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Role of Wheat Plant Morphological Characters in the Mediating Abundance of Wheat Aphid (*Schizaphis gramium* R.)

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ABSTRACT

Wheat *Triticum aestivum* (L.) is one of the world's most consumed cereal grains. Aphids *Schizaphis gramium* R. is a prominent wheat pest that lowers the seed yield through direct and indirect damages. From an integrated pest management point of view, it is important to develop aphid-resistant cultivars. In this study, we determined the role of different morphological traits of wheat in linking the aphid population on 15 cultivars of wheat at Cotton Research Station, Multan, Punjab Pakistan during 2017-2019. The goal of the project was to determine the individual role of each factor *viz*., plant height, leaf color, number of trichomes on midrib, leaf moisture content, leaf perimeter, leaf area, angle of awns, number of awns, spike length, number of the floret, length of awns, grain moisture content on a wet basis, grain moisture content on dry basis on mean aphid infestation per season per year. Results revealed that aphids preferred varieties with dark green color, moderate trichomes density, high grain moisture content, and a significantly high number of awns, while plant height and spike length remained non-significant characters underlying resistance against aphids. Variety Lasani-08 proved a highly resistant cultivar. Varieties with low trichome intensity, lower numbers of awns, and broad awn angle varieties should be developed.

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FMS performed the experimental work along with AH and wrote the manuscript. NM did statistical analysis and critically reviewed the manuscript.

Key words
Aphids, Antixenosis, Plant morphological character, Leaf color, Awns, Yield

INTRODUCTION

Wheat *Triticum aestivum* (L.) is a major staple food crop of poor people of Pakistan and alone this crop contributes 3% to GDP. In 2020, Pakistan produced 25.2 million tons of wheat (GOP, 2022), although wheat production in Pakistan has quadrupled during last 4 decades from 6.4 to 25.2 million tons (from 1970 to 2020) (Barrientos and Soria, 2022; Prikhodko and Zrilyi, 2022), however, the per hectare yield is still lower than other countries and Pakistan has to import wheat to meet the food demands of growing Pakistani population. Pakistan produces around 2.5 to 3 tons of wheat per hectare while the agroecological potential for this land is around 6 tons per hectare (Prikhodko and Zrilyi, 2022). Pakistan can produce around 38 million tons of wheat per year if major constraints are properly handled (Prikhodko and Zrilyi, 2022). The major constraints are poor pest management (Abbas *et al*., 2005; Khan *et al*., 2021), reduction in crop area due to urbanization (Mehmood, 2022), late sowing (Abbas *et al*., 2005; Hassan *et al*., 2010), water shortage (Mehmood, 2022), lower use of fertilizer (Buneri, 2021), and increase in cost of production of other inputs (Abbas *et al*., 2005; Khan *et al*., 2021; Mehmood, 2022).

Among the insect pests, aphids (*Shizaphis gramium* R., *Rhopalosiphum padi* F., and *Sitobian avena* F.) are an important pest of wheat crop in Pakistan (Faheem *et al*., 2019) causing 35-40% direct yield loss. Among this aphid species complex, the most abundant is *Shizaphis gramium* R. which badly destroys wheat crops (Ahmad *et al*., 2015) through direct damage and indirectly through the transfer of barley yellow dwarf virus disease (BYDV-SGV) belonging to family Tombusviridae (Domier, 2008). Parthenogenetic, viviparous reproduction (Ogawa and Miura, 2014; Shufran *et al*., 1997), production of virgin pure (Blackman *et al*., 1987), ability to transfer BYDV-SGV (Domier, 2008), short life cycle (Vakhide and Safavi, 2014), polyphagous nature (Sambaraju and Pendleton, 2005), invasion on all biotypes of wheat (Rojas *et al*., 2020), ability to deplete nitrogen contents, decrease carbon assimilation rates,

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transpiration and total chlorophyll content (Zhang *et al*., 2019) makes it economically threatening pest of winter wheat crop (Khan *et al*., 2012). Aphids suck cell sap and secrete honeydew which interferes with the photosynthesis process and eventually yield is reduced to a greater extent (Al-Mousawi *et al*., 1983; Sattar *et al*., 2001; Zhang *et al*., 2019).

Host plant resistance (HPR) is an important, economically friendly, sustainable and cost-effective tool in aphid management on spring wheat crops (Emden, 2017; Rustamani *et al*., 1999). HPR lessens the chances of biotypes development (Lowe, 1987; Riazuddin and Khattak, 2004). Breeders throughout the world are continuously struggling to develop spring wheat varieties that should resistant/ tolerant to wheat aphid attack (Liu *et al*., 2001). Authors across the world report that morphological characters of plants play a predominant role in conferring resistance or susceptibility against aphids in wheat cultivars (Kiplagat, 2005; Smith, 1989; Starks and Merkle, 1977). Length of awns and angle of awns play a critical role in significant dispersal of aphids (Li *et al*., 2010). Trichomes on wheat significantly reduce aphid movement and hence aphid numbers (Hosseini and Modares, 2013). Leaf pubescence in wheat lines have long been regarded as an important character stimulating resistance or susceptibility in winter wheat cultivars against aphid complex (Bahlmann *et al*., 2003; Srinivasan and Uthamasamy, 2005). It is needed to develop pest resistant wheat varieties through breeding and selection programs.

The present work was conducted to explore the role of plant physiological and morphological characters e.g., plant height, length of the spike, number of florets, length of awns, angles of awns, the density of hairs on midrib and lamina, leaf color, leaf area, leaf moisture contents, grain moisture contents of various wheat genotypes in regulating wheat aphid population.

MATERIALS AND METHODS

Plant samples

Seeds of different varieties were obtained from Wheat Research Institute Faisalabad and Regional Agricultural Research Institute Bahawalpur, (Ayub Agricultural Research Institute Faisalabad) Pakistan. Fifteen varieties *viz*., Sehar 2010, Lasani-08, Shafaq-06, Uqab 2000, AARI 2011, Pasban 90, Inqalab 91, Millet 2011, Faisalabad 2008, Punjab 2011, Fareed-06, VO6377, Mairaj 2008, AAS-2011 and VO6309 were planted to check resistance or susceptibility to wheat aphid.

Layout of experiment

Field studies were conducted during 2017-2019 on highly organic muck soil at Cotton Research Institute, Multan which is located 30°12 North, longitude 071°26 East, 122 meter above the sea level. Fifteen varieties of wheat were planted in randomized complete block design consisting of 3 replicates.

Preparation of land

The land was prepared by plowing deep to remove stubbles and fine soil preparation. Cotton-wheat rotation was adopted to maximize the yield. The field was irrigated 10 days before planting a wheat crop and plowed at that time so that structure was not destroyed and no big clods remained. A wooden plank was plowed over the soil to break down the clods and make a fine smooth seed bed. Two to three ploughings were done to make a desirable smooth seedbed for planting wheat with a hand drill. The row-to-row distance was maintained at 15 cm to make harmonized seed bed for seed emergence. Organic manure was applied 40-50 days before sowing and was incorporated into the soil. Nitrogen and phosphorus fertilizers were applied in a ratio of 1:1. Seed rate used was 150 kg/hectare. Sowing was done with a hand drill. Each row of wheat was separated by 6 inches. No inter-culture and no weeding was done. No weedicide or herbicide was applied. Five irrigations from crop emergence to maturity were applied on the wheat experiment. No pesticide was used to control pest attacks.

Insect counts

Aphid population was recorded from 5 tillers per plant (Hammon *et al*., 1996). Ten plants were observed per replicate per variety. Total 150 tillers were observed per replicate. From each variety 45 tillers were observed. The data was initiated from the onset of cropping season to crop maturity. The Aphid population was recorded from January 1st to 30th April of each year. Averages of pest populations were taken.

Physiological and morphological characters

Different plant characters such as leaf color and plant height were recorded. Leaf color was measured through visual observation while plant height was measured plant height scale at the crop maturity stage. Leaf characters *viz*., leaf perimeter, leaf area, and leaf length were determined after plucking the leaf from plants at the maturity stage through a digital leaf area meter (UFL 040C, Nice sound electronics Ltd. Zhejiang China). Several hairs on the midrib were counted from 3 leaves upper, middle, and lower each taken through a compound microscope (Labomed Lx 400; USA) fitted with a micrometer.

For physiological characters, leaf moisture content on a wet basis and leaf moisture content on a dry weight

basis were determined after picking 10 leaves of plant per replicate. Leaf weight on a wet basis was determined by weighing each fresh leaf on a weighing balance. Then leaves were dried in an oven and dry weight was noted. Leaf moisture content on a dry basis and wet basis was determined through the formulae given below.

$$\text{Leaf moisture content on wet basis} = \frac{\text{Leaf weight on wet basis} - \text{Leaf weight on dry basis}}{\text{Leaf weight on wet basis}}$$

$$\text{Leaf moisture content on dry basis} = \frac{\text{Leaf weight on wet basis} - \text{Leaf weight on dry basis}}{\text{Leaf weight on dry basis}}$$

Various spike characters *viz*., spike length (cm), number of floret per spike, angle of awns, number of awns, and number of grains per spike were taken from 3 spikes per replicate per each treatment.

Grain moisture content on wet basis and dry basis was determined by collecting the 10 fresh bushels from the field and the grains were sorted. The grains were sorted then dried in sunlight and the dried grains weight was determined. Moisture content in the grains was determined through formulae.

Grain moisture content on dry basis = (1000 grain weight on wet basis −1000 grain weight on dry basis)/1000

Yield parameters

Yield parameters *viz*., yield in kg/acre, bushel weight (kg/acre), straw weight (kg/acre), and 1000 grain weight (g) was also calculated.

The following criterion was adopted for the determination of resistance and susceptibility of genotypes against aphids.

Data analysis

Data was statistically analyzed through R-studio version 1.1.453 R-Studio incorporation. Correlation analysis was made between insect counts and morphological parameters to ascertain the role of each factor in modulating pest population dynamics using R. Means were separated by Tukey highly significant difference test at a 5% level of significance.

RESULTS

Field studies during 2017-2019 showed that wheat varieties and advanced wheat lines had variable levels of resistance/susceptibility against wheat aphids on wheat crops planted in irrigated belts of south Punjab.

Aphid abundance on various cultivars

Two-way ANOVA analysis showed significant difference among varieties (DF, 14; F-value, 14; F-value, 164.7; P<0.01 and years DF, 1; F-value, 229.206; P<0.01). The interaction of years and varieties was also highly significant (DF, 14; F-value, 3.171; P<0.01). Overall, the aphid population was significantly higher in 2019 compared to 2018. Variety V06377 had a higher number of aphids in 2019 (10.27) while Lasani-08 had the lowest number of aphids (1.43) (Fig. 1).

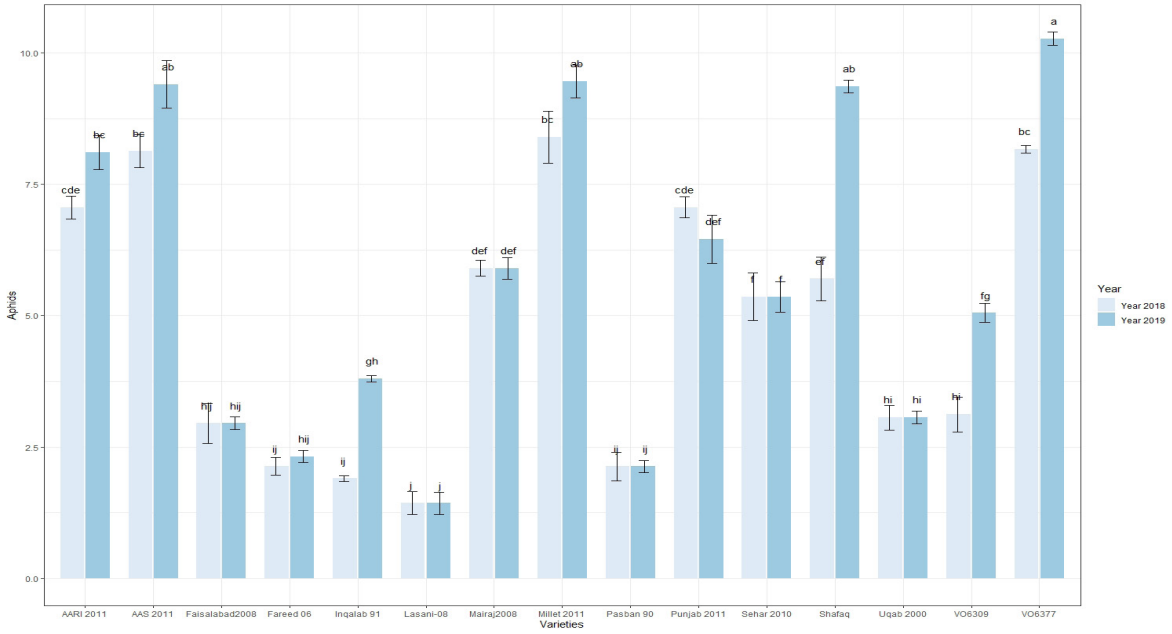

Fig. 1. Resistance of wheat crop varieties against aphid population during 2017-2019. For interaction of years and varieties: DF, 14; F-value, 3.171; P<0.01. Error bars represent standard error.

Table I. Criterion for evaluation of susceptibility or resistance of genotypes.

Resistance scale	Resistance	Aphid indexes
0	Immunity	0.00
1	Highly resistant	1.0-3.0
2	Moderately resistant	3.0-3.5
3	Lowly resistant	3.5-4.5
4	Lowly susceptible	4.51-6.
5	Moderately susceptible	6.0-7.5
6	Highly susceptible	>7.5

Role of plant characters in susceptibility/resistance against aphids

Plant height and leaf color showed variable responses to aphid abundance. Plant height was significantly different (DF, 14; F-value 16.0; P<0.01) in all 15 cultivars of wheat. Varieties Sehar 2010, AARI 2011, AAS 2011, and Mairaj 2008 were at par, while Inqalab-91 was comparatively short (83.0 cm). Five varieties *viz*., Sehar 2010, Shafaq, Millet 2011, Faisalabad 2008, and Mairaj 2008 had green color. Three varieties *viz*., Lasani-08, Inqalab-91, and Fareed-06 had grayish Green color. Five varieties *viz*., Uqab 2000, Punjab 2011, AARI 2011, Pasban 90, and VO6309 had light green color. One varietyVO6377 had dark green color while AAS-2011 had pale green color. The Aphid population was significantly higher on VO6377 while it was lowest on Lasani-08 during both years 2017-2018 and 2018-2019 (Table II).

Role of leaf characters against aphid population

Effect of different leaf extracts such as trichomes on midrib, moisture content, leaf perimeters and leaf area are shown in Table III. Trichomes on midrib were different on various cultivars of wheat crop (DF=14; F-value=304.97; p<0.01). Trichomes on midrib were maximum in Punjab 2011 (12.33) followed by Mairaj 2008 (8.33), Faisalabad 2008 (8.0), Millet 2011 (7.66), Fareed-06 (7.66), AARI 2011 (7.66), VO6309 (6.33), Shafaq (5.66), VO 6377 (4.66), Uqab 2000(4.34), Pasban 90 (4.00), Lasani-08 (2.33) and Inqalab 91(1.00). Lasani-08 had minimum hairs on the midrib and also a minimum number of aphid densities was observed on the Lasani-08 variety (Table III). Punjab 2011 harbored significantly maximum aphid numbers.

Leaf moisture content on wet basis was non-significantly different among all cultivars of wheat however maximum leaf moisture content on wet basis was observed on Mairaj 2008; VO6377 (0.66) and Inqalab-91 (0.6) while minimum leaf moisture content was observed on variety Sehar 2010 (0.437) and Punjab 2011 (0.58) (Table III). Maximum leaf moisture content on a dry basis was observed in VO6309 (2.367) followed by Millet 2011, Pasban 90, while minimum leaf moisture content observed on a dry basis was observed in cultivar VO6377 (0.33).

Leaf perimeter and leaf area were significantly different in all cultivars of wheat. Maximum leaf perimeter viz., 89.42 was observed on Punjab 2011 while minimum on Millet 2011 and Lasani 08 (Table III). Maximum leaf area was observed on Mairaj 2008. However, Sehar 2010, Lasani-08, Shafaq, Uqab 2000, AARI 2011, Pasban90, Inqalab 91, Millet 2011, Faisalabad 2008, Punjab 2011, VO 6307 and AAS-2011 were all at par.

Table II. Plant characters of different wheat cultivars were observed during 2017-2018.

Varieties	Plant height (cm±SEM)	Leaf color
Sehar 2010	101.33 ± 2.02 a	Green
Lasani-08	91.00 ± 2.64 bcd	Grayish green
Shafaq	96.33 ± 1.20 abc	Green
Uqab 2000	90.64 ± 3.48 bcd	Light green
AARI 2011	102.66 ± 1.20 a	Light green
Pasban 90	84.33 ± 0.88 d	Light green
Inqalab 91	83.00 ± 1.15 d	Grayish green
Millet 2011	95.67 ± 1.20 abc	Green
Faisalabad 2008	96.00 ±1.52 abc	Green
Punjab 2011	98.67 ± 0.66 ab	Light green
Fareed 06	90.33 ± 0.577 cd	Grayish green
VO6377	86.00 ± 0.66 d	Dark green
Mairaj2008	99.33 ± 0.88 a	Green
AAS 2011	100.33 ± 1.20 a	Pale green
VO6309	95.33 ± 0.66 abc	Light green
F-value	16.02	
P-value	<0.01	

Role of spike characters of wheat cultivars against aphid population

Table IV shows effect of various spike charecters of wheat cultivars number and lengths of awns, spike length and number of floreto on aphid population. The angle and number of awns was significantly different among all cultivars of wheat. However, Inqalab-91, Pasban 90, and AARI 2011 were more out fringed than any other cultivar. VO6377 had a narrower angle of 65°. VO 6377 was susceptible in both years and harbored a maximum number of aphids.

Table III. Leaf characters of different wheat cultivars observed during crop season 2017-2018.

Varieties	Number of trichomes on Midrib	Leaf moisture content (Wet basis)	Leaf moisture content (g) (Dry weight basis)	Leaf perimeter	Leaf area
Sehar 2010	5.66 ± 0.05 c	0.43 ± 0.00 e	1.28 ± 0.11 cd	77.89 ± 0.33 efg	17.72 ± 0.88 abc
Lasani-08	2.333 ± 0.088 e	0.563 ± 0.01 abcd	1.400 ± 0.10 cd	75.10± 0.57 g	15.43± 0.28 ab
Shafaq	5.66 ± 0.08c	0.58 ± 0.00 abcd	1.45± 0.10 cd	87.06± 2.02 ab	18.50± 0.14 ab
Uqab 2000	4.33 ± 0.08 d	0.58± 0.00 abcd	1.48 ± 0.08 cd	81.59± 0.50 cde	15.53± 0.76 bc
AARI 2011	7.66± 0.13b	0.56 ± 0.01 bcd	1.300 ± 0.11 cd	76.21± 0.88 fg	14.23± 0.37 cd
Pasban 90	4.00 ± 0.11 d	0.62 ± 0.01 abc	1.67± 0.11 bc	74.85± 0.60 fg	14.26± 0.30 cd
Inqalab 91	1.00± 0.11 f	0.60 ± 0.02 a	1.49± 0.06 cd	79.84± 1.20 def	11.75± 0.60 de
Millet 2011	7.66± 0.20 b	0.65 ± 0.02 abc	2.06± 0.14 ab	45.88± 0.57 h	14.33± 1.20 cd
Faisalabad- 08	8.00± 0.26 b	0.43 ± 0.05 e	1.08 ± 0.07 d	84.27± 0.88 abc	16.76± 1.20 bc
Punjab 2011	12.33± 0.18 a	0.58 ± 0.01 abcd	1.10 ± 0.05 d	89.42± 0.57 a	16.03± 0.57 bc
Fareed 06	7.66± 0.34 b	0.53 ± 0.00 cd	1.16 ± 0.03 d	73.14± 1.20 g	10.43± 0.29 e
VO 6377	4.66± 0.05 d	0.50 ± 0.01 a	0.33± 0.08 e	76.25± 0.66 efg	15.30± 0.57 bcd
Mairaj 2008	8.33± 0.088 b	0.660 ± 0.017 a	1.727± 0.1 bc	84.490± 0.72 abc	20.533± 0.16 a
AAS 2011	6.33± 0.10 c	0.58 ± 0.01 abcd	1.50 ± 0.05 cd	83.95± 1.76 bcd	11.83± 0.16 de
VO6309	6.33± 0.10 c	0.66 ± 0.02 ab	2.36± SE a	84.75± 0.33 abcd	18.03± 0.57 ab
F-value	304.97	11.65	22.91	110.5	15.12
p-value	<0.01	<0.01	<0.01	<0.01	<0.01

Table IV. Spike characters of different wheat cultivars observed during 2017-2018.

Varieties	Angle of Awns	Number of awns	Spike length (inch)	Number of floret	Length of awns (cm)
Sehar 2010	75.00 ± 0.0g	55.66 ± 1.20def	9.16 ± 0.60 ab	55.66 ± 1.45 cdef	6.33 ± 0.60 a
Lasani-08	75.66 ± 0.0f	50.00 ± 1.20 fg	9.60 ± 0.23 ab	52.33±1.45 cdef	6.93 ± 0.20 a
Shafaq	73.33 ± 0.0i	55.000± 1.52efg	10.63 ± 0.44 ab	55.00±2.33 cdef	6.90 ± 0.14 a
Uqab 2000	74.00 ± 0.0h	61.333± 0.88bcd	8.12 ± 0.66 ab	61.00 ± 1.76 bc	6.667 abcde
AARI 2011	81.00± 0.0c	65.66 ± 0.33ab	9.90 ± 0.57 ab	65.667±1.76 ab	5.73 ± 0.66 a
Pasban 90	81.66± 0.0b	59.00 ± 0.57cde	11.06 ± 1.15 ab	58.66 ± 0.88 bcd	6.10 ± 0.14 a
Inqalab 91	81.66± 0.0a	70.33 ± 1.20 a	11.66 ±1.2 ab	70.00 ± 1.20a	5.66±0.56e
Millet 2011	68.33± 0.0k	60.00 ± 1.0 bcde	9.86 ± 0.16 ab	54.66 ±0.88 cdef	5.83 ±0.44 a
Faisalabad-08	70.00± 0.0j	50.33 ±1.20fg	8.93 ± 0.28 ab	48.00± 0.88fg	6.96±0.44a
Punjab 2011	76.00± 0.0e	63.66 ± 1.15 bc	11.73 ±0.33 ab	63.66±0.88bc	6.70 ± 0.33a
Fareed 06	75.66± 0.0f	42.00 ± 0.577 h	9.60 ± 0.33 ab	42.00±1.45 g	7.20 ± 0.12a
VO6377	65.00± 0.0m	59.66 ± 1.45 cde	8.96 ± 0.33 ab	59.66 ± 2.72 cde	6.53 ± 0.20a
Mairaj2008	67.33± 0.0l	61.66±1.85 bc	11.33 ± 0.33 ab	61.66 ± 0.88 bc	7.34 ± 0.03a
AAS 2011	78.33± 0.0d	58.33 ±0.57 cde	12.10 ± 1.45 a	58.33±03.33 bcd	6.86 ± 0.03a
VO6309	78.33± 0.0d	49.33 ± 0.33 g	7.00 ± 0.66b	49.33 ± 0.57 efg	6.16 ± 0.08
F-value	13.35	11.36	2.81	24.27	2.43
p-value	<0.01	3.922	<0.01	<0.01	0.02

The varieties Punjab 2011 and AARI 2011, Inqalab 91 also had significantly higher number of awns while VO6309 had a significantly minimum number of awns. Varieties *viz*., Sehar 2010, Lasani-08, Shafaq, Uqab2000,

Pasban 90, VO6377, Mairaj2008, AAS-2011 and VO6309 were at par in terms of several awns.

Spike length (in inches) was significantly higher on AAS 2011(12.10) followed by Mairaj2008 (11.33), Punjab 2011(11.73), Inqalab 91 (11.6), Pasban 90(11.06), Shafaq (10.63), AARI 2011(9.90), Shafaq(10.63),VO6377 (8.96), Shafaq (10.63), Fareed 06(9.60), Faisalabad08 (8.93), Uqab 2011(8.12) and VO6309 (7.0) VO6309 had minimum spike length (7.0). The number of florets was significantly maximum on Inqalab91 (70.00) while minimum florets were observed in Fareed-06. Length of awns of Mairaj2008 was significantly higher (7.34) while minimum awn length was observed in AARI 2011 (5.73) (Table IV).

Varieties elaborated significant variation in grain moisture content on a wet basis (Table V). However, VO6307 had maximum grain moisture content on a wet basis while VO6377 had minimum moisture content on dry basis. Grain moisture content on a dry basis was significantly different among various cultivars of wheat. Millet2011 had maximum moisture content on dry basis followed by Pasban-90, Faisalabad 08, Sehar 2010, Uqab 2000, Lasani-08, Punjab 2011, Inqalab 91, VO6377, AAS 2011, Shafaq AARI 2011, Mairaj2008 and Fareed-06 (Table V).

Yield and yield components of wheat crop

Table VI shows yield and yield components of wheat crop. Bushel weight was significantly different among various cultivars of wheat. However, Inqalab-91 had a maximum bushel weight *viz*., 5600 kg while AAS2011 had a minimum bushel weight (3166 kg). Straw weight was non-significantly among various cultivars of wheat. Shafaq and AARI 2011 had significant maximum straw weight whilst Faisalabad 2008 enumerated minimum straw weight.

Table V. Spike characters of different wheat cultivars observed during 2017-2018.

Varieties	Grain moisture content (µg) wet basis	Grain moisture content on dry weight basis (µg)
Sehar 2010	433.33 ± 3.33 bcde	1.243± 0.18 abc
Lasani-08	500.67 ± 5.0 c	1.06 ± 0.13 abcde
Shafaq	523.33 ± 8.89 bc	0.68 ± 0.04 e
Uqab 2000	520.33 ± 6.00 bc	1.13 ± 0.03 abcd
AARI 2011	437.33 ± 1.45bcde	0.81 ±0.66 cde
Pasban 90	493.33 ± 1.45bcd	1.33 ± 0.08 ab
Inqalab 91	540.33 ± 7.63 b	0.91 ± 0.05 bcde
Millet 2011	550.00 ± 3.33b	1.43± 0.03 a
Faisalabad2008	450.00 ± 10.40bcde	0.79 ±0.03 de
Punjab 2011	420.67 ± 2.08cde	1.04 ± 0.03 abcd
Fareed 06	393.00 ± 5.78de	0.68 ± 0.01 e
VO 6377	337.33 ± 4.33e	1.21 ± 0.03 abcd
Mairaj2008	433.00 ± 8.81bcde	0.84± 0.05 cde
AAS 2011	453.00 ± 3.33bcde	0.86 ± 0.02 cde
VO6309	673.33 ± 9.83a	1.20 ± 0.16 abcd
F-value	165.75	8.25
p-value	<0.01	<0.01

Table VI. Yield and Yield components of different varieties of wheat crop 2017-2018.

Varieties	Bushel weight (Kg/acre)	Yield (kg)/acre	Straw weight (kg/acre)	1000 grain weight (g)
Sehar 2010	4876.66 ± 36.55 abcd	1556.66 ± 80.89 fgh	3326.66 ± 37.11 ab	39.10 ± 0.57 abc
Lasani-08	5083.33 ± 44.09 ab	2613.33 ± 46.66 b	2463.33 ± 31.79 bcd	40.00 ± 0.57 abc
Shafaq	4883.33 ± 44.09 abcd	1370.00 ± 35.11 gh	3516.66 ± 72.64 a	39.50 ± 0.57 abc
Uqab 2000	4733.33 ± 116.66 bcd	1803.533 ± 60.82 def	3483.33 ± 44.09 a	38.80 ± 0.58 bc
AARI 2011	4975.0 ± 267.31 abc	1496.667± 60.64 fgh	2866.66 ± 33.33 abc	38.53 ± 0.57 bc
Pasban 90	4150.00 ± 229.12 de	2061.66 ± 31.13 cde	2103.33 ± 306.61 cd	38.56 ± 0.57 bc
Inqalab 91	5600.00 ± 104.08 a	2100.00 ± 57.73 cd	3017.00 ± 57.73 abc	39.40 ± 0.57 abc
Millet 2011	3933.33 ± 44.09 ef	4200.0 ± 57.73 a	2750.00 ± 57.73 abcd	41.00 ± 0.57 ab
Faisalabad2008	3943.33 ± 92.43 ef	1863.33 ±31.79 def	1844.00 ± 57.73 d	42.02 ± 0.57 a
Punjab 2011	3400.0 ± 115.47 fg	1528.33 ± 25.87fgh	2870.00 ± 57.73 abc	41.00 ± 0.57 ab
Fareed 06	3392.33 ± 225.17 fg	2450.0 ± 50.00 bc	2425.00 ± 57.73 bcd	37.00 ± 0.57 c
VO6377	3396.66 ± 54.87 fg	2066.667 ± 233.33 cde	2365.00 ± 57.73 cd	39.0 ± 0.57 bc
Mairaj2008	4772.66 ± 75.10 bcd	1183.333 ± 16.66 h	2209.00 ±57.73 cd	41.0 ± 0.57 ab
AAS 2011	3166.66 ± 202.75 g	1680.00 ± 41.63 efg	2906.00 ± 57.73 abc	41.00 ± 0.57 ab
VO6309	4283.33 ± 148.13 cde	1743.33 ± 72.18 defg	2925.00 ± 577.35 abc	41.0 ± 0.57 ab
F-value	28.09	87.25	8.018	5.46
p-value	<0.01	<0.01	<0.01	<0.01

Regarding yield one thousand grain weight of Faisalabad 2008 was significantly higher *viz*., 42.067 grams while AARI 2011 and Pasban-90 had a minimum 1000 grain weight.

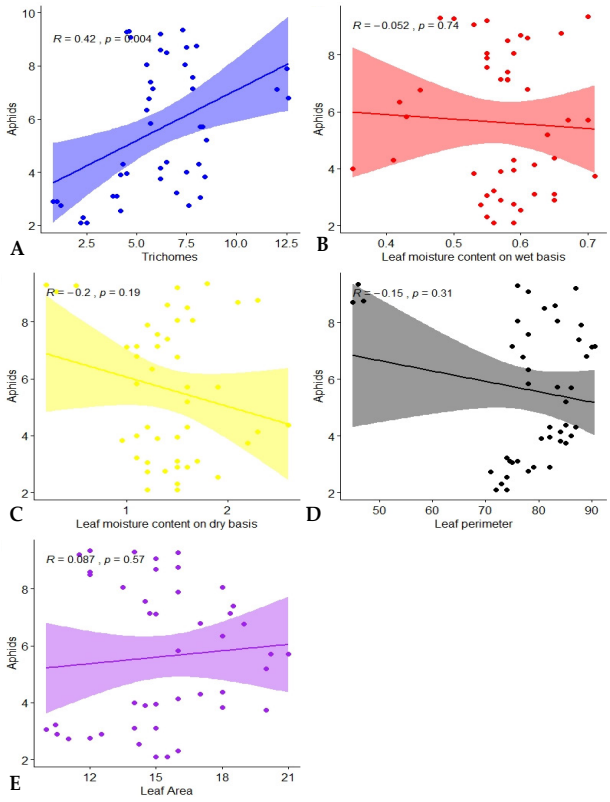

Fig. 2. Correlation of leaf morphological characters to cumulative aphid abundance during 2017-2019. Here on the y-axis aphids represent an average number of aphids observed during both years 2017-2019 field crop seasons. (A) Regression and correlation analysis between average number of aphids on each variety and leaf trichomes. (B) Regression and correlation analysis between average number of aphids on each variety and leaf moisture content on wet basis (fresh weight). (C) Regression and correlation analysis between average number of aphids on each variety and leaf moisture content on dry weight basis. (D) Regression and correlation analysis between average number of aphids on each variety and leaf perimeter. (E) Regression and correlation analysis between average number of aphids on each variety and leaf area.

Correlation between leaf morphological characters and aphid abundance

Overall, a positive correlation was observed between trichomes and aphid numbers (Fig. 2A). However, a comparison among varieties and insects counts showed a negative correlation between hairs and aphid density in six cultivars *viz*., Shafaq, Uqab 2000, AARI 2011, Pasban 90, Inqalab 91 and Mairaj 2008. Sehar 2010 had medium hair density on mid rib viz., 5.6 and medium aphid density 7.2 (Supplementary Table I).

Leaf moisture content on a wet basis and dry basis had a non-significant negative correlation with aphid counts (Fig. 2B, C). Varieties *viz*., Sehar 2010, Uqab 2000 and AARI 2011 demonstrated a negative correlation between aphid numbers and leaf moisture content on dry basis (Supplementary Table I). Lasani-08, Shafaq, Faisalabad 2008, Punjab 2011, Fareed-06, VO6377, Mairaj2008, AAS 2011, and VO6309 demonstrated a positive correlation between aphid numbers and leaf moisture content on a dry basis (Supplementary Table I).

Leaf perimeter and aphids correlation were non-significantly negative (Fig. 2D). Aphid susceptibility is the feature of chemical and morphological characteristics complex in varieties. Five varieties *viz*., Sehar 2010, Shafaq, Uqab 2000, Inqalab91, and Millet 2011 demonstrated a negative correlation between aphid density and leaf perimeter (Supplementary Table I).

Overall, the correlation of leaf area with the aphid numbers was non-significant and negative (Fig. 2E). Among the varieties, leaf area had a negative correlation with aphid density in three cultivars of wheat viz., Uqab 2000, Inqalab 91, and Millet 2011, while 12 varieties had non-significant positive correlation with aphid counts (Supplementary Table I).

Correlation between spike, grain characters, and aphid abundance

Overall, spike length and varietes had a non-significant positive correlation with aphid counts during 2017-2019 (Fig. 3A, B). Spike length had a positive correlation with aphid abundance in thirteen cultivars of wheat *viz*., Sehar 2010, Lasani-08, Shafaq, Uqab2000, AARI 2011, Pasban 90, Millet 2011, Faisalabad2008, Punjab 2011, Fareed-06, VO6377 and Mairaj2008. However, cultivars Inqalab-91 and AAS-2011 demonstrated a negative correlation with aphid density (Supplementary Table II). Moreover, among varieties Shafaq, Uqab 2000, AARI 2011, Pasban 90, Inqalab91, Millet 2011, Faisalabad2008, Punjab 2011, Fareed-06, VO6377, Mairaj2008, AAS-2011, and VO6309 had a positive correlation with aphid. While highly positive significant correlation was observed with the Lasani-08 variety. Sehar 2010 negative correlation between the number of florets and aphid abundance (Supplementary Table II).

Overall, a significantly positive correlation was observed between aphid counts and several awns (Fig. 3C), whereas a negative correlation of angle of awns was observerd with aphid counts (Fig. 3D) (Supplementary

Table II, Fig. 3C) show that all varieties had a positive correlation except Punjab 2011 thus as the number of awns increases similarly aphid population also increases. Sehar 2010 had a significant positive correlation with the angle of awns (Supplementary Table II). Nearly all varieties had a positive correlation between the angle of awns and aphid density. Thus if awns are close to spike then a maximum number of aphids occur in that variety (Supplementary Table II).

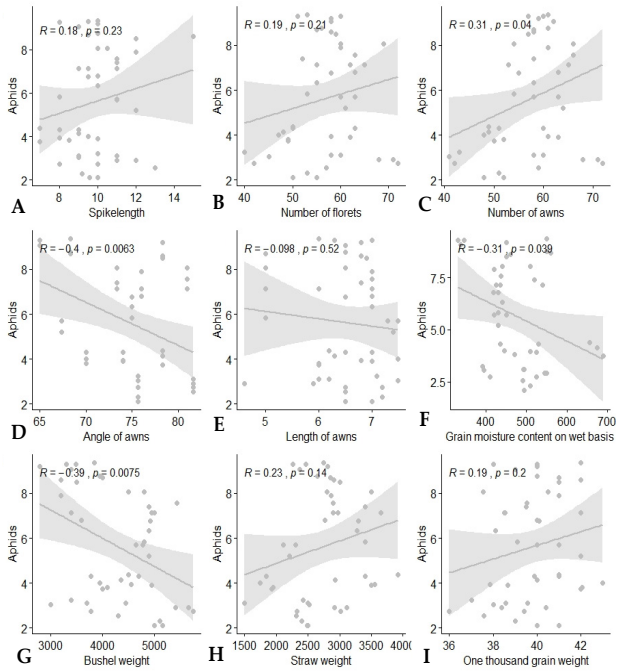

Fig. 3. Regression and correlation of spike, bushel and grain characters on aphid abundance during 2017-2019. (A) Regression and correlation analysis between average number of aphids on each variety and spike length. (B) Regression and correlation analysis between average number of aphids on each variety and number of florets. (C) Regression and correlation analysis between average number of aphids on each variety and number of awns. (D) Regression and correlation analysis between average number of aphids on each variety and angle of awns. (E) Regression and correlation analysis between average number of aphids on each variety and lwngth of awns. (F) Regression and correlation analysis between average number of aphids on each variety and grain moisture content on wet basis. (G) Regression and correlation analysis between average number of aphids on each variety and bushel weight. (H) Regression and correlation analysis between average number of aphids on each variety and straw weight. (I) Regression and correlation analysis between average number of aphids on each variety and one thousand grain weight.

Overall, a highly significant negative correlation was observed among varieties and the aphid counts (Fig. 3E). Eight varieties had a positive correlation with aphid density thus if the angle of awns is greater than more aphid accumulates on that variety. While four varieties viz., Sehar 2010, Inqalab91, Faisalaabad-08, Punjab 2011, and Mairaj2008 had a negative correlation with aphid numbers (Supplementary Table II). Figure 3F and Supplementary Table II, show that grain moisture content on wet and dry basis had a significantly negative correlation with aphid counts. Figure 3G and Supplementary Table II shows that fourteen varieties of wheat had a positive correlation with aphid numbers thus as bushel weight increases aphid density also increases .

All varieties except Inqalab91 and Fareed-06 demonstrated a non-significant positive correlation between straw weight and aphid numbers (Fig. 3H; Supplementary Table II). Results of present studies clearly divulge that as plant biomass increases insect numbers also increase.

Overall, 1000 grain weight and aphid counts association were non-significant and positive (Fig. 3I). All varieties except Mairaj 2008 demonstrated a positive correlation between aphid numbers and wheat weight. Thus more succulent juicy grains are preferred by aphids (Supplementary Table II).

Varieties demarcation as resistant/susceptible on basis of criterion established

Table VII divulges that during 2017-2019 Shafaq, AARI 2011, VO6377, and AAS2011 were highly susceptible while VO6309, Mairaj08 and Faisalabad 2008 were lowly susceptible. Fareed 2006, Inqalab 91, and Pasban 90 were lowly resistant. Lasani 2008 proved highly resistant during both years.

DISCUSSION

In the present studies, the role of wheat morphological characters was evaluated concerning aphid abundance in 15 genotypes of wheat during 2017-2019. The aphid population was significantly different on different cultivars of wheat. However, cumulatively during both years, Lasani-08 proved a highly resistant cultivar while VO6377 proved a highly susceptible cultivar of wheat (Table VII). Remainder varieties were in between lowly susceptible to moderately resistant depending upon the number of aphids abundant (Table VII). Khan *et al*. (2011) compared 5 genotypes of wheat and concluded Inqalab 91 was a resistant cultivar with an aphid population of 0.35 per tiller while we found 3.1 aphids per tiller. It may be the case that Khan *et al*. (2011) conducted studies in

drought conditions where plant height is short and plants are less succulent hence attack of aphids is not prominent. Also, they observed aphids from 5 tillers/plant while we observed aphids infestation from the whole plant which comprises 15-20 tillers/cultivar.

Table VII. Varietal screening based on resistance level established against aphids.

Varieties	Resistance level
Sehar 2010	Moderately susceptible
Lasani-08	Highly resistant
Shafaq	Highly susceptible
Uqab 2000	Lowly susceptible
AAR1 2011	Highly susceptible
Pasban 90	Lowly resistant
Inqalab 91	Lowly resistant
Millet 2011	Highly susceptible
Faisalabad2008	Lowly susceptible
Punjab 2011	Highly susceptible
Fareed 06	Lowly resistant
VO6377	Highly susceptible
Mairaj2008	Lowly susceptible
AAS 2011	Highly susceptible
VO6309	Lowly susceptible

Plant height was non-significantly different in 15 cultivars of wheat. It remained a non-significant character attributing to the afflux of aphids in the entire season. Nasir (2001) also studied the effect of physio-morphic characteristics on wheat aphids and concluded that plant height contributes as a non-significant character in the quantification of aphids on wheat cultivars. Our results were also similar to Rasool (2010) who elaborated that plant height remained a non-significant character in evaluating the resistance of wheat lines against wheat aphids in Pakistan.

Overall, we found aphids were abundant in dark green varieties and were less abundant in number in greyish green varieties (Fig. 1, Table II). Leaf color is an important character attracting high density of aphids to lush green color while aphids don't prefer grayish green varieties (Archetti and Leather, 2005). The same was the case with Lasani-08 which was greyish green color while VO6377 was a dark green color, more succulent, and more attractant to aphids abundance. Inqalab 91 and Fareed-06 were also grayish-green in color and were lowly resistant cultivars in terms of aphid abundance. Sehar 2010, Shafaq, Millet 2011, Faisalabad 2008 and Mairaj2008 were green in color and highly susceptible cultivars which harbored 5.0 to 9.3 aphids per season AARI 2011, Pasban 90, Inqalab 91 and VO6309 were light green and were highly susceptible-lowly susceptible cultivars. AAS 2011 was dark green and it was a highly susceptible cultivar. Present studies were in agreement with Archetti and Leather (2005) who stated that aphids *Rhapalosiphum padi* preferred dark green colored leaves. Aphids prefer plants with dark green color. An increase in nitrogen content in plants increases the lush green color in plants which attributes to the intrinsic rate of aphid reproduction in plants (Nevo and Coll, 2001). However, the results were in contradiction with those authors (Döring and Chittka, 2007) who reported that aphids preferred yellow color.

We found trichomes on the midrib of leaf blades were abundant in Punjab 2011 while a minimum number of trichomes were observed in Inqalab 91and Lasani-08. Our studies clearly state that Punjab 2011 was highly susceptible. Whereas Inqalab 91 was lowly resistant and Lasani-08 was a highly resistant cultivar. We may confirm that though trichomes play a prominent role in mediating the abundance or prevalence of aphids. Leaf pubescence was character that increased resistance in wheat lines against aphids. Similar results were reported by Starks and Merkle (1977) who reported that *S. gramium* do not prefer varieties with pubescent while hairy varieties were preferred. However, we noticed attraction and establishment of aphids on hairy varieties which was contrasted to finding of Roberts and Foster (1983), Webster *et al*. (1994), and Anitha and Nandihalli (2009).

In the present study, we observed non-significant variations between leaf moisture content in different varieties of wheat. However, maximum leaf moisture content was observed in VO6309 which was highly susceptible to aphid attack during both years. Our results were similar to Riedell (1989).

Leaf perimeter and leaf area have a predominant effect on aphid abundance. In the present studies, we noted significant variation in leaf area between different varieties. Variety Fareed-06 had the lowest significant leaf area (10.43). While variety Mairaj 2008 had significantly larger leaf blades compared to other varieties. Fareed-06 was lowly resistant. Leaf area has a significant effect on aphid infestation. However, in the present studies, Lasani-08 proved highly resistant cultivar which had a 15.43 leaf area. Aphid infestation on different varieties is the results of the interaction of various morphological biochemical and physiological traits. Among these leaf blade area and leaf perimeter are one of those traits. Gianoli and Hannunen (2000) described that leaf plasticity, leaf area, and leaf thickness had a prominent effect on herbivory. Herbivory increased with an increase in leaf area and leaf

perimeter.

The angle of awns remained a non-significant character underlying resistance/ susceptibility of wheat lines against aphids. Awns had a predominant role in the dispersal of aphids. We noticed a significant maximum number of awns in Inqalab91, AARI 2011, and Punjab 2011 while a minimum number of awns were reported in Fareed06. AARI 2011 and Punjab 2011 were highly susceptible cultivars while Fareed06 was lowly resistant. We conferred based on results that several awns had a significant positive role in mummified aphid dispersal and susceptibility of wheat lines against aphid attack. Our results were in contradiction with Acreman and Dixon (1986).

Grain moisture content on a wet basis remained a non-significant character underlying resistance or susceptibility of wheat lines against attack. However, grain moisture content on dry basis remained a significant factor underlying resistance against aphid attack. We observed significantly low grain moisture content in Fareed -06 while significantly higher moisture content was observed in Millet 2011. Fareed-06 during both years was a lowly resistant cultivar while millet 2011 was a highly susceptible cultivar. We preclude based on our results that aphids prefer varieties with elevated grain moisture content. Heavy infestation of Russian wheat aphids cause drought resistance symptoms in the leaves of infested plants even in the presence of ample moisture in roots (Beckendorf *et al*., 2008).

CONCLUSIONS

This study concludes that aphids prefer varieties with dark green color, moderate trichome number, high grain moisture content, a significantly higher number of awns, and high 1000 grain weight varieties while plant height, angle of awns and spike length remained a non-significant character underlying resistance/susceptibility against aphids. Overall, we suggest that breeders should focus on plant characters and develop aphid-resistant varieties, as host plant resistance is an ecosystem-friendly pest management approach.

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Supplementary materials

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Statement of conflict of interest

The authors have declared no conflict of interest.

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