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RESEARCH ARTICLE

Prevalence and management of aphids (Hemiptera: Aphididae) in different wheat genotypes and their impact on yield and related traits

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Abstract

Wheat (*Triticum aestivum* L.) production is significantly altered by the infestation of sucking insects, particularly aphids. Chemical sprays are not recommended for the management of aphids as wheat grains are consumed soon after crop harvests. Therefore, determining the susceptibility of different wheat genotypes and selecting the most tolerant genotype could significantly lower aphid infestation. This study evaluated the susceptibility of six different wheat genotypes ('Sehar-2006', 'Shafaq-2006', 'Faisalabad-2008', 'Lasani-2008', 'Millat-2011' and 'Punjab-2011') to three aphid species (*Rhopalosiphum padi* Linnaeus, *Schizaphis graminum* Rondani, *Sitobion avenae* Fabricius) at various growth stages. Seed dressing with insecticides and plant extracts were also evaluated for their efficacy to reduce the incidence of these aphid species. Afterwards, an economic analysis was performed to compute cost-benefit ratio and assess the economic feasibility for the use of insecticides and plant extracts. Aphids' infestation was recorded from the seedling stage and their population gradually increased as growth progressed towards tillering, stem elongation, heading, dough and ripening stages. The most susceptible growth stage was heading with 21.89 aphids/tiller followed by stem elongation (14.89 aphids/tiller) and dough stage (13.56 aphids/tiller). The genotype 'Punjab-2011' recorded the lower aphid infestation than 'Faisalabad-2008', 'Sehar-2006', 'Lasani-2008' and 'Shafaq-2006'. *Rhopalosiphum padi* appeared during mid-February, whereas *S. graminum* and *S. avenae* appeared during first week of March.

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Significant differences were recorded for losses in number of grains/spike and 1000-grain weight among tested wheat genotypes. The aphid population had non-significant correlation with yield-related traits. Hicap proved the most effective for the management of aphid species followed by Hombre and Husk among tested seed dressers, while *Citrullus colocynthis* L. and *Moringa oleifera* Lam. plant extracts exhibited the highest efficacy among different plant extracts used in the study. Economic analysis depicted that use of Hombre and Hicap resulted in the highest income and benefit cost ratio. Therefore, use of genotype Punjab-2011' and seed dressing with Hombre and Hicap can be successfully used to lower aphid infestation and get higher economic returns for wheat crop.

Introduction

Wheat (*Triticum aestivum* L.) is an imperative, nutritious and economical source for staple food in the world [1], which is utilized by >35% of global human population [2]. Wheat is consumed by >70% of total population in Pakistan; therefore, obtaining high grain yield is necessary to feed rapidly increasing population [3]. However, average wheat yield of the country is below than the advanced countries of the world. Several factors are responsible for yield reduction of wheat in the country, including low yielding varieties, inappropriate use of irrigation and fertilizers, sowing date, and infestation of weeds and insect pests [4–7].

Different insect pests attack wheat crop and among these aphids (Hemiptera: Aphididae) are responsible for major economic damages as these directly feed on the plants and indirectly transmit diseases [8,9]. *Rhopalosiphum padi* Linnaeus, *Schizaphis graminum* Rondani and *Sitobion avenae* Fabricius are the most abundant aphid species prevailing in wheat crop in Pakistan [10,11]. These species suck the sap from leaves and shoot and transmit numerous plant diseases [12,13]. Sap-sucking from leaves, shoot and inflorescence cause significant yield reduction (35–40% directly and 20–80% indirectly by transmission of viral and fungal diseases) [14]. *Rhopalosiphum padi* causes damage through sap-sucking starting from two-leaf stage and that result in 40–60% yield losses [15]. In the case of *S. graminum*, 30% yield losses have been recorded in unsprayed experimental field, *S. avenae* outbreak caused 20–30% yield losses [11].

Insecticides are employed to manage the aphids' infestation in cereal crops, particularly wheat [12]. However, numerous aphid species have evolved resistance against various pesticides used for their management [13]. Nonetheless a narrow range of pesticides is available and registered for use in wheat crop, which ultimately results in lower wheat production [14,15]. Moreover, it is predicted that climate change will favor the infestation of aphids, which would reduce wheat yields and pose negative impacts on global economy [16–18]. These facts demand for the alternative management strategies for aphid species to sustain wheat production and ensure future food security.

Frequent use of pesticides has significant negative impacts on atmosphere, and human and animal health [19–22]. Therefore, finding natural plant-based solutions could be explored for pest management. Strawberry aphids [*Chaetosiphon fragaefolii* (Cockerell)] have been reported to be suppressed by Neem (*Azadirachta indica* L.) [23,24]. Similarly, large pine weevil has been successfully controlled by neem oil. Volatile oils from eucalyptus (*Eucalyptus globulus* L.) controlled larval periods of rice lepidopteran. Significant aphid mortality has been reported using plant extracts [24]. However, the use of plant extracts has merely been tested for their efficacy in controlling aphid populations infesting different wheat genotypes.

Considering the significant role of aphid species in yield reduction, current study was planned to develop alternative and sustainable management strategies for three different aphid species. These experiments assessed population dynamics of three aphid species in six wheat genotypes for two cropping seasons. The efficacy of some seed dressing insecticides and plant extracts was evaluated. Aphid infestation was correlated with different yield-related traits for better understanding of its impacts on wheat yield. It was hypothesized that different wheat genotypes will differ in their susceptibility to aphids' infestation. It was further hypothesized that various seed dressing insecticides and plant extracts will also differ in their efficacy in managing target aphid species. The results of the study would help to select the genotype with the lowest susceptibility to aphids. Furthermore, the study will help to identify the alternative management options for aphid infestation in wheat crop.

Materials and methods

Population dynamics of aphid species in different wheat genotypes

Field experiment regarding population dynamics of *R. padi*, *S. graminum*, and *S. avenae* at various growth stages of different wheat genotypes was conducted at the research area of the Entomological Research Institute (31° 25' 45" N, 73° 4' 44" E), Ayub Agricultural Research Institute, Faisalabad, Pakistan. There were no permits required to conduct the study and experiments being conducted at research institutes are exempt from the permits. Six wheat genotypes, i.e., 'Sehar-2006', 'Shafaq-2006', 'Faisalabad-2008', 'Lasani-2008', 'Millat-2011' and 'Punjab-2011' were sown in third week of December 2015 and 2016 under randomized complete block design (RCBD) with five replications. Uniform agronomic practices recommended by Wheat Research Institute, Faisalabad, Pakistan were opted during both study years.

The Zadoks scale illustrating 10 development stages of wheat, i.e., germination, seedling, tillering, stem elongation, booting, heading, flowering, milking, dough and ripening was opted for the recognition and reporting of the growth stages in the current study [25]. The population data of winged and wingless aphid species were recorded by shaking five wheat tillers from each replication to get aphids on a white paper. The aphid species were identified based on morphological characteristics and counted separately. The data were recorded fortnightly until harvesting of the crop.

Assessment of yield losses

Heavily infested plants (>50 aphids/tiller) were kept under observation by tagging to estimate the yield losses. To compare the yield losses in the presence and absence of aphids, yield-related traits such as the number of spikelets per spike, spike length, number of grains per spike, number of damaged grains per spike and 1000-grain weight were noted. The data were recorded from five plants selected randomly in each replication. Aphid-free area was maintained by power spraying of water.

Application plant extracts and seed dressing with insecticides

To evaluate the reduction in aphid infestation, five insecticides were applied to wheat seeds as seed dressing. Each insecticide was applied at two different doses. Wheat seeds were kept with each insecticide in a plastic jar and shake thoroughly to get a protective layer on the seeds. After germination, each treatment was scouted weekly to record aphid population. As the aphid population crossed economic threshold level (ETL), the plots were sprayed with nine plant extracts. Crop was harvested at maturity and the economics were computed based on yield per treatment.

Statistical analysis

One-way analysis of variance (ANOVA) was used to test the significance in the data [26]. Data were tested for normality by Shapiro-Wilk normality [27] test prior to ANOVA. The data were normally distributed; therefore, the analysis was performed on original data. The means were compared by Tukey's HSD post-hoc test to estimate statistical difference at 5% of significance level. Pearson correlation was computed to check the association between aphid population and yield-related traits. All computations were done on SPSS statistical software version 20.0 [28].

Results and discussion

Different genotypes significantly differed for the infestation of studied aphid species (Table 1). The winged aphids appeared from the last week of December and their population increased gradually. The maximum population was estimated during March. The aphid infestation varied from 0.16 to 21.90 aphids per tiller at various growth stages. Heading, stem elongation and dough stages recorded higher infestation with 21.90, 14.90 and 13.56 aphids/tiller, respectively (Fig 1).

The increasing aphid population trend from tillering to the heading stage is in consonance with earlier studies [29–36] who recorded peak infestation during March as temperature is relatively high compared to February which favors aphid multiplication.

Wheat was continuously infested by *R. padi*, *S. graminum* and *S. avenae* with varying degree of infestation. The *R. padi* was the first species recorded during mid-February and increased gradually with the peak infestation recorded on March (14.17 aphid/tiller). Its population decreased gradually to a minimum level during April (0.05 aphid/tiller). *Shizaphis graminum* appeared late in March (15.47 aphid/tiller) and its infestation reached to minimum level during April (0.02 aphid/tiller). *Sitobion avenae* appeared later than *R. padi* and *S. graminum* during the second week of March (5.99 aphid/tiller) and remained until the second week of April on spike (Fig 2). These findings are in close conformity with Zeb et al. [36]. They identified second week of March as the most crucial by indicating peak population on the wheat crop. Shahzad et al. [30] also found that *R. padi* and *S. graminum* on wheat crop before *S. graminum* [33,34].

Since *R. padi* was the first species infesting wheat crop, it mainly sucks sap from leaves and shoots, whereas *S. graminum* fed on the shoots and spikes and *S. avenae* fed on flowers/ears. Several investigations reported that aphid population density reached at its peak during March [35–41].

Table 1. Incidence of aphid species on different wheat genotypes used in the current study (n = 150).

Genotypes	2016				2017			
	<i>R. padi</i>	<i>S. graminum</i>	<i>S. avenae</i>	Total	<i>R. padi</i>	<i>S. graminum</i>	<i>S. avenae</i>	Total
'Sehar-2006'	7.03±0.64 cd	2.21±0.47 bc	0.7±0.092 b	09.94	8.23±0.94 b	2.27±0.32 b	1.10±0.19 bc	11.60
'Shafaq-2006'	7.29±0.58 c	1.69±0.26 de	1.09±0.28 ab	10.07	7.98±0.82 bc	3.69±0.45 a	1.29±0.09 b	12.96
'Faisalabad-2008'	6.59±0.42 bc	3.53±0.59 a	0.52±0.05 c	10.64	7.89±0.43 c	2.13±0.74 bc	0.92±0.04 c	10.94
'Lasani-2008'	7.62±0.57 b	1.75±0.43 d	1.16±0.07 a	10.53	9.72±1.23 a	1.65±0.83	0.86±0.05 cd	12.23
'Millat-2011'	8.01±0.49 a	2.41±0.41 b	0.77±0.35 b	11.19	7.41±0.56 d	2.27±0.48 b	1.97±0.07 a	11.65
'Punjab-2011'	6.65±0.34 e	2.07±0.38 c	0.45±0.02 cd	09.17	6.85±0.23 e	1.97±0.56 c	0.65±0.05 d	09.47

Means followed by different letters are statistically different from each other at 5% probability level.

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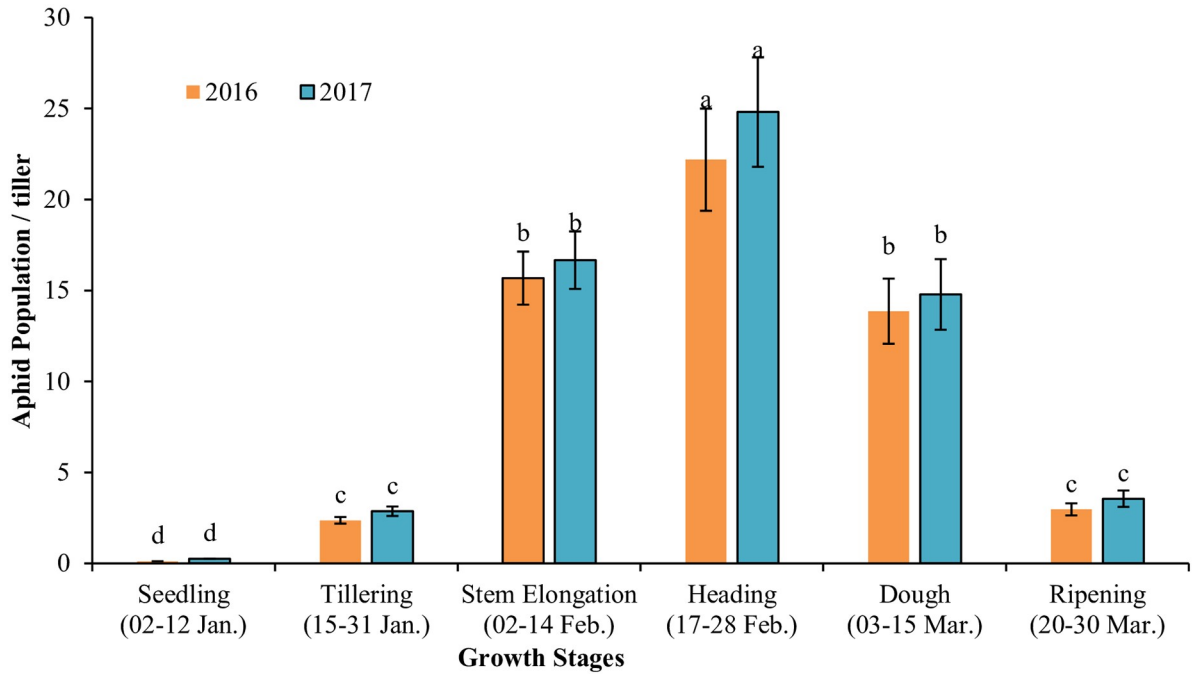


Fig 1. Aphid infestation at different growth stages of wheat crop (n = 1800).

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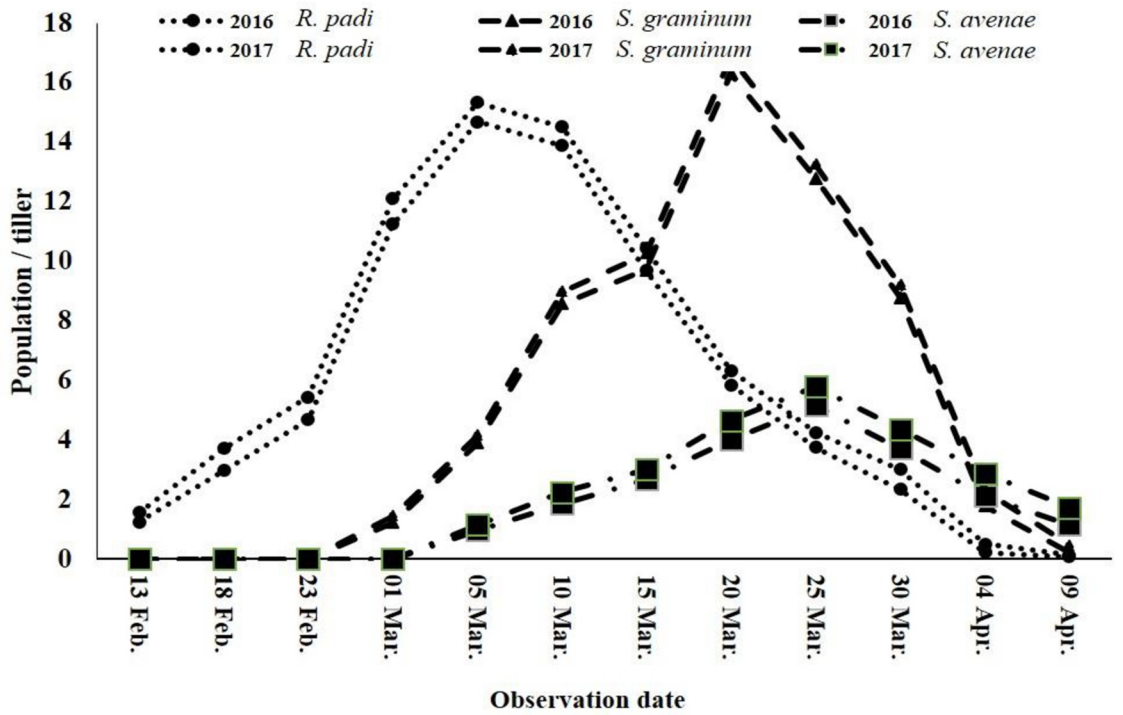


Fig 2. Dominance of different wheat aphid species with time (n = 1800).

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Table 2. The assessment of losses caused by different aphid species in yield related traits of wheat crop (n = 300).

S. #	Parameters Premeditated	Treatments		T-value	Lower CI	Upper CI	P-value
1	No of spikelets/spike	AFA	20.17±3.54	4.85	0.087	1.472	0.040
		AIA	19.39±1.61				
2	Length of spike (cm)	AFA	14.62±2.76	4.58	0.029	0.950	0.044
		AIA	14.13±1.23				
3	No of grains/spike	AFA	53.29±4.89	20.28	3.143	4.834	0.002
		AIA	49.30±3.85				
4	Damage grains/spike (%)	AFA	04.35±1.78	-22.17	-2.459	-1.660	0.002
		AIA	06.41±0.94				
5	1000 grain weight (gm)	AFA	41.33±2.98	19.20	2.397	3.782	0.002
		AIA	38.24±2.73				

AFA: Aphid free area, AIA: Aphid infested area, CI: Confidence interval.

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Aphid-free and -infested areas significantly differed for losses caused in the yield-related traits. Higher number of spikelets per spike (0.78), longer spikes (0.49), a greater number of grains/spike (3.99), less damaged grains per spike (2.06) and increased 1000-grain weight (2.49) were recorded for aphid-free than aphid-infested area (Table 2).

Elmali and Toros [42] studied several characters, i.e., 1000 grain weight, spikelets per spike, grain per spike, plant height and spike length to estimate losses where 10.16% loss in 1000-grain weight, 6.70% reduction in length of spike and 1.22% reduction in tiller length was recorded. *Sitobion avenae* was most damaging species for the grains by causing huge loss in spike biomass for wheat crop [42–45] that deteriorates the flour quality in baking industries.

Pearson correlation revealed that weather attributes were non-significantly correlated with aphid infestation in tested genotypes during both years of study. Maximum temperature has weak negative association with aphid population, whereas all other abiotic factors correlated positively (but weak) with aphid population (Table 3).

Similarly, correlation analysis of aphid population with yield-related traits in aphid-free and -infested area was also statistically non-significant. In aphid-free area, number of spikelets per spike and damaged grains per spike showed weak negative correlation with the aphid population, while other parameters behaved positively. In aphid-infested area, only number of grains per spike had negative correlation with aphid population, whereas other tested parameters demonstrated positive association (Table 4).

Table 3. Correlation analysis of abiotic factors with aphid population in different wheat varieties.

Varieties	2016				2017			
	T (max.) (°C)	T (min.) (°C)	RH (%)	RF (mm)	T (max.) (°C)	T (min.) (°C)	RH (%)	RF (mm)
Sahar-2006	-0.1088	0.3982	0.2384	0.3759	-0.1165	0.4058	0.2273	0.3510
Shafaq-2006	-0.1006	0.4088	0.2328	0.3788	-0.1141	0.4073	0.2360	0.3595
Faisalabad-2008	-0.1018	0.4064	0.2340	0.3811	-0.1174	0.4085	0.2432	0.3642
Lasani-2008	-0.1003	0.4087	0.2334	0.3805	-0.1150	0.4119	0.2472	0.3664
Millat-2011	-0.1013	0.3929	0.2322	0.3674	-0.1182	0.4030	0.2323	0.3563
Punjab-2011	-0.1015	0.4112	0.2341	0.3828	-0.1076	0.4218	0.2411	0.3688

T max.) = maximum temperature, T (min.) = minimum temperature, RH = relative humidity, RF = rainfall.

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Table 4. Correlation analysis of aphid population with yield related components in aphid free and aphid infested areas.

Yield-related traits	Aphid population	
	Aphid-free area	Aphid-infested area
Number of spikelets per spike	-0.0215	0.0507
Length of spike (cm)	0.6644	0.2728
Number of grains per spike	0.6716	-0.4971
Damaged grains per spike (%)	-0.5326	0.4801
1000-grain weight (g)	-0.4728	0.1434

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The results indicated that seed treatment with insecticides restricted the aphid population level in comparison with control by 62.59 to 87.96%, whereas plant extract suppressed aphid infestation by 17.09 to 61.37% (Table 5).

Tumma and Moringa extracts proved the most effective in suppressing aphid infestation. Actara was the most effective as seed treatment with yield enhancement up to 1295.1 kg per

Table 5. Economic analysis of different protection measures adapted to manage different aphid species in wheat crop during 2016 and 2017.

	Treatment	Aphid Reduction (%)	Yield (kg/hectare)	Net Profit (\$/hectare)	BCR
Seed Treat- ment Insecti- cides	Hicap 70 WS	70.58 (68.65)	5479.28 (5329.27)	664.49 (652.41)	8.84 (8.67)
	Hicap 70 WS	75.36 (73.17)	5637.02 (5473.52)	773.33 (751.94)	5.14 (4.99)
	Hombre 372.5 FS	66.94 (65.12)	5412.87 (5265.05)	618.66 (608.09)	8.68 (8.53)
	Hombre 372.5 FS	84.59 (82.07)	5774.83 (5602.95)	868.42 (841.24)	6.09 (5.9)
	Confidor 70 WS	66.94 (65.02)	5412.87 (5257.15)	618.66 (602.64)	5.75 (5.6)
	Confidor 70 WS	64.52 (62.67)	5296.64 (5144.52)	538.46 (524.92)	2.50 (2.44)
	Actara 75 WG	80.74 (78.07)	5695.13 (5506.12)	813.42 (774.43)	3.06 (2.91)
	Actara 75 WG	87.96 (85.80)	5811.36 (5668.15)	893.62 (886.24)	2.24 (2.22)
	Husk 372.5 FS	62.59 (60.87)	5130.60 (4989.4)	423.90 (417.89)	7.26 (7.16)
	Husk 372.5 FS	72.48 (70.27)	5562.30 (5392.5)	721.77 (696.04)	6.18 (5.96)
Plant Extract Sprays	Tumma (<i>Citrullus colocynthis</i>)	61.37 (59.33)	5112.34 (4941.98)	411.29 (385.17)	7.74 (7.24)
	Neem (<i>Azadirachta indica</i>)	36.14 (34.89)	4937.99 (4766.11)	291.00 (263.83)	5.61 (5.09)
	Ak (<i>Calotropis procera</i>)	28.83 (27.83)	4841.69 (4674.23)	224.55 (200.43)	4.44 (3.96)
	Citrus (<i>Citrus sinensis</i>)	34.60 (33.45)	4949.62 (4784.88)	299.02 (276.78)	5.49 (5.08)
	Bakain (<i>Melia azedarach</i>)	28.63 (27.67)	4791.88 (4630.75)	190.18 (170.43)	3.58 (3.21)
	Castor (<i>Ricinus communis</i>)	27.89 (27.02)	4737.09 (4589.26)	152.37 (141.8)	3.01 (2.8)
	Dhatura (<i>Dhatura stramonium</i>)	31.07 (30.14)	4914.75 (4766.11)	274.96 (263.83)	5.30 (5.09)
	Moringa (<i>Moringa oleifera</i>)	54.92 (53.43)	5029.32 (4892.58)	354.01 (351.09)	6.50 (6.45)
	Eucalyptus (<i>Eucalyptus cameldulensis</i>)	17.09 (16.59)	4718.83 (4580.37)	139.77 (135.66)	2.76 (2.68)
	Control		4055.71 (4041.13)		

Price of wheat \$ 0.31/- per kg, values in the parenthesis are for 2017.

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hectare followed by Hombre, whereas Husk was least effective. In case of plant extract sprays, Tumma was the most effective in aphid population reduction as well as yield enhancement followed by Moringa. The benefit cost ratio (BCR) was considered as main contributors for farmers benefits in terms of economics. Seed treatment with insecticides was better and useful indicating Hicap as the most effective restrictor with enhancement/increment of 8.84 times economics followed by Hombre (8.68) and Husk (7.26) at the dose of 2 g/acre. Tumma was found the most economical with CBR 7.74 followed by Moringa (6.5) in plant extract applications.

It was observed that aphid proliferation is directly proportional to the host plants and their prevailing climatic conditions [46]. An early season incidence of winged aphids appeared during January, however, was unable to reproduce. Seed dressing with insecticides induced continuing residual influence that reduced aphid settlement and colonization on early succulent cropping interval [47–49]. The residual influence remained effective up to 1st week of February. Colonization remained low in seed-treated plots. Neonicotinoids had whole wheat plant protection by checking the aphids' population due to systemic properties. These insecticides have no risk to wheat plant as well as bio-control agents such as ladybird beetles, syrphid flies and spiders [50–53]. On the other hand, application of botanicals [54–57] exhibited potential to control aphids. The botanicals possess certain primary as well as secondary compounds that produce adverse action on the life processes of harmful insects [58–60].

Conclusion

The current findings exhibit that the population of three aphid species varied significantly among tested wheat genotypes due to varying level of susceptibility. The *R. padi* was the most dominant aphid species followed by *S. graminum* and *S. avenae* during both cropping seasons. Concerning the aphid population at different Aphid infestation gradually increased from seedling to heading stage and then declined from heading to ripening stage. This implies that aphid species prefer to feed on soft tissues, whereas hard seed at ripening stage deter aphid population. Considerable yield losses were observed due to aphid infestation as aphids suck cell sap, ultimately resulting in lower photosynthesis causing significant yield reduction. Seed dressing with insecticides proved a good alternative to foliar sprays. Plant extracts also proved effective in protecting wheat crop from aphid infestation. It is recommended that the least susceptible genotype should be sown either with seed dressing or application of plant extracts to get higher economic returns.

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References

1. Khan MR, Anjum FM, Zahoor T, Nawaz H. Biochemical and Technological characterization of Pakistani spring wheat. *Pak J Agric Sci.* 2009; 46: 2076–2086.
2. Khakwani AA, Dennett MD, Munir M, Abid M. Growth and yield response of wheat varieties to water stress at booting and anthesis stages of development. *Pak J Bot.* 2012; 44: 879–886.
3. FAOSTAT (2015). Food and agricultural commodities production/Countries by commodity. 2015. <http://faostat3.fao.org/browse/rankings/countriesbycommodity/E>.
4. Khan AM, Khan AA, Afzal M, Iqbal MS. Wheat crop yield losses caused by the aphids infestation. *J Bio-fertil Biopest.* 2012; 3(4): 1–3.
5. Memon RA, Bhatti GR, Khalid S, Mallah A, Ahmed S. Illustrated weed flora of wheat crop of Khairpur District, Sindh. *Pak J Bot.* 2013; 45: 39–47.
6. John F, Saeed NA, Nadeem S, Hamed M. Integration of planting time and insecticide to manage aphid infestations in wheat for better crop productivity. *Pak J Zool.* 2017; 49: 1343–1351.
7. Yahya M, Saeed NA, Nadeem S, Hamed M, Shokat S. Role of wheat varieties and insecticide applications against aphids for better wheat crop harvest. *Pak J Zool.* 2017; 49(6): 2217–2225.
8. Bukvayova N, Henselova M, Vajcikova V, Kormanova T. Occurrence of dwarf virus of winter wheat and barley in several regions of Slovakia during the growing seasons 2001–2004. *PI Soil Environ.* 2006; 52: 392–401.
9. Ali S, Khalid S, Ali S, Akhtar K, Khan MS, Ali A, et al. Preferential influence of wheat genotypes on the distribution pattern and population dynamics of cereal aphids and their natural enemies in Peshawar valley. *Pak J Zool.* 2015; 47: 223–233.
10. Shah AK, Farmanullah, Hussain N, Saljoqi AUR, Hayat Y, Sattar S. Distribution pattern of the cereals aphids in the wheat growing areas of the province Khyber Pukhtunkhwa of Pakistan. *Sarhad J Agri.* 2006; 22: 655–959.
11. Ahmad T, Hassan MW, Jamil M, Iqbal J. Population dynamics of aphids (Hemiptera: Aphididae) on wheat varieties (*Triticum aestivum* L.) as affected by abiotic conditions in Bahawalpur, Pakistan. *Pak J Zool.* 2016; 48(4): 1039–1044.
12. Tanguy S. & Dedryver C. Reduced BYDV–PAV transmission by the grain aphid in a *Triticum monococcum* line. *Eur. J. Plant Pathol.* 123, 281–289 (2009).
13. Foster S. P. et al. A mutation (L1014F) in the voltage-gated sodium channel of the grain aphid, *Sitobion avenae*, is associated with resistance to pyrethroid insecticides. *Pest Manag. Sci.* 70, 1249–1253 (2014). <https://doi.org/10.1002/ps.3683> PMID: 24227679
14. Carvalho F. P. Agriculture, pesticides, food security and food safety. *Environ. Sci. Policy* 9, 685–692 (2006).
15. Pickett J. A. Food security: Intensification of agriculture is essential, for which current tools must be defended and new sustainable technologies invented. *Food Energy Secur.* 2, 167–173 (2013).

16. Bezemer T. M., Jones T. H. & Knight K. J. Long-term effects of elevated CO₂ and temperature on populations of the peach potato aphid *Myzus persicae* and its parasitoid aphidius matricariae. *Oecologia* 116, 128–135 (1998). <https://doi.org/10.1007/s004420050571> PMID: 28308517
17. Van Der Putten W. H., Macel M. & Visser M. E. Predicting species distribution and abundance responses to climate change: Why it is essential to include biotic interactions across trophic levels. *Philos. Trans. R. Soc. B.* 365, 2025–2034 (2010). <https://doi.org/10.1098/rstb.2010.0037> PMID: 20513711
18. Simon Amma L., Caulfield John C., Hammond-Kosack Kim E., Field Linda M., and Aradottir Gudbjorg I. "Identifying aphid resistance in the ancestral wheat *Triticum monococcum* under field conditions." *Scientific reports* 11, no. 1 (2021): 1–12. <https://doi.org/10.1038/s41598-021-92883-9> PMID: 34188110
19. Teke M. A., & Mutlu Ç. (2021). Insecticidal and behavioral effects of some plant essential oils against *Sitophilus granarius* L. and *Tribolium castaneum* (Herbst). *Journal of Plant Diseases and Protection*, 128(1), 109–119.
20. Mutlu Ç., Karaca V., Tonga A., Erol Ş., & Mamay M. (2019). Infestation and Damage Caused by Wheat Stem Sawflies (Hymenoptera: Cephidae) to Some Wheat Cultivars in Southeast Anatolia Region, Turkey. *Journal of the Kansas Entomological Society*, 92(1), 359–375
21. Mamay M., & Mutlu C. (2019). Optimizing container size and rearing density for rapid and economic mass rearing of *Oenopia conglobata* (Linnaeus, 1758)(Coleoptera: Coccinellidae). *Turkish Journal of Entomology*, 43(4), 395–408.
22. Duman M., & Mutlu C. (2019). Efficacy of different sampling methods in pest monitoring of direct seeded rice at different growth stages. *Applied Ecology and Environmental Research*, 17(4), 10207–10220.
23. Lowery D. T., & Isman M. B. (1993). Antifeedant activity of extracts from neem, *Azadirachta indica*, to strawberry aphid, *Chaetosiphon fragaefolii*. *Journal of chemical ecology*, 19(8), 1761–1773. <https://doi.org/10.1007/BF00982306> PMID: 24249239
24. Farooq M., Jabran K., Cheema Z. A., Wahid A., & Siddique K. H. (2011). The role of allelopathy in agricultural pest management. *Pest management science*, 67(5), 493–506. <https://doi.org/10.1002/ps.2091> PMID: 21254327
25. Akhter IH, Khaliq A. Impact of plant phenology and coccinellid predators on the population dynamic of rose aphid *Macrosiphum rosaeiformis* Das (Aphididae: Homoptera) on rose. *Plant Sci.* 2003; 2: 119–122.
26. Steel, R. G. D., & Torrie, J. H. DA Dic ey (1997). Principles and procedures of statistics: A biometrical approach. McGraw-Hill Co. Inc, New York NY.
27. Royston P. (1992). Approximating the Shapiro-Wilk *W*-test for non-normality. *Statistics and computing*, 2(3), 117–119.
28. Stehlik-Barry, K., & Babinec, A. J. (2017). Data analysis with IBM SPSS statistics. Packt Publishing Ltd.
29. Yousof DE, Elhassan IM, Abbas AI. Evaluation of the efficacy of imidacloprid and tebuconazole mixture products as seed-dressing treatments against insect pests and seeds bed fungal diseases on wheat. *Persian Gulf Crop Prot.* 2014; 3:52–57.
30. Shahzad MW, Razaq M, Hussain A, Yaseen M, Afzal M, Mehmood MK. Yield and yield components of wheat (*Triticum aestivum*) affected by aphid feeding and sowing time at Multan, Pakistan. *Pak J Bot.* 2013; 45(6): 2005–2011.
31. Taheri S, Razmjou J, Rastegari N. Fecundity and development rate of the bird cherry-oat aphid, *Rhopalosiphum padi* (L) (Hom: Aphididae) on six wheat cultivars. *PI Prot Sci.* 2010; 46 (2): 72–78.
32. Fowler DB. Winter wheat production manual. A practical guide to successful winter wheat production. Chapter 10: Growth stages of wheat. 2018; Ducks Unlimited Canada and Conservation Production Systems Ltd.
33. Aheer GM, Munir M, Ali A. Impact of weather factors on population of wheat aphids at Mandi Baha-ud-Din district. *J Agric Res.* 2007; 45 (1): 61–66.
34. Iqbal J, Ashfaq M, Ali A. Screening of wheat varieties/advanced lines against aphids. *Pak Entomol.* 2008; 30 (1): 77–81.
35. Ullah S, Bibi R, Bashir MA, Ibrahim M, Saeed S, Hussain MA. Population dynamics of aphid and its bio-control agents in wheat crop. *Pak J Nutrition.* 2014; 13 (3): 146–150.
36. Zeb Q, Badshah H, Ali H, Shah R, Rehman M. Population of aphids on different varieties/lines of wheat and their effect on yield and thousands grain weight. *Sarhad J Agric.* 2011; 27(3): 443–450.
37. Honek A, Martinkova Z, Saska P and Dixon AFG. Aphids (Homoptera: Aphididae) on winter wheat: predicting maximum abundance of *Metopolophium dirhodum*. *J Econ Ent*, 2018; 111(4): 1751–1759. <https://doi.org/10.1093/jee/toy157> PMID: 29897464

38. Faheem M, Saeed S, Sajjad A, Wang S, Ali A. Spatio-temporal variations in wheat aphid populations and their natural enemies in four agroecological zones of Pakistan. *PLoS ONE* 2019; 14(9):1–14.
39. Tabasum S, Noorka IR, Afzal M, Ali A. Screening best adopted wheat lines against aphid (*Schizaphis graminum* Rondani) population. *Pak Entomol.* 2012; 34: 51–53.
40. Ali L, Ali MA, Ali M, Waqar MQ. Inorganic fertilization of wheat in relation to aphid infestation, natural enemies population, growth and grain yield. *Inter J Agri Biol.* 2013; 15(4): 719–724.
41. Suhail A, Iqbal J, Arshad M, Gogi MD, Arif MJ, Shafait T. Comparative efficacy of insecticides as seed treatment against wheat aphid and its *Coccinellid* predator. *Pak Entomol.* 2013; 35:17–22.
42. Elmali M, Toros S. Effect of *Sitobion avenae* (Homoptera: Aphididae) on wheat yield and quality. *Turk Ent Derg.* 1997; 21: 109–118.
43. Migui S, Lamb R. Patterns of resistance to three cereal aphids among wheat in the genus *Triticum* (Poaceae). *Bull Entomol Res.* 2003; 93: 323–333. <https://doi.org/10.1079/ber2003246> PMID: 12908918
44. Khattak MK, Riazuddin, Anayatullah M. Population dynamics of aphids (Aphididae: Homoptera) on different wheat cultivars and response of cultivars to aphids in respect of yield and yield related parameters. *Pakistan J. Zool.*, 2007; 39(2): 109–115.
45. Ahmed T, Aslam M, Hussan MW, Iqbal J. Aphids (*Schizaphis graminum* R.) infestation on different wheat (*Triticum aestivum* L.) varieties and their comparative yields. *J. Agric. Res.*, 2015, 53(2):209–216.
46. Aqueel MA, Leather SR. Effect of nitrogen fertilizer on the growth and survival of *Rhopalosiphum padi* (L.) and *Sitobion avenae* (F.) (Homoptera: Aphididae) on different wheat cultivars. *Crop Prot.* 2011; 30: 216–221.
47. Zhang P, Zhang X, Zhao Y, Wei Y, Mu W, Liu F. Effects of imidacloprid and clothianidin seed treatments on wheat aphids and their natural enemies on winter wheat. *Pest Manag Sci.* 2015; 72: 1141–1149. <https://doi.org/10.1002/ps.4090> PMID: 26248607
48. Hamada AM, Fatehi J, Jonsson LMV. Seed treatments with thiamine reduce the performance of generalist and specialist aphids on crop plants. *Bull Entomol Res.* 2017; 108(1): 1–9. <https://doi.org/10.1017/S0007485317000359> PMID: 28416024
49. Kirkland LS, Pirtle EI, Umina PA. Responses of the Russian wheat aphid (*Diuraphis noxia*) and bird cherry oat aphid (*Rhopalosiphum padi*) to insecticide seed treatments in wheat. *Crop & Pasture Science.* 2018; 69: 966–973.
50. Ali A, Desneux N, Lu YH, Wu KM. Key aphid natural enemies showing positive effects on wheat yield through biocontrol services in northern China. *Agrics Ecosyst Environ.* 2018; 266:1–9.
51. Ostman O, Ekborm B, Bengtsson J. Yield increase attributable to aphid predation by ground-living polyphagous natural enemies in spring barley in Sweden. *Ecol Econ.* 2003; 45: 149–158.
52. Jankovic M, Plecas M, Sandic D, Popovic A, Petrovic A, Petrovic-Obradovic O, et al. Functional role of different habitat types at local and landscape scales for aphids and their natural enemies. *J Pest Sci.* 2017; 90: 261–273.
53. Saleem S, Ullah F, Ashfaq M. Population dynamics and natural enemies of aphids on winter wheat in Peshawar, Pakistan. *Pak J Zool.* 2009; 41: 505–513.
54. Elliott NC, Kieckhefer RW. Response by coccinellids to spatial variation in cereal aphid density. *Popul Ecol.* 2000; 42: 81–90.
55. Brewer MJ, Elliott NC. Biological control of cereal aphids in North America and mediating effects of host plant and habitat manipulations. *Ann Rev Entomol.* 2004; 49: 219–242. <https://doi.org/10.1146/annurev.ento.49.061802.123149> PMID: 14651463
56. Iqbal MF, Kahloon MH, Nawaz MR, Javaid MI. Effectiveness of some botanical extracts on wheat aphids. *The Journal of Animal & Plant Sciences*, 2011; 21(1): 114–115.
57. Farooq Z, Fareed S, Karar H, Rubab M, Shah SFH. Efficacy of some botanical extracts against wheat aphids *Sitobion avenae* (Homoptera: Aphididae) and their impact on predators population. *J Agric Res.* 2016; 54(4): 697–706.
58. Shah FM, Razaq M, Ali A, Han P, Chen J. Comparative role of neem seed extract, moringa leaf extract and imidacloprid in the management of wheat aphids in relation to yield losses in Pakistan. *PLoS ONE* 2017; 12(9):1–24. <https://doi.org/10.1371/journal.pone.0184639> PMID: 28953894
59. Tavares WR, Barreto MCB, Seca AML. Aqueous and Ethanolic Plant Extracts as Bio-Insecticides—Establishing a Bridge between Raw Scientific Data and Practical Reality. *Plants.* 2021; 10(920): 1–30. <https://doi.org/10.3390/plants10050920> PMID: 34064367
60. Dheeraj M, Shukla AK, Dixit AK, Singh K. Insecticidal activity of vegetable oils against Mustard aphid, *Lipaphis erysimi* Kalt under field condition. *J. Oleo Sci.* 2006; 55 (5):227–231.