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Spatial Distribution Pattern and Population Density of *Rhopalosiphum padi* L. (Hemiptera: Aphididae) and its Effect on the Yield of Some Wheat Cultivars and Lines under Upper Egypt Conditions

Moustafa M.S. Bakry [1*], M.M. Mohiy [2] and Nagdy F Abdel-Baky [3]**
[1] Scale Insects and Mealybugs Research Dept., Plant Protection Research Institute, A.R.C, Dokii, Giza, Egypt.
[2] Wheat Research Department, Field Crop Research Institute, A.R.C, Giza, Egypt.
[3] Economic Entomology Dept., Fac. Agric., Mansoura University, Mansoura-35516 Egypt. [**]Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, P.O. Box 6622, Buraidah 51452, Qassim, Saudi Arabia.
[*]Corresponding author email id: md.md_sabry@yahoo.com

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***Abstract* – Field experiments were conducted at El-Mattana Agricultural Research Station, Luxor Governorate, Egypt during two successive growing seasons (2017/2018 and 2018/2019) to study the response of some wheat lines and cultivars to infestation by *Rhopalosiphum padi* L. (Hemiptera: Aphididae) and their spatial distribution pattern. As well, studying the relation between the infestation and yield of different wheat lines and cultivars. Results indicated that the total population density of *R. padi* during the first growing season (2017/2018) was higher than second growing season (2018/2019). As well, the mean total *R. padi* population through the whole season was 48.04 ± 1.26 and 22.74 ± 0.55 individuals per 10 tillers over 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 *R. padi* 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 distribution indices. All distribution indices indicated a significant aggregation behaviour during each growing season in all the tested wheat cultivars and lines. It was clear that the reflection of the insect infestation levels in all tested wheat cultivars and lines on the yield and its component was negatively and highly significant. Meaning, whenever increase infestation rates by pest, would decrease the studied measurements of yield (negative relationship). Furthermore, the distribution and different wheat genotypes presented here could be used as a tool for future research on pest management methods for this pest in this area ecosystem.**

***Keywords* – Aphids, Wheat Cultivars, *Rhopalosiphum padi*, Population Abundance, Spatial Distribution.**

I. Introduction

Wheat, *Triticum aestivum* L. (Family: Gramineae) is one of the most important cereal crops in Egypt. It is using for human food, as well as in animal and poultry feeding. Many pests attack wheat plants from planting to harvest. Among several pests, Aphids are one of the most destructive pests attacking wheat plants in Egypt, mentioned by **Tantawi, (1985)**, who recorded losses in crop averaged 7.5 – 18.7% of the total production. The bird cherry-oat aphid, *Rhopalosiphum padi* (Linnaeus) is one of the 14 aphid species considered of most agricultural importance worldwide **(Blackman and Eastop, 2007).** This pest causes severe damage to infested plants by sucking the plant sap with the mouth parts, causing thereafter deformations, by the action of the toxic saliva and excreting large amount of honeydew that encourages the growth of sooty mould. This in turn inhibits photosynthesis and decreased vegetative growth of the infested plants and, finally transmission of viral diseases to plants **(El-Fatih, 2000 and 2006).** *R. padi* was found as the most abundant aphid species in Egyptian wheat fields **(El-Heneidy, 1994).** In recent years, *R. padi* has become the most frequent species on wheat crop, and is abundant throughout all developmental stages of wheat plants **(Parizoto *et al*., 2013 and Ahmad *et al*., 2016).**

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 and Zhou et al., 2011).** 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).** No field sampling can be efficient without understanding the underlying spatial distribution of the population **(Taylor 1984).** 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 and Binns *et al*. 2000).** 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 1994; Southwood and Henderson 2000).**

Temperatures accelerate organ development in few days without any increase in net photosynthesis and assimilate resulting in smaller biomass **(Fischer, 1985) and (Shpiler and Blum, 1986).** Yield in stressed environments depends upon susceptibility or tolerance level of grown plants. Therefore, the productive genotypes under stress conditions are the highest tolerant genotypes for these conditions.

No information is available in the literature regarding the spatial distribution of *R. padi*. Therefore, the present study was undertaken to determining the suitable wheat cultivar or line to manage aphids infesting wheat and its spatial distribution pattern on some wheat cultivars and lines. As well, estimate the relationship between the infestation and yield of different wheat lines and cultivars. The results of this research can be used to draft monitoring methods for this pest and ultimately to establish pest management programme strategies for *R. padi*.

II. Materials and Methods

1. *Population Densities of R. padi 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 *R. padi* 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).** 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-seasons 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 and Nosser, 1996)** 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)** 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)** and were depicted graphically by Microsoft Excel 2010.

3. *Spatial Distribution of R. padi:*

To study the spatial distribution of *R. padi* among the sample units was determined using twenty two 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).**

- Mean ($\bar{X}$): the mean number of individuals as a general average per sample (10 tillers) during the whole season.
- Range of means of a population: The difference between the maximum mean number of a population and the minimum for the whole season was calculated by applying the following equation:
- Range of Density (R) = Population density maximum – Population density minimum during the whole season.
- Variance (S^2), standard deviation (S), standard error (SE) and median (Me) for samples were determined.
- Coefficient of variance (*C.V.*): To assess the fidelity of sampling, the coefficient of variation values for the studied seasons were compared.

$$C.V. = \frac{S}{\bar{X}} \times 100$$

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

- Relative Variation (*R.V.*) is employed to compare the efficiency of various sampling methods **(Hillhouse and Pitre, 1974).** The relative variation for the studied years 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 ($S^2/\bar{X}$):

The simplest approach used for determining the insect distribution was variance to mean ratio suggested by **Patil and Stiteler (1974).** The value of variance-to-mean is one for 'Poisson' distribution, less than one for positive binomial and more than one for negative binomial distribution. Dispersion of a population can be classified through a calculation of the variance-to-mean ratio; 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 *R. padi*

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

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

- Cassie index (*Ca*): $Ca = (S^2 - \overline{X})/\overline{X}^2$

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

- 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).** The *k* values were calculated by the moments method **(Costa *et al.* 2010),** and given by: $K = \overline{X}^2 / (S^2 - \overline{X})$

- Departure from a random distribution can be tested by calculating the index of dispersion (I_D), where, n: denotes the number of samples: $I_D = (n\text{-}1)S^2 / \overline{X}$

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: $Z = \sqrt{2I_D} - \sqrt{(2v - 1)}$, $v = n - 1$

If $1.96 \geq Z \geq -1.96$, 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).

- Index of mean clumping (I_{DM}) **(David and Moore 1954):** $(I_{DM}) = (S^2/\overline{X}) - 1$

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

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).**

- Index of patchiness (I_P): is dependent upon quadrate size: $I_p = (\overset{*}{X} / \overline{X})$

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

- Green's index (GI): $GI = [(S^2 / \overline{X}) - 1] / (n - 1)$

This index is a modification of the index of cluster size that is independent of n **(Green, 1966).** 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 *R. padi* population during the studied seasons, an aggregation index (1/*k*) **(Southwood and Henderson 2000)** was used.

It was calculated by the formula of $1/k = (\overset{*}{X} / \bar{X}) - 1$

where: 1/k is aggregation index or Cassie's index C and $(\overset{*}{X} / \bar{X})$ 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).**

The population aggregations mean (λ) **(Blackith, 1961)** was used to analysis the causes for the insect population being in an aggregated state, and was calculated as follows: $\lambda = m / 2k \times \gamma$

Where, y equals to $X^2_{0.5}$ when the value of the degree of freedom is 2*K*. The aggregation of insect individuals is caused by environmental factors when λ < 2; on the other hand, if λ > 2, the phenomenon is caused by aggregation behavior or the aggregation behavior works in combination with the environment.

4. *Measurements of Wheat Yield and its Components:*

Data were recorded for agronomic characters in all test wheat cultivars and lines, were taken from every replicate as following:

A. Number of spikes/m^2: as an average number of spikes/m^2 of three collected samples from each experimental plot.

B. Number of kernels/spike: estimated as an average from ten spikes.

C. 1000-kernel weight (g): was determined as a weight of 1000 grains from the bulk of the plot.

D. Grain yield (ton/fed): was computed from the weight of grains from the (plot area 9 m^2).

To determine the relationship between the measured parameters for wheat plants represented as dependent variable (y) and the different infestation rates by *R. padi* represented as independent factor (X) in all tested wheat cultivars and lines during the two successive seasons of (2017/2018 and 2018/2019). The simple regression was used to show the variability in the measured parameters that could be caused by pest during the different infestation levels. The equation of linear regression was calculated according to the following formula of **Fisher (1950)** and **Hosny *et al.* (1972)**: **Y = a ± bx**

Where:

Y = Prediction value (Dependent variable)

a = Constant (y - intercept)

b = Regression coefficient

x = Independent variable

This method was helpful for demonstrating basic information about the amount of variability in the measured parameters, and also to find out the explained variance (E.V. %). Obtained data were subjected to statistical analysis using a complete randomized block design. Means were compared according to LSD test at $P \leq 0.05$ to clarify the significance between obtained rates of infestation.

III. Result and Discussion

1. *Population Densities of R. padi on Certain Wheat Cultivars and Lines:*

Data presented in Table (1) and illustrated in Fig. (1), showed that the total population density of *R. padi* during the first growing season (2017/18) was higher than the second growing season (2018/19). The increase reached approximately 2.11 times. The mean total population through the whole season was 48.04 ± 1.26 and 22.74 ± 0.55 individuals per 10 tillers over first and second growing seasons, respectively. The statistical analysis of data indicated that, there were highly significant differences among the wheat cultivars and lines regarding the level of infestation by *R. padi* were obtained (L.S.D values; 2.70 and 1.66) throughout the two growing seasons, respectively.

Table 1. Average numbers of *R. padi* per 10 tillers and sensitivity degrees of certain wheat lines and cultivars during the two successive growing seasons (2017/18 and 2018/19).

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	33.04 ± 3.11 j	MR	16.89 ± 1.56 g	MR
Line 2	53.29 ± 6.21 de	S	24.33 ± 2.06 e	S
Line 3	39.31 ± 3.97 i	MR	17.97 ± 1.21 g	MR
Line 4	23.73 ± 2.17 l	R	9.31 ± 0.90 i	R
Line 5	49.25 ± 4.89 fg	S	26.36 ± 1.93 d	S
Line 6	72.82 ± 7.49 b	HS	35.03 ± 2.84 b	HS
Line 7	54.84 ± 6.12 d	S	23.56 ± 1.93 e	S
Line 8	44.41 ± 4.76 h	RR	21.39 ± 1.76 f	RR
Line 9	50.78 ± 4.67 ef	S	24.72 ± 2.10 de	S
Line 10	46.65 ± 4.73 gh	RR	21.75 ± 1.72 f	RR
Line 11	66.84 ± 6.78 c	HS	33.33 ± 2.81 c	HS
Line 12	23.88 ± 2.08 l	R	9.47 ± 0.93 i	R
Line 13	66.71 ± 6.73 c	HS	32.89 ± 2.70 c	HS
Giza 12	73.04 ± 6.90 b	HS	33.08 ± 2.70 c	HS
Sakha 95	55.00 ± 6.31 d	S	24.11 ± 1.95 e	S
Giza 171	80.12 ± 7.90 a	HS	42.36 ± 2.96 a	HS
Misr 2	33.43 ± 3.05 j	MR	18.56 ± 1.27 g	MR

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
Misr 3	39.51 ± 3.48 i	MR	18.97 ± 1.33 g	MR
Shandwel 1	29.22 ± 2.92 k	R	11.28 ± 1.01 h	R
Sides 14	24.82 ± 2.54 l	R	9.53 ± 0.79 i	R
Mean	48.04 ± 1.26		22.74 ± 0.55	
L.S.D. at 0.05 between lines and Cultivars	2.70 **		1.66**	

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).

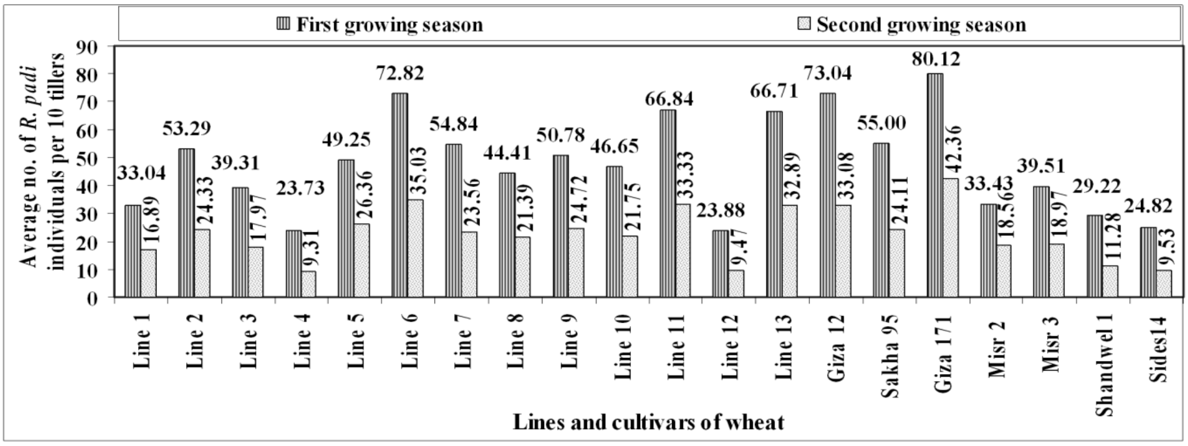

Fig. 1. Average numbers of *R. padi* individuals per 10 tillers on certain wheat lines and cultivars during two successive growing seasons (2017/2018 and 2018/2019).

It is clear from the results that the highest number of *R. padi* individuals was observed on Giza 171 and Giza 12 cultivars and lines of wheat (6, 11 and 13), with an a general average of (80.12 ± 7.90, 73.04 ± 6.90, 72.82 ± 7.49, 66.84 ± 6.78 and 66.71 ± 6.73 individuals per 10 tillers) during the first growing season, and it was (42.36 ± 2.96, 33.08 ± 2.70, 35.03 ± 2.84, 33.33 ± 2.81 and 32.89 ± 2.70 individuals per 10 tillers) throughout the second growing season, respectively, as compared with the other tested wheat lines and cultivars, 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 *R. padi* individuals on the basis of a general average of (29.22 ± 2.92, 24.82 ± 2.54, 23.73 ± 2.17 and 23.88 ± 2.08) during the first season and it was (11.28 ± 1.01, 9.53 ± 0.79, 9.31 ± 0.90 and 9.47 ± 0.93) 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 *R. padi* infestation (MR).

In general, it could be concluded that the mean maximum population density of *R. padi* was observed on Giza 171 with an average of (80.12 ± 7.90 and 42.36 ± 2.96 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 23.73 ± 2.17 and 9.31 ± 0.90 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), Aslam *et al*. (2005), El-Rawy *et al*. (2007), Aheer *et al*. (2007), El - Rawy (2013), Helmi and Rashwan (2013), El-Mitwally *et al*. (2013) and Hegab (2019).**

2. *Sampling Program:*

The obtained values in Table (2 and 3) showed that the relative variation (R.V.%) for the primary sampling data of *R. padi* indicated that the population densities of pest ranging from (8.73 to 11.65%) and (6.71 to 9.84%) 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 *R. padi* indicated that the mean population densities was 9.83 and 7.62% 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)** 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. **Bakry (2020)** recorded that the *R.V.* (%) for the primary sampling data of *Parlatoria oleae* on mango trees indicated that the total population density was 2.41, 2.35 and 1.73% during the first and second years, and for the two years combined, respectively. **Bakry and Arbab (2020)** reported that the relative variation for the primary sampling data of *Icerya seychellarum* ((Hemiptera: Monophlebidae) on guava trees indicated that total population density was 4.07 (2017- 2018), 5.62 (2018-2019) and 3.55% (pooled). **Bakry and Abdel-Baky (2020)** recorded that the relative variation for the primary sampling data of *Aulacaspis tubercularis* (Newstead) (Hemiptera: Diaspididae) indicated that the mean population densities were 5.49, 4.69, and 4.78% during the first and second years, and for the two years combined, respectively. **Bakry and Shakal (2020)** mentioned that the relative variation for the primary sampling data of *Schizaphis graminum* (Hemiptera: Aphididae) on wheat plants indicated that the mean population densities was 9.78 and 8.04% during the first and second growing seasons, respectively.

Table 2. Estimated parameters for spatial distribution of *R. padi* 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	Sak-ha 95	Giza 171	Misr 2	Misr 3	Shand-wel 1	Sides 14
Max.	72.00	135.00	91.00	53.00	112.00	160.00	135.00	106.00	112.00	108.00	170.00	52.00	145.00	156.00	134.00	170.00	72.00	82.00	68.00	60.00
Min.	0.00	0.00	1.00	1.00	0.00	2.00	0.00	2.00	2.00	2.00	1.00	3.00	6.00	3.00	1.00	2.00	1.00	4.00	4.00	3.00
Mean	33.04	53.29	39.31	23.73	49.25	72.82	54.84	44.41	50.78	46.65	66.84	23.88	66.71	73.04	55.00	80.12	33.43	39.51	29.22	24.82

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	Sak-ha 95	Giza 171	Misr 2	Misr 3	Shand-wel 1	Sides 14
Range of Mean	72.00	135.00	90.00	52.00	112.00	158.00	135.00	104.00	110.00	106.00	169.00	49.00	139.00	153.00	133.00	168.00	71.00	78.00	64.00	57.00
Medi-an	25.00	36.00	40.00	20.00	53.00	80.00	38.00	36.00	46.00	38.00	70.00	21.00	66.00	73.00	42.00	85.00	32.00	38.00	21.00	17.00
S^2	492.24	1967.09	803.74	239.40	1220.83	2864.51	1912.97	1157.29	1112.81	1139.75	2344.73	221.47	2311.77	2425.04	2033.04	3182.67	475.53	617.69	433.81	328.87
S	22.19	44.35	28.35	15.47	34.94	53.52	43.74	34.02	33.36	33.76	48.42	14.88	48.08	49.24	45.09	56.42	21.81	24.85	20.83	18.13
SE	3.11	6.21	3.97	2.17	4.89	7.49	6.12	4.76	4.67	4.73	6.78	2.08	6.73	6.90	6.31	7.90	3.05	3.48	2.92	2.54
CV	67.15	83.22	72.11	65.22	70.94	73.49	79.75	76.60	65.69	72.37	72.44	62.31	72.08	67.42	81.98	70.42	65.23	62.90	71.29	73.05
RV	9.40	11.65	10.10	9.13	9.93	10.29	11.17	10.73	9.20	10.13	10.14	8.73	10.09	9.44	11.48	9.86	9.13	8.81	9.98	10.23
S^2/m	14.90	36.91	20.44	10.09	24.79	39.33	34.88	26.06	21.91	24.43	35.08	9.27	34.66	33.20	36.96	39.72	14.22	15.63	14.85	13.25
Lewis Index	3.86	6.08	4.52	3.18	4.98	6.27	5.91	5.10	4.68	4.94	5.92	3.05	5.89	5.76	6.08	6.30	3.77	3.95	3.85	3.64
Cassie Index	0.42	0.67	0.49	0.38	0.48	0.53	0.62	0.56	0.41	0.50	0.51	0.35	0.50	0.44	0.65	0.48	0.40	0.37	0.47	0.49
K	2.38	1.48	2.02	2.61	2.07	1.90	1.62	1.77	2.43	1.99	1.96	2.89	1.98	2.27	1.53	2.07	2.53	2.70	2.11	2.03
I_D	744.93	1845.51	1022.21	504.53	1239.30	1966.75	1744.04	1302.91	1095.63	1221.68	1753.91	463.66	1732.81	1660.09	1848.22	1986.25	711.20	781.70	742.43	662.41
Z Value	28.65	50.80	35.27	21.82	39.84	52.77	49.11	41.10	36.86	39.48	49.28	20.50	48.92	47.67	50.85	53.08	27.76	29.59	28.58	26.45
I_{dm}	13.90	35.91	19.44	9.09	23.79	38.33	33.88	25.06	20.91	23.43	34.08	8.27	33.66	32.20	35.96	38.72	13.22	14.63	13.85	12.25
X*	46.94	89.20	58.76	32.82	73.04	111.16	88.72	69.47	71.70	70.08	100.92	32.16	100.36	105.24	90.96	118.84	46.66	54.14	43.06	37.07
X*/m	1.42	1.67	1.49	1.38	1.48	1.53	1.62	1.56	1.41	1.50	1.51	1.35	1.50	1.44	1.65	1.48	1.40	1.37	1.47	1.49
GI	0.28	0.72	0.39	0.18	0.48	0.77	0.68	0.50	0.42	0.47	0.68	0.17	0.67	0.64	0.72	0.77	0.26	0.29	0.28	0.24
$1/k$	0.42	0.67	0.49	0.38	0.48	0.53	0.62	0.56	0.41	0.50	0.51	0.35	0.50	0.44	0.65	0.48	0.40	0.37	0.47	0.49
λ	1.60	7.59	2.90	1.04	3.54	5.71	7.16	3.73	2.40	3.49	5.08	0.77	5.01	3.70	7.60	5.77	1.52	1.68	2.06	1.82

Table 3. Estimated parameters for spatial distribution of R. padi 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	Shand-wel 1	Sides 14
Max.	38.00	50.00	36.00	26.00	46.00	70.00	50.00	40.00	52.00	42.00	68.00	26.00	68.0 0	68.00	50.00	80.00	28.00	32.00	26.00	21.00
Min.	2.00	2.00	7.00	1.00	6.00	8.00	2.00	3.00	3.00	3.00	6.00	2.00	6.00	6.00	3.00	8.00	2.00	3.00	2.00	1.00
Mean	16.89	24.33	17.97	9.31	26.36	35.03	23.56	21.39	24.72	21.75	33.33	9.47	32.8 9	33.08	24.11	42.36	18.56	18.97	11.28	9.53
Range of Mean	36.00	48.00	29.00	25.00	40.00	62.00	48.00	37.00	49.00	39.00	62.00	24.00	62.00	62.00	47.00	72.00	26.00	29.00	24.00	20.00
Median	17.00	23.50	17.00	8.50	25.50	35.00	23.50	22.00	24.50	22.00	34.00	9.00	33.00	33.00	24.00	41.00	20.00	20.00	11.00	9.00
S^2	87.36	153.49	52.37	28.96	134.12	290.88	134.54	111.16	159.01	106.25	285.26	31.28	262.62	263.05	137.42	314.58	57.91	63.68	37.06	22.60
S	9.35	12.39	7.24	5.38	11.58	17.06	11.60	10.54	12.61	10.31	16.89	5.59	16.21	16.22	11.72	17.74	7.61	7.98	6.09	4.75
SE	1.56	2.06	1.21	0.90	1.93	2.84	1.93	1.76	2.10	1.72	2.81	0.93	2.70	2.70	1.95	2.96	1.27	1.33	1.01	0.79
CV	55.3 4	50.91	40.27	57.83	43.93	48.69	49.24	49.29	51.01	47.39	50.67	59.05	49.27	49.02	48.62	41.87	41.01	42.06	53.98	49.89
RV	9.22	8.49	6.71	9.64	7.32	8.12	8.21	8.22	8.50	7.90	8.44	9.84	8.21	8.17	8.10	6.98	6.84	7.01	9.00	8.32
S^2/m	5.17	6.31	2.91	3.11	5.09	8.30	5.71	5.20	6.43	4.89	8.56	3.30	7.98	7.95	5.70	7.43	3.12	3.36	3.29	2.37
Lewis Index	2.27	2.51	1.71	1.76	2.26	2.88	2.39	2.28	2.54	2.21	2.93	1.82	2.83	2.82	2.39	2.73	1.77	1.83	1.81	1.54
Cassie Index	0.25	0.22	0.11	0.23	0.16	0.21	0.20	0.20	0.22	0.18	0.23	0.24	0.21	0.21	0.19	0.15	0.11	0.12	0.20	0.14
K	4.05	4.58	9.39	4.41	6.45	4.80	5.00	5.10	4.55	5.60	4.41	4.11	4.71	4.76	5.13	6.59	8.75	8.05	4.93	6.94
I_D	181.04	220.77	101.99	108.93	178.08	290.65	199.91	181.90	225.11	170.98	299.52	115.60	279.47	278.29	199.47	259.92	109.23	117.49	115.02	83.02
Z Value	10.72	12.71	5.98	6.45	10.57	15.80	11.69	10.77	12.91	10.19	16.17	6.90	15.34	15.29	11.67	14.49	6.47	7.02	6.86	4.58
I_{dm}	4.17	5.31	1.91	2.11	4.09	7.30	4.71	4.20	5.43	3.89	7.56	2.30	6.98	6.95	4.70	6.43	2.12	2.36	2.29	1.37
X*	21.06	29.64	19.89	11.42	30.45	42.33	28.27	25.59	30.15	25.64	40.89	11.78	39.87	40.03	28.81	48.79	20.68	21.33	13.56	10.90
X*/m	1.25	1.22	1.11	1.23	1.16	1.21	1.20	1.20	1.22	1.18	1.23	1.24	1.21	1.21	1.19	1.15	1.11	1.12	1.20	1.14
GI	0.12	0.15	0.05	0.06	0.12	0.21	0.13	0.12	0.16	0.11	0.22	0.07	0.20	0.20	0.13	0.18	0.06	0.07	0.07	0.04
1/*k*	0.25	0.22	0.11	0.23	0.16	0.21	0.20	0.20	0.22	0.18	0.23	0.24	0.21	0.21	0.19	0.15	0.11	0.12	0.20	0.14
λ	0.28	0.32	0.05	0.13	0.17	0.39	0.25	0.22	0.33	0.19	0.45	0.16	0.42	0.37	0.25	0.26	0.06	0.08	0.12	0.05

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

Parameters	First Season (2017/21018)	Second Season (2018/21019)
Max.	105.70	43.30
Min.	2.35	4.25
Mean	48.04	22.74
Range of mean	103.35	39.05
Median	47.00	22.50
S^2	1137.53	108.10
S	33.73	10.40
SE	4.72	1.73
CV	70.21	45.71
RV	9.83	7.62
S^2/m	23.68	4.75
Lewis Index	4.87	2.18
Cassie Index	0.47	0.17
K	2.12	6.06
I_D	1184.06	166.36
Z Value	38.71	9.93
I_{dm}	22.68	3.75
X*	70.72	26.50
X* /m	1.47	1.17
GI	0.45	0.11
I/*k*	0.47	0.17
λ	3.38	0.17

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 *R. padi* population on different cultivars and lines of wheat was greater than the general average of the population densities by *R. padi*, 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 *R. padi* 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 *R. padi* distribution was greater than zero; therefore, *R. padi* on the all tested cultivars and lines of wheat had an aggregated distribution.

The *K* values of the negative binomial distribution of *R. padi* 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 2.12 and 6.06% during the first and second growing seasons, respectively, thus indicating moderate aggregation (Table 4). **Elliott and Kieckhefer (2000)** stated that the multiple factors affect spatial distribution of aphids including climatic conditions and some biotic factors such as quality of host plants, dispersal efficacy of aphids and natural enemies.

The Index values of mean clumping ($I_{D\,M}$) 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 *R. padi* 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 *R. padi* 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 values of population aggregations (λ) over the first growing season (2017/2018) were all higher than 2 in all tested wheat cultivars and lines indicating that the aggregation behavior works in combination with the environment, except, the wheat lines (1, 4 and 12) and Misr 2, Misr 3 and Sides14 cultivars were less from 2 indicating that the aggregation phenomenon may be caused by environment variations only (Tables, 2 and 3). On the other hand, during the second growing season (2018/2019), the values of population aggregations (λ) were all less higher than 2 in all tested wheat cultivars and line indicating that the aggregation phenomenon may be caused by environment variations only (Tables 2 and 3). A similar conclusion was found to occur in distribution of *Parapoynx crisonalis* (Lepidoptera: Crambidae) on water chestnuts plant (**Li et al., 2017)** and **Bakry and Abdel-Baky (2020)** who examined the spatial distribution pattern of *A. tubercularis* (Hemiptera: Diaspididae) on certain mango cultivars and recorded that the aggregation phenomenon of pest may be caused by environment variations.

Results in Table (4) show that the values of distribution indices of mean population density of *R. padi* 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 *R. padi* was 48.04 ± 1.26 per 10 tillers during the first season was higher than in the second one (22.74 ± 0.55 individuals per 10 tillers).

It is clear that the cultivars and lines of wheat affect the population density and spatial distribution of *R. padi*. Therefore, the spatial distribution for the population of *R. padi* using twenty two 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 *R. padi*. Studying different insect species and different hosts, **Chellappan *et al.* (2013)** 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)** 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)** 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 (2018)** studied the spatial distribution of *W. mimosae* on sunt trees using 14 dispersion indices and recorded that all the models exhibited an aggregated distribution and followed a negative binomial distribution pattern for all the different live stages and for the total population of *W. mimosae* over all seasons and for the pooled data over the two years of study (2016 to 2018). **Bakry (2020)** recorded that the spatial distribution of *P. oleae* on mango trees using twenty two distribution indices and stated that all indices of distribution indicated significant aggregated behaviour in each year, except, the K values of the negative binomial distribution of the total population ranged about 15-17 for each year during the two successive years, indicating random behavior. **Bakry and Arbab (2020 a)** studied that the spatial distribution of *I. seychellarum* on guava trees using distribution indices, indicated aggregated behaviour over the entire year. **Bakry and Shakal (2020)** recorded that the spatial distribution pattern of *Schizaphis graminum* (Hemiptera: Aphididae) on some wheat cultivars and lines. They found that all distribution indices indicated a significant aggregated behaviour during each growing season in all the tested wheat cultivars and lines.

4. *Estimate the Relationship between the Infestation by R. padi and yield of different Wheat Lines and Cultivars:*

A. *Number of Spikes/m^2:*

Data tabulated in Table (5) revealed that the differences in number of tillers/m^2 among different wheat cultivars and lines was significant and highly significant (L.S.D values; 29.15 and 26.18) during the two growing seasons, respectively. Statistical analysis of simple correlation showed that strongly highly significant negative correlations between the different infestation rates by pest and number of tillers/m^2 (r values were -0.94 and -0.95) in all tested wheat cultivars and lines, during the two growing seasons, respectively, Table (6). The unit effect regression coefficient (b) indicated that an increase of one insect per 10 tillers, would cause 0.73 and 1.58 decrease in the number of tillers/m^2. Also, the percentage of variability that could be attributed to the effect of different infestation rates by pest on the number of tillers/m^2, were 88.46 and 90.24% for the two seasons, respectively, Table (6).

B. *NO. Grains / Spike:*

Analysis of variance indicated significant and highly significant differences between the number of grains per spike at the all tested wheat cultivars and lines (L.S.D. values; 6.50 and 5.50), during the two growing seasons, respectively, Table (5). Results of simple correlation, revealed that strongly highly significant negative correlations between the different infestation rates by *R. padi* and number of grains per spike, r values were (-0.96 and -0.96) in all tested wheat cultivars and lines, during the two growing seasons, respectively. The unit effect regression coefficient (b) indicates that an increase of one individual of aphid per 10 tillers, would decrease the number of grains per spike by 0.18 and 0.42 numbers during the two growing seasons, respectively. The amount of variability that could be attributed to the effect of different infestation rates by pest on the number of grains per spike, were 92.07 and 92.65 % for the two seasons, respectively, Table (6).

C. *1000-kernel Weight (gm):*

Data in Table (5) indicated that the statistical analysis of data, revealed there were highly significant differences in 1000-kernel weight for wheat plants between the different infestation levels at the all tested wheat cultivars and lines (L.S.D. values; 4.92 and 4.38) for both the two growing seasons, respectively, Table (5). An significantly strongly negative correlations between the different infestation rates by *R. padi* and 1000-kernel weight for wheat plants, r values were (-0.96 and -0.95) in all tested wheat cultivars and lines, during the two growing seasons, respectively. In the same time, the regression coefficient indicates that an increase of one individual of aphid per 10 tillers, would decrease the 1000-kernel weight for wheat plants by 0.21 and 0.41 gm for the two seasons, respectively, Table (6). Also, the influence of different infestation rates on 1000-kernel weight (gm) was expressed as percentage of explained variance which was 95.00 and 90.21% through the two growing season, respectively, Table (6).

D. *Grain Yield (ton/fed):*

For both seasons of growing, the analysis of variance indicated highly significant differences and varied greatly between the grain yield at the all tested wheat cultivars and lines (L.S.D. values; 0.45 and 0.37), during the two growing seasons, respectively, Table (5). Moreover, the simple correlation coefficient (r) between the different infestation rates by pest and the grain yield of wheat were strongly negative and highly significant (r values were -0.97 and -0.95) for the two seasons, respectively (Table, 6). As well as, simple regression coefficient (b) indicates that an increase of one individual of aphid per 10 tillers, would decrease the grain yield by 0.03 and 0.05 ton/feddan during the two growing seasons, respectively. The percentages of explained variance (E.V.%) indicated that the effect of infestation rates by pest were responsible for 93.58 and 89.59 % of the changes of grain yield of wheat, respectively (Table, 6).

It was clear that the reflection of the insect infestation levels in all tested wheat cultivars and lines on the yield and its component was negatively and highly significant, that refers to the increase infestation rates by pest, would decrease the yield measurements (negative relationship).

The present data regarding the respond of the investigated vegetative growth measurements, yield and its components of wheat plants are in general agreement with the findings of **Ghanim and El-Adl (1983)** in Egypt, they determined the wheat yield loss caused by the English Grain Aphid, *Sitobion avenae* (Hemiptera- Aphididae) was 40%. **Kurppa (1989),** in Finland, determined the yield loss caused by outbreak of aphid specie *Rhopalosiphum padi* (20- 60 individuals per tiller), synchronized with seedling emergence, being 153 kg/ha. Infestation caused decreased yield by a mean of 30 kg/ha per day, and decreased to 41 kg/ha per day when delayed. **Aheer *et al.* (1994)** found that a single aphid individual caused 2.20 percent loss in grain yield. Losses ranged from 30 to 40% at 15 aphids individuals/plant has also been reported by **Keickhefer and Kantack (1980). El-Heneidy *et al.* (2003)** reported that, the stress of a massed cereal aphids *R. padi* and *Schizaphis graminum* (Hemiptera: Aphididae) caused yield reduction by every species and the two species together (21.2-75%, 21.3-80.8% and 22.2-84.2%, respectively). **Wains *et al.* (2010)** in Pakistan, stated that the number of aphids/tiller was positively correlated with loss in grain yield. **Abbas and Niaz (2019),** in Pakistan, mentioned that the mean spike length, number of grains per spike, 100 grains weight and yield kg/ha was significantly affected by the population density of an aphid species.

Table 5. Effect of infestation by *R. padi* per 10 tillers on yield and its components of certain wheat lines and cultivars at Esna district, Luxor Governorate during the two successive growing seasons (2017/2018 and 2018/2019).

Parameters / Wheat cultivars and lines	First Growing Season (2017/2018)					Second Growing Season (2018/2019)				
	Aphids Count per 10 tillers	NO. of tillers/m^2	NO. of Grains/Spike	1000-Kernel Weight (gm)	Grain Yield (ton/fed)	Aphids Count per 10 Tillers	NO. of Tillers/m^2	NO. of Grains/ Spike	1000-Kernel Weight (gm)	Grain Yield (ton/fed)
Line 1	33.04	407.33	45.33	47.90	4.10	16.89	426.67	52.00	50.46	4.45
Line 2	53.29	396.00	42.67	42.63	3.57	24.33	410.67	47.00	44.63	3.64
Line 3	39.31	402.00	44.67	46.19	4.05	17.97	422.67	51.33	50.16	4.43
Line 4	23.73	431.00	49.33	50.20	4.38	9.31	453.33	56.67	53.35	4.69
Line 5	49.25	397.33	43.67	42.79	3.82	26.36	406.67	46.00	43.80	3.58
Line 6	72.82	382.67	39.33	39.94	3.00	35.03	400.00	42.33	40.77	3.28
Line 7	54.84	390.67	41.33	41.97	3.28	23.56	413.33	47.33	45.08	3.90
Line 8	44.41	398.67	43.67	43.69	3.89	21.39	414.67	48.33	45.98	4.17
Line 9	50.78	396.67	42.67	42.67	3.58	24.72	412.00	47.00	45.07	3.84
Line 10	46.65	398.67	43.67	43.10	3.86	21.75	413.33	47.33	45.11	4.17
Line 11	66.84	385.33	39.67	40.46	3.04	33.33	402.67	44.67	42.96	3.30
Line 12	23.88	420.00	49.33	49.84	4.19	9.47	434.67	54.00	53.11	4.55
Line 13	66.71	390.67	40.33	40.67	3.24	32.89	406.67	45.00	43.75	3.53
Giza 12	73.04	382.67	38.33	38.64	2.97	33.08	402.67	44.67	43.18	3.31
Sakha 95	55.00	390.67	40.67	41.43	3.24	24.11	410.67	47.00	43.87	3.59
Giuza 171	80.12	378.67	36.67	37.89	2.91	42.36	381.33	41.67	40.20	3.35
Misr 2	33.43	402.67	45.00	46.45	4.06	18.56	422.67	50.33	48.87	4.02
Misr 3	39.51	399.33	43.67	44.19	4.01	18.97	420.00	48.67	47.30	4.13
Shandwel 1	29.22	414.67	45.33	48.12	4.14	11.28	430.67	52.00	50.52	4.19
Sides 14	24.82	416.00	45.67	48.81	4.15	9.53	433.33	54.00	52.22	4.13
Mean	33.04	399.08	43.05	43.88	3.67	22.74	415.93	48.37	46.52	3.91
L.S.D. at 0.05 between Cultivars and Lines	2.70**	29.15*	6.50*	4.92**	0.45**	1.66**	26.18**	5.50**	4.38**	0.37**

Table 6. Simple correlation and regression values when the counts of the mean numbers of *R. padi* individuals per 10 tillers were plotted versus the yield and its components of certain wheat cultivars and line at Esna district, Luxor Governorate during the two successive.

Statistical Analysis	First Season (2017/2018)				Second Growing Season (2018/2019)			
	NO. of Spikes/ m^2	NO. of Grains/Spike	1000-Kernel Weight (gm)	Grain Yield (ton/fed)	NO. of Spikes/ m^2	NO. of Grains/Spike	1000-Kernel Weight (gm)	Grain Yield (ton/fed)
r =	-0.94	-0.96	-0.96	-0.97	-0.95	-0.96	-0.95	-0.95
b =	-0.73	-0.18	-0.21	-0.03	-1.58	-0.42	-0.41	-0.05
Standard Error	0.06	0.013	0.01	0.002	0.12	0.03	0.032	0.004
T Value	11.74**	14.47**	18.50**	16.15**	12.90**	15.05**	12.88**	12.48**
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y = a ± bx	-0.73x + 434.01	-0.18x + 51.81	-0.21x + 53.84	-0.03x+ 4.95	-1.58x + 452.02	-0.42x + 57.82	-0.41x + 55.81	-0.05x + 5.12
R^2	0.885	0.921	0.950	0.936	0.902	0.927	0.902	0.896
E.V. %	88.46	92.07	95.00	93.58	90.24	92.65	90.21	89.59

r = Simple correlation; b = Simple regression; t = t- test; S.E = Standard error; R^2 = Coefficient of determination; E.V% = Explained variance; * Significant at $P \leq 0.05$; ** Highly significant at $P \leq 0.01$.

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AUTHOR'S PROFILE

First Author
Moustafa M.S. Bakry, Plant Protection Research Institute, A.R.C, Dokki, Giza, Egypt.

Second Author
Mohamed M. Mohiy, Wheat Research Department, Field Crop Research Institute, A.R.C, Giza, Egypt.

Third Author
Nagdy F Abdel-Baky, Economic Entomology Dept., Fac. Agric., Mansoura University, Mansoura-35516 Egypt. *Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, P.O. Box 6622, Buraidah 51452, Qassim, Saudi Arabia.