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ORIGINAL RESEARCH ARTICLE

Distribution pattern and sequential sampling plan for chilli thrips, *Scirtothrips dorsalis* Hood (Thripidae: Thysanoptera)

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Abstract

Spatial distribution and sequential sampling plan for chilli thrips, *Scirtothrips dorsalis* Hood were analyzed through Taylor's power law (TPL) and Iwao's mean crowding regression (IMC) for rainy and summer seasons during 2016–17 on chilli crop. The results revealed that the mean number of thrips in the field was low (1.07 thrips/plant) at early crop growth stages (32 days after transplanting (DAT)) and increased gradually with a peak (21.53 thrips/plant) at 56 DAT. Inconsistency in the mean number of thrips with shifting variance was noticed. The variance of thrips population increased with increase in its density with the best variance (122.41) observed at 56 DAT. Samples of thrips showed variance to mean ratio (S^2/X), Lloyd's patchiness index (X*/X), as well as Morisita Index more than one, revealing clumped distribution. The data on thrips population was best fit to TPL (a = 0.184, b = 1.27, $R^2 = 0.66$) and the IMC ($\alpha = 0.93$, $\beta = 1.14$, $R^2 = 0.94$). Larger variability in sample size *vis-a-vis* mean population density was also achieved at 10 and 20% precision levels. Considering TPL parameters, the decisive lines of sequential sampling for *S. dorsalis* was chosen at $d = 13n \pm 8.07\sqrt{n}$. The sequential sampling plan will thus help in reducing the costs for an effective and efficient management of *S. dorsalis* on chilli.

Keywords Thrips · *Scirtothrips dorsalis* · Sampling · Sample size · Taylor's power law

Introduction

Chilli (*Capsicum annuum* L), crop is regularly infested by thrips, *Scirtothrips dorsalis* Hood (Thripidae: Thaysanoptera) which cause direct damage by sucking the sap from tender plant parts. The affected leaves and fruits get deformed, twisted, brittle and crumpled (Reddy and Puttaswamy 1983). It is also known to transmit tospo viral disease in chilli, together causing a yield loss ranging from 60.56 to 74.31% of green chillies (Fereres 2015; Raccah and Fereres 2009; Patel and Gupta 1996). The severity with in pest varies in different seasons, years, prevailing weather and biotic mortality factors (Patel et al. 2009; Kumar et al. 2014). Uses of insecticide is often not effective because of the rapid reproducibility and potential to develop resistance (Bielza 2008). On the other hand, the essential application of plant protection theme depends on spatiotemporal distribution of the pest (Perry 1994). Data on the dispersion of pest populations *vis a vis* time and space is expected to enhance sampling method, assuring sensible utilization of insecticides (Kakkar et al. 2012). The quantitative assessment of pest damage for implementation of Integrated Pest Management (IPM) varies with costs, threshold levels etc. In this context, the sequential sampling method is taken into consideration as an excellent method to evaluate faster choices on control of pest populations (Binns and Nyrop 1992). The sequential sampling helps in saving up to 50% of the time and labour compared to other sampling techniques (Kao 1984; Wilson et al. 1989; Chander 1997; Parajulee et al. 2006; Rajna and Chander 2013). Apart from this, distribution and movement of thrips, the rate of spread of viral diseases in the field would be ascertained. Albeit, *S. dorsalis* is a major pest and important vector on chillies, information is limited on its spatial characteristics from the prominent chilli grown states of India viz., Karnataka, Andhra Pradesh, Telangana, Maharashtra and Tamil Nadu. The present study was designed to find the distribution and to develop a sequential sampling plan for *S. dorsalis* under field conditions.

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Materials and methods

The investigation was undertaken at ICAR-Indian Institute of Horticultural Research, Bengaluru (12°58'N; 77°35'E) during rainy and summer seasons of 2016–17 and 2017–18 on chilli hybrid 'Arka Meghana'. Four chilli crops were planted at intervals of 10 days. The crops were raised in 10 m^2 area with row to row spacing of 45 cm and plant-plant 30 cm. Crop I was planted on 06-08-2016 during rainy season with average temperature of 26° C, whereas II crop was sown on 3-02-2017 in summer with average temperature of 32° C. The crop was provided with recommended agronomic practices except insecticidal applications and was irrigated through drip system. In order to record thrips population, the 10 m^2 area was further divided into smaller plots, each measuring 2.5 m^2 with 18 plants/plot. Five plants were randomly selected from each small plot and thus a total of fifteen plants (sample size) were randomly tapped from three plots to record thrips incidence starting from 32 to 35 days after transplanting (DAT) at weekly interval. The sampling was continued up to 163 and 128 days in rainy and summer seasons, respectively, till the crop completed more than 50% of fruiting. The thrips were collected in 70% ethanol, sent to ICAR- National Bureau of Agricultural Insect Resources, Bengaluru for further taxonomic identification and confirmation. Since there was no significant difference between the data during similar seasons of both the years, the data were pooled season wise before statistical analysis.

Statistics

The distribution pattern of *S. dorsalis vis –a- vis* time was assessed using variance (S^2) to mean (X) ratio as S^2/X; where, if the value of the ratio is less than 1(< 1), equal to 1 (=1) and more than 1 (> 1) indicates regular, random and aggregated distribution of the pest populations, respectively (Southwood 1978; Sujithra and Chander 2015).

Generalised distribution pattern was studied by using Lloyd's patchiness index (X*/X) as the value of the ratio $X^*/X < 1$ signifies regular distribution, $X^*/X = 1$, random distribution and $X^*/X > 1$ indicates clumped distribution of the population.

The Morisita index of dispersion is evaluated as;

$$I_M = n*\left(\Sigma\left(xi^2\right) - \Sigma(xi)\right) / \left(\Sigma(xi)^2 - \Sigma(xi)\right)$$

where *xi* is the number of individuals in sample *i*, and *n* is the number of samples (*i* = *1, 2, ..., n*). I_M has values from 0 to *n*. In regular distributed patterns the value ranged from 0 and 1, whereas in clumped patterns it appears between 1 and *n* (Morisita 1959, 1962).

Further, confirmation of the distribution was made using Taylor's Power law (TPL) (Taylor 1961), depicts the variance (S^2) of population to be corresponding to the mean density (X), such as $S^2 = aX^b$ wherein 'a' is the sampling parameter and 'b' is the aggregation parameter, both are invariable for a species. Here the value of 'b' specifies distribution pattern of a species as, if $b < 1$ indicates regular distribution, $b = 1$ then random distribution and $b > 1$ indicates clumped distribution.

Iwao's mean crowding (IMC) regression (Iwao 1968), related to mean crowding (X*) with mean density (X), illustrated as $X^* = \alpha + \beta X$. Where α is the index of basic contagion and β is the density contagiousness coefficient. The $\beta < 1$ represents regular distribution, $\beta = 1$ represents random distribution, while $\beta > 1$ represents clumped distribution.

Since the variance-mean relationships of TPL is extremely useful as it permits the prediction of variances for estimated means and this in turn allows development of sequential sampling procedures (Binns and Nyrop 1992). Therefore to develop sequential sampling plan with precision levels of 0.10 and 0.20, optimum sample size needs to be calculated using the critically important parameters (a and b) of the TPL as; $n = aX^b/C^2X^2$ where a, b and X are aforementioned and C is the desired precision level (Green 1970; Southwood 1978).

Sequential sampling plan for *S. dorsalis* was developed using the TPL (Ekborm 1985)

$$d = nm_o \pm t\left(\sqrt{n}\ a\ m^b{}_o\right)$$

where $d_{1=}$ nm_o $_+$ t ($\sqrt{n}$ a $m^b{}_o$) and $d_{1=}$ nm_o t ($\sqrt{n}$ a $m^b{}_o$) indicate the upper and lower decision lines of sequential sampling, respectively; d_0 is the lower limit of the confidence interval for the cumulative number of *S. dorsalis;* d_1 upper limit of the confidence interval for the cumulative number of *S. dorsalis; n* is the number of sampling units observed; m_o is the economic injury level (EIL) of *S. dorsalis*; *t* is the student's *t*-test at 20% probability (t = 1.28); 'a' and '*b*' are the sampling and aggregation parameter of the TPL, respectively.

The maximum number of samples required if the cumulative number of larval population remained between the upper and lower limit was computed as

$$n_{\max} = t^2 \text{ x } a\, m_0{}^b / p^2$$

where $p = t.Sx$ (*t* is the value of normal deviate and *Sx* is the SE of the mean). The standard Error (SE) as 25% of the mean was adjudged as admissible (Southwood and Henderson 2000) and at 20% probability level, the value of 't' used was 1.28. All the analysis was carried out using Microsoft excel spreadsheet.

Table 1 Distribution indices for thrips on chilli, rainy season, 2016 and 2017

	Crop I						Crop II						Crop III						Crop IV					
	Mean (X)	variance (S^2)	S^2/X	X*	X*/X		Mean (X)	variance (S^2)	S^2/X	X*	X*/X	IM	Mean (X)	variance (S^2)	S^2/X	X*	X*/X	I_M	Mean(X)	Variance (S^2)	S^2/X	X*	X*/X	I_M
32DAT	1.07	4.5	4.21	4.28	4.01	4.00	0.33	0.24	0.71	0.05	0.14	0.75	0.13	0.12	0.93	0.06	0.46	0.00	0.71	0	0	−0.29	−0.41	0.53
36 DAT	4.73	19.21	4.06	7.79	1.65	1.58	1.27	3.78	2.98	3.25	2.57	0.96	0.2	0.17	0.86	0.06	0.29	0.25	0.07	0.07	1	0.07	1	0.45
45 DAT	2.87	4.27	1.49	3.36	1.17	1.13	2.67	6.1	2.29	3.95	1.48	1.45	0.53	0.55	1.04	0.57	1.07	0.80	0.2	0.17	0.86	0.06	0.29	0.25
50 DAT	11.47	72.41	6.31	16.78	1.46	1.42	12.33	57.24	4.64	15.97	1.3	1.15	10.6	26.69	2.52	12.12	1.14	1.07	4.2	11.46	2.73	5.93	1.41	0.84
56 DAT	21.53	122.41	5.68	26.22	1.22	1.19	21.53	122.41	5.68	26.22	1.22	1.19	28.87	232.55	8.06	35.92	1.24	1.21	14.4	131.97	9.16	22.56	1.57	1.53
59 DAT	18.8	103.17	5.49	23.29	1.24	1.17	18.8	103.17	5.49	23.29	1.24	1.17	17.27	97.35	5.64	21.9	1.27	1.20	9.27	20.21	2.18	10.45	1.13	1.12
64DAT	12.93	56.21	4.35	16.28	1.26	1.14	12.93	56.21	4.35	16.28	1.26	1.14	10.53	50.7	4.81	14.35	1.36	1.31	7.2	18.74	2.6	8.8	1.22	1.20
80 DAT	17.6	34.83	1.98	18.58	1.06	1.01	14	31.86	2.28	15.28	1.09	0.76	12.27	21.5	1.75	13.02	1.06	0.96	5.67	3.95	0.7	5.36	0.95	0.90
86DAT	2.93	4.5	1.53	3.47	1.18	1.05	2.73	2.5	0.91	2.65	0.97	0.89	3.33	2.1	0.63	2.96	0.89	0.87	1.73	1.21	0.7	1.43	0.83	0.62
95DAT	4.07	1.92	0.47	3.54	0.87	0.84	3.6	2.97	0.83	3.43	0.95	0.70	3.8	2.31	0.61	3.41	0.9	0.88	1.93	1.64	0.85	1.78	0.92	0.85
104DAT	6.73	8.35	1.24	6.97	1.04	1.00	6.87	10.27	1.5	7.36	1.07	1.00	5.2	4.17	0.8	5	0.96	0.94	3	2.86	0.95	2.95	0.98	0.95
110DAT	11.47	23.12	2.02	12.48	1.09	0.95	12	19.29	1.61	12.61	1.05	0.90	11.53	32.98	2.86	13.39	1.16	1.13	6.6	6.4	0.97	6.57	1	0.90
118DAT	6.13	20.55	3.35	8.48	1.38	1.22	6.4	17.83	2.79	8.19	1.28	0.67	7.2	16.03	2.23	8.43	1.17	1.10	3.2	4.03	1.26	3.46	1.08	1.05
148DAT	8.33	7.24	0.87	8.2	0.98	0.92	7.73	10.35	1.34	8.07	1.04	0.82	7.87	8.84	1.12	7.99	1.02	0.98	3.73	3.5	0.94	3.67	0.98	0.86
155DAT	6.93	33.21	4.79	10.72	1.55	1.48	6.27	29.78	4.75	10.02	1.6	0.66	5.67	8.24	1.45	6.12	1.08	0.82	4.6	12.97	2.82	6.42	1.4	1.35
163DAT	4.53	12.12	2.67	6.21	1.37	1.08	6.8	9.74	1.43	7.23	1.06	0.99	4.53	9.41	2.08	5.61	1.24	1.21	2.93	4.21	1.44	3.37	1.15	0.94

Based on number of sampling units *N* = 15; X* = Lloyds's mean crowding index; X*/X = Lloyd's patchiness index; I_M = Morisita Index: pooled data 2016 and 2017

Table 2 Distribution indices for thrips on chilli, summer season, 2016 and 2017

Crop Stage	Crop I						Crop II						Crop III						Crop IV					
	Mean (X)	variance (S^2)	S^2/X	X*	X*/X	I_M	Mean (X)	variance (S^2)	S^2/X	X*	X*/X	I_M	Mean (X)	variance (S^2)	S^2/X	X*	X*/X	I_M	Mean (X)	variance (S^2)	S^2/X	X*	X*/X	I_M
35 DAT	5.73	5.92	1.03	5.77	1.01	0.95	5.13	12.41	2.42	6.55	1.28	1.25	4.47	4.41	0.99	4.45	1	0.98	0.8	1.03	1.29	1.09	1.36	1.36
46 DAT	5.27	5.64	1.07	5.34	1.01	0.95	7.87	21.41	2.72	9.59	1.22	1.20	5.93	9.5	1.6	6.53	1.1	1.03	1.07	1.35	1.27	1.33	1.25	1.00
52 DAT	19.87	49.12	2.47	21.34	1.07	1.02	19.53	94.27	4.83	23.36	1.2	1.06	17.53	72.27	4.12	20.66	1.18	1.00	6.4	13.4	2.09	7.49	1.17	1.15
58 DAT	26.33	69.24	2.63	27.96	1.06	0.99	28.6	114.54	4	31.6	1.11	1.04	17.27	125.92	7.29	23.56	1.36	1.02	7.8	17.6	2.26	9.06	1.16	0.94
65 DAT	39.27	390.64	9.95	48.22	1.23	1.18	77.53	794.12	10.24	86.78	1.12	0.99	51.87	407.12	7.85	58.72	1.13	1.03	24.67	212.95	8.63	32.3	1.31	1.28
72 DAT	38.07	566.07	14.87	51.94	1.36	1.33	68.4	578.97	8.46	75.86	1.11	1.03	49.33	445.95	9.04	57.37	1.16	1.00	26.33	379.81	14.42	39.76	1.51	1.07
80 DAT	17.27	119.5	6.92	23.19	1.34	1.25	24.53	325.27	13.26	36.79	1.5	1.45	35.4	528.54	14.93	49.33	1.39	1.30	16.2	191.31	11.81	27.01	1.67	1.44
88 DAT	10.27	39.21	3.82	13.09	1.27	1.03	23.2	126.46	5.45	27.65	1.19	1.10	30.27	396.5	13.1	42.37	1.4	1.25	15.2	171.03	11.25	25.45	1.67	1.63
96 DAT	14.73	142.64	9.68	23.41	1.59	1.54	18	54.29	3.02	20.02	1.11	1.05	16.73	118.64	7.09	22.82	1.36	1.28	9.6	63.26	6.59	15.19	1.58	1.52
104 DAT	9.2	30.6	3.33	11.53	1.25	1.23	15.27	32.64	2.14	16.4	1.07	0.99	24.73	158.07	6.39	30.12	1.22	1.12	12.07	109.07	9.04	20.11	1.67	1.51
112 DAT	11.73	22.07	1.88	12.61	1.08	0.86	12.2	29.6	2.43	13.63	1.12	1.09	12.8	22.74	1.78	13.58	1.06	1.00	7.47	27.27	3.65	10.12	1.36	1.24
120 DAT	10.47	58.41	5.58	15.05	1.44	1.31	9.73	28.21	2.9	11.63	1.2	1.17	11.13	35.84	3.22	13.35	1.2	1.08	7.27	12.35	1.7	7.97	1.1	1.03
128 DAT	6.6	19.54	2.96	8.56	1.3	1.27	11.73	23.21	1.98	12.71	1.08	1.00	11.73	31.07	2.65	13.38	1.14	1.02	6.07	14.78	2.44	7.5	1.24	1.18

Based on number of sampling units N = 15; X* = Lloyds's mean crowding index; X*/X = Lloyd's patchiness index; I_M = Morisita Index; pooled data 2016 and 2017

Table 3 Taylor's power Law and Iwao's mean regression for rainy season, 2016 and 2017

Crop	No. of Samples	Taylor's Power Law (TPL)*			Iwao's Mean regression (IMC)*		
		Sampling parameter (a)	Aggregation parameter (b)	Co-efficient of determination (R^2)	Index of basic contagion (α)	Density contagiousness coefficient (β)	Coefficient of determination (R^2)
I	16	1.53	1.27	0.66	0.93	1.14	0.94
II	16	1.11	1.4	0.88	0.06	1.19	0.97
III	16	1.06	1.32	0.92	−0.77	1.26	0.99
IV	16	0.0007	4.28	0.1	−1.20	1.46	0.95

* Pooled data 2016 and 2017

Results and discussion

The mean number of thrips in the field was low (1.07 thrips/plant) at the initial crop growth stage and increased gradually reaching a peak (21.53 thrips/plant) at 56 DAT during rainy season and at 65 DAT (39.27 thrips/plant) during summer season (Tables 1 and 2). A change in the mean number of thrips during both the seasons was evident with variable variance. The variance of thrips population increased with an increase in density was maximum at 56 DAT for all the four crops during rainy season (crop- I & -II- 122.41, crop- III- 232.55 and crop- IV- 131.97) and 72 DAT during summer (Crop-I- 566.07, Crop-II- 578.97, Crop-III- 445.95, Crop-IV- 379.89). Most of the samples during both the seasons showed variance to mean ratio (S^2/X) as well as Lloyd's patchiness index (X*/X) values more than one, indicating clumped distribution of thrips (Tables 1 and 2). Under field conditions, even at low levels the thrips distribution followed an aggregated/clumped pattern. The variance to mean ratio and Lloyd's patchiness index are well known to be influenced by mean value (X*). Hence, Morisita Index was used to study the distribution patterns of thrips population as it is superior in computing aggregation tendency. The index also revealed aggregated in the majority of the sample units particularly during summer seasons. On the other hand, in rainy season, variation in the distribution of thrips on chilli planted at different times was observed. This variation in the distribution pattern could be attributed to the washing effect of continuous rainfall (34.63 mm in 2016; 23.40 mm in 2017) for the period of 10–15 days. High temperature coupled with continuous dryness during summer seasons resulted in building up of thrips population under field conditions. Summer seasons are more congenial for thrips multiplication due to high temperatures (Gill et al. 2015). Further, the relationship between means and variances of thrips population was studied using Taylor and Iwao models. TPL equations for pooled data of four crops during rainy and summer seasons are shown in Tables 3 and 4.

S. dorsalis showed aggregated or clumped distribution with a density contagiousness coefficient (β => 1) for both the seasons on all the crops (Tables 3 and 4). However, the negative value of the index of basic contagion (α) for crop III and IV in rainy and crop I and IV in summer indicated a repelling behaviour of the pest such that the basic component of distribution has single thrips. The repelling behaviour may be to avoid the intra and inter specific competition for food, space and mate. General distribution rarely happens in populations with strong intra-specific competition (Terry and Schneider 1993). In the present study, thrips showed a strong propensity among the population to avoid intra-specific competition. After hatching from egg they may have fed by staying together or clustering, once attaining sufficient number they tend to disperse or spread themselves from one plant to the next (Croteau 2010). The aggregated distribution, S^2/X and X*/X values of a few samples in all four crops during rainy seasons also indicated random distribution. This might be due to the fluctuations in weather parameters particularly the rainfall and

Table 4 Taylor's Power Law and Iwao's Mean Regression for summer, 2016 and 2017

Crop	No. of Samples	Taylor's Power Law (TPL)*			Iwao's Mean Regression (IMC)*		
		Sampling parameter (a)	Aggregation parameter (b)	Coefficient of determination (R^2)	Index of basic contagion (α)	Density contagiousness coefficient (β)	Coefficient of determination (R^2)
I	13	0.36	1.9	0.82	−0.33	1.27	0.96
II	13	0.65	1.63	0.91	1.25	1.11	0.99
III	13	0.26	2	0.94	0.64	1.20	0.97
IV	13	0.97	1.72	0.93	−0.68	1.51	0.97

*Pooled data 2016 and 2017

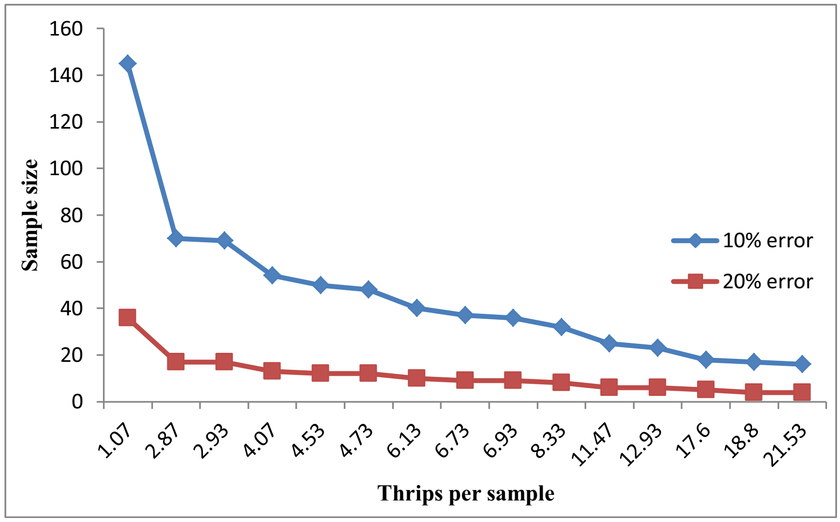

Fig. 1 Relationship between mean population density and required sample size for achieving fixed precision levels of 0.1 and 0.2% for *S. dorsalis* on chilli during rainy season of 2016 and 2017

wind speed during the study. Rainfall coupled with wind velocity dislodges the tiny insects, particularly sucking pests like thrips. Similar effect of meteorological parameters has been observed for cotton thrips and mites (Khan et al. 2008; Janu et al. 2017).

On the other hand, both TPL and IMC have also indicated the aggregated distribution of the pest, though the trend was not same in all the four crops; it was mainly due to the changes in the crop age or stage/phenophase and the environmental heterogeneity. The tendency may also be due to the distribution indices represented for weekly distribution pattern of the pest, whereas the regression models determined the most predominant kind of distribution based on the population levels for the entire season (Sujithra and Chander 2015). In general, intensity of host plants also decides the distribution pattern of insects. In *S. dorsalis*, immature stages and adults tend to feed on the growing parts of the plant and hence they may aggregate (Suel et al. 2012). Besides, the distribution of thrips depends upon the dispersal ability, where random distribution occurs when thrips are with high dispersal ability and clumped distribution shows low dispersal ability in the field (Kumar et al. 2014). In insects, generally crowding is characterised due to intrinsic factors of the population. Females oviposit eggs in clumps and ecological heterogeneity would make certain plants reasonable for oviposition (Southwood 1978; Kirk and Hamilton 2004). Similar aggregation behaviour has been recorded in western flower thrips, *Frankliniella occidentalis* (Pergande) and sometimes fighting behaviour may often occur among the males for getting the female to mate (Olaniran and Kirk 2012). In addition, specific chemicals released by males also act as an aggregation pheromone which attracts other males and females (Hamilton et al. 2005; Kuno 1991; Niassy et al. 2016 and 2019).

Larger variability in sample size *vis-a-vis* mean population density was achieved at 10 and 20% precision levels. Since crop one is at normal planting time (6th August during rainy and 3rd Feb during summer) and thrips distribution trend was similar for the remaining

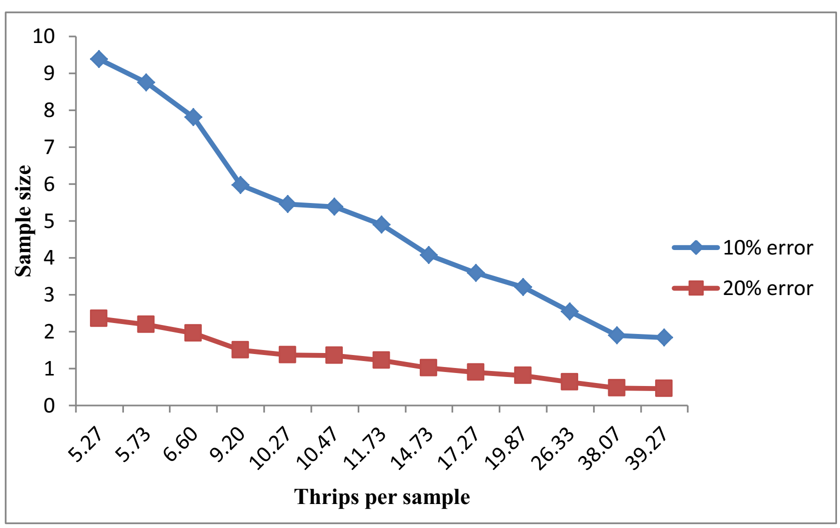

Fig. 2 Relationship between mean population density and required sample size for achieving fixed precision levels of 0.1 and 0.2% for *S. dorsalis* on chilli during summer season of 2016 and 2017

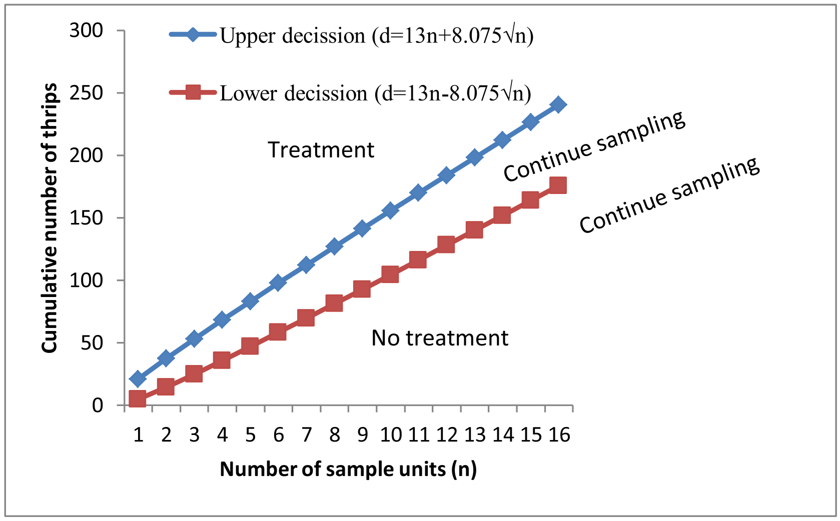

Fig. 3 Sequential sampling plan for rainy season (2016 and 2017) for decision making against *S. dorsalis* on chilli

three crops, hence, optimum sample size for crop one is only discussed in this paper. The optimum sample size for crop one during rainy season ranged from 15.68–144.91 sample units for 10% and 3.92–36.23 units for 20% error (Fig. 1). Whereas, for summer, the optimum sample size ranged from 1.84–9.37 units for 10% and 0.46–2.34 units for 20% error, respectively (Fig. 2). An inverse relationship was observed between sample size requirement and pest density.

The required sample size for 10% precision was four times higher compared to 20% precision. Hence, as the precision level increased the sample size requirement also increased. Detection of thrips infestation at ETL (13 thrips), pest density for rainy season ranged 12.93–11.47 and their corresponding sample units 22.87–25 for 10% and 5.72–6.25 for 20% precision levels, respectively. Whereas, for the summer season, pest density ranged from 11.73–14.73 and their corresponding sample units 4.90–4.07 for 10% and 1.22–1.02 for 20% precision, respectively (Fig. 1 & Fig. 2).

The decision making from the sample size with 20% precision could be economical, as observations on thrips are made through tapping on white card board sheet. Based on parameters from the regression models, the sampling errors have been reduced by minimizing variations in the sampling precision (Payandeh et al. 2010; Southwood and Henderson 2000). Sequential sampling methods were additionally improved to reliably distinguish thrips incidence on chillies. In addition, the decisions of sequential sampling plans for thrips were determined based on TPL parameters viz., aggregation parameter (b) and sampling parameter (α), EIL as 13 thrips per plant and adequate error in assessment as 20% (t = 1.28), decision lines of sequential sampling

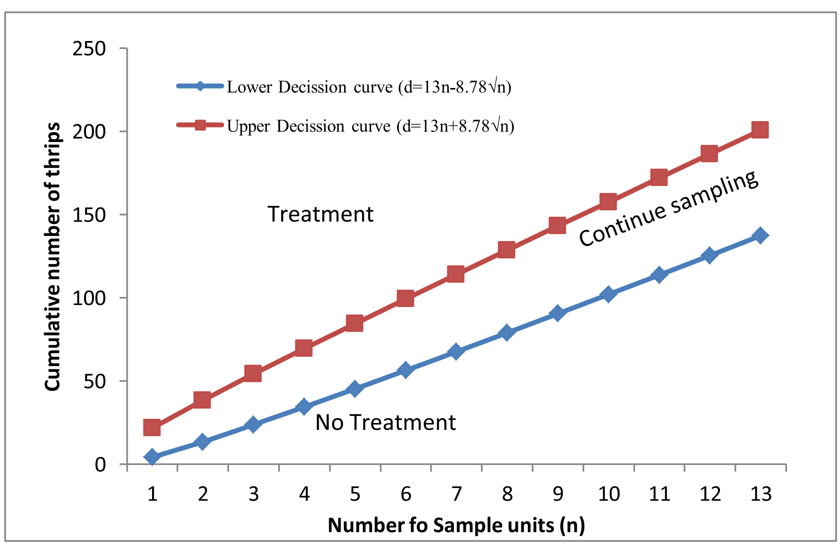

Fig. 4 Sequential sampling plan for summer season (2016 and 2017) for decision making against *S. dorsalis* on chilli

plans for thrips during rainy seasons of 2016 and 2017 (Fig.3):

$$d_1 = 13n + 8.07\sqrt{n} \ \textit{Upper decision line}$$
$$d_o = 13n - 8.07\sqrt{n} \ \textit{Lower decision line}$$

Similarly for summer seasons of 2016 and 2017, the decision lines of sequential plans (Fig. 4):

$$d = 13n + 8.78\sqrt{n} \ \textit{Upper decision line}$$
$$d = 13n - 8.78\sqrt{n} \ \textit{Lower decision line}$$

Two sample units corresponded to an aggregate thrips population of 5 and 21 thrips on lower and upper decision lines, respectively (Fig. 3), i.e., after observing two plants, if the thrips population is below 5, it indicates that the pest population is below ETL, consequently not recommending any plant protection measures. On the other hand, cumulative thrips population of more than 21 per plant implied the pest incidence having surpassed ETL, signifying recommendation of plant protection measures. However, the cumulative thrips number between 5 and 21 require further observations on the third sampling unit and so on. In this sampling method, sample counts are added one after another, with a check after every inclusion to choose whether the information yet permits enough conclusions about infestation. This approach assures a great savings in sampling efforts such as time and resources; as it can identify the fact when additional sampling would return too little extra information to merit its cost (Sujithra and Chander 2015). Maximum sample size in sequential sampling of *S. dorsalis* was five sampling units that would be seen on account of uncertainty. Even after observing five sample units, decision on application of pesticides remains confused, then sampling would then be suspended and continued after seven days. Decisions when thrips population is either low or high can be made with relatively low sampling units. In the present study, a maximum of five sampling units were required for sequential sampling compared to simple random sampling (Fig. 1), where sample size requirement particularly at lower thrips density (1.07 thrips/plant) was 3.92–36.23 sample units even at 20% precision. From the present study, it was found that through sequential sampling plan, requirement of sample size could be reduced to assess *S. dorsalis* population for an effective application of pest management options. In order to understand the spatio-temporal distribution of the pest, assessing pest populations in diversified habitats and correlate it to biotic and abiotic factors is essential (Hurlbert 1990). Commonly adopted sampling techniques such as random sampling, stratified sampling, and systematic sampling are time-consuming and labour demanding (Southwood 1978).

Conclusion

In the present study, distribution indices revealed that *S. dorsalis* tend to distribute in aggregate manner under field conditions. Based on TPL parameters, the decision lines of sequential sampling plan for *S. dorsalis* could be achieved. Five sampling units were required to enumerate maximum sample size in sequential sampling of *S. dorsalis* under moderate pest density. When the thrips population number reaches 21, further sampling could be stopped and requires management interventions. Sequential sampling plan for *S. dorsalis* therefore will help in taking decisions concerning thrips management. The effect of bio-control agents on pest populations can be incorporated to enhance the efficiency of sequential sampling plans.

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Compliance with ethical standards

Conflict of interest Authors have no conflict of interest to express.

References

Bielza P (2008) Insecticide resistance management strategies against the western flower thrips, *Frankliniella occidentalis*. Pest Manag Sci 64:1131–1138

Binns MR, Nyrop JP (1992) Sampling insect populations for the purpose of IPM decision making. Annu Rev Entomol 37:427–453

Chander S (1997) Enumerative and sequential sampling of aphids infesting rapeseed. J Aphidol 11:111–116

Croteau EK (2010) Causes and consequences of dispersal in plants and animals. Nature Edu Know 3(10):12

Ekborm BS (1985) Spatial distribution of *Rhopalosiphum padi* (L.) in spring cereals in Sweden and its importance for sampling. Environ Entomol 14:312–316

Fereres A (2015) Insect vectors as drivers of plant virus emergence. Curr Opin Virol 10:42–46

Gill HK, Garg H, Gill AK, Gillett-Kaufman JL, Nault BA (2015) Onion Thrips (Thysanoptera: Thripidae) biology, ecology, and Management in Onion Production Systems. J Integ Pest Mngmt 6(1):6

Green RH (1970) On fixed precision level sequential sampling. Res Popul Ecol 12:249–251

Hamilton JGC, Hall DR, Kirk WDJ (2005) Identification of a male-produced aggregation pheromone in the western flower thrips, *Frankliniella occidentalis*. J Chem Ecol 31:1369–1379

Hurlbert SH (1990) Spatial distribution of the montane unicorn. Oikos 58:257–271

Iwao S (1968) A new regression method for analyzing the aggregation pattern of animal populations. Res Popul Ecol 10:1–20

Janu A, Dahiya KK, Kumar Y, Jakhar P (2017) Influence of meteorological parameters on population dynamics of thrips (Thrips tabaci Lindeman) in BT cotton. J Entomol Zoology Stud 5(5):1991–1993

Kakkar G, Seal DR, Stansley PA, Liburd OE, Kumar V (2012) Abundance of *Frankliniella schultzei* (Thysanoptera: Thripidae) in flowers on major vegetable crops of South Florida. Florida Entomol 95:468–475

Kao SS (1984) Sequential sampling plans for insect pests. Phytopathol Entomol NTU 11:102–110

Khan MA, Khaliq A, Subhani MN, Saleem MW (2008) Incidence and development of *Thrips tabaci* and *Tetranychus urticae* on field grown cotton. Int J Agri Biol 10:232–234

Kirk WDJ, Hamilton JGC (2004) Evidence for a male-produced sex pheromone in the western flower thrips, *Frankliniella occidentalis*. J Chem Ecol 30:167–174

Kumar V, Kakkar G, Seal DR, Schuster DJ, McKenzie C, Colle J, Osborne LS (2014) Temporal and spatial distribution of an invasive thrips species *Scirtothrips dorsalis* (Thysanoptera: Thripidae). Crop Protec 55:80–90

Kuno E (1991) Sampling and analysis of insect populations. Annu Rev Entomol 36:285–304

Morisita M (1959) Measuring of interspecific association and similarity between communities. Mem Fac Sci Kyushu Univ Ser E Bio 3:65–80

Morisita M (1962) Iδ -INDEX, a measure of dispersion of individuals. Res Popul Ecol 4:1–7

Niassy S, Ekesi S, Maniania NK, Orindi B, Moritz GB, Kogel WJ, Subramanian S (2016) Active aggregation among sexes in bean flower thrips (*Megalurothrips sjostedti*) on cowpea (*Vigna unguiculata*). Entomol Exp Appl 158(1):17–24

Niassy S, Tamiru A, Hamilton JGC et al (2019) Characterization of male-produced aggregation pheromone of the bean flower Thrips *Megalurothrips sjostedti* (Thysanoptera: Thripidae). J Chem Ecol 45:348

Olaniran OA, Kirk WDJ (2012) Fighting behaviour of male Western flower Thrips, *Frankliniella occidentalis* (Pergande). Acta Phytopathol et Entomol Hung 47(1):125–132

Parajulee MN, Shreshta RB, Leser JF (2006) Sampling methods, dispersion patterns and fixed sequential sampling plans for western flower thrips and cotton leafhoppers in cotton. J Econ Entomol 99:568–577

Patel BH, Koshiya DJ, Korat DM (2009) Population dynamics of chilli thrips, *Scirtothrips dorsalis* Hood in relation to weather parameters. Karnataka J Agric Sci 22(1):108–110

Patel VN, Gupta HCL (1996) Efficacy of insecticides against chilli thrips, *S. dorsalis* Hood. Indian J Appl Ent 10:29–34

Payandeh A, Kamali K, Fathipour Y (2010) Population structure and seasonal activity of *Ommatissus lybicus* in bam region of Iran (Homoptera: Tropiduchidae). Munis Entomol Zool 5:726–733

Perry JN (1994) Sampling and applied statistics for pests and diseases. Asp Appl Biol 37:1–14

Raccah B, Fereres A (2009) *Plant Virus Transmission by Insects*. In: eLS. John Wiley and Sons, ltd: Chichester. https://doi.org/10.1002/9780470015902.a0000760.pub2

Rajna S, Chander S (2013) Sequential sampling plan for rice plant hoppers with incorporation of predator effect. J Biol Control 27:10–17

Reddy DNR, Puttaswamy (1983) Pest infesting chilli (*Capsicum annuum* L.) – in the nursery. Mysore J Agric Sci 17:246–251

Southwood TRE (1978) Ecological methods with particular reference to the study of insect populations: the English language book society and chapman and Hall. London, pp 524

Southwood TRE, Henderson PA (2000) Ecological methods. Blackwell Science Ltd, London, p 575

Suel H, Muhamad R, Omar D, Hee AKW, Zazali C (2012) Dispersion pattern and sampling of *Diaphorina citri* Kuwayama (Hemiptera: Psylidae) populations on *Citrus suhuiensis* Hort. Ex Tanaka in Padang Ipoh Terengganu, Malaysia. Pertanika J Trop Agric Sci 35:2536

Sujithra M, Chander S (2015) Distribution pattern and sequential sampling plan for spotted pod borer, *Maruca vitrata* (Fabricius) (Lepidoptera: Crambidae) on pigeon pea, *Cajanus cajan* L. Int J Pest Manage 62(1):64–68

Taylor LR (1961) Aggregation, variance and the mean. Nature 189:732–735

Terry I, Schneider M (1993) Copulatory behaviour and mating frequency of the western flower thrips, *Frankliniella occidentalis* (Insecta: Thysanoptera). J Pure Appl Zool 4:339–354

Wilson LT, Sterling WL, Rummel DR, DeVay JE (1989) Quantitative sampling principles in cotton IPM. In: Frisbie RE, Elzik KM, Wilson LT (eds) Integrated Pest management systems and cotton production. Wiley, New York, pp 85–119