J. Crop Prot. 2014, 3 (Supplementary): 645-654

Research article

Spatial distribution of overwintered adults of *Eurygaster integriceps* (Hemiptera: Scutelleridae) in wheat fields of Ardabil province

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Abstract: In this study, the spatial distribution of overwintered adults of Sunn pest, *Eurygaster integriceps* Puton, was investigated by using dispersion parameters and indices, mathematical distribution, and regression techniques in rainfed wheat fields by sample size of 1 m^2 in 2009 and 2010. The dispersion parameters including: mean-variance test and clumping parameter (K) showed that the overwintered adults of Sunn pest population followed the negative binomial distribution pattern. Furthermore, the dispersion indices including: variance to mean ratio, Lloyd's index of mean crowding and Morisita index also confirmed the aggregated distribution pattern of overwintered adults of Sunn pest. Also, mathematical distribution and Taylor's power law ($b = 1.14$) and Iwao's patchiness regression ($\beta = 1.11$) showed the contagious distribution of overwintered adults of *E. integriceps*. These results can be useful in patch spraying for control of overwintered adults of *E. integriceps* in early season in wheat fields.

Keywords: The Sunn pest, distribution, wheat fields, Ardabil region

Introduction

Winter wheat, *Triticum aestivum* L., is an important crop in Iran. In Ardabil region alone 177000 and 57000 ha is under rainfed and irrigated wheat cultivation, respectively (Anonymous, 2009). The sunn pest, *Eurygaster integriceps* Puton (Hemiptera: Scutelleridae), is one of the most important pests of wheat and barely in Iran and many Middle-Eastern countries (Javahery, 1995; Radjabi, 2007). Nymphs and adult bugs cause damage to host plants and reduce yields by feeding on leaves, stems and developing grains. Meanwhile by feeding the protein of the grain it reduces the baking qualities of the flour (Radjabi, 2007). Economic losses due to Sunn pest feeding are highly variable and depend on the density of the bug population, weather conditions, crop moisture availability, and the susceptibility of the cultivar (Kinaci *et al.,* 1998).

Economic losses due to Sunn pest have increased in some parts of Ardabil region during recent years (Honarmand, 2007). The spatial distribution studies of pest population serves as a basis for decision making to implement management tactics in field (Kao, 1984; Taylor, 1984). Insect populations follow three distinct distribution patterns that include: (a) binomial, uniform or regular, (b) random or poison, and (c) negative binomial, aggregated or clumped (Southwood, 1978).

Handling Editor: Mostafa Haghani

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Received: 08 June 2013, Accepted: 26 July 2014
Published online: 27 July 2014

A good understanding of insect movement within and among crops is essential for the development of pest control strategies. For example, the careful timing of insecticide sprays, or their application to restricted areas, may mitigate negative impacts on pest natural enemies (Ferguson *et al.,* 2003). Since data is currently lacking on the spatial distribution of *E. integriceps* in Ardabil region, this study was conducted to ascertain the distribution pattern of overwintered adults of Sunn pest in rainfed wheat fields in Ardabil region for correct management of this pest.

Materials and Methods

Study area

This study was conducted in rainfed wheat fields in Ardabil region in 2009 and 2010. Seeds of wheat (cv. Sardari) were planted in 12 separate experimental fields, each approximately 1 ha. Plant population averaged 400 plants per m^2 and all fields were fallow the year prior to planting. The wheat crop was managed according to local conventions for rainfed fields. An application of bromoxynil herbicide (2S formulation, Bayer Crop Science) was used to control annual broadleaf weeds before the boot stage, but no insecticide was applied.

Sampling

Experimental fields were sampled every day beginning with the migration of overwintered adults of Sunn pest from overwintering sites to wheat fields at stem elongation growth stage and continued until ripening stage of wheat. In each experimental field, 15 quadrat of 1 m^2 were randomly selected, each sample was 10 m away from each other. Sampling was conducted between 10:00 and 12:00 a.m.; all wheat plants were examined and all overwintered adults of *E. integriceps* counted within each quadrat. The optimum sample size (N = 60 quadrats) was calculated by the following formula (Hsu *et al*., 2001):

$$N = \left(\frac{Z_{\alpha/2}}{D}\right)^2 \left(\frac{S}{\bar{x}}\right)^2$$

where, N is the optimum sample size, S is standard deviation, $\bar{x}$ is mean density, D is precision level and value of $Z_{\alpha/2}$ is 1.96.

Analysis of spatial distribution

In this study, the distribution of overwintered adults of Sunn pest was analyzed using the following methods:

I. Dispersion parameters

(1) *Mean-variance test*. For collected data the mean ($\bar{x}$) and variance (s^2) were first calculated and compared to know the distribution. The ratio of s^2 and $\bar{x}$ is index of aggregation that indicates either uniform ($s^2 < \bar{x}$), random ($S^2 = \bar{x}$) or aggregated ($S^2 > \bar{x}$).

(2) Calculating of *'K'*. The clumping or dispersion parameter (K) was worked out by the following methods as given by Southwood (1978):

(a) *Moment estimate of 'K'*. This was computed using the following formula:

$$k = \frac{\bar{x}^2}{s^2 - \bar{x}}$$

(b) *Accurate 'K'*. Trial and error method was used to estimate the accurate K by the formula:

$$N \ln\left(1 + \frac{\bar{x}}{k}\right) = \sum_{x=0}^{\infty}\left(\frac{A_X}{k + x}\right)$$

where A_X is the sum of all frequencies of sampling units containing more than x individuals.

(c) *Common 'K'*. The common K (K_c) which is the representative dispersion parameter for the entire period of study (2009 and 2010) was also worked out using the moment and regression method of Bliss and Owen (1958) and is given by the formula:

$$K_c = \bar{x}^2 - (s^2/N)/s^2 - \bar{x}$$

For all the three types of *K* estimates, a value of less than eight indicates aggregation while values of more than eight signify random or poison distribution.

II. Dispersion indices

(1) *Variance to mean ratio or index of dispersion* (ID). This test was based on the equality of variance and mean in a poison series. This index often departs from unity, a value of zero implies random distribution, while a value greater than one implies aggregate or contagious distribution (Pedigo, 1994).

(2) *David and Moore's index* (IDM). This index was computed by the formula $S^2/\bar{x} - 1$. Here values greater than zero indicate aggregation.

(3) *K of negative binomial, an index of aggregation.* The reciprocal of *K*, i.e 1/*K*, were used to measure clumping of the individuals. Values for 1/K which were more than zero indicate contagious distribution.

(4*) Lloyd's index of mean crowding* (x^*). This index provides the degree of crowding experienced by the individual adult sunn pest and was worked out using the formula: $x^* = \bar{x} + ((s^2/\bar{x}) - 1)$. When values for this index depart from the poison series, it indicates aggregation.

(5) *Morisita index* (I_δ). Reasoning that the diversity of numbers of individuals per quadrat could be used as a measure of spatial pattern, Morisita developed the index I_δ by this formula:

$$I_\delta = \sum_{i=1}^{N} n_i(n_i - 1)/n(n-1)N$$

Where, n_i represents the number of individuals in the i^{th} quadrat and *N* is the total number of individuals sampled in *n* quadrats. The I_δ value is an index of aggregation that indicates either uniform (I_δ < 1), random (I_δ = 1) or aggregated (I_δ > 1) dispersion patterns.

III. Mathematical distribution to describe dispersion

In this method, data was set by one of the distribution models (negative binomial or poison) with the following formula:

For poison;

$$P(x) = \frac{e^{-\mu}\mu^x}{x!}$$

And for negative binomial;

$$p(x) = \left(\frac{k+n-1}{x}\right)\left(\frac{\mu}{\mu+k}\right)p(x-1)$$

Where, x is number of insects in per sample, μ is the mean density of insects in each quadrate, k is aggregation parameter and $p(x)$ is the probability of finding a certain number of individuals in each quadrate.

For each date, the observed frequency of insects fitted the expected frequency of each of the mathematical frequency distribution models. A chi-square test was used to determine if the data were fitted to negative binomial model (Young and Young, 1998).

IV. Regression techniques for evaluating dispersion

For the characterization of the spatial pattern of overwintered adults of Sunn pest, Taylor's power law (Taylor, 1961) and Iwao's patchiness regression (Iwao, 1968) were used. Taylor's power law regression quantifies the relation between sample variance (s^2) and sample mean density ($\bar{x}$) by means of the formula:

$$Log(s^2) = Log(a) + bLog(\bar{x})$$

where *b* reflects the distribution of the population in space and *a* is a scaling factor related to sample size (Pedigo, 1994).

Mean crowding index (x^*) and mean density ($\bar{x}$) were calculated at each of wheat growth stage using Lloyd's (1967) formula:

$$x^* = \bar{x} + ((s^2/\bar{x}) - 1)$$

Then Iwao's patchiness regression quantifies the relation between Lloyd's (1967) mean crowding index ($x*$) and mean density ($\bar{x}$) using the formula:

$$x^* = \alpha + \beta\bar{x}$$

where α is the index of basic contagion and indicates the tendency toward crowding (positive) or repulsion (negative). The slopes b (Taylor's regression) and β (Iwao's regression) are indices of aggregation that indicate either uniform ($b < 1$), random ($a = b = 1$) or aggregated ($b > 1$) dispersion patterns (Southwood, refer to the latest edition Wang and Shipp, 2001). Goodness-of-fit for each model was evaluated by coefficients of determination (R^2). A T-test:

$$t = (slope - 1) / SE_{slope}$$

was used to estimate whether the slopes of the regression lines were significantly different from one. Slopes significantly greater than one indicate a clumped distribution (Feng and Nowierski, 1992; Elliott *et al.,* 2003; Arnaldo and Torres, 2005).

Results

I. Dispersion parameters

(1) *Mean and variance.* The values of $\bar{x}$ and s^2 for 13 dates are presented in Tables 1 and 2. The results indicated that the variance is greater than the corresponding mean values for all sampling dates. The mean numbers of pest varied from 0.5 to 3.5 per quadrate.

(2) *Dispersion parameter K.* The distribution of overwintered adults of Sunn pest was also studied by estimating the dispersion parameter *K.* From tables 1 and 2, it is evident that the values for *K* worked out with mean and variance, ranged from 1.12 up to 22.94. Furthermore, a common *K* of 4.5 was calculated by moments and regression method.

II. Dispersion indices

(1) *Index of dispersion.* The results from this test (Tables 3 and 4) indicate that in 57% of cases, the values of $s^2 / \bar{x}$ are significantly more than one.

(2) *David and Moore's index*. From Tables 3 and 4, it is evident that the observed values of David and Moore's index were greater than the value of maximum regularity (-1) and randomness (0).

(3) *K of negative binomial.* In this study, the reciprocal of *K*, i.e. 1/*K*, ranged from 0.04 up to 0.89 (Table 3 and 4).

(4) *Lloyd's index of mean crowding* (x^*). The values of mean crowding were in 84% of cases, more than one indicating aggregation dispersion of overwintered adults of Sunn pest (Tables 3 and 4).

(5) *Morisita index* (I_δ). With this index, in 55% of cases I_δ value was significantly greater than one indicating aggregation pattern of this pest.

III. Mathematical distribution

The majority of frequency distributions of overwintered adults of Sunn pest fitted the negative binomial distribution. From a series of 45 samples date, 31 frequency distributions fitted this distribution and 14 fitted the poison distribution.

IV. Regression techniques

Both Iwao's patchiness regression and Taylor's power law provided a better fit for the overwintered adults of Sunn pest, as revealed by a higher correlation coefficient (R^2) (Table 5). The aggregation indices (b and β) were both significantly greater than one, indicating an aggregated distribution of overwintered adults of *E. integriceps*. Also there were no significant differences in b and β values between the data collected in 2009 and 2010 (F = 0.16, P = 0.69 for Taylor power law and F = 0.06, P = 0.81 for Iwao's patchiness regression). Thus, regression based on pooled data for both years provided an adequate description of $\bar{x}$ - x^* and log (s2)-log ($\bar{x}$) relationship (Fig. 1).

Table 1 Dispersion parameters for the overwintered adults of *Eurygaster integriceps* in wheat fields of Ardabil region.

Date[1]	Mean	Variance	*K*
1	0.67	0.73	6.56
2	0.75	1.10	1.60
3	0.95	1.20	3.61
4	0.95	1.20	3.61
5	1.23	2.05	1.87
6	1.35	2.20	2.15
7	1.70	2.79	2.65
8	1.95	2.75	4.78
9	2.60	4.07	4.58
10	3.10	4.67	6.13
11	3.30	5.87	4.24
12	3.50	5.37	6.54
13	2.70	3.79	6.71
14	1.65	2.03	7.20
15	1.48	2.29	2.73
16	1.17	1.23	22.94
17	0.98	1.14	6.36
18	0.92	1.09	4.72
19	0.83	1.17	2.03
20	0.80	1.17	1.74
21	0.78	0.88	6.07
22	0.73	0.78	12.86
23	0.60	0.89	1.25
24	0.60	0.92	1.12
25	0.50	0.63	1.97

[1] Date numbers 1 to 25 are from 1-May to 19-June 2009.

Table 2 Dispersion parameters for the overwintered adults of *Eurygaster integriceps* in wheat fields of Ardabil.

Date	Mean	Variance	*K*
1	0.80	1.01	3.05
2	0.90	1.27	2.19
3	1.10	1.55	2.69
4	1.20	1.48	5.06
5	1.37	1.73	5.17
6	1.45	2.02	3.69
7	1.47	2.39	2.33
8	1.52	2.19	3.42
9	1.60	2.40	3.20
10	1.60	2.28	3.76
11	1.80	2.30	6.48
12	1.90	3.01	3.25
13	2.30	3.71	3.75
14	2.70	4.56	3.92
15	1.70	2.08	7.65
16	0.92	1.33	2.02
17	0.90	1.01	7.59
18	0.80	0.91	5.90
19	0.77	0.89	4.62
20	0.73	0.80	8.07

[1] Date numbers 1 to 20 are from 8-May to 16-June 2010.

Table 3 Dispersion indices for the overwintered adults of *Eurygaster integriceps* in wheat fields of Ardabil region.

Date	*ID*	*IDM*	1/ *K*	x^*	I_δ
1	65	0.10	0.15	0.77	1.15
2	87	0.47	0.62	1.22	1.62
3	75	0.26	0.28	1.21	1.28
4	75	0.26	0.28	1.21	1.28
5	98	0.66	0.53	1.89	1.53
6	96	0.63	0.46	1.98	1.46
7	97	0.64	0.38	2.34	1.38
8	83	0.41	0.21	2.36	1.21
9	92	0.57	0.22	3.17	1.22
10	89	0.51	0.16	3.61	1.16
11	105	0.78	0.24	4.08	1.24
12	91	0.54	0.15	4.04	1.15
13	83	0.40	0.15	3.10	1.15
14	73	0.23	0.14	1.88	1.14
15	91	0.54	0.37	2.03	1.37
16	62	0.05	0.04	1.22	1.04
17	68	0.15	0.16	1.14	1.16
18	70	0.19	0.21	1.11	1.21
19	83	0.41	0.49	1.24	1.49
20	86	0.46	0.58	1.26	1.58
21	67	0.13	0.16	0.91	1.16
22	62	0.06	0.08	0.79	1.08
23	87	0.48	0.80	1.08	1.80
24	91	0.54	0.89	1.14	1.89
25	74	0.25	0.51	0.75	1.51

[1] Date numbers 1 to 25 are from 1-May to 19-June 2009.

Table 4 Dispersion indices for the overwintered adults of *Eurygaster integriceps* in wheat fields of Ardabil.

Date	*ID*	*IDM*	**1/*K***	$\mathbf{x}^*$	I_δ
1	75	0.26	0.33	1.06	1.33
2	83	0.41	0.46	1.31	1.46
3	83	0.41	0.37	1.51	1.37
4	73	0.24	0.20	1.44	1.20
5	75	0.26	0.19	1.63	1.19
6	82	0.39	0.27	1.84	1.27
7	96	0.63	0.43	2.10	1.43
8	85	0.44	0.29	1.96	1.29
9	89	0.50	0.31	2.10	1.31
10	84	0.43	0.27	2.03	1.27
11	75	0.28	0.15	2.08	1.15
12	93	0.58	0.31	2.48	1.31
13	95	0.61	0.27	2.91	1.27
14	100	0.69	0.26	3.39	1.26
15	72	0.22	0.13	1.92	1.13
16	86	0.45	0.49	1.37	1.49
17	66	0.12	0.13	1.02	1.13
18	67	0.14	0.17	0.94	1.17
19	69	0.17	0.22	0.93	1.22
20	64	0.09	0.12	0.82	1.12

[1] Date numbers 1 to 20 are from 8-May to 16-June 2010.

Discussion

Results of the mean and variance test in dispersion parameters indicated that the variance was greater than the mean in all sampling dates, suggesting the aggregative distribution of overwintered adults of Sunn pest population in the field. Mohiseni *et al.* (2010) investigated the effect of sample unit size in population density of *Thrips tabaci* Lind. and reported that when sample size increased, variance/mean ratio increased, too. Several works have used this basic test to determine the distribution pattern of insect pest population in different crops (Faleiro *et al.,* 2002; Liu *et al.*, 2002; Afshari, 2005; Ahmadi *et al.*, 2005; Arbab, 2006). The variance to mean ratio is the simplest and the most fundamental index, and is useful for assessing agreement of the data set to the poison series (Pedigo, 1994). However, Pielou (1977) has pointed out that the reliability and usefulness of this index is limited because it is highly dependent on quadrat size.

Further, the dispersion parameter K was in 95% of cases less than eight, indicating that the overwintered adults of Sunn pest population followed the aggregative distribution. Southwood (1978) suggested that when the values of K were less than eight, it indicates aggregation of the population. While K values more than eight, signify that the distribution is random or poison. Furthermore, in our study the common dispersion parameter (K_c) was calculated 4.5 using the moments and regression method. Therefore, the population of overwintered adults of Sunn pest was confirmed to follow the negative binomial distribution pattern, because the common dispersion parameter value is less than eight (Radjabi, 2000).

Table 5 Results of Iwao's and Taylor's power law regressions for number of overwintered adults of *Eurygaster integriceps* in rainfed wheat fields of Ardabil region in 2009 and 2010.

Model	Year	$\alpha \pm$ SE	Slope ± SE	R^2	df	t
Iwao's regression	2009	0.23 ± 0.069	1.111 ± 0.041	0.97	25	2.71*
	2010	0.12 ± 0.090	1.144 ± 0.061	0.95	20	2.36*
	2009-2010	0.17 ± 0.071	1.117 ± 0.040	0.96	45	2.68*
Taylor's power law	2009	1.34 ± 0.012	1.123 ± 0.048	0.96	25	2.56**
	2010	1.26 ± 0.012	1.148 ± 0.063	0.95	20	2.35*
	2009-2010	1.28 ± 0.012	1.144 ± 0.051	0.95	45	2.82**

* and ** indicate that slopes have significant differences from 1 in probability level of $P \leq 0.05$ and $P \leq 0.01$, respectively.

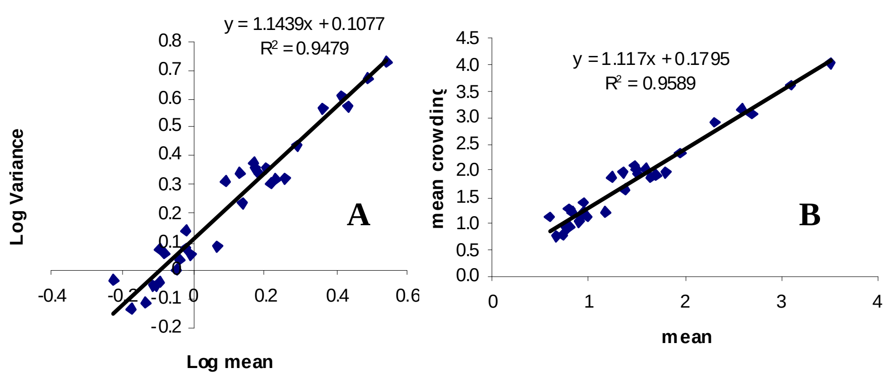

Figure 1 Iwao's patchiness regression (A) and Taylor's power law regression (B) for overwintered adults of *Eurygaster integriceps*. A regression line was calculated using the pooled data from two studied years.

The aggregated nature of overwintered adults of Sunn pest in wheat fields in Ardabil region was further confirmed by calculating the indices of dispersion or the variance to mean ratio test. From a series of 45 samples date, from 1-May to 19-June-2009 and 8-May to 16-June-2010, the variance to mean ratio was greater than one, suggesting aggregation distribution. Patil and Stiteler (1974) showed that when this ratio was zero, the distribution was random, while a value greater than one implied aggregated distribution.

In addition, the David and Moore's index values were also found to be greater than maximum regularity and randomness, confirming the contagious nature of overwintwred adults of Sunn pest. Kumar (1996) obtained similar results while using this test to confirm the distribution of brown plant hopper *Nilaparvata lugens* Stal. in rice field.

Reciprocal of exponent K, i.e. $1/K$, is also a measure of clumping of individuals (Southwood, 1978). In this study, the $1/K$ values were more than zero for all cases. Thereby, suggesting aggregation of overwintered adults of Sunn pest population. Reddy *et al.* (1993) used this test to ascertain the aggregated nature of leaf and plant hopper distribution in rice field. Also, Lloyd's index of crowding (x^*) showed aggregated pattern of overwintered adults of Sunn pest. Furthermore, from a series of 45 samples date, from 1-May to 19-June-2009 and 8-May to 16-June-2010, the Morisita index values were greater than one, suggesting aggregative distribution of overwintered adults of Sunn pest. Other studies have used this index to determine the distribution pattern of insect pest population in different crops (Afshari, 2005; Arbab, 2006).

The results of the mathematical distribution test showed that in 68 percent of cases, the population of overwintered adults of Sunn pest fitted with the negative binomial distribution. Mohiseni *et al.* (2007) reported that in 70% of sample dates, spatial pattern of overwintered adults of Sunn pest was aggregate.

Also, in our study the aggregation indices (b and β) were both significantly greater than one, indicating an aggregated distribution of overwintered adults of *E. integriceps*. In this study, both Taylor's power law and Iwao's patchiness regression had high determination coefficients (R^2) values. Therefore, both models could describe spatial distribution of overwintered adults of Sunn pest. Other studies showed aggregated distribution of this pest, too (Moin-Namini *et al.*, 2000; Parker *et al.,* 2002; Abdollahi, 2004; Mohiseni *et al.,* 2009). Arnaldo and Torres (2005) described an aggregated distribution for *Thaumetopoea pityocampa* (Den. & Schiff.) egg hatches, because the aggregation indices (b and β) were both significantly greater than one. Lee *et al.* (2005) reported an aggregated distribution pattern for leafminer in tomato greenhouses, because all b values from Taylor's power law regressions were significantly greater than one. Furthermore, aggregated distribution of other pests using the aggregation indices have been reported in previous studies (Wang and Shipp, 2001; Elliott *et al.,* 2003; Opit *et al.,* 2003).

In summary, our results indicated that the distribution pattern of overwintered adults of Sunn pest population in rainfed wheat fields in Ardabil region is aggregated and follows the negative binomial distribution. High clumped distribution patterns were observed when the overwintered adults of Sunn pest aggregated for reproduction. This result helps us to apply insecticides where the overwintered adults of Sunn pest are aggregated in fields, i.e. patch spraying. Patch spraying can be useful in conservation of natural enemies, since widespread spraying of insecticides will destroy natural enemies of *Eurygaster integriceps* in wheat fields.

Acknowledgement

The Research Council of Mohaghegh Ardabili University (Iran) is gratefully acknowledged for their financial support of this research.

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توزیع فضایی حشرات کامل زمستان‌گذران *Eurygaster integriceps* (Hemiptera: Scutelleridae) در مزارع گندم استان اردبیل

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دریافت: ۱۸ خرداد ۱۳۹۲؛ پذیرش: ۴ مرداد ۱۳۹۳

چکیده: سن گندم، *Eurygaster integriceps* Puton، یکی از آفات مهم گندم در استان اردبیل است. در این تحقیق، توزیع فضایی حشرات کامل زمستان‌گذران سن گندم با استفاده از پارامترها و شاخص‌های پراکنش، توزیع ریاضی و روش‌های رگرسیونی در مزارع گندم دیم با استفاده از کادر یک متر مربعی طی سال ۱۳۸۸ و ۱۳۸۹ مطالعه شد. پارامترهای پراکنش شامل روش میانگین- واریانس و شاخص ازدحام (K) نشان دادند که جمعیت حشرات کامل زمستان‌گذران سن گندم از الگوی توزیع دو جمله‌ای منفی تبعیت می‌کند. علاوه بر آن، شاخص‌های پراکنش شامل نسبت واریانس بر میانگین، شاخص میانگین ازدحام لوید و شاخص موریسیتا الگوی توزیع تجمعی حشرات کامل زمستان‌گذران سن گندم را تایید کردند. همچنین، توزیع ریاضی و مدل‌های رگرسیون تیلور و ایوائو نیز نشان دادند که توزیع حشرات کامل زمستان‌گذران سن گندم از نوع تجمعی است. این یافته‌ها می‌تواند در سمپاشی موضعی برای کنترل حشرات کامل زمستان‌گذران سن گندم در اوایل فصل در مزارع گندم استان اردبیل مفید باشد.

واژگان کلیدی: سن گندم، توزیع، کنترل، مزارع گندم، استان اردبیل