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# Population size and spatial distribution pattern of *Schizaphis graminum* (Hemiptera: Aphididae) on some wheat cultivars and lines

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**Abstract**

Field experiments were conducted at wheat program of El-Mattana Agricultural Research Station, Luxor Governorate, Egypt during two successive growing seasons (2017/2018 and 2018/2019) to study the performance of some wheat cultivars and lines to infestation by *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae) and their spatial distribution pattern. Results indicated that the total population density of *S. graminum* during the first growing season (2017/2018) was higher than second growing season (2018/2019). Also, the total mean of *S. graminum* population through the whole season was 20.83 ± 0.54 and 13.57 ± 0.34 individuals per 10 tillers over the first and second growing seasons, respectively.

The obtained results indicated that Giza 171 and Giza 12 cultivars and lines of wheat (6, 11 and 13) were the highly susceptible varieties (HS) during the two seasons. On the other hand, Shandwel 1 and Sides 14 cultivars and lines 4 and 12 were rated as resistance to infestation (R) during the two seasons, these cultivars and lines of wheat plants should be promoted in the areas of high aphid infestation. It was also, noticed that the mean maximum population density of *S. graminum* was observed on Giza 171 cultivar, while, the minimum individuals of population were recorded on line 4 of wheat plants through the two growing seasons. Data were analysed using 21 distribution indices. All distribution indices indicated a significant aggregation behaviour during each growing season in all the tested wheat cultivars and lines. These pieces of information can be useful for planning an IPM program of aphid on wheat plants.

**Keywords:** Aphids**,** wheat cultivars**,** *Schizaphis graminum*, population abundance, spatial distribution

## Introduction

Wheat, *Triticum aestivum* L. (Family: Gramineae) is one of the most important cereal crops in Egypt. It is used for human food, as well as in animal and poultry feeding**.** During different growth stages, wheat plants are attacked by many insect pest species which aphids are the most destructive the crop loss assessment was 7.5-18.7% (Tantawi, 1985) [38].

The green cereal aphid, *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae) is one of the 14 aphid species that considered as a worldwide key pest (Blackman and Eastop, 2007) [7]. Usually, this insect weakens the infested plant itself by sucking the sap with the mouth parts causing thereafter deformations by the action of the toxic saliva. In addition, this pest excrete a large amount of honeydew that cover plant leaves and attract ants on leaves and encourages the growth of sooty mould fungus which give the infested dirty black appearance that affect on photosynthesis and respiration and otherwise reduces the quality of the plant causing considerable economic injury (El-Fatih, 2000; 2006) [15, 16]. In recent years, *S. graminum* has become the most frequent species on wheat crop, and is abundant throughout all developmental stages of wheat plants (Youssef, 2006; Parizoto *et al*., 2013; Ahmad *et al*., 2016; Awadalla *et al.*, 2018) [40, 32, 2, 3].

The aphid infestations significant affect wheat cultivars. As well, the host plant resistance is an important part of IPM for aphids (Khan *et al*., 2011; Zhoui *et al*., 2011) [25, 41]. Spatial distribution is one of the most characteristic properties of insect populations; in most cases, it allows us to define them and is an important characteristic of ecological communities (Debouzie and Thioulouse 1986) [12]. No field sampling can be efficient without understanding the underlying spatial distribution of the population (Taylor, 1984) [39]. An understanding of the spatial distribution (*i.e.* regular, random, or aggregated) of populations provides useful information, not only for theoretical population biology but also for field monitoring programmes, especially sequential sampling (Feng *et al*. 1993; Binns *et al*. 2000) [21, 6].

A reliable sampling programme for estimating the population density should include a proper sampling time (date of sampling), sampling unit, and number of samplings in which the determination of spatial distribution is crucial (Pedigo and Buntin 1994; Southwood and Henderson 2000) [34, 37].

No information is available in the literature regarding the spatial distribution of *S. graminum*. Therefore, the present study was undertaken to determining the suitable wheat cultivar or line to manage aphids infesting wheat as well as the estimated the spatial distribution pattern for monitoring of this pest on some wheat cultivars and lines. The results of this research can be used to draft monitoring methods for this pest and ultimately to establish pest management programme strategies for *S. graminum*.

## Materials and Methods

### 1. Population densities of *S. graminum* on some wheat cultivars and lines

Field trials were carried out at wheat program of El-Mattana Agricultural Research Station, Luxor Governorate during two successive growing seasons (2017/2018 and 2018/2019), was at an altitude of 99 m a.s.l., a latitude and longitude of 25.67° N and 32.71° E, respectively.

Seven commercial cultivars of wheat viz. (Giza 12, Sakha 95, Giza 171, Misr 2, Misr 3, Shandwel 1 and Sides 14) and thirteen lines of wheat *i.e*. (line 1, ……… to line 13).

Four replicates for each line or cultivar of wheat (replicate dimensions: 3 m × 3 m log ═ 9 $m^2$) were distributed in completely randomized block design, were sown in optimum sowing date (in November, $25^{th}$ per each season). All agricultural practices were applied except for pest control throughout the whole period of the study. For estimating the population densities of *S. graminum* on different lines and cultivars of wheat plants, random samples of ten tillers per replicate *i.e*. (30 tillers per each cultivar or line); at early morning, were picked up weekly, began as soon as the plants appeared above ground and continued until the crop harvesting in each season.

Direct count of aphid samples was conducted at the same day according to Dewar *et al*. (1982) [13]. Numbers of alive insects (Nymphs and Apterae individuals) on wheat tillers were counted and recorded, linked to the inspection date, and presented as mean number of individuals per 10 tillers ± standard error (SE), to express the population size of pest, using 10x lenses in the field. Identification of aphid was carried out by taxonomy specialists at the Department of Piercing-Sucking insects, Plant Protection Research Institute, Agriculture Research Center, Giza, Egypt

### General sampling method

All sampling was conducted from 23200 tillers on 29 dates over a 2-season period, *i.e*. 4 replicate × 10 tillers × 20 (cultivars/lines) × 29 dates.

### 2. Susceptibility degrees

Classification of the tested wheat lines and cultivars to their susceptibility degrees was adopted as described by (Semeada, 1985; Nosser, 1996) [35, 31] based on a quantitative approach found to the following assumptions:

**A. Varieties were grouped into five categories:** i.e. resistant (R), moderate resistant (MR), relative resistant (RR), susceptible (S), and highly susceptible (HS).

**B. General mean number of individuals** = (MN)

**C. Range of change (RC):** Between the maximum mean number values and minimum for the lines and cultivars of wheat plants was calculated by applying the following equation:

**RC = MN max – MN min**

Where,

MN max = maximum number of individuals/ lines or cultivars.

MN min= minimum number of individuals/ lines or cultivars.

**D. Unit change in wheat lines or cultivars (UC):** Was the amount of change in lines or cultivars from one degree of resistance or susceptibility to the preceding degree (from MR to R or from MR to RR …etc).

**According to the above mentioned equation, the tested wheat lines or cultivars could be classified as the follows**

1. **The highly susceptible group (HS):** lines or cultivars of wheat with infestation more than (MN+ UC).
2. **The susceptible group (S):** lines or cultivars of wheat with infestation ranging from MN to (MN+UC).
3. **The relative resistant group (RR):** lines or cultivars of wheat with infestation less than MN to (MN-UC).
4. **The moderate resistant group (MR):** lines or cultivars of wheat with infestation ranging from < (MN-UC) to (MN-2UC).
5. **The resistant group (R):** lines or cultivars of wheat with infestation less than (MN- 2UC).

However, it is an important to point out herein that the pest mean numbers must refer to and / or agree with the resistance degree of cultivars and lines of wheat.

The data obtained were statistically analyzed according to the complete randomized block design. The means were compared according to Duncan's Multiple Range Test (Duncan, 1955) [14] and Least Significant Difference test (LSD) at the 5% level were used to determine the significance among means of lines and varieties of wheat, was carried out by computer (MSTATC Program software, 1980) [28] and were depicted graphically by Microsoft Excel 2010.

### 3. Spatial distribution of *S. graminum*

To study the spatial distribution of *S. graminum* among the sample units was determined using 21 indices of distribution.

### Distribution indices

Several estimates are based on sample means and variances, such as index of dispersion, clumping, crowding and Green's index (Green, 1966) [22].

- Mean ($\bar{X}$), range of means, variance ($S^2$), standard deviation (S), standard error (SE), median (Me) and coefficient of variance (C.V.%) for samples were determined.
- Relative Variation (*R.V.*) is employed to compare the efficiency of various sampling methods (Hillhouse and Pitre 1974) [24]. The relative variation for the studied seasons was calculated as follows:

$$R.V. = (SE / \bar{X}) \times 100$$

Where, *SE* is the standard error of the mean and $\bar{X}$ is the mean of population.

**Variance to mean ratio**

Dispersion of a population can be classified through a calculation of the variance-to-mean ratio suggested by Patil and Stiteler [33]; namely: $S^2/\bar{X}$ = 1 random distribution, < 1 regular distribution, and > 1 aggregated distribution (where, $S^2$ = sample variance; $\bar{X}$ = mean of population).

**Index of Lewis ($I_L$)**

Lewis index was also calculated as per the formula given hereunder to determine the dispersion of *S. graminum*.

$$I_L = \sqrt{S^2 / \bar{X}}$$

The value of this index revealed >1 contagious; <1: regular and =1 random distribution.

**Cassie index (*Ca*)**

$$Ca = (S^2 - \bar{X}) / \bar{X}^2$$

The spatial distribution pattern is aggregative, random and uniform when *Ca*>0, *Ca* = 0 and *Ca*<0, respectively (Cassie, 1962) [8].

**The *K* value of negative binomial distribution**

The parameter *k* of the negative binomial distribution is one measure of aggregation that can be used for insect species having clumped or aggregated spatial pattern. When *k* values are low and positive (*k* < 2), they indicate a highly aggregated population; *k* values ranging from 2 to 8 indicate moderate aggregation; and values higher than 8 (*k* > 8) indicate a random population (Southwood, 1995) [36]. The *k* values were calculated by the moments method (Costa *et al.*, 2010) [10], and given by:

$$K = \bar{X}^2 / (S^2 - \bar{X})$$

- Departure from a random distribution can be tested by calculating the index of dispersion ($I_D$), where, n: denotes the number of samples:

$$I_D = (n-1) S^2 / \bar{X}$$

$I_D$ is approximately distributed as $x^2$ with *n*-1 degrees of freedom. Values of $I_D$ which fall outside a confidence interval bounded with *n*-1 degrees of freedom and selected probability levels of 0.95 and 0.05, for instance, would indicate a significant departure from a random distribution.

This index can be tested by *Z* value as follows:

$$Z = \sqrt{2I_D} - \sqrt{(2\nu - 1)}$$

$v = n - 1$

If 1.96 ≥ *Z* ≥ -1.96, the spatial distribution would be random, but if *Z* < -1.96 or *Z* > 1.96, it would be uniform and aggregated, respectively (Patil and Stiteler 1974) [33].

- Index of mean clumping ($I_{DM}$) (David and Moore 1954) [11]:

$$I_{DM} = \frac{S^2}{\bar{X}} - 1$$

The David and Moore index of clumping values increase with increasing aggregation. If the index value = 0, the distribution is random, positive value for negative binomial (aggregated) and negative value for positive binomial (regular).

**Lloyd's mean crowding ($\overset{*}{X}$)**

Mean crowding ($\overset{*}{X}$) was proposed by Lloyd to indicate the possible effect of mutual interference or competition among individuals. Theoretically mean crowding is the mean number of other individuals per individual in the same quadrate:

$$\overset{*}{X} = \bar{X} + [(S^2 / \bar{X}) - 1]$$

As an index, mean crowding is highly dependent upon both the degree of clumping and population density. To remove the effect of changes in density, Lloyd introduced the index of patchiness, expressed as the ratio of mean crowding to the mean. As with the variance-to-mean ratio, the index of patchiness is dependent upon quadrate size (Lloyd, 1967) [27].

**Index of patchiness ($I_P$):** is dependent upon quadrate size.

$$I_P = (\overset{*}{X} / \bar{X})$$

If IP = 1 random, < 1 regular and > 1 aggregated

**Green's index (GI):**

$$GI = [(S^2 / \bar{X}) - 1] / (n - 1)$$

This index is a modification of the index of cluster size that is independent of n (Green, 1966) [22]. If GI > 0 or positive values are indicative of aggregation dispersion, GI < 0 or negative values indicative of uniformity or regular dispersion, and GI = 0 or negative values closer to 0 indicate randomness.

- To evaluate temporal changes in spatial pattern of *S. graminum* population during the studied seasons, an aggregation index (1/*k*) (Southwood and Henderson, 2000) [37] was used.

It was calculated by the formula of

$$1/k = (\overset{*}{X} / \overline{X}) - 1$$

where: 1/k is aggregation index or Cassie's index C and ( $\overset{*}{X} / \overline{X}$ ) is Lloyd's patchiness index. The values of $1/k < 0$, $= 0$, and $> 0$ represent regularity, randomness, and aggregation of the population in spatial pattern, respectively (Feng and Nowierski 1992) [20].

**Results and Discussion**

**1. Population densities of *S. graminum* on certain wheat cultivars and lines**

Data presented in Table (1) and illustrated in Fig. (1), showed that the total population density of *S. graminum* during the first growing season (2017/18) was higher than the second growing season (2018/19). The increase reached approximately 1.54 times. The mean total population through the whole season was 20.83 ± 0.54 and 13.57 ± 0.34 individuals per 10 tillers over first and second growing seasons, respectively.

The statistical analysis of data indicated that, there was a highly significant differences among the wheat cultivars and lines regarding the level of infestation by *S. graminum* were obtained (L.S.D were 1.26 and 1.04) throughout the two growing seasons, respectively.

It is clear from the results that the highest number of *S. graminum* individuals was observed on Giza 171 and Giza 12 cultivars and lines of wheat (6, 11 and 13), with an a general average of (35.12 ± 3.31, 31.33 ± 2.95, 31.53 ± 3.21, 28.92 ± 2.95 and 28.69 ± 2.88 individuals per 10 tillers) during the first growing season, and it was (25.86 ± 1.96, 19.67 ± 1.69, 20.75 ± 1.73, 19.89 ± 1.74 and 19.58 ± 1.67 individuals per 10 tillers) throughout the second growing season, respectively, as compared with the other tested lines and cultivars of wheat, and these wheat cultivars and lines of was rated as highly susceptible (HS).

On the other hand, Shandwel 1 and Sides 14 cultivars and lines 4 and 12 demonstrated the lowest number of *S. graminum* individuals on the basis of a general average of (12.69 ± 1.28, 10.94 ± 1.12, 10.43 ± 0.93 and 10.43 ± 0.93) during the first season and it was (6.61 ± 0.62, 5.36 ± 0.48, 5.47 ± 0.56 and 5.61 ± 0.57) through the second growing season, respectively, and these cultivars and lines of wheat was rated as resistance to infestation (R), these cultivars and lines of wheat plants, should be promoted in the areas of high aphid infestation.

While, Sakha 95 cultivar and lines of wheat (2, 5, 7 and 9), exhibited sensitivity degree as susceptible to infestation (S). But, the lines of wheat 8 and 10 showed some sort of resistance and appeared as relatively resistant (RR). However, Misr 2 and Misr 3 cultivars and lines of wheat (1 and 3) were moderately resistant to *S. graminum* infestation (MR).

In general, it could be concluded that the mean maximum population density of *S. graminum* was observed on Giza 171 with an average of (35.12 ± 3.31 and 25.86 ± 1.96 individuals per 10 tillers) during the two growing seasons, respectively. While, the minimum individuals of population were recorded on line 4 of wheat plants with an average of 10.43 ± 0.93 and 5.47 ± 0.56 individuals per 10 tillers through the two seasons, respectively.

We concluded that the host plant affects the development of pest and that the choice of the most resistance cultivar can help to reduce pest infestation, and are therefore an additional component to be included in the integrated pest management of wheat plants.

Variations in the aphid populations among the different wheat cultivars has been reported by several researchers like (Muhammed *et al.* 2004; Aheer *et al.*, 2007; El-Rawy 2013; El-Rawy *et al.*, 2007; El-Mitwally *et al.*, 2013; Hegab 2019) [29, 1, 18, 19, 17, 23].

**2. Sampling program**

The obtained values in Table (2 and 3) showed that the relative variation (R.V.%) for the primary sampling data of *S. graminum* indicated that the population densities of pest ranging from (8.90 to 11.56%) and (7.21 to 10.28%) in the all different cultivars and lines of wheat through the two growing seasons, respectively. As well, the *R.V.* (%) for the primary sampling data of *S. graminum*indicated that the mean population densities was 9.78 and 8.04% during the first and second growing seasons, respectively (Table, 4). The values of *R.V.*% were very appropriate for a sampling program. However, with different insect species and different host, *Naeimamini et al.* (2014) [30] stated that the relative variation for the primary sampling data of different stages of *Pulvinaria floccifera* (Hemiptera: Coccidae) were less than 25% and were acceptable.

**3. Spatial distribution**

The results in Tables (2 and 3) showed that the spatial distribution among the sample units was determined by 21 indices of distribution. The results of distribution using the variance of *S. graminum* population on different cultivars and lines of wheat was greater than the general average of the population densities by *S. graminum*, and thus the variance-to-mean ratio ($S^2$/m) was greater than one were recorded in the all tested cultivars and lines of wheat. Therefore, the spatial distribution of *S. graminum* individuals was an aggregated distribution for all cultivars and lines of wheat and over the entire growing season.

The Lewis index of the pest was significantly greater than the index of contagious dispersion. Similar conclusions were made from the results of the Cassie index. The mean population of *S. graminum* distribution was greater than zero; therefore, *S. graminum* on the all tested cultivars and lines of wheat had an aggregated distribution. The *K* values of the negative binomial distribution of *S. graminum* population ranged from 2 to 8 in the all cultivars and lines of wheat during first season, thus indicating moderate aggregation (Table, 2). But, the cultivars and lines of wheat which the higher than 8 ($K > 8$) indicate a random distribution during the second season (Table, 3). On the other hand, the *K* value for the mean population densities was 2.27 and 6.28% during the first and second growing seasons, respectively, thus indicating moderate aggregation (Table, 4).

The Index values of mean clumping ($I_{DM}$) of the pest in the all cultivars and lines of wheat were positive for the negative binomial. The Z-test values were greater than 1.96. The index of patchiness was greater than one and Green's index was greater than zero (Tables, 2 and 3). All these indices showed an aggregated distribution for the population of *S. graminum* in the all the different cultivars and lines of wheat during the two growing seasons (Table, 4).

The temporal changes in the spatial distribution pattern of *S. graminum* population during each growing season were evaluated using 1/*k* (the aggregation index). The value was greater than zero, thus indicating an aggregated pattern that became more dispersed with time in all tested cultivars and lines of wheat and over the entire growing season (Tables, 2 -4).

The results in Table (4) show that the values of distribution indices of mean population density of *S. graminum* were higher in the first season (2017/2018) as compared the second season (2018/2019). This evidence may be due to the general average of population density *S. graminum* was 20.83 ± 0.54 per 10 tillers during the first season was higher than in the second one (13.57 ± 0.34 individuals per 10 tillers).

It is clear that the cultivars and lines of wheat affect the population density and spatial distribution of *S. graminum*. Therefore, the spatial distribution for the population of *S. graminum* using 21 distribution indices indicated an aggregated distribution in the all cultivars and lines of wheat in the two successive seasons (Table, 2-4).

However, there is no study in the literature regarding the distribution patterns of *S. graminum*. Studying different insect species and different hosts, Chellappan *et al*. (2013) [9] reported that the value of mean crowding increased with an increase in the mean population density of *Paracoccus marginatus* (Hemiptera: Pseudococcidae). Li *et al.* (2017) [26] recorded that the K value of the negative binomial distribution, aggregation index, and Cassie index were all higher than zero during May. This would indicate that *Parapoynx crisonalis* (Lepidoptera: Crambidae) larvae were in an aggregated distribution. Bala and Kumar (2018) [5] recorded that the values of the Lewis index for all sampling dates of the bug, *Chauliops fallax* (Hemiptera: Malcidae) population on soybean were also found to be more than one, thus indicating that the distribution of the bug population was aggregated. Bakry (2020) [4] studied the spatial distribution of *Parlatoria oleae* (Hemiptera: Diaspididae) on mango trees using twenty one distribution indices. All indices of distribution indicated significant aggregation behaviour in each year, except, the *K* values of the negative binomial distribution of the total *P. oleae* population ranged about 15-17 for each year during the two successive years, indicating random behavior.

## Conclusion

Carried study proved that Giza 171 and Giza 12 cultivars and lines of wheat (6, 11 and 13) were the highly susceptible varieties (HS) during the two seasons. On the other hand, Shandwel 1 and Sides 14 cultivars and lines 4 and 12 were rated as resistance to infestation (R) during the two seasons, these cultivars and lines of wheat plants should be promoted in the areas of high aphid infestation. All distribution indices indicated a significant aggregation behaviour during each growing season in all the tested wheat cultivars and lines. The results of this research can be used to draft monitoring methods for this pest and planning an IPM program of aphid on wheat plants.

**Table 1:** Average numbers of *S. graminum* per 10 tillers and sensitivity degrees of certain wheat lines and cultivars during the two successive growing seasons (2017/2018 and 2018/2019).

| Wheat lines and cultivars | Average no. of individuals of insect per 10 tillers ± S.E | | | |
|---|---|---|---|---|
| | First season (2017/2018) | | Second season (2018/2019) | |
| | Mean ± SE | Sensitivity degree | Mean ± SE | Sensitivity degree |
| Line 1 | 14.45 ± 1.34 i | MR | 9.92 ± 0.94 h | MR |
| Line 2 | 23.08 ± 2.67 de | S | 14.86 ± 1.37 de | S |
| Line 3 | 17.02 ± 1.73 h | MR | 10.89 ± 0.79 gh | MR |
| Line 4 | 10.43 ± 0.93 k | R | 5.47 ± 0.56 j | R |
| Line 5 | 21.57 ± 2.13 f | S | 15.64 ± 1.23 d | S |
| Line 6 | 31.53 ± 3.21 b | HS | 20.75 ± 1.73 b | HS |
| Line 7 | 23.94 ± 2.64 d | S | 14.36 ± 1.25 e | S |
| Line 8 | 19.10 ± 2.06 g | RR | 12.47 ± 1.07 f | RR |
| Line 9 | 21.92 ± 2.04 ef | S | 14.78 ± 1.33 de | S |
| Line 10 | 20.18 ± 2.05 g | RR | 12.86 ± 1.07 f | RR |
| Line 11 | 28.92 ± 2.95 c | HS | 19.89 ± 1.74 bc | HS |
| Line 12 | 10.43 ± 0.93 k | R | 5.61 ± 0.57 ij | R |
| Line 13 | 28.69 ± 2.88 c | HS | 19.58 ± 1.67 c | HS |
| Giza 12 | 31.33 ± 2.95 b | HS | 19.67 ± 1.69 bc | HS |
| Sakha 95 | 23.78 ± 2.74 d | S | 14.56 ± 1.27 de | S |
| Giza 171 | 35.12 ± 3.31 a | HS | 25.86 ± 1.96 a | HS |
| Misr 2 | 14.25 ± 1.31 i | MR | 10.92 ± 0.82 gh | MR |
| Misr 3 | 17.22 ± 1.53 h | MR | 11.31 ± 0.86 g | MR |
| Shandwel 1 | 12.69 ± 1.28 j | R | 6.61 ± 0.62 i | R |
| Sides 14 | 10.94 ± 1.12 k | R | 5.36 ± 0.48 j | R |
| Mean | 20.83 ± 0.54 | | 13.57 ± 0.34 | |
| L.S.D. at 0.05 between lines and cultivars | 1.26 ** | | 1.04 ** | |

Means followed by the same letter(s), in each column, are not significantly different at 0.05 level probability, by Duncan's multiple range test (DRMT).

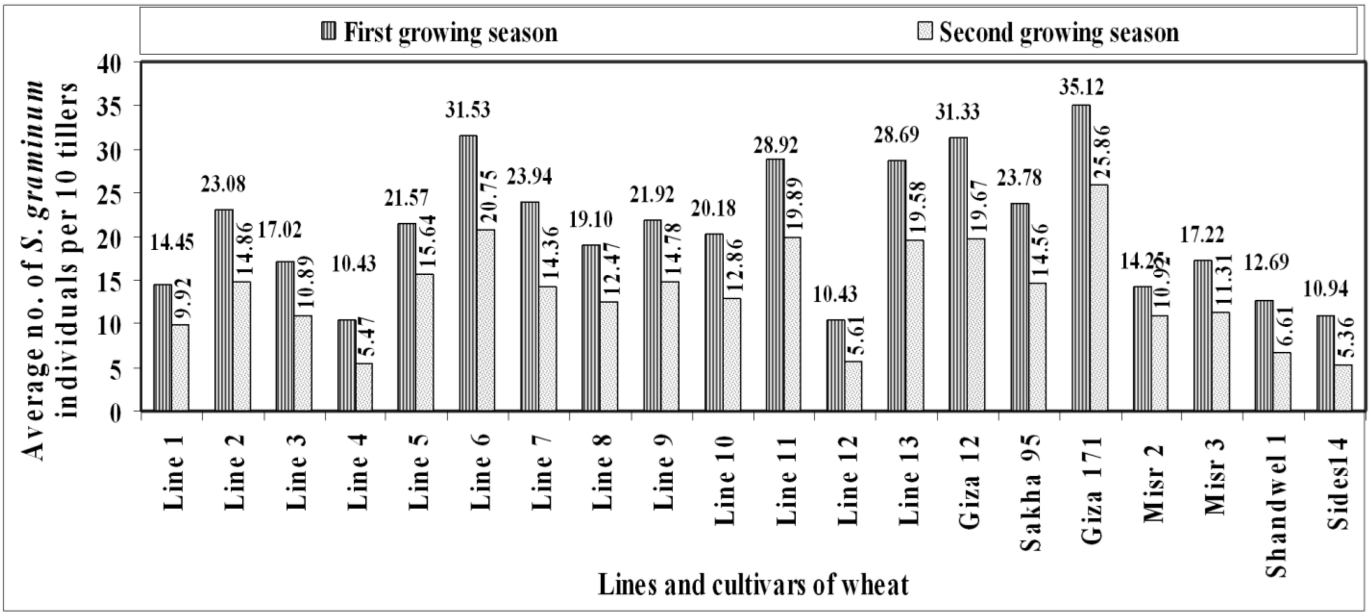


**Fig 1:** Average numbers of *S. graminum* per 10 tillers on certain wheat lines and cultivars during two successive growing seasons (2017/2018 and 2018/2019).

**Table 2:** Estimated parameters for spatial distribution of *S. graminum* individuals on some cultivars and lines of wheat during the first growing season (2017/2018).

| Parameters | Line 1 | Line 2 | Line 3 | Line 4 | Line 5 | Line 6 | Line 7 | Line 8 | Line 9 | Line 10 | Line 11 | Line 12 | Line 13 | Giza 12 | Sakha 95 | Giza 171 | Misr 2 | Misr 3 | Shandwel 1 | Sides 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. | 33.00 | 59.00 | 39.00 | 23.00 | 50.00 | 70.00 | 59.00 | 46.00 | 48.00 | 47.00 | 75.00 | 22.00 | 63.00 | 68.00 | 58.00 | 72.00 | 32.00 | 36.00 | 30.00 | 26.00 |
| Min. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 14.45 | 23.08 | 17.02 | 10.43 | 21.57 | 31.53 | 23.94 | 19.10 | 21.92 | 20.18 | 35.12 | 10.43 | 28.69 | 31.33 | 23.78 | 28.92 | 14.25 | 17.22 | 12.69 | 10.94 |
| Range of mean | 33.00 | 59.00 | 39.00 | 23.00 | 50.00 | 69.00 | 59.00 | 46.00 | 48.00 | 47.00 | 74.00 | 22.00 | 63.00 | 68.00 | 58.00 | 72.00 | 32.00 | 36.00 | 30.00 | 26.00 |
| Median | 11.00 | 16.00 | 18.00 | 9.00 | 23.00 | 35.00 | 17.00 | 16.00 | 20.00 | 16.00 | 37.00 | 9.00 | 29.00 | 31.00 | 18.00 | 30.00 | 14.00 | 17.00 | 10.00 | 8.00 |
| $S^2$ | 91.49 | 362.83 | 152.14 | 44.25 | 231.37 | 524.29 | 354.82 | 215.69 | 211.63 | 214.67 | 560.39 | 44.25 | 422.82 | 445.11 | 382.69 | 444.59 | 87.67 | 119.77 | 83.14 | 64.26 |
| S | 9.57 | 19.05 | 12.33 | 6.65 | 15.21 | 22.90 | 18.84 | 14.69 | 14.55 | 14.65 | 23.67 | 6.65 | 20.56 | 21.10 | 19.56 | 21.09 | 9.36 | 10.94 | 9.12 | 8.02 |
| SE | 1.34 | 2.67 | 1.73 | 0.93 | 2.13 | 3.21 | 2.64 | 2.06 | 2.04 | 2.05 | 3.31 | 0.93 | 2.88 | 2.95 | 2.74 | 2.95 | 1.31 | 1.53 | 1.28 | 1.12 |
| CV | 66.19 | 82.54 | 72.47 | 63.77 | 70.52 | 72.62 | 78.68 | 76.90 | 66.36 | 72.62 | 67.41 | 63.77 | 71.68 | 67.33 | 82.25 | 72.91 | 65.69 | 63.57 | 71.87 | 73.26 |
| RV | 9.27 | 11.56 | 10.15 | 8.93 | 9.88 | 10.17 | 11.02 | 10.77 | 9.29 | 10.17 | 9.44 | 8.93 | 10.04 | 9.43 | 11.52 | 10.21 | 9.20 | 8.90 | 10.06 | 10.26 |
| $S^2/m$ | 6.33 | 15.72 | 8.94 | 4.24 | 10.73 | 16.63 | 14.82 | 11.29 | 9.65 | 10.64 | 15.96 | 4.24 | 14.74 | 14.21 | 16.09 | 15.37 | 6.15 | 6.96 | 6.55 | 5.87 |
| Lewis Index | 2.52 | 3.97 | 2.99 | 2.06 | 3.28 | 4.08 | 3.85 | 3.36 | 3.11 | 3.26 | 3.99 | 2.06 | 3.84 | 3.77 | 4.01 | 3.92 | 2.48 | 2.64 | 2.56 | 2.42 |
| Cassie index | 0.37 | 0.64 | 0.47 | 0.31 | 0.45 | 0.50 | 0.58 | 0.54 | 0.39 | 0.48 | 0.43 | 0.31 | 0.48 | 0.42 | 0.63 | 0.50 | 0.36 | 0.35 | 0.44 | 0.45 |
| *K* | 2.71 | 1.57 | 2.14 | 3.22 | 2.22 | 2.02 | 1.73 | 1.86 | 2.53 | 2.09 | 2.35 | 3.22 | 2.09 | 2.37 | 1.58 | 2.01 | 2.77 | 2.89 | 2.28 | 2.25 |
| $I_D$ | 316.56 | 786.09 | 446.95 | 212.10 | 536.36 | 831.44 | 741.02 | 564.69 | 482.71 | 531.98 | 797.87 | 212.10 | 736.97 | 710.28 | 804.51 | 768.62 | 307.52 | 347.86 | 327.68 | 293.65 |
| Z value | 15.21 | 29.70 | 19.95 | 10.65 | 22.80 | 30.83 | 28.55 | 23.66 | 21.12 | 22.67 | 30.00 | 10.65 | 28.44 | 27.74 | 30.16 | 29.26 | 14.85 | 16.43 | 15.65 | 14.28 |
| $I_{dm}$ | 5.33 | 14.72 | 7.94 | 3.24 | 9.73 | 15.63 | 13.82 | 10.29 | 8.65 | 9.64 | 14.96 | 3.24 | 13.74 | 13.21 | 15.09 | 14.37 | 5.15 | 5.96 | 5.55 | 4.87 |
| X* | 19.78 | 37.80 | 24.96 | 13.67 | 31.30 | 47.16 | 37.76 | 29.39 | 30.58 | 29.82 | 50.08 | 13.67 | 42.43 | 44.54 | 38.87 | 43.29 | 19.41 | 23.17 | 18.24 | 15.81 |
| X*/m | 1.37 | 1.64 | 1.47 | 1.31 | 1.45 | 1.50 | 1.58 | 1.54 | 1.39 | 1.48 | 1.43 | 1.31 | 1.48 | 1.42 | 1.63 | 1.50 | 1.36 | 1.35 | 1.44 | 1.45 |
| GI | 0.11 | 0.29 | 0.16 | 0.06 | 0.19 | 0.31 | 0.28 | 0.21 | 0.17 | 0.19 | 0.30 | 0.06 | 0.27 | 0.26 | 0.30 | 0.29 | 0.10 | 0.12 | 0.11 | 0.10 |
| 1/*k* | 0.37 | 0.64 | 0.47 | 0.31 | 0.45 | 0.50 | 0.58 | 0.54 | 0.39 | 0.48 | 0.43 | 0.31 | 0.48 | 0.42 | 0.63 | 0.50 | 0.36 | 0.35 | 0.44 | 0.45 |

**Table 3:** Estimated parameters for spatial distribution of *S. graminum* individuals on some cultivars and lines of wheat during the second growing season (2018/2019).

| Parameters | Line 1 | Line 2 | Line 3 | Line 4 | Line 5 | Line 6 | Line 7 | Line 8 | Line 9 | Line 10 | Line 11 | Line 12 | Line 13 | Giza 12 | Sakha 95 | Giza 171 | Misr 2 | Misr 3 | Shandwel 1 | Sides 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. | 22.00 | 30.00 | 21.00 | 15.00 | 28.00 | 40.00 | 30.00 | 25.00 | 30.00 | 24.00 | 47.00 | 15.00 | 40.00 | 40.00 | 30.00 | 40.00 | 20.00 | 22.00 | 15.00 | 12.00 |
| Min. | 1.00 | 1.00 | 4.00 | 0.00 | 4.00 | 4.00 | 1.00 | 1.00 | 2.00 | 2.00 | 5.00 | 1.00 | 4.00 | 3.00 | 1.00 | 3.00 | 1.00 | 2.00 | 0.00 | 0.00 |
| Mean | 9.92 | 14.86 | 10.89 | 5.47 | 15.64 | 20.75 | 14.36 | 12.47 | 14.78 | 12.86 | 25.86 | 5.61 | 19.58 | 19.67 | 14.56 | 19.89 | 10.92 | 11.31 | 6.61 | 5.36 |
| Range of mean | 21.00 | 29.00 | 17.00 | 15.00 | 24.00 | 36.00 | 29.00 | 24.00 | 28.00 | 22.00 | 42.00 | 14.00 | 36.00 | 37.00 | 29.00 | 37.00 | 19.00 | 20.00 | 15.00 | 12.00 |
| Median | 10.00 | 14.00 | 10.50 | 5.00 | 16.00 | 21.00 | 15.00 | 12.00 | 15.50 | 14.00 | 25.00 | 5.00 | 19.00 | 19.50 | 14.00 | 19.00 | 11.50 | 12.00 | 6.00 | 5.50 |
| $S^2$ | 32.08 | 67.55 | 22.22 | 11.40 | 54.07 | 108.08 | 56.12 | 41.11 | 63.26 | 41.21 | 138.41 | 11.84 | 100.59 | 103.43 | 57.80 | 109.53 | 24.42 | 26.33 | 13.90 | 8.29 |
| S | 5.66 | 8.22 | 4.71 | 3.38 | 7.35 | 10.40 | 7.49 | 6.41 | 7.95 | 6.42 | 11.76 | 3.44 | 10.03 | 10.17 | 7.60 | 10.47 | 4.94 | 5.13 | 3.73 | 2.88 |
| SE | 0.94 | 1.37 | 0.79 | 0.56 | 1.23 | 1.73 | 1.25 | 1.07 | 1.33 | 1.07 | 1.96 | 0.57 | 1.67 | 1.69 | 1.27 | 1.74 | 0.82 | 0.86 | 0.62 | 0.48 |
| CV | 57.11 | 55.31 | 43.29 | 61.70 | 47.02 | 50.10 | 52.17 | 51.41 | 53.82 | 49.91 | 45.49 | 61.34 | 51.21 | 51.71 | 52.23 | 52.62 | 45.27 | 45.39 | 56.40 | 53.72 |
| RV | 9.52 | 9.22 | 7.21 | 10.28 | 7.84 | 8.35 | 8.69 | 8.57 | 8.97 | 8.32 | 7.58 | 10.22 | 8.54 | 8.62 | 8.71 | 8.77 | 7.54 | 7.56 | 9.40 | 8.95 |
| $S^2/m$ | 3.23 | 4.55 | 2.04 | 2.08 | 3.46 | 5.21 | 3.91 | 3.30 | 4.28 | 3.20 | 5.35 | 2.11 | 5.14 | 5.26 | 3.97 | 5.51 | 2.24 | 2.33 | 2.10 | 1.55 |
| Lewis Index | 1.80 | 2.13 | 1.43 | 1.44 | 1.86 | 2.28 | 1.98 | 1.82 | 2.07 | 1.79 | 2.31 | 1.45 | 2.27 | 2.29 | 1.99 | 2.35 | 1.50 | 1.53 | 1.45 | 1.24 |
| Cassie index | 0.23 | 0.24 | 0.10 | 0.20 | 0.16 | 0.20 | 0.20 | 0.18 | 0.22 | 0.17 | 0.17 | 0.20 | 0.21 | 0.22 | 0.20 | 0.23 | 0.11 | 0.12 | 0.17 | 0.10 |
| *K* | 4.44 | 4.19 | 10.47 | 5.05 | 6.36 | 4.93 | 4.94 | 5.43 | 4.50 | 5.83 | 5.94 | 5.05 | 4.73 | 4.62 | 4.90 | 4.41 | 8.82 | 8.51 | 6.00 | 9.80 |
| $I_D$ | 113.22 | 159.09 | 71.41 | 72.91 | 121.00 | 182.30 | 136.78 | 115.37 | 149.83 | 112.14 | 187.32 | 73.88 | 179.78 | 184.07 | 138.98 | 192.75 | 78.30 | 81.52 | 73.60 | 54.15 |
| Z value | 6.74 | 9.53 | 3.64 | 3.77 | 7.25 | 10.79 | 8.23 | 6.88 | 9.00 | 6.67 | 11.05 | 3.85 | 10.66 | 10.88 | 8.37 | 11.33 | 4.21 | 4.46 | 3.83 | 2.10 |
| $I_{dm}$ | 2.23 | 3.55 | 1.04 | 1.08 | 2.46 | 4.21 | 2.91 | 2.30 | 3.28 | 2.20 | 4.35 | 1.11 | 4.14 | 4.26 | 2.97 | 4.51 | 1.24 | 1.33 | 1.10 | 0.55 |
| X* | 12.15 | 18.41 | 11.93 | 6.56 | 18.10 | 24.96 | 17.27 | 14.77 | 18.06 | 15.07 | 30.21 | 6.72 | 23.72 | 23.93 | 17.53 | 24.40 | 12.15 | 12.63 | 7.71 | 5.91 |
| X*/m | 1.23 | 1.24 | 1.10 | 1.20 | 1.16 | 1.20 | 1.20 | 1.18 | 1.22 | 1.17 | 1.17 | 1.20 | 1.21 | 1.22 | 1.20 | 1.23 | 1.11 | 1.12 | 1.17 | 1.10 |
| GI | 0.06 | 0.10 | 0.03 | 0.03 | 0.07 | 0.12 | 0.08 | 0.07 | 0.09 | 0.06 | 0.12 | 0.03 | 0.12 | 0.12 | 0.08 | 0.13 | 0.04 | 0.04 | 0.03 | 0.02 |
| 1/*k* | 0.23 | 0.24 | 0.10 | 0.20 | 0.16 | 0.20 | 0.20 | 0.18 | 0.22 | 0.17 | 0.17 | 0.20 | 0.21 | 0.22 | 0.20 | 0.23 | 0.11 | 0.12 | 0.17 | 0.10 |

**Table 4:** Estimated parameters for spatial distribution of *S. graminum* individuals on some wheat cultivars and lines during the two growing seasons (2017-2019).

| Parameters | First season (2017/2018) | Second season (2018/2019) |
|---|---|---|
| Max. | 45.90 | 25.20 |
| Min. | 0.50 | 2.25 |
| Mean | 20.83 | 13.57 |
| Range of mean | 45.40 | 22.95 |
| Median | 20.35 | 14.18 |
| $S^2$ | 211.70 | 42.87 |
| S | 14.55 | 6.55 |
| SE | 2.04 | 1.09 |
| CV | 69.85 | 48.26 |
| RV | 9.78 | 8.04 |
| $S^2/m$ | 10.16 | 3.16 |
| Lewis Index | 3.19 | 1.78 |
| Cassie index | 0.44 | 0.16 |
| *K* | 2.27 | 6.28 |
| $I_D$ | 508.18 | 110.58 |
| Z value | 21.93 | 6.56 |
| $I_{dm}$ | 9.16 | 2.16 |
| X* | 29.99 | 15.73 |
| X*/m | 1.44 | 1.16 |
| GI | 0.18 | 0.06 |
| 1/*k* | 0.44 | 0.16 |

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