Pakistan J. Zool., vol. 49(6), pp 2217-2225, 2017. DOI: http://dx.doi.org/10.17582/journal.pjz/2017.49.6.2217.2225

Role of Wheat Varieties and Insecticide Applications against Aphids for Better Wheat Crop Harvest

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ABSTRACT

Wheat (*Triticum aestivum* L.), is a major cereal and staple food crop which plays the vital role in the economy of Pakistan. This wheat crop suffers a heavy toll in yield due to aphid attack, which affects plant vitality and grain production. Planting resistant/tolerant varieties against pests is the main way to overcome these field losses. Present study is an effort to screen different wheat varieties/lines against aphids under field conditions. Wheat varieties, Galaxy-13, Millat-11, Lasani-08, Faisalabad-08, and two wheat lines NW-1-8183-8 and NW-3-3341-7 were sown at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad during the crop season 2015-2016. The aphid infestation started in mid-January on all wheat varieties at stem elongation stage and increased gradually with the growth of plants. Three aphid species were recorded *i.e.*, *Rhopalosiphum padi* (L.), *Schizaphis graminum* (R.) and *Sitobion avenae* (F.). Mean seasonal aphid population (no. of aphids/tiller) on wheat plants during the whole season was the highest in NW-1-8183-8 and NW-3-3341-7 and the lowest in Faisalabad-08. However, grain yield was the highest in Galaxy-13 and the lowest was in Lasani-08 variety. Two applications of insecticide, (imidacloprid @ 625 ml/ hectare), significantly controlled the aphid population and enhanced the yield of all wheat varieties. The higher aphid infestations in untreated plots resulted in less chlorophyll content and reduced photosynthetic activity. Photosynthetic rate and chlorophyll contents were significantly higher in insecticide treated plots. Maximum cost-benefit ratio was found (1:9.2) in NW-1-8183-8 when treated against aphids. Wheat varieties, Galaxy-13 and Faisalabad-08 were found tolerant against aphid damage. Wheat variety Lasani-08 should be avoided because it was found susceptible to aphid infestations, and give low net yield. It is inferred that infestation of aphids significantly reduced the grain yield when not protected by insecticide. Insecticide protected crops give maximum net returns. Integration of varietal resistance and insecticides showed an effective reduction of aphids and gave a significant increase in grain yield.

Article Information
Received 25 November 2016
Revised 12 March 2017
Accepted 21 July 2017
Available online 24 November 2017

Authors' Contribution
MY did the experiments and data observations. NAS conceived, designed and drafted the field study. SS analyzed the data statistically. SN and MH critically edited the manuscript.

Key words
Wheat varieties, Aphid, Insecticide, Grain yield, Cost and benefit ratio.

INTRODUCTION

Globally, the utilization of wheat (*Triticum aestivum* L.) is reported as 65% of grain in human food, 21% as animal feed, 8% as seed and 6% for industrial processing (Khan *et al*., 2009). Pakistan is the 8th largest wheat producer worldwide (FAOSTAT, 2015), by cultivating an area of 9.180 million hectares (Anonymous, 2015). Yield per hectare in Pakistan is far less than many wheat producing countries. Yield losses, due to feeding of insect pests particularly the aphids, are massive in wheat crop (Akhtar *et al*., 2010; Khan *et al*., 2011; John *et al*., 2017).

Aphids (Homoptera: Aphididae) are the major economic insect-pests that cause yield losses in different crops worldwide, especially in temperate regions (Blackman and Eastop, 2000). Damage by aphids to cereal crops are much alarming particularly in wheat crop, though stay for a short period of time, but they have fast multiplication rate and have potential to demolish the crop within few days (Jarosik *et al*., 2003). Aphids are known as the highest damaging pest on wheat crop in Pakistan (Khan *et al*., 2011). The abundance of aphid on plants results in less chlorophyll level, decreased plant transpiration (Ahmed and Nasir, 2001) and reduced photosynthetic activity (Burd and Elliott, 1996). Infested plants suffer with leave curling, delayed head emergence and improper grains with reduced grain weight (Ciepiela, 1993). *Sitobion avenae* (English grain aphid), *Rhopalosiphum padi* (Bird cherry-oat aphid), and *Schizaphis graminum* (Green-bug) are reported on wheat in Pakistan (Shahid *et al*., 2012; John *et al*., 2017). Occasionally, infestations of *R. maidis* were also reported on wheat (Khan, 2005).

Due to aphid feeding, variable yield losses are reported in wheat crop. Yield losses can be up to 7.9 to

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0030-9923/2017/0006-2217 $ 9.00/0
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34.2% with aphid infestation (Akhtar *et al*., 2010). Direct sucking of aphid can cause 10-50% losses while, indirect losses can be 20-80% (Trdan and Milevoj, 1999). For instance, the yield loss can be 35 to 40% with the presence of 15 aphids tiller^{-1}(Brewer and Elliott, 2004) whereas, 34 to 67% decrease in harvest is possible if aphid born viral diseases spread in wheat crop (Riedell *et al*., 2003).

Plant growth stages directly influence the growth, development and fecundity of insect-pest (Yazdani and Agarwal, 1997). In case of aphids, infestations occur in less numbers in earlier plant growth stages and gradually increase during vegetative growth stage of crop, peaked at heading stage and gradually decline with crop maturity (Aheer *et al*., 2006; Khan *et al*., 2012). Aphid infestation between ear emergence and flowering can cause maximum loss in yield that may reach up to 14% (Liu *et al*., 1986). Therefore, the early detection and management of aphid incidence is important.

Host plant resistance is an important part in managing aphids (Khattak *et al*., 2007; Khan *et al*., 2011) which can aid to overcome the economic losses (Akhtar *et al*., 2006). Utilization of resistant wheat varieties along with judicial use of appropriate insecticides is a better option to manage aphid infestations in wheat crop (Iqbal, 2003; Wains *et al*., 2010).

The objectives of the present study were: to screen wheat varieties/lines against aphid infestations under sprayed and unsprayed conditions; to determine wheat yield losses; and to estimate cost and benefit ratio of insecticides used against aphids to save crop yield harvests.

MATERIALS AND METHODS

Experiment and crop husbandry

During 2015-16, the experiment was conducted in the research area, Nuclear Institute for Agriculture and Biology (NIAB) Faisalabad. Four commercial varieties of wheat *viz*., Galaxy-13, Millat-11, Lasani-08, Faisalabad-08, and two wheat lines, NW-1-8183-8, and NW-3-3341-7 developed at NIAB, were sown on 28 November, 2015. The experiment was laid out in split plot design with three replicates. Wheat varieties were kept in main plots and insecticide sprays in sub-plots. The subplot area was 4.9×1.8m^2. Sowing was done by hand drill, using recommended seed rate (125 kg per hectare). Seeds of each entry were planted in strips of adjacent plots with 6 rows distanced at 30.5cm. Inter plot distance was 122cm. Standard agronomic practices were done uniformly throughout the experiment. Diammonium phosphate (DAP: 50 kg bag having 46% P and 18% N) and Urea (50 kg having 46% N) were used at recommended rate of 2.5 bags per hectare. In addition to pre-sowing irrigation, three irrigations were given to crop. Weeds were managed by using three herbicides during the season. Firstly, Stomp® 330EC (Pendimethalin by FMC United Pakistan) @ 2.5 liter/hectare was done as a pre-sowing herbicides on November 28, 2015. Second herbicide, Buctril Super® 600 EC (Bromoxynil + MCPA by Bayer Pakistan) @ 750 ml/hectare, was applied on December 29th 2015 as post emergence against broadleaf weeds. Third herbicide, Axial® 100EC (Pinoxanden and safener cloquintocet-mexyl by Syngenta Pakistan) @ 825 ml/hectare, was applied on January 26, 2016 as post emergence against narrow leaf weeds.

Insecticidal treatments and data observations

Two insecticidal sprays, Confidor® 20SL (Imidacloprid by Bayer Pakistan) @ 625 ml/hectare, were applied to manage aphids at fourteen days interval. Applications were done on 9th Feb. and 23rd Feb., 2016 by using knapsack hand sprayer with water volume as 250 liters/hectare. Data collection was initiated at appearance of aphids till maturity of crop. Aphids were scouted from randomly selected 6 tillers per plot at 7 days interval. During data collection, the growth stage (GS) of the crop was also recorded, as illustrated by Laycock (2004), in order to observe onset and progress of aphid infestations with crop phenology. At each observation, aphid samples were brought to the laboratory for species wise identification. Available taxonomic keys were used to identify collected aphid species according to Blackman and Eastop (2000).

For the determination of photosynthetic rate (*A*), a battery operated instrument Steady-State Porometer (Li-1600; LI-COR Inc., Lincoln, NE) was used. Stomatal conductance and transpiration rate were measured as described by Ashraf *et al*. (1992). Flag leaves were kept under the sensor of instrument until the stable readings were given on the screen. Chlorophyll content was measured by a hand-held device, atLEAF+ chlorophyll meter by using flag leaves. The chlorophyll meter gives the relative amount of chlorophyll content by measuring the absorbance in two wavelength regions (660 and 940nm). The LCD displayed the measurement number and value. Photosynthetic rate and chlorophyll contents were assessed on at GS 55 (50% emergence of ears).

Grain yield (g) samples were taken by harvesting of 10 tillers (from 0.6 sq. ft area) from randomly selected 3 spots (30 tillers) per plot. These tillers from each replicate were threshed and weighed separately. The difference of grain yield data (g) from treated and untreated plots were recorded separately and yield data were converted to kg per hectare.

Table I.- Occurrence of aphid infestation (aphids/tiller) in relation to wheat crop phenology.

Varieties	Incidence on 19 Jan		Peak infestation at different dates		Decline on 9 Mar	
	Crop phenology	Infestation*	Crop phenology	Infestation	Crop phenology	Infestation
Galaxy-13	Start of stem elongation (GS30)	-	Booting stage (GS 49) on 2nd March	26.0±0.4	Ear 50% emerged (GS 55)	4.2±0.2
Millat-11	Start of stem elongation (GS30)	-	Booting stage (GS 49) on 2nd March	25.7±0.5	Ear 50% emerged (GS 55)	1.7±0.5
NW-1-8183-8	Start of stem elongation (GS30)	-	Booting stage (GS 49) on 2nd March	18.5±0.5	Ear 50% emerged (GS 55)	0.3±0.2
NW-3-3341-7	Start of stem elongation (GS30)	-	Flag leaf fully emerged (GS39) on 23rd Feb	19.2±0.3	Ear 50% emerged (GS 55)	0.2±0.1
Lasani-08	Start of stem elongation (GS30)	-	Flag leaf just visible (GS37) on 16th February	21.0±0.1	Ear 50% emerged (GS 55)	0.9±0.1
Faisalabad -08	Start of stem elongation (GS30)	-	Flag leaf fully emerged (GS39) on 23 February	11.2±0.3	Ear 50% emerged (GS 55)	1.1±0.5

*negligibly small; GS, growth stages of wheat plant; S, Seeding; 11, first leaf; 13, Three leaves; 21, Start of tillering stage; 25, five tillers; 29, End of tillering stage; 30, Start of stem elongation; 31, First node visible; 32, Second node visible; 37, Flag leaf just visible; 39, Flag leaf fully emerged; 49, Booting; 55, Ear 50% emerged; 59, Ears fully emerged; 69, End of flowering; 89, Fully ripe.

Table II.- Mean number of different aphid species on wheat crop during crop year 2015-16.

Aphid Species (S)	Varieties (V)	2/2/16 GS 32	9/2/16 GS 32	16/2/16 GS 37	23/2/16 GS 39	2/3/16 GS 49	9/3/16 GS 55	Seasonal Mean
R. padi	V1	0.1±0.0	0.6±0.2 b	3.1±0.1 h	0.8±0.0 f	0.8±0.0 e	-	1.1±0.1 j
	V2	0.3±0.2	1.4±0.1 a	3.6±0.0 g	0.7±0.1 f	0.8±0.0 e	-	1.4±0.1 ij
	V3	0.3±0.2	1.0±0.1 a	3.2±0.0 gh	2.7±0.0 e	0.6±0.0 e	-	1.6±0.0 ij
	V4	0.1±0.0	1.2±0.0 a	3.5±0.0 gh	3.8±0.1 d	0.5±0.0 e	-	1.8±0.0 i
	V5	0.0±0.0	0.5±0.0 b	4.2±0.0 f	2.3±0.1 e	0.3±0.0 e	-	1.5±0.0 ij
	V6	0.3±0.1	0.7±0.4 a	1.8±0.0 i	2.8±0.1 de	0.3±0.0 e	-	1.1±0.1 ij
	Mean	0.2±0.1 N.S	0.9±0.2 A	3.2±0.5 B	2.2±0.6 B	0.5±0.1 B	-	1.4±0.1 C
S. graminum	V1	0.1±0.0	0.5±0.0 b	12.3±0.2 d	3.4±0.1 de	-	-	4.0±0.1 h
	V2	0.3±0.2	0.4±0.0 b	14.2±0.0 b	2.8±0.3 de	-	-	4.4±0.1 gh
	V3	0.3±0.2	0.2±0.0 b	13.0±0.1 c	10.7±0.1 b	-	-	6.1±0.0 f
	V4	0.1±0.0	0.3±0.0 b	13.8±0.1 b	15.4±0.2 a	-	-	7.4±0.0 e
	V5	0.0±0.0	0.1±0.0 b	16.8±0.1 a	9.3±0.4 c	-	-	6.6±0.1 f
	V6	0.3±0.1	0.2±0.1 b	7.00±0.1 e	11.4±0.2 b	-	-	4.7±0.0 gh
	Mean	0.2±0.1 N.S	0.3±0.1 B	12.9± 1.8 A	8.8±2.8 A	-	-	5.5±0.7 B
S. avenae	V1	-	-	-	-	25.2±0.2 a	4.2±0.2 a	14.7±0.2 a
	V2	-	-	-	-	24.9±0.5 a	1.7±0.5 b	13.3±0.1 b
	V3	-	-	-	-	17.9±0.4 b	0.3±0.1 c	9.1±0.3 c
	V4	-	-	-	-	16.3±0.2 c	0.2±0.1 c	8.2±0.1 d
	V5	-	-	-	-	9.1±0.3 d	0.9±0.1 bc	5.0±0.2 g
	V6	-	-	-	-	9.0±0.2 d	0.8±0.0 bc	4.9±0.1 g
	Mean	-	-	-	-	17.1±4.1 A	-	9.0±2.3 A
ANOVA								
Species		0.91	105.71	110.12	6230.11	14973.6	-	9208.62
F (P) Tukey HSD		0.4411N.S	0.0093*	0.000*	0.0000*	0.0000		0.000*
		1.492	0.2550	0.1252	0.1810	0.295		0.143
Var.		4.05	4.94	1053.39	339.19	410.56	31.46	218.77
F (P) Tukey HSD		0.0106*	0.0042*	0.000*	0.0000*	0.0000*	0.0000*	0.000*
		0.3276	0.4354	0.2791	0.8087	0.8962	1.302	0.3924
Species × Var.		0.00	3.35	379.22	315.94	442.24	-	730.07
F (P) Tukey HSD		1.0000N.S	0.0232*	0.0000*	0.0000*	0.0000*		0.000*
		0.4944	0.8178	0.4828	1.1217	1.4138		0.6743

V1, Galaxy-13; V2, Millat-11; V3, NW-1-8183-8; V4, NW3-3341-7; V5, Lasani-08; V6, Faisalabad -08; N.S, Non significant; * , significant at 0.05 α; GS, growth stages of wheat plant; S, Seeding; 11, first leaf; 13, Three leaves; 21, Start of tillering stage; 25, five tillers; 29, End of tillering stage; 30, Start of stem elongation; 31, First node visible; 32, Second node visible; 37, Flag leaf just visible; 39, Flag leaf fully emerged; 49, Booting; 55, Ear 50% emerged; 59, Ears fully emerged; 69, End of flowering; 89, Fully ripe.

Statistical analysis

The data were analyzed following split plot design (Steel *et al*., 1997) with statistical software Statistix 8.1 (Analytical software, Statistix; Tallahassee, Florida, USA, 1985-2005). A repeated-measures ANOVA was also done considering number of observations as additional factor. Means were compared with Tukey HSD test of significance (P = 0.05).

RESULTS

The incidence of aphids in negligibly low numbers was started on 19th January when crop was at stem elongation stage (GS 30) on all wheat varieties/lines (Table I). The aphid population increased gradually with the growth of plants during reproductive stages. Peak infestations was earliest on 16th February (GS 37: flag leaf just visible) on Lasani-08, on 23rd February (GS 39: flag leaf fully emerged) on both NW-3-3341-7 and Faisalabad-08. On Galaxy-13, Millat-08, and NW-1-8183-8, peaks of aphids were noted on 2nd March (GS 49: booting stage). Aphids started to decline on 9th March (GS 55: 50% emergence of ear).

From incidence (GS30: start of stem elongation) to decline (GS55: ear emergence stage), aphid complex comprised of three species (Table II) which were identified as *Rhopalosiphum padi* (L.), *Schizaphis graminum* (R.), and *Sitobion avenae* (F.). *R. padi* was dominant over population of *S. graminum* at GS 32. The population of *S. graminum* increased gradually and peaked at flag leaf stage (GS 37) and became dominant over *R. padi*. The population of both *S. graminum* and *R. padi* started to decline at full emergence of flag leaf (GS 39). Third species, *S. avenae* appeared late at booting stage (GS 49). The population of *S. avenae* was higher than *R. padi* at GS 49. The population of *S. avenae* declined at GS 55 (with 50% ears emergence). During the entire season, mean population of three species *i.e*., *R. padi, S. graminum,* and *S. avenae* were 1.4, 5.5, and 9.0 aphids/tiller, respectively.

At GS 32 (with the visibility of 2nd node) on 2nd Feb., aphid population was observed non-significant for all the varieties and treatments (Table III). Maximum aphid number was observed on Millat-11 and minimum on Lasnai-08. On 9th Feb., aphid infestation was found significant for varieties and treatments. The highest mean aphid population was observed on NW-3-3341-7 and the lowest mean aphid population was found on Galaxy-13 (1.0). Aphids were high in numbers at booting stage (GS 49).

First application of imidacloprid was done on 9th Feb. (at GS32: visibility of 2nd node) on all wheat varieties after aphid data collection (Table III). Aphid population was higher on Lasani-08 and lower in Faisalabad-08. Aphid population was lower under imidacloprid treated plots of all wheat cultivars while the highest under untreated regime.

Second application of imidacloprid was done on 23rd Feb. (at GS39: full emergence of flag leaf) on all wheat varieties after aphid data collection (Table III). Aphid population at booting stage (GS 49) was significant on varieties and treatments. The highest aphid infestation was observed on Millat-11, while, the lowest was on Lasani-08 and Faisalabad-08.

Aphid infestation was the highest on untreated plots of Galaxy (26.0 aphids/tiller) and Millat-08 (25.7 aphids/tiller). Aphid population was the lowest in NW-3-3341-7, Lasani-08 and Faisalabad-08 in imidacloprid treated plots. The overall mean seasonal infestation was higher on wheat line NW-3-3341-7 (6.4 aphid/tiller) and on NW-1-8183-8 (6 aphid/tiller). The lowest aphid population (4 aphid/tiller) was observed on Faisalabad-08.

All wheat varieties/lines showed chlorophyll measurement value above 35 indicating that the crop was in good health (Table IV). Chlorophyll content and photosynthetic rate were statistically the highest in imidacloprid treated plots as compared to untreated plots.

Grain yield was observed statistically significant for all varieties and treatments. Maximum mean grain yield was observed in Galaxy which was at par with other wheat varieties Millat-11 and NW-1-8183-8. Lowest grain yield was observed in Lasani-08. The highest grain yield was found in imidacloprid treated plots of Galaxy-13 and the lowest in untreated plots of Lasani-08 (Table IV). The imidacloprid sprayed plots gave the highest yield as compared to untreated plot of all varieties. Similarly, percent yield loss was higher in Lasani-08 and lesser in Galaxy. Based on the mean seasonal aphid infestation and mean yield gain from all wheat varieties, Galaxy-13, Millat-11, NW-1-8183-8, NW-3-3341-7 and Faisalabad-08 were found tolerant against aphid damage. Wheat variety Lasani-08 was found susceptible by having low yield even with low numbers of aphids.

Applications of imidacloprid reduced aphid infestation than untreated plots. The imidacloprid treated plots showed less aphid infestation, higher chlorophyll content and photosynthetic rate of all the tested varieties (Table IV). Due to heavy aphid infestations, plants of untreated plots showed low photosynthetic rate and chlorophyll content, resulting lower yield harvests than treated plots. Imidacloprid applications resulted in good return for better grain yield. Cost benefit ratios were higher in NW-1-8183-8 (1:9.2) and lower in NW-3-3341-7 and Lasani-08 (1:7.4).

Table III.- Split plot analysis: Main plot (varieties) and subplots (treated and untreated plots): Mean aphid infestations (per tiller ± S.E) during the crop season.

Aphid	Varieties	2 Feb (GS32)	9 Feb (GS32)	16 Feb (GS37)	23Feb (GS39)	2Mar (GS 49)	9Mar (GS55)	Seasonal Mean
Main plot analysis								
Var.	Galaxy-13	0.3±0.0	1.0±0.4 c	7.8±0.2 c	3.5±0.3 d	16.0±0.5 b	4.0±0.2 a	5.4±0.2 c
	Millat-11	0.6±0.3	1.7±0.1 abc	9.1±0.1 b	3.6±0.4 d	17.8±0.4 a	1.6±0.4 b	5.7±0.1 b
	NW-1-8183-8	0.4±0.2	1.8±0.1 ab	8.2±0.1 c	12.1±0.2 b	14.1±0.4 c	0.2±0.1 b	6.1±0.1 a
	NW-3-3341-7	0.3±0.1	2.0±0.1 a	8.8±0.1 b	15.3±0.4 a	11.8±0.3 d	0.2±0.1 b	6.4±0.1 a
	Lasani-08	0.2±0.1	1.2±0.5 abc	10.6±0.1 a	8.5±0.6 c	7.3±0.3 e	0.7±0.2 b	4.8±0.1 d
	Faisalabad-08	0.4±0.2	1.1±0.4 bc	4.4± 0.1 d	9.3±0.3 c	7.6±0.2 e	1.1±0.5 b	4.0±0.1 e
	Mean	0.4±0.1 E	1.5±0.2 D	8.2±0.8 C	8.7±1.9 B	12.5±1.8A	1.3±0.6 D	-
				ANOVA				
	Var. (F)	0.78	6.25	454.41	243.83	314.60	21.65	255.37
	Var. (P)	0.5835 N.S	0.0070*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	Tukey HSD	0.8011	0.8580	0.4749	1.4624	1.2105	1.5261	0.2755
	Var × OBD (F)	-	-	-	-	-	-	200.89
	Var × OBD (P)							0.0000
	Tukey HSD							-
	Var ×Trt ×OBD (F)	-	-	-	-	-	-	67.83
	Var ×Trt ×OBD (P)							0.0000*
	Tukey HSD							-
Subplot analysis								
I_0	Galaxy-13	0.2±0.1	0.4±0.3 b	15.3±0.3 d	4.2±0.2 ef	26.0±0.4 a	4.2±0.2 a	8.4±0.2 b
	Millat-11	0.7±0.3	1.8±0.1 ab	17.8±0.1 b	3.5±0.4 ef	25.7±0.5 a	1.7±0.5 b	8.5±0.1 b
	NW-1-8183-8	0.7±0.3	1.2±0.1 ab	16.2±0.1 c	13.3±0.1 b	18.5±0.5 b	0.3±0.2 b	8.4±0.1 b
	NW-3-3341-7	0.2±0.1	1.5±0.1 ab	17.3±0.1 b	19.2±0.3 a	16.8±0.2 b	0.2±0.1 b	9.2±0.0 a
	Lasani-08	0.0±0.0	0.7±0.4 b	21.0±0.1 a	11.7±0.5 bc	9.3±0.3 c	0.9±0.1 b	7.3±0.1 c
	Faisalabad-08	0.5±0.3	0.8±0.4 ab	08.8±0.1 e	11.2±0.3 bc	9.3±0.2 c	1.1±0.5 b	5.3±0.1 d
I_2	Galaxy-13	0.3±0.1	1.5±0.4 ab	0.2±0.1 f	2.8±0.3 f	6.3±0.5 d	3.9±0.1 a	2.5±0.1 fg
	Millat-11	0.5±0.3	1.7±0.1 ab	0.3±0.2 f	3.6±0.3 ef	9.9±0.3 c	1.6±0.3 b	2.9±0.1 f
	NW-1-8183-8	0.2±0.1	2.4±0.1 a	0.2±0.1 f	10.8±0.3 c	9.8±0.3 c	0.2±0.1 b	3.9±0.1 e
	NW-3-3341-7	0.4±0.1	2.5±0.1 a	0.4±0.2 f	11.2±0.5 bc	6.8±0.3 d	0.2±0.1 b	3.6±0.1 e
	Lasani-08	0.4±0.2	1.7±0.5 ab	0.2±0.1 f	5.4±0.6 de	5.2±0.2 d	0.6±0.3 b	2.2±0.1 g
	Faisalabad-08	0.4±0.1	1.4±0.4 ab	0.1±0.1 f	7.4±0.3 d	5.8±0.1 d	1.0±0.5 b	2.7±0.1 fg
Trt.	I_0	0.4±0.2	1.1±0.2	16.1±1.6 A	10.5±2.4 A	17.6±3.0 A	1.4±0.3	7.8±0.1 A
	I_2	0.4±0.2	1.9±0.2	0.2±0.2 B	6.9±1.4 B	7.3±0.3 B	1.2±0.2	2.9±0.1 B
				ANOVA				
	Trt. F	0.08	16.09	51444.3	371.01	2847.11	1.15	4041.67
	Trt. P	0.7887 N.S	0.0017*	0.0000*	0.0000*	0.0000*	0.3053 N.S	0.0000*
	Tukey HSD	0.2210	0.4348	0.1522	0.4138	0.4206	0.2488	0.1665
	Var.×Trt. F	1.49	0.94	553.42	40.94	184.48	0.42	41.11
	Var.×Trt P	0.2647 N.S	0.4896 N.S	0.0000*	0.0000*	0.0000*	0.8229 N.S	0.0000*
	Tukey HSD	1.1803	1.7090	0.7412	2.1740	1.9573	1.9773	0.6189

I_0, Untreated control; I_2, two imidacloprid sprays on 9th Feb and 23rd Feb; N.S, Non significant; * , significant at 0.05 α; GS, growth stages of wheat plant; S, Seeding; 11, first leaf; 13, Three leaves; 21, Start of tillering stage; 25, five tillers; 29, End of tillering stage; 30, Start of stem elongation; 31, First node visible; 32, Second node visible; 37, Flag leaf just visible; 39, Flag leaf fully emerged; 49, Booting; 55, Ear 50% emerged; 59; Ears fully emerged; 69, End of flowering; 89, Fully ripe.

Table IV.- A summary table on wheat aphid (per tiller), chlorophyll content, photosynthetic rate, grain yield and cost and benefit ratio.

Aphid	Varieties	Mean aphid infestation/tiller	Photosynthetic rate	Chlorophyll contents	Grain yield (grams)	Yield/ha. (40Kg/ha)	Cost: Benefit
I_0	Galaxy-13	8.4±0.2 b	0.4±0.2	56.0±0.1 d	21.0±1.1 bcde	94.3	-
	Millat-11	8.5±0.1 b	0.4±0.1	55.3±0.1 de	19.4±0.7 cdef	87.1	-
	NW-1-8183-8	8.4±0.1 b	0.7±0.1	55.9±0.3 de	18.1±0.9 defg	81.3	-
	NW-3-3341-7	9.2±0.1 a	0.5±0.3	56.3±0.3 cd	15.5±0.6 fg	69.5	-
	Lasani-08	7.3±0.1 c	0.6±0.1	52.5±0.5 f	13.0±0.3 g	58.1	-
	Faisalabad-08	5.3±0.1 d	0.5±0.1	57.8±0.3 bc	17.4±1.1 efg	78.2	-
I_2	Galaxy-13	2.5±0.1 fg	1.0±0.2	61.9±0.2 a	26.3±1.5 a	119.5	1:8.6
	Millat-11	2.9±0.1 f	0.7±0.1	61.3±0.2 a	25.0±0.6 ab	112.2	1:8.5
	NW-1-8183-8	3.9±0.1 e	0.7±0.3	56.6±0.5 cd	24.2±1.8 abc	108.3	1:9.2
	NW-3-3341-7	3.6±0.1 e	0.7±0.3	58.5±0.3 b	20.4±0.2 bcdef	91.4	1:7.4
	Lasani-08	2.2±0.1 g	1.4±0.3	54.4±0.3 e	17.8±0.2 defg	79.9	1:7.4
	Faisalabad-08	2.7±0.1 fg	0.5±0.1	60.4±0.4 a	22.7±0.3 abcd	101.6	1:8.0
Trt.	I_0	7.8±0.1 A	0.5±0.2 B	55.6±0.3 B	17.4±1.2 B	-	-
	I_2	2.9±0.1 B	0.8±0.2 A	58.9±0.3 A	22.8±1.3 A	-	-
				ANOVA			
	Trt. F	4041.67	8.50	356.45	101.57	-	-
	Trt. P	0.0000*	0.0130*	0.0000*	0.0000*		
	Tukey HSD	0.1665	0.2327	0.3727	1.1621		
	Var.×Trt. F	41.11	1.36	27.74	0.13	-	-
	Var.×Trt P	0.0000*	0.3043 N.S	0.0000*	0.9832 N.S		
	Tukey HSD	0.6189	0.9846	1.5773	5.2381		

I_0, Untreated control; I_2, two imidacloprid sprays on 9th Feb and 23rd Feb; N.S, Non significant; * , significant at 0.05 α.

DISCUSSION

Results of our studies are in line with those of the previous workers who reported aphid incidence on wheat crop during early crop stages (GS30: stem elongation) during month of January (Ali *et al*., 2015; Shafiq *et al*., 2015). The results are also similar to (Ahmed *et al.*, 2015) who observed aphid incidence 55 days after sowing. Thereafter, the population of aphid increase at exponential rate and reached its peak on 16th Feb., at GS37 (Flag leaf just visible) on Lasani-08. The peak population of aphids was recorded in February (Akhtar and Perveen, 2002; Ali *et al*., 2012, 2015). On wheat cultivars Galaxy-13, Millat-11 and NW-1-8183-8 the infestation of aphids was higher on 16th Feb., to 2nd Mar., at booting stage. Results are consistent to researchers, who have found peak infestation of aphid during late February (Ali *et al*., 2012; Tabasum *et al*., 2012). Occurrence of aphid peaks were also reported during March (Shahzad *et al*., 2013; Ahmed *et al*., 2015).

We observed less aphid's infestation in earlier growth stages of wheat crop. The results are similar to those researchers who found slower multiplication of aphid population at vegetative stages and gradual increase in population with the growth of plants (Riazuddin and Khattak, 2004; Ahmed *et al*., 2015; John *et al*., 2017). Both quality and quantity of plant produce are affected by crop growth stage (Ahmed and Nasir, 2001; Ahmed *et al*., 2015) which directly effects insect growth and development and insect fecundity (Yazdani and Agarwal, 1997).

Aphid populations started to decline at ear emergence stage on 9th to 16th Mar. Our findings are in consistent with Ahmed *et al*. (2015) and Ali *et al*. (2015) who reported that aphid population decline when the crop reached to maturity and population disappears in the last week of March. However, the results are quite contradictory that aphid incidence in February (Muhammad *et al*., 2013; Ahmed *et al*., 2015), peaked in April (Helmi and Rashwan, 2013) and decline in April (Shahid *et al*., 2012; Ahmed *et al*., 2015).

The results of the study are in agreed with various investigators, who identified that three aphid species *i.e.*, *R. padi*, *S. avenae* and *S. graminum*, as major wheat insect-pests on different wheat varieties in Pakistan (Zeb *et al*., 2011; Shahid *et al*., 2012; Ali *et al*., 2015). Some studies showed only *S. graminum* and *R. padi* infestation on wheat cultivar (Akhtar and Perveen, 2002; Shahzad *et al*., 2013). While, other studies showed *R. maidis*, *R. padi* and *S. avenae* infest different wheat cultivars (Helmi and Rashwan, 2013). The results can also be compared with Ali *et al*. (2015), who found that *R. padi* dominates during vegetative growth stage and *S. avenae* dominates during reproductive crop stages. Results are also in line to the previous researchers who reported that *S. graminum* and

R. padi showed maximum density in February which at the end shifted to the ears (Akhtar and Perveen, 2002).

The outcomes of our result are in conformity with those (Khattak *et al*., 2007; Ali *et al*., 2011) who found that resistance levels were varied in different wheat cultivars. Our results are inconsistent to those who reported serious aphids attack on Faisalabad-08 (Ahmed *et al*., 2015), reasons might be due to different locations of the experiment. They reported that mean seasonal aphids infestation/tiller was 34.55 aphids/tiller on Faisalabad-08 and 24.68 on Lasani-08. It was also reported that aphid population on Lasani-08 remained less than Faisalabad-08. While, our results showed less aphid infestation on Faisalabad-08 than Lasani-08. The results are in close conformity with those who reported that the variety Faisalabad-08 suffered the minimum grain weight loss and was found resistant as compared to other tested varieties (Wains *et al*., 2010; Ali *et al*., 2011). They also found that grain weight was lower on Lasani-08 under both treated and untreated condition. The results can be compared with Shafiq *et al*. (2015), who reported that Galaxy-2013 and Millat-2011 for having better varietal resistance against *Schizaphis graminum*. The results are similar to the findings of (Shafiq *et al*., 2015; Shafique *et al*., 2016), where Galaxy 2013 as resistant variety with minimum aphids per plant.

The present findings can be compared with those (Ahmed *et al*., 2001; Ali *et al*., 2011), who reported that the application of imidacloprid efficiently controls aphids. Treatment of Confidor 25WP @ 500 ml/ha controlled aphids infestation/tiller significantly and showed reduction in aphid density/tiller nearly to zero (Wains *et al*., 2010). The results can be compared with Migui and Lamb (2003), who reported all species of aphids (*R. padi*, *S. avenae* and *S. graminum*) survived and reproduced on all wheat varieties, and caused reduction in spike biomass compared to treated plots. The results are also comparable to Shafiq *et al*. (2015), who found that imidacloprid as the most effective and persistent insecticide with maximum aphid mortality at 14 days of post treatment.

Both the chlorophyll content and photosynthetic rate were the highest in imidacloprid treated plots and the lowest in untreated control. The results are in conformity with Razaq *et al*. (2014a), who reported that photosynthetic rate and chlorophyll was lower in aphid infested plants as compared to that in aphid protected plants of canola crop. Similar results were reported by Hussain *et al*. (2014) as aphid feeding on *Brassica campestris* crop caused abatement of photosynthetic rate. Photosynthetic rate of wheat are similar to researchers, who reported a reduction in the photosynthesis rate of the cotton plants when infested by whitefly (Lin *et al*., 1999). Photosynthetic rate of rice crop showed reduction in the photosynthesis rate of plants when fed by plant hopper (Watanabe and Kitagawa, 2000). These findings suggested that reduction in photosynthetic rate was related with some change in metabolism due to aphid infestation as observed recently in okra (Razaq *et al*., 2014b).

High yielding wheat cultivars were observed to be the most susceptible varieties to aphid infestations. We found similar trend in variety Galaxy-13 which was heavily infested by aphids but it gave the highest yield. The results are also at par (Shafique *et al*., 2016), who has sorted Galaxy-13 as moderately resistant wheat cultivar against wheat aphids with the highest grain yield as compared to other cultivars. The grain yield in present study is not comparable with those researchers who found that grain weight was the lowest in Faisalabad-08 and higher in case of Lasani-08 (Ahmed *et al*., 2015). It was reported that varieties attacked by aphid showed poorer grain weight and thus, yield elements and aphid infestation level has inverse relationship. Finding of Ali *et al*. (2011) matches to our results in case of Faisalabad-08, which had less aphid infestations and showed good yield.

Results can also be compared with Shahzad *et al*. (2013) where single as well as two imidacloprid sprays could significantly increase grain weight. In our results, two imidacloprid applications resulted in maximum cost-benefit ratio in NW-1-8183-8 (1:9.2) and minimum in Lasani-08 (1:7.4). Findings of Aziz *et al*. (2013) supports that the application of imidacloprid resulted maximum cost-benefit ratio of 1:1.34 followed by neem seed kernel extract 5% giving ratio as 1:1.31. Net economic benefits from aphid control (CRDC, 2010) averaged \$33-\$37/ha from an active seed treatment (imidacloprid) and well-timed spray of foliar insecticide (pirimicarb or dimethoate).

CONCLUSION

Applications of imidacloprid significantly control the aphid infestations on wheat crop. Photosynthetic rate and chlorophyll are significantly higher in treated plots. With higher grain yield, wheat varieties, Galaxy-13 Millat-11, NW-1-8183-8, NW-3-3341-7 and Faisalabad-08 are tolerant against aphid infestations. Wheat variety Lasani-08 was susceptible to aphid infestations and results in less grain yield.

Statement of conflict of interest

Authors have declared no conflict of interest.

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