribution and $\alpha = 0$ and $\beta = 1$ corresponds to random distribution, whereas $\alpha = 0$ and $\beta > 1$ uniform distribution.

Optimum number of samples

The optimum number of samples (N_{opt}) required for achieving 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 per cent 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 of student's t at $p = 0.05$, D is the desired precision/standard error, X is the mean density and a and b are Taylor's regression coefficient.

RESULTS AND DISCUSSION

Spatial distribution of *Brevicoryne brassicae* on cauliflower

The aphid appeared on the crop during fourth standard week and persisted throughout the cropping season with peak during twelfth standard week during 2017 (Table 1). The variance was higher than the mean density for all the sampling dates indicating an aggregated or negative binomial distribution for the cabbage aphids throughout the crop growing period. The variance to mean ratio (σ^2/X) varied from 2.46 to 664.18 during 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 ID and z -values were calculated to determine the departure of the distribution from randomness to poison. Z -values varied from 5.67 to 245.28 for different sampling dates. Since all these values were more than 1.96, the null hypothesis that the aphid follows poison distribution was rejected with confirmation of aggregated or negative binomial spatial distribution. The David More Index (IDM) also confirmed the negative binomial distribution of the aphid. The Lloyd's mean crowding (X^*) varied from 3.25 to 867.44 during for different sampling dates. The mean crowding to

mean ratio (X^*/X) ranged from 1.28 to 4.25 which again verified the aggregated nature of the spatial distribution of the aphid. The patchiness regression fitted to the negative binomial was $X^* = 28.850 + 1.798X$ ($R^2=0.778$) (Fig. 2) and Taylor's power equation was $\sigma^2 = 1.701X^{1.914}$ ($R^2=0.976$) (Fig. 1) during 2017 confirming the strong contiguous and dependence of variance on mean density.

Similar to present findings Rai and Singh (1993) reported the contiguous distribution of mustard aphid on *Brassica* crops and Devi (1998) on Cole crops. The value of dispersion parameter 'k' was calculated for each sample.

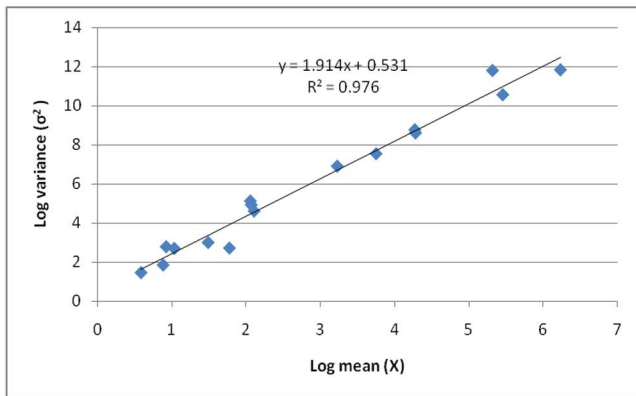


Fig. 1. Taylor power equation for *Brevicoryne brassicae* during 2017. Linear regression between log variance and log mean.

It fluctuated from 0.37 to 1.86 during 2017. The maximum value of 'k' was found in the twelfth standard week i.e. 4th week of March, 2017. The present findings corroborate the findings of Verma *et al.* (2017) for cabbage aphid and Akhtar *et al.* (2010) for *Lipaphis erysimi* reported that the value of dispersion parameter 'k' fluctuated between 1.41 and 6.13 during 2006-07 and 2.72 and 8.80 during 2007-08. Arbab and Mirphakhar (2016) reported similar results that Taylor's b and Iwao's β were both significantly more than 1, indicating that adults and larvae of *Bactrocera oleae* in olive orchards had aggregated spatial distribution. Pino *et al.*, (2011) reported that density of *Cydia fagiglandana* showed a heterogenous and aggregated distribution and spatio-temporal stability

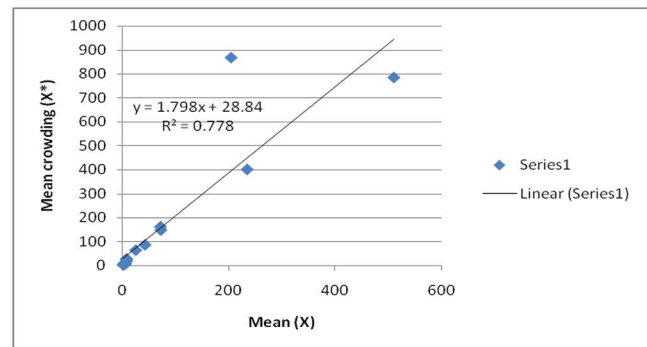


Fig. 2. Iwao's patchiness regression for *Brevicoryne brassicae* during 2017. Linear regression between mean crowding and mean.

Table 1. Spatial distribution of *Brevicoryne brassicae* on cauliflower during 2017

Standard week	Population density and indices of dispersion							
	X	σ^2	σ^2/X	K	z	IDM	X^*	X^*/X
IV(Jan)	1.79	4.40	2.46	1.23	5.67	1.46	3.25	1.82
V(Feb)	2.41	6.51	2.70	1.42	6.42	1.70	4.11	1.71
VI(Feb)	2.80	15.11	5.39	0.64	13.15	4.39	7.19	2.57
VII(Feb)	4.42	20.51	4.64	1.21	11.48	3.64	8.06	1.82
VIII(Feb)	25.19	1016.90	40.37	0.64	53.05	39.37	64.56	2.56
IX(March)	72.36	5576.60	77.07	0.95	77.06	76.07	148.43	2.05
X(March)	71.68	6566.42	91.61	0.79	84.90	90.61	162.29	2.26
XI(March)	234.52	39351.72	167.79	1.40	118.38	166.79	401.32	1.71
XII(March)	510.09	140593.90	275.63	1.86	154.50	274.63	784.72	1.54
XIII(April)	204.26	135664.50	664.18	0.31	245.28	663.17	867.44	4.25
XIV(April)	42.51	1927.21	45.33	0.96	56.81	44.34	86.85	2.04
XV(April)	5.89	15.45	2.62	3.63	6.18	1.62	7..51	1.28
XVI(April)	2.51	16.53	6.59	0.45	15.56	5.59	8.09	3.22
XVII(April)	7.81	171.22	21.92	0.37	36.50	20.92	28.73	3.68
XVIII(May)	8.21	102.59	12.49	0.71	25.15	11.49	19.71	2.40
XIX(May)	7.91	140.60	17.77	0.47	31.89	16.77	24.68	3.12
Taylor's power equation	$\sigma^2 = 1.701X^{1.914}$ ($R^2=0.976$)							
Iwao's Regression	$X^* = 28.845 + 1.798X$ ($R^2=0.778$)							

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

in holm oak (*Quercus ilex* L.) forest. Singh *et al.*, (2016) reported similar results that the variance to mean ratio (σ^2/X) was more than one during 2013 and 2014, exhibiting a negative binomial distribution of the *Eriosoma lanigerum* during both the years.

Spatial distribution of *Diaeretiella rapae*

The mummies of *Diaeretiella rapae* appeared on cabbage aphid during the fourth standard week and persisted throughout the season and attained the peak at twelfth standard week and maximum parasitization was observed at fifteenth standard week during 2017. Table 2 reveal that *D. rapae*, a parasitoid of *Brevicoryne brassicae* followed aggregated or negative binomial distribution throughout the season except for the beginning and at the end of season where it followed uniform or random. When parasitoid density was low, the distribution was uniform. As the density increased, the distribution shifted from uniform to random to aggregate. During 2017, the parasitoid activity started during the last week i.e. fourth week of January with mean density of 0.32 parasitized aphids per leaf resulting in 7.32 per cent parasitization of *B. brassicae*. At this stage, the parasitoid was uniformly distributed ($z = -1.83$; $IDM = -0.34$; $\sigma^2 / X = 0.66$; $X^* = -0.02$ and $X^*/X = -0.06$) (Table 2). The

parasitoid density increased gradually and attained the peak (9.58 parasitized aphids/leaf) during last week of March coinciding with the peak activity of the aphid. Thereafter, the population of the parasitoid started to decline. A decline in the parasitoid population after peak could be justified by the drastic reduction in the aphid population resulted by heavy parasitization. At low host density, parasitoid might have found difficulty in finding the host and the population of the parasitoid also reduced consequently. At higher densities (3.59 to 9.58) during the main activity period, the parasitoid followed a negative binomial distribution ($z = 6.44-22.87$; $IDM = 1.71-9.93$; $\sigma^2 = 9.72-93.09$; $k = 0.86-2.59$; $X^* = 5.29 -18.44$ and $X^*/X = 1.47-9.18$). 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 was $X^* = 0.158 + 1.726x$ ($R^2 = 0.935$) (Fig. 4.) and Taylor’s power equation was $\sigma^2 = 2.205X^{1.454}$ ($R^2 = 0.939$) (Fig. 3.) respectively, confirming the strong contiguous and dependence of variance on mean density. Decline in parasitoid population was observed towards the end of the cropping season (April onwards) as well as with the decline in the host population.

The decline in host population was possibly due to the

Table 2. Spatial distribution of *Diaeretiella rapae* on cauliflower under mid-hill during 2017

Standard week	Population density and indices of dispersion								
	X	Parasitization (%)	σ^2	σ^2/X	k	z	IDM	X*	X*/X
IV(Jan)	0.32	7.32	0.21	0.66	-0.93	-1.83	-0.34	-0.02	-0.06
V(Feb)	0.17	6.51	0.10	0.59	-0.41	-2.26	-0.41	-0.24	-1.41
VI(Feb)	0.32	8.13	0.16	0.50	-0.64	-2.85	-0.50	-0.18	-0.56
VII(Feb)	0.07	1.20	0.02	0.29	-0.09	-4.56	-0.70	-0.64	-9.14
VIII(Feb)	0.22	0.88	0.32	1.45	0.48	2.09	0.45	0.67	3.05
IX(March)	0.60	0.86	1.59	2.65	0.36	6.27	1.65	2.25	3.75
X(March)	0.90	1.26	1.60	1.78	1.16	3.35	0.78	1.68	1.87
XI(March)	3.59	1.52	9.72	2.71	2.10	6.44	1.71	5.29	1.47
XII(March)	9.58	1.85	55.14	5.76	2.01	13.90	4.76	14.34	9.18
XIII(April)	8.52	3.99	93.09	10.93	0.86	22.87	9.93	18.44	-1.29
XIV(April)	4.63	8.83	12.90	2.79	2.59	6.68	1.78	6.42	2.23
XV(April)	4.05	43.80	20.20	4.99	1.02	12.26	3.99	8.04	1.12
XVI(April)	0.21	8.37	0.43	2.05	0.20	4.32	1.05	1.26	3.25
XVII(April)	0.20	2.70	0.30	1.50	0.40	2.28	0.50	0.70	2.21
XVIII(May)	0.12	1.80	0.31	2.58	0.08	6.06	1.58	1.70	1.57
XIX(May)	0.22	2.20	0.40	1.82	0.27	3.49	0.85	1.04	2.31
Taylor’s power equation	$\sigma^2 = 2.206X^{1.454}$ ($R^2 = 0.938$)								
Iwao’s Regression	$X^* = 0.158 + 1.726X$ ($R^2 = 0.936$)								

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

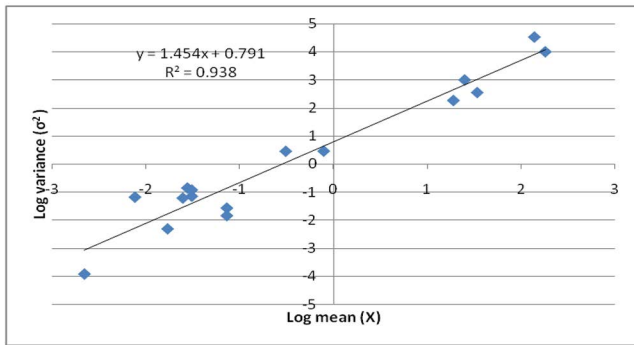


Fig. 3. Taylor power equation for *Diaeretiella rapae* during 2017. Note: Linear regression between log variance and log mean.

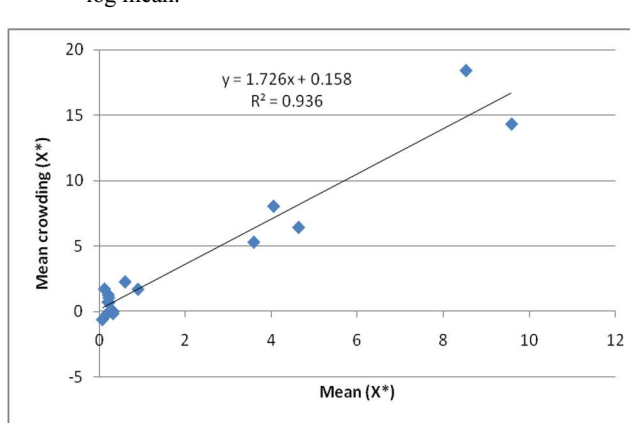


Fig. 4 Iwao's patchiness regression for *Diaeretiella rapae* during 2017. Note: Linear regression between log variance and log mean.

combined action of the parasitoid and prevailing climatic conditions, which has led to the decline in the parasitoid density. In the present findings during the end of the cropping season the parasitoid's spatial distribution pattern shifted from negative binomial to uniform distribution. Similar results were obtained by Amini and Madadi (2014) who observed that by using the Taylor's power law the b coefficient for *D. rapae* on *B. brassicae* was 1.493 and 1.527 at two canola fields during 2014. The b coefficient at field was almost similar to the present findings. Singh *et al.* (2016) recorded Taylor's coefficient b as 1.6449 and 1.8688 during 2013 and 2014, respectively for parasitoid *Aphelinus mali* (Haldeman) parasitizing *Eriosoma lanigerum* (Hausmann).

Optimum number of samples

Data presented in Table 3 and 4 reveal that the optimum number of samples required varied with the mean density and the precision level desired for the aphid and its parasitoid. At low densities (10 in case of *Brevicoryne brassicae* and 2 in case of *Diaeretiella rapae*, large sample size (62.85 for *B. brassicae* and 67.94 for *D. rapae*) is required for achieving same precision level (20%). It can therefore be concluded that during the beginning and towards the end of the season when the mean densities of aphid (up to 10 aphids) and its parasitoid (up to 2 parasitized aphids)

Table 3. Optimum number of samples of *Brevicoryne brassicae*

Density (X)	Precision (D)		
	0.1	0.2	0.3
10	429.57	62.85	17.92
100	353.98	51.64	14.72
300	321.41	47.02	13.40
500	307.71	45.01	12.83

Table 4. Optimum number of samples of *Diaeretiella rapae*

Density (X)	Precision (D)		
	0.1	0.2	0.3
2	464.37	67.94	19.37
5	281.69	41.21	11.75
10	192.97	28.23	8.05

were low, more number of samples were required to achieve the desired precision of the estimate. Whereas, in the middle of the season, when densities of the aphid and the parasitoid were high upto 500 and 10 for *B. brassicae* and *D. rapae*, respectively, even less number of samples will achieve same level of precision. Similar results have been reported by Vajargah *et al.* (2011) for alfalfa weevil, *Hypera postica* (Gyllenhal) at 15, 20 and 30 per cent level of precision and further observed that to acquire higher level of precision, the 15 per cent level could be adopted whereas in IPM programmes 20 per cent level would be acceptable. Singh *et al.* (2016) also concluded reliable results for Apple woolly aphid, *E. lanigerum* and its parasitoid, *A. mali* at 10, 20 and 30 per cent level of precision.

The variance to the mean ratio of cabbage aphid, *B. brassicae* and its parasitoid, *D. rapae* was more than one, which showed a negative binomial distribution during the season. However, for *D. rapae* distribution was uniform at the beginning of the active season. The optimum number of samples required varied with mean population density and more number of samples is required at low densities and higher precision and vice versa for population estimation. Further investigation into these effects would enhance the understanding to the delivery of biological control potential of *D. rapae* in developing integrated pest management programme for cabbage aphid.

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