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RESEARCH ARTICLE

# Effect of Sowing Date and Cultivars on Aphid Infestation in Wheat with Climate Change Adaptation Perspective

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**Abstract** Four field experiments, two experiments each during winter season of 2012–2013 and 2013–2014, were conducted to evaluate effect of sowing time and four wheat cultivars on population of wheat aphids. Wheat crop was found infested with *Rhopalosiphum padi* and *Sitobion avenae* in various proportions in different experiments. During vegetative crop phase, December (late) sown crop had in general higher aphid population than November (timely) sown crop, while during reproductive crop stage, timely sown crop harboured more aphids on ear heads than late planted one. October (early) and January (very late) sown crop evaded aphid attack on ear heads. Significant differences in peak aphid populations among different plantings indicated that alteration of sowing time might disturb phenological synchrony between aphids and wheat crop, affecting pest population. Aphid population was positively influenced by the temperature. Sowing dates were also found to significantly affect the crop yield. Among varieties, WR-544 was observed to have lower number of aphids than other cultivars during vegetative crop stage. Because alteration in sowing time is deemed to be one of the adaptation strategies to sustain agricultural productivity under climate change, effect of sowing time on aphid population is the need to be heeded while formulating such strategy for effective crop management.

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## Introduction

Wheat (*Triticum aestivum* L.) is an important cereal serving as a staple food along with rice in India. It was cultivated on an area of 29.64 million hectare with the production of 92.46 million tonnes and the productivity of 3.12 t/ha during the year 2012–2013 [1]. In India, wheat was in general considered as a crop having fewer pest problems in the field. However, with advent of rice–wheat cropping system in Indo-gangetic plains following the "green revolution'', insects such as aphids, pink borer and army worm that were hitherto considered as minor pests of wheat have been reported to inflict serious damage to the crop in certain years after 1980 [2]. In India, wheat crop is attacked by more than 11 aphid species, but only four species, *S. avenae* (Fab.), *S. miscanthi* (Takahashi), *R. padi* (L.) and *R. maidis* (Fitch) are reported to be predominant [3]. The aphids attack wheat crop from seedling stage onwards, but are not easily detected on the crop especially during vegetative stage owing to their small size and green colour [4]. Aphids cause yield loss either directly by sap sucking from plants or indirectly by excreting honey dew on which sooty mould develops that interferes with plant photosynthesis [5]. Economic threshold level for wheat aphids was established as five aphids/earhead or ten aphids/tiller during vegetative stage, which being a low population level reflected their economic importance [6].

Climate change is most important global issue being debated these days and it has implications for development and survival of organisms including insects. The probable effects of climate change on insects include expansion of their ranges, change in population growth rates, increased period of activity, changes in interspecific interactions and alteration in crop-pest interactions [7–9]. Climate change in terms of increased temperature, rainfall pattern and extreme climate events would affect crop productivity directly as well through changes in crop-pest interactions [10–12]. 'Terminal heat' that is sudden rise in temperature during grain filling stage, adversely affected wheat yields due to accelerated maturity and reduced grain size during certain years in India [13, 14]. The terminal stress last time was witnessed during 2010 in India, which had adversely affected the wheat yield. Temperature also influences aphid populations that multiply better at low temperature and are prone to washing by heavy rains [4, 15, 16]. Adaptation measures need to be taken to sustain agricultural productivity in changed climate. Changes in agronomic management including changes in sowing time, use of short duration cultivar and optimum use of water and nutrients are deemed to be important for sustaining crop productivity [17]. However, changes in planting time would affect crop-pest phenological synchrony influencing pest densities [5]. It thus becomes important to evaluate effect of sowing dates on aphid dynamics that needs to be heeded while formulating climate change adaptation strategy for effective crop management to sustain agricultural productivity.

## Material and Methods

Two sets of field experiments henceforth referred as set-1 and set-2 were conducted that comprised of one experiment each during winter season of 2012–2013 and 2013–2014 at Indian Agricultural Research Institute, New Delhi (28°66′N, 77°15′E). In set-1 experiments, each of the four wheat varieties, HD-2967, HD-2285, HD-2932 and WR-544 were sown on seven different dates in 6 × 1.5 m plots at a row spacing of 20 cm with 80 kg/ha seed rate in a randomized block design (RBD) with three replicates during two years. Sowings were done at fortnightly intervals between first week of October and first week of January during both the years, encompassing early (October), timely (November), late (December) and very late (January) sowing conditions. The fertilizers, N, $P_2O_5$ and $K_2O$ were applied @ 120, 60 and 60 kg/ha, respectively in the form of urea, DAP and muriate of potash. One-third N and entire amount of $P_2O_5$ and $K_2O$ were applied as basal dose, while remaining two-third N was given in equal splits at maximum tillering and heading stage of the crop. Crop was irrigated five times at crucial phenological stages. Observations on aphid incidence were begun at 50 days after sowing in each of the plantings and continued at 10 days interval until crop maturity. Aphids were counted on ten randomly selected tillers in each plot. All the aphids, irrespective of the species, were counted on leaves, leaf sheaths and stem of tillers during vegetative stage, while these were counted only on ear heads (panicles) of tillers during reproductive phase of the crop. Mean aphid population per tiller or population per ear head was then accordingly computed for analysis. None of the wheat diseases occurred on the crop in damaging proportion.

In set-2 experiments, three wheat varieties, HD-2967, HD-2932 and WR-544 were sown on three different dates in 2 × 7 m plots in three replicates. Row spacing, seed rate and experimental design were similar to the set-1 experiments during both years. The fertilizer application as well as irrigation was also undertaken as in case of set-1 experiments. Sowings were done at fortnightly intervals between last week of November and last week of December during 2012–2013, while crop was planted at 10 days intervals between first week of December and last week of December during 2013–2014. Observations on aphid incidence were begun at 55 days after sowing in each of the planting and continued at 10 days intervals until crop maturity. Aphids were counted on contiguous five tillers at each of the 12 randomly selected spots. All the aphids, irrespective of species, were counted manually on leaves, leaf sheaths and stem of tillers during vegetative stage, while these were counted only on ear heads of tillers during reproductive phase of the crop. Mean aphid population per five tillers or population per five ear heads was computed for analysis. In all the experiments, aphid numbers were transformed to square roots prior to two-way analysis of variance (ANOVA) for a factorial RBD through SPSS statistical package. Only peaks of aphid population observed in different staggered plantings in four experiments were analysed and compared. Wheat yields in set-2 experiments during 2 years were analysed by two-way ANOVA for a factorial RBD through SPSS statistical package.

Mean aphid population observed in Set-1 experiments during 2012–2013 as well as 2013–2014 were correlated with weather parameters like maximum temperature (Tmax, °C), minimum temperature (Tmin, °C), mean temperature (Tmean, °C), mean relative humidity (RHmean, %) and rainfall (mm), using Microsoft Excel 2010 version. Average values of the weather parameters, based on 10 days period preceding aphid population counts, were used in computing correlation coeffcients.

## Results and Discussion

### Set-1 Experiments

#### *Vegetative Crop Stage*

Wheat crop was found infested with *R. padi* (L.) and *S. avenae,* and results are based on mixed counts of both the species. During 2012–2013, highest aphid population was recorded on 20th December sown crop that did not differ significantly from the population on 4th January planting (Table 1). These populations were, however, significantly higher than the pest population in other plantings. During 2013–2014, aphid incidence on the crop was higher than that of previous year (Table 2). Highest aphid incidence was found on 15th December sown crop that differed significantly from that on 31st December planted one. The latter in turn was also significantly higher than aphid population on 15th January sown crop. Wheat crop planted around mid-October to mid-November had very low aphid incidence during the 2 years of study. The WR-544 had significantly less aphid population than all or fewer other cultivars during the 2 years. Interaction effect of varieties and sowing dates on aphid population was observed to be significant during both the years. During vegetative crop stage, aphid population showed a peak during December in early crop, in February in timely sown crop, and in 1st week of March in late and very late crop. However, quantum of aphid population peaks varied widely among different staggered plantings. Study thus revealed that wheat crop sown during second fortnight of December (late) and 1st week of January (very late) harboured more aphids than November (timely) sown crop during vegetative crop stage.

*Reproductive Crop Stage*

During 2012–2013, maximum aphid incidence on ear heads occurred in 19th November sown crop that differed significantly from that on 5th November planting (Table 1), the latter however not deviating significantly from 5th December sown crop. During 2013–2014, maximum aphids on ear heads were found on 15th November sown crop that was at par with aphid population on 30th November planted one; both however being significantly different from 31st October planting (Table 2). Interaction effect of wheat cultivars and sowing dates on aphid population was also significant during the two years. The WR-544 had lower aphid population than all or fewer other cultivars. November sown (timely sown) wheat thus had higher aphids on ear heads than December (late sown) or October sown (early sown) crop during both the years. In December last and January sown crop, ear heads were not at all infested by aphids.

Set-2 Experiments

*Vegetative Crop Stage*

During 2012–2013, 22nd December sown crop had maximum aphid population that differed significantly from the population on 7th December planting; the latter however being at par with 23rd November sown crop (Table 3). Aphid population differed significantly only among different staggered plantings, while varietal effect as well as interaction effect of sowing dates and varieties was not significant. Although, aphid population was initially more in 7th December sown crop, peaks were however attained simultaneously during last week of February in all staggered plantings. During 2013–2014, aphid population during vegetative crop phase was higher than that of previous season. The 6th December sown crop had maximum number of aphids that differed significantly from that on 27th December and 16th December planted ones (Table 4). The aphid population on 27th and 16th December sown crop, however, did not differ significantly. Varieties also influenced aphid population significantly, wherein WR-544 had lower population than others. Interaction effect of sowing dates and varieties on aphid population happened to be non-significant. The 6th December sown crop had higher aphid infestation during vegetative stage throughout, but peak aphid incidence was attained simultaneously in 3rd week of February in the three staggered plantings; however, quantum of peak aphid population differed significantly among the three plantings.

*Reproductive Crop Stage*

During 2012–2013, 23rd November sown crop had maximum number of aphids that differed significantly from that on 7th December planting; the latter also being significantly different from 22nd December sown crop (Table 3). Varieties did not influence aphid population, however aphids were significantly influenced by interaction effect of sowing dates and varieties. Aphid population showed a peak during 1st week of March on the crop. During 2012–2013, yield of three cultivars, HD2967, WR544 and HD2932 did not differ from each other. However, sowing date had significant effect on wheat yield, wherein 23rd November sown crop (timely) had higher yield than that sown later on (Table 5).

During 2013–2014, 6th December sown crop had maximum aphids that differed significantly from that on 16th and 27th December sown crops (Table 4). The aphid population, however, was at par in 16th and 27th December sown crop. Only sowing dates significantly influenced aphid population on the crop. In 6th December sown crop, aphid population peaked in March 1st week, while in 16th December and 27th December sown crop, it peaked in 3rd week of March.

During 2013–2014, no change in aphid infestation pattern was witnessed during vegetative and reproductive crop stages as 6th December sown crop harboured maximum population during both the stages. On the other hand, in other experiments mid-December sown crop had maximum

**Table 1** Effect of sowing dates and wheat cultivars on peak aphid infestation during winter 2012–2013 (Set-1 experiment 1)

| Variety | Sowing date | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | $S_1$ (19.10.12) | $S_2$ (05.11.12) | $S_3$ (19.11.12) | $S_4$ (05.12.12) | $S_5$ (20.12.12) | $S_6$ (04.01.13) | $S_7$ (21.01.13) | |
| | Vegetative stage (Aphids/tiller) | | | | | | | |
| HD-2967 | [1]0.1 (1.04) | 1.6 (1.40)[2] | 0.1 (1.04) | 3.9 (2.02) | 19.0 (3.97) | 20.9 (4.35) | 18.9 (4.29) | *9.2 (2.59)$^{ab}$ |
| HD-2932 | 0 (1.0) | 0.9 (1.24) | 2.2 (1.44) | 3.6 (1.99) | 30.6 (5.50) | 27.7 (5.14) | 16.3 (4.02) | 11.6 (2.91)$^{b}$ |
| HD-2285 | 0.3 (1.11) | 4.0 (1.86) | 0.4 (1.14) | 3.9 (2.09) | 32.8 (5.50) | 28.6 (5.31) | 16.9 (4.10) | 12.4 (3.02)$^{bc}$ |
| WR-544 | 0 (1.0) | 3.2 (1.64) | 0.6 (1.21) | 6.1 (2.33) | 15.1 (3.70) | 16.7 (3.93) | 7.2 (2.76) | 7.0 (2.37)$^{a}$ |
| Mean | [3]0.1 (1.03)$^{a}$ | 2.4 (1.54)$^{b}$ | 0.8 (1.20)$^{ab}$ | 4.4 (2.11)$^{c}$ | 24.4 (4.67)$^{e}$ | 23.5 (4.68)$^{e}$ | 14.8 (3.79)$^{d}$ | |
| LSD ($P = 0.05$) | | | | | | | | |
| Sowing date | | 0.47 | | | | | | |
| Variety | | 0.33 | | | | | | |
| Sowing date × Variety | | 0.94 | | | | | | |
| | Ear head stage (Aphids/ear head) | | | | | | | |
| HD-2967 | [1]0 (1.0) | 4.4 (2.06)[2] | 13.3 (2.94) | 6.0 (2.38) | 3.7 (1.62) | 0 (1.0) | 0 (1.0) | *3.9 (1.71)$^{a}$ |
| HD-2932 | 0 (1.0) | 4.8 (2.03) | 5.2 (2.16) | 4.3 (2.12) | 1.2 (1.40) | 0 (1.0) | 0 (1.0) | 2.2 (1.53)$^{a}$ |
| HD-2285 | 0.3 (1.1) | 15.9 (3.37) | 37.5 (5.65) | 1.7 (1.45) | 0.8 (1.27) | 0 (1.0) | 0 (1.0) | 8.0 (2.12)$^{b}$ |
| WR-544 | 0 (1.0) | 4.9 (1.99) | 4.4 (2.04) | 3.6 (1.81) | 1.1 (1.27) | 0 (1.0) | 0 (1.0) | 2.0 (1.45)$^{a}$ |
| Mean | [3]0.1 (1.03)$^{a}$ | 7.5 (2.37)$^{b}$ | 15.1 (3.20)$^{c}$ | 3.9 (1.94)$^{b}$ | 1.7 (1.39)$^{a}$ | 0 (1.0)$^{a}$ | 0 (1.0)$^{a}$ | |
| L.S.D. ($P = 0.05$) | | | | | | | | |
| Sowing date | | 0.47 | | | | | | |
| Variety | | 0.33 | | | | | | |
| Sowing date × Variety | | 0.93 | | | | | | |

[1] Each value is the average of 10 tillers/ear heads

[2] Figures in parentheses are square root transformations

[3] Means with same superscript in the row and the *column in the respective sections of the table do not differ significantly

aphid population during vegetative stage, while mid-November sown crop harboured highest population during reproductive stage. The wheat sowing in first week of December fell mid-way between timely planting and late planting, and this could be the reason for maximum aphid population in this sowing both during vegetative and reproductive crop phases. Moreover, unlike other experiments, sowings in this experiment were restricted only to December and therefore aphid population could not be compared to November sown crop. During 2013–2014, HD2967 had higher yield than WR544 that in turn differed significantly from HD2932. The 6th December sown crop had higher yield than 16th and 26th December sown ones (Table 5).

## Aphid Population and Weather Parameters

Aphid population on wheat was positively influenced by the temperature during the 2 years (Table 6). The Tmax had significant effect on the aphids during the first year ($r = 0.88^*$) as well in the second year ($0.82^*$), while Tmean showed significant effect on the aphids only during the second year ($r = 82^*$). The effect of Tmin on aphid population was not significant. Aphid population had non-significant negative relationship with RHmean during the first year ($r = -0.55^{NS}$) and practically no relationship with it during the second year. Aphid population exhibited non-significant negative ($r = -0.46^{NS}$) and positive ($r = 0.75$) relationship with rainfall during the first and second year, respectively. It was observed that aphid population remained very low during mid-November to mid-December, when the temperature was relatively high (Tmax = 22.6 − 27.3 °C, Tmin = 7.5 − 8.9 °C, Tmean = 16.9 − 18.1 °C). Likewise, aphid populations were also negligible during January, when temperature was comparatively low (Tmax = 17.0 − 19.0 °C, Tmin = 4.5 − 8.0 °C, Tmean = 11.0 − 13.0 °C). On the other hand, aphid populations multiplied substantially during February under moderate temperature conditions (Tmax = 20.0 − 23.0 °C, Tmin = 6.0 − 8.5 °C, Tmean = 13.0 − 15.0 °C).

**Table 2** Effect of sowing date and wheat cultivars on peak aphid infestation during winter 2013–2014 (Set-1 experiment 2)

| Variety | Sowing date | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | $S_1$ (15.10.13) | $S_2$ (31.10.13) | $S_3$ (15.11.13) | $S_4$ (30.11.13) | $S_5$ (15.12.13) | $S_6$ (31.12.13) | $S_7$ (15.1.14) | |
| | Vegetative stage (Aphids/tiller) | | | | | | | |
| HD-2967 | [1]0.6 (1.19) | 0.4 (1.17)[2] | 4.7 (2.18) | 33.8 (5.72) | 294.0 (16.94) | 216.5 (14.56) | 67.5 (8.07) | *88.2 (7.12)$^{bc}$ |
| HD-2932 | 0.1 (1.04) | 0.3 (1.12) | 9.3 (2.93) | 48.7 (6.75) | 247.5 (15.36) | 276.5 (16.55) | 69.5 (8.32) | 93.1 (7.44)$^{c}$ |
| HD-2285 | 0 (1.00) | 0.2 (1.08) | 0.8 (1.31) | 104 (10.14) | 199.5 (13.79) | 101.0 (10.02) | 82.5 (8.77) | 69.7 (6.59)$^{b}$ |
| WR-544 | 0.4 (1.12) | 0.1 (1.04) | 0.2 (1.08) | 34.8 (5.69) | 94.0 (9.15) | 102.5 (9.96) | 73.0 (8.42) | 43.6 (5.21)$^{a}$ |
| Mean | [3]0.3 (1.09)$^{a}$ | 0.3 (1.10)$^{a}$ | 3.8 (1.88)$^{a}$ | 55.3 (7.07)$^{b}$ | 208.8 (13.81)$^{e}$ | 174.1 (12.77)$^{d}$ | 73.1 (8.39)$^{c}$ | |
| LSD ($P$ = 0.05) | | | | | | | | |
| Sowing date | | 0.82 | | | | | | |
| Variety | | 0.62 | | | | | | |
| Sowing date × Variety | | 1.64 | | | | | | |
| | Ear head stage (Aphids/ear head) | | | | | | | |
| HD-2967 | [1]12.0 (2.80) | 22.9 (4.03)[2] | 24.4 (4.94) | 13.4 (3.64) | 0.4 (1.17) | 0 (1.0) | 0 (1.0) | *10.4 (2.66)$^{ab}$ |
| HD-2932 | 7.6 (2.23) | 18.5 (3.93) | 73.4 (7.97) | 28.0 (4.71) | 0.1 (1.04) | 0 (1.0) | 0 (1.0) | 18.2 (3.13)$^{b}$ |
| HD-2285 | 5.9 (1.98) | 44.7 (5.89) | 49.0 (6.93) | 75.5 (8.26) | 0.2 (1.08) | 0 (1.0) | 0 (1.0) | 25.0 (3.74)$^{c}$ |
| WR-544 | 0.3 (1.12) | 13.9 (3.50) | 15.6 (3.95) | 31.3 (5.36) | 0 (1.0) | 0 (1.0) | 0 (1.0) | 8.7 (2.42)$^{a}$ |
| Mean | [3]6.5 (2.04)$^{b}$ | 25.0 (4.34)$^{c}$ | 40.6 (5.95)$^{d}$ | 37.1 (5.49)$^{d}$ | 0.2 (1.07)$^{a}$ | 0 (1.0)$^{a}$ | 0 (1.0)$^{a}$ | |
| LSD ($P$ = 0.05) | | | | | | | | |
| Sowing date | | 0.72 | | | | | | |
| Variety | | 0.55 | | | | | | |
| Sowing date × Variety | | 1.45 | | | | | | |

[1] Each value is the average of 10 tillers/ear heads

[2] Figures in parentheses are square root transformations

[3] Means with same superscript in the row and the *column in the respective sections of the table do not differ significantly

Table 3 Effect of sowing date and wheat cultivars on peak aphid infestation during winter 2012–2013 (Set-2 experiment 1)

| Variety | Sowing date | | | Mean |
|---|---|---|---|---|
| | $S_1$ (23.11.12) | $S_2$ (7.12.12) | $S_3$ (22.12.12) | |
| | Vegetative stage (Aphids/5 tillers) | | | |
| HD-2967 | [1]26.2 (4.99) | 48.0 (6.92)[2] | 97.0 (9.62) | 57.1 (7.18) |
| WR-544 | 16.4 (3.80) | 9.4 (2.99) | 59.1 (7.65) | 28.3 (4.81) |
| HD-2932 | 34.3 (5.78) | 70.2 (8.13) | 80.2 (8.86) | 61.3 (7.59) |
| Mean | [3]25.6 (4.86)$^a$ | 42.5 (6.01)$^a$ | 78.8 (8.71)$^b$ | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 1.45 | | |
| Variety | | NS | | |
| Sowing date × Variety | | NS | | |
| | Ear head stage (Aphids/5 ear heads) | | | |
| HD-2967 | [1]44.1 (6.42) | 50.0 (7.04)[2] | 19.0 (4.29) | 37.7 (5.92) |
| WR-544 | 48.3 (6.87) | 12.2 (3.47) | 23.1 (4.74) | 27.3 (5.03) |
| HD-2932 | 37.2 (6.03) | 31.1(5.58) | 14.2 (3.77) | 27.7 (5.13) |
| Mean | [3]43.2 (6.44)$^c$ | 31.1 (5.36)$^b$ | 18.8(4.27)$^a$ | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 0.94 | | |
| Variety | | NS | | |
| Sowing date × Variety | | 1.63 | | |

[1] Each value is the average of 12, 5-tiller/ear head sample units

[2] Figures in parentheses are square root transformations

[3] Means with same superscript in the row in the respective sections of the table do not differ significantly

Present study, based on four experiments, revealed that during vegetative crop phase December sown (late) crop had in general higher aphid population than November sown (timely) crop, while during reproductive crop stage, timely sown crop harboured more aphids on ear heads than late planted one. During vegetative crop stage, aphids might prefer late and very late sown crops owing to their more succulence than timely sown crop. Ear head emergence in timely sown wheat coincided with peak activity of aphids, while by the time ear head emerged in late sown crop, aphid population had started declining owing to high temperature and prevalence of predators. It has been opined earlier that aphids might damage late sown wheat badly if the cool weather continued until March [18]. However, in the present study although late sown wheat had more aphids during vegetative crop phase, but it harboured less aphids during reproductive crop phase than timely planted one because weather did not remain cool in March.

Sowing dates were found to significantly influence crop yield during the two years (Table 5), which could probably be attributed to differential aphid incidence on crop sown in staggered manner. In set-2 experiment during 2012–2013, timely sown (November) crop was found to have lower aphid population than late sown ones during vegetative crop stage, but it had more aphids during reproductive crop phase. More grain yield in timely sown crop, thus indicated that aphid incidence was more injurious to the crop during vegetative crop stage than that during reproductive stage, probably due to longer duration of aphid infestation. During 2013–2014, three sowings were done between 6–26 December and the first sowing still had significantly higher yield as compared to other sowings despite having significantly higher aphid population both during vegetative and reproductive crop growth stages. However, comparison of yield data of respective sowings during 2 years showed a yield reduction of 12.7–14.0 % during second year. This could perhaps be ascribed to higher aphid population during the second year and also to delay in undertaking first sowing that was done on 6th December instead of 23rd November in the first year. Variability in wheat yield among sowing dates could thus be accounted for by aphid incidence levels on the crop.

It was also observed that last week of December and January (very late) sown crop escaped aphid infestation on ear heads, while October sown (early) crop also almost evaded aphid attack during both vegetative and reproductive crop phases. It has also been reported earlier that the potential for aphid infestation could be reduced by early sowing of wheat [18, 19]. However, October sowing seems

**Table 4** Effect of sowing date and wheat cultivars on peak aphid infestation during winter 2013–2014 (Set-2 experiment 2)

| Variety | Sowing date | | | Mean |
|---|---|---|---|---|
| | $S_1$ (06.12.13) | $S_2$ (16.12.13) | $S_3$ (27.12.13) | |
| | Vegetative stage (Aphids/5 tillers) | | | |
| HD-2967 | [1]206.1 (14.36) | 123.2 (11.09)[2] | 122.5 (11.01) | *150.5 (12.15)[b] |
| HD-2932 | 194.2 (13.89) | 128.4 (11.29) | 127.1 (11.27) | 149.9 (12.15)[b] |
| WR-544 | 142.3 (11.9) | 95.3 (9.72) | 119.0 (10.97) | 118.9 (10.84)[a] |
| Mean | [3]181.0 (13.39)[b] | 115.6(10.70)[a] | 122.9(11.06)[a] | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 0.77 | | |
| Variety | | 0.77 | | |
| Sowing date × Variety | | NS | | |
| | Ear head stage (Aphids/5 ear heads) | | | |
| HD-2967 | [1]48.0 (6.89) | 0.90 (1.38)[2] | 2.1 (1.74) | 17.0 (3.34) |
| HD-2932 | 66.8 (8.18) | 1.0 (1.41) | 1.5 (1.58) | 23.1 (3.70) |
| WR-544 | 42.4 (6.46) | 1.0 (1.41) | 1.3 (1.51) | 14.9 (3.06) |
| Mean | [3]52.4 (7.18)[b] | 1.0 (1.40)[a] | 1.6 (1.61)[a] | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 0.74 | | |
| Variety | | NS | | |
| Sowing date × Variety | | NS | | |

[1] Each value is the average of 12, 5-tiller/ear head sample units

[2] Figures in parentheses are square root transformations

[3] Means with same superscript in the row and the *column in the respective sections of the table do not differ significantly

impractical as it is not possible to vacate and prepare land quickly after rainy season harvest especially in rice–wheat system. Likewise, January sown (very late) wheat generally results in poor yields. Between November (timely) and December (late) planting, November planted crop harboured more aphids on ear heads. Earlier, highest population build-up of aphids was observed in wheat and barley at heading stage in March [20]. As aphid infestation during vegetative stage proved more damaging than that during reproductive crop phase, early sowing thus seemed better option to minimize yield loss due to aphids in wheat. Besides, in view of threat of terminal heat in late planted wheat, timely sowing is also deemed to be one of the agronomical adaptations under climate change [21, 22]. Earliness in wheat is also considered a key to adaptation under terminal and continual high temperature stress [17]. Early sowing of wheat thus appears to be appropriate option both from crop production and crop protection point of view.

Based on aphid activity on the crop with regard to weather factors, it could be deduced that Tmin < 6.0 °C and Tmax > 24.0 °C did not favour aphid multiplication on wheat. Earlier, temperature between 7.0–25.0 °C was found to favour multiplication of wheat aphids, but temperature beyond 27.0 °C triggered their decline [23]. It is probable that with temperature rise under climate change, aphids might get favourable temperature for faster multiplication during January. However, ambient temperature might prove unfavourable during February–March which is their main multiplication period under prevailing conditions. Weekly total rainfall during aphid multiplication period was slightly more during the first year (5.4–39.8 mm) than the second year (4.3–29.5 mm). Effect of rainfall on aphid population during 2 years could thus differ probably due to difference in quantity of rainfall received. Adverse effect of rainfall on aphid population has also been reported earlier, wherein aphids were washed away from plants [15]. The negative relationship between aphid population and rainfall during the first year, when rainfall was comparatively more, thus seemed somewhat logical.

Earlier the wheat crop was sown, sooner aphid population peaks were attained in different staggered plantings. Significant differences in peak aphid populations among different plantings indicated that alteration of sowing time might disturb phenological synchrony between aphids and wheat crop, affecting pest population which then would influence crop yield. Among varieties, WR-544 was observed to have lower number of aphids than other cultivars during vegetative crop stage. The WR-544 is a short

**Table 5** Effect of sowing date and aphids on grain yield of wheat cultivars during winter 2012–2014 and 2013–2014 (Set-2 experiment 1 and experiment 2)

| Variety | Sowing date | | | Mean |
|---|---|---|---|---|
| | $S_1$ (23.11.12) | $S_2$ (7.12.12) | $S_3$ (22.12.12) | |
| | Grain yield (q/ha) | | | |
| HD-2967 | [1]58.3 | 51.7 | 46.3 | 52.1 |
| WR-544 | 56.0 | 49.3 | 43.7 | 49.7 |
| HD-2932 | 61.0 | 55.0 | 44.3 | 53.4 |
| Mean | [2]58.4$^{a}$ | 52.0$^{b}$ | 44.8$^{c}$ | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 3.34 | | |
| Variety | | NS | | |
| Sowing date × Variety | | 5.79 | | |
| | $S_1$ (6.12.13) | $S_2$ (16.12.13) | $S_3$ (27.12.13) | |
| HD-2967 | [1]57.3 | 50.9 | 42.7 | *50.3$^{a}$ |
| WR-544 | 46.9 | 44.7 | 40.0 | 43.8$^{b}$ |
| HD-2932 | 46.3 | 42.3 | 34.5 | 41.1$^{c}$ |
| Mean | [2]50.2$^{a}$ | 46.0$^{b}$ | 39.1$^{c}$ | |
| LSD ($P = 0.05$) | | | | |
| Sowing date | | 1.36 | | |
| Variety | | 1.36 | | |
| Sowing date × Variety | | 2.37 | | |

[1] Each value is the average of three replications

[2] Means with same superscript in the row and the *column in the respective sections of the table do not differ significantly

**Table 6** Simple linear correlation coefficients between aphid population on wheat and weather parameters

| Weather parameter | Crop season | |
|---|---|---|
| | Winter 2012–2013 | Winter 2013–2014 |
| Maximum temperature (Tmax, °C) | 0.88* | 0.82* |
| Minimum temperature (Tmin, °C) | 0.68$^{NS}$ | 0.38$^{NS}$ |
| Mean temperature (Tmean, °C) | 0.78$^{NS}$ | 0.82* |
| Mean relative humidity (RH mean, %) | −0.55$^{NS}$ | 0.083$^{NS}$ |
| Rainfall (mm) | −0.46$^{NS}$ | 0.75$^{NS}$ |
| | df = 4, $P = 0.05$ | df = 3, $P = 0.05$ |

*NS* non-significant, *df* degrees of freedom

* Significant ($P = 0.05$)

duration cultivar possessing terminal heat tolerance along with high level of resistance to leaf and stem rusts, and leaf blight [24]. However, more investigation is needed regarding aphid population pattern on this and other cultivars. From future perspective, there is a need to search for temperature insensitive sources of resistance against wheat aphids. Emergence of new pests of wheat needs to be watched carefully. Climate change impact on aphid-natural interactions also needs to be analysed.

## Conclusion

To sustain agricultural productivity under climate change, agronomic management adaptations including alteration in sowing time would be indispensible. However, change in sowing time would also influence long-evolved crop-pest phenological synchrony, affecting pest densities on crops. Crop production and crop protection recommendations thus need to be in tandem to ensure a meaningful crop management adaptation strategy in the changed climate.

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