# RESISTANCE SCREENING AND EVALUATION OF FIVE WHEAT CULTIVARS (*TRITICUM AESTIVUM*) TO CEREAL APHID (*SITOBION AVENAE*) INFESTATION

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**Abstract.** Resistant variety screening is an effective method for the *Sitobion avenae* infestation management. The purpose of this study was to assess the potential resistance traits of five wheat cultivars against the *S. avenae*. The aphid quantity ratio (AQR) indicated that Jinmai No. 105 and Linhan No. 9 had high resistance against *S. avenae* compared with other cultivars. The immature developmental duration of Jinmai No. 105 were exponentially the highest in the first and second instar while were the lowest in the third and fourth instar compared with other cultivars. The findings also indicated that *S. avenae* reared on Changmai No. 6878 displayed the highest intrinsic rate of increase (0.16 $d^{-1}$) while the lowest was recorded on the Jinmai No. 105 (0.04 $d^{-1}$). The highest proteolytic activity was quantified in larvae that fed on the Changmai No. 6878 cultivars (2.11 U $mg^{-1}$) while the lowest occurred in larvae feeding on the Jinmai No. 105 cultivars (0.36 U $mg^{-1}$). Larvae fed on Jinmai No. 105 (0.86 U $mg^{-1)}$ and Linhan No.9 (0.42 U $mg^{-1}$) cultivars exhibited the highest and lowest levels of amylolytic activity, respectively. These findings provide critical cues for screening and improving aphid resistant wheat varieties or breeding efforts that involve *S. avenae* management.
**Keywords:** *wheat, Sitobion avenae, aphid resistance, biological parameters, enzyme activity*

## Introduction

Wheat (*Triticum aestivum* L.) is the world's third most important cereal source, its production accounts for 21% of the global food demand, more than half of the global population depended on it as a source of protein and calories. Globally, over 700 million tons of wheat are produced annually from 220 million hectares of estimated area (Luo et al., 2021). However, the production and productivity of wheat are highly challenged by biotic and abiotic stresses, the global climate warming brings great challenges to the sustainability of global wheat production, wheat aphid largely influenced wheat yield and quality coincident with increasing concentration of carbon dioxide ($CO_2$) (Awmack et al., 1996). They are piercing-sucking pests that causes damage to agricultural crop production through sucking nutrients, depositing honeydew, and transmitting plant viruses. These damages inflict serious economic problems on cultivated plants in agriculture worldwide (Li et al., 2021). In Northwestern China, *Sitobion avenae* damage affects approximately 13 million hectares of estimated area annually and produces 40% wheat yield loss (Yang et al., 2020).

The management of *S. avenae* has recently become a continuous problem in most wheat-producing regions of the world (Li et al., 2022). The research community has agreed that entomologists developed aphid-resistant cultivars as an important strategy and primary task for aphid management (Dogimont et al., 2010). Plants have developed


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a sophisticated immune system to thwart and escape various insect attacks over 350 million years of plants-insects co-evolution (Du et al., 2004). Host-plant resistance triggers the immune system of host against pest attack through further resistance evaluation of antibiosis (reduced aphid development or fecundity) and antixenosis (aphid nonpreference) (Marimuthu et al., 2012), for example, plant cultivars resistance can be identified through the traits of minimizing the developmental stages, reproductive potential, and fecundity of insect herbivores (Price et al., 1980; Smith et al., 2012; Karimi et al., 2014). However, the lack of in-depth characterization of wheat-aphid biological parameters limits the research capacity to investigate controlling strategies.

The construction of life tables could contribute fundamental knowledge and provide insight into the population dynamics of resistance/susceptibility wheat cultivars against *S. avenae*. Life-history constituted a set of parameters and adopted the record keeping system and mathematical approach to interpret insect population dynamics (Harcourt et al., 1969). Traditionally, the construction of age- or stage-specific life tables solely focused on female individuals and failed to distinguish developmental stages and the stage overlapping (Araujo et al., 2016), such as the age specific life tables of the aphids *Sitobion avenae,* soft scale *Coccus hesperidum*, mealybug *Pseudococcus* and psyllid *Trioza magnisetosa* (Xie et al., 2022). The age-stage, two-sex life table takes account of both sexes and developmental stages to give a comprehensive understanding for evaluating the performance of insects, including growth (Saska, 2021), insect mass rearing (Ma et al., 2019), pest control timing (Ullah et al., 2020), host preference and herbivore performance (Güncan et al., 2017).

Herbivore performance is influenced by the nutritional content and biochemical metabolites of host plants (Shirinbeik et al., 2022). Host-plant resistance influenced the growth development and changes the composition and content of chemical substances in herbivores (Heidari et al., 2020). Therefore, elucidating digestive physiology of pests probably help explain differences in demographic and physiological responses and assist in selection of resistance traits (Nouri et al., 2018). For instance, *Spodoptera littoralis* amylase was negatively correlated with developmental time of legume cultivars (Seyed et al., 2022), *Helicoverpa armigera* developed sophisticated system to regulate their digestive proteases (Hemati et al., 2012); *Acyrthosiphon pisum* midgut protease prove particularly important for digestion of legumes (Pereira et al., 1999), elucidating digestive physiology of pests has benefited development of target-specific insecticide (Babamir et al., 2022). But limited comprehensive information was published on demographics and digestive responses of *S. avenae* among possible cultivatable wheat (Gacemi et al., 2019).

In the current investigation, we conducted life table analyses and assessed both proteolytic and amylolytic activities of *S. avenae* on five wheat cultivars, and aims to identify potential sources of variation in resistance/susceptibility of wheat cultivars again *S. avenae*. Our findings probably provide resistance mechanisms of wheat cultivars against *S. avenae* for use in integrated programs that aim to reduce chemical inputs.

## Methods

### *Wheat cultivars*

The experiment was carried out at Shanxi Normal University's Insect Ecology Laboratory in Taiyuan, China (38°25'N, 103°410'E, 2670 m above sea level). Jinmai


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No. 105, Zhongmai No. 175, Changmai No. 6878, Linhan No.9 and Pinyu No. 8012 were the wheat varieties used in the experiment. Seeds of these five varieties were obtained from Shanxi Agricultural University's Agronomy College in China. Prior to

the sowing, the experimental seeds were surface disinfected by soaking for 10 min in sodium hypochlorite solution, and subsequently washed with sterile distilled water for 1 min. Wheat seeds were cultivated in soil-filled plastic pots (10 cm × 10 cm × 9 cm), and then the uniformly germinating seeds were transferred to the artificial intelligence illumination incubator (Shanghai Yuejin Medical Instruments Co., Ltd., Shanghai, China) controlled at temperature 25 ± 1℃ and photoperiod 14:10 (L:D).

### *Insect rearing*

The grain aphids *Sitobion avenae* Fabricius were initially obtained from the experimental field of the Shanxi Agricultural University. A single colony fed on wheat seedlings (variety: Xinong 3517) in an artificial intelligence illumination incubator (Shanghai Yuejin Medical Instruments Co., Ltd., Shanghai, China) at (25 ± 1℃, 65 ± 5% RH, and a 16:8 h light–dark photoperiod) for ten generations. Then, the nymphs reared on leaves of each wheat varieties in an artificial intelligence illumination incubator under conditions given above. Prior to experiments, nymphs were reared on leaves of experimental wheat stated above for two generations. Subsequently, the third-generation colony was available for life history parameter qualifications and aphid resistance evaluation and digestive enzyme qualification. This work was aimed to minimize the possible effects of host rearing/experience on comparisons of cultivars as host plants.

### *Aphid resistance evaluation in the laboratory*

Ten seedlings were chosen from each pot on the seventh day after planting. Each seedling was infested with five nymph aphids. The infested seedlings covered with anti-insect white mesh external dimensions of 35 × 35 × 28 cm to keep the aphids at bay. Each variety infested a total of 20 wheat cultivars with three biological replications. All pots were watered evenly to keep the soil moist. The number of aphids colonized were determined 7 and 13 d after infestation, respectively.

The resistance of the selected wheat varieties to *S. avenae* were evaluated by using the method of the aphid quantity ratio (AQR). The parameters of AQR was calculated as follows (Zhang et al., 2021):

$$\text{AQR} = \frac{\text{Average number of aphids per plant of a given cultivar}}{\text{Average number of aphids per plant for all observed wheat cultivars}}$$

The wheat resistance/susceptibility level was identified according to the literature (Tu et al., 2018). The criterion of wheat resistance to the aphid is categorized into 7 grades: immune (I), highly susceptible (HS), moderately susceptible (MS), low susceptible (LS), low resistant (LR), moderately resistant (MR), highly resistant (HR) (*Table 1*).

### *Life history of immature stages of Sitobion avenae on various wheat cultivars*

Life table parameters of *S. avenae* nymphs laid within 24 h period on each wheat variety were initially collected. We established a total of 30 newly-laid nymphs per


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wheat at the onset of the experiment, these nymphs were removed carefully using a fine brush. After hatching, the nymphs born within 24 h were collected and individually transferred into a Petri dishes (diameter 9 cm, depth 2 cm) on the same leaves. The developmental duration of four instar stages, and pre-adult period were subsequently quantified. Furthermore, we determined the survival rate until adult emergence of *S. avenae*. Petri dishes were still maintained in an artificial intelligence illumination incubator (25 ± 1°C, 65 ± 5% RH, and a 16:8 h light–dark photoperiod) and recorded daily to evaluate the viability and duration of developmental stages on each wheat variety. As nymphs matured, fresh leaves from the original cultivars were replaced every 24 h for each cultivar to recorded the aphid production per day. Additionally, a moist filter paper placed in a Petri dishes was kept each leaf to delay desiccation.

***Table 1.*** *Classification criterion of wheat cultivars resistance to the aphid*

| Resistance grade | AQR | Resistance level |
|---|---|---|
| 0 | 0 | Immune (I) |
| 1 | 0.01–0.30 | Highly resistant (HR) |
| 2 | 0.31–0.60 | Moderately resistant (MR) |
| 3 | 0.61–0.90 | Low resistant (LR) |
| 4 | 0.91–1.20 | Low susceptible (LS) |
| 5 | 1.21–1.50 | Moderately susceptible (MS) |
| 6 | > 1.50 | Highly susceptible (HS) |

AQR—aphid quantity ratio

### *Life table variables of adult S. avenae developing on various wheat cultivar*

After emergence of adult individuals, the number of nymphs laid by each adult female was counted daily and replaced with fresh leaves until all adults died. The total preoviposition period (TPOP, the time counted from the nymph birth), oviposition period, longevity, and fecundity (number of eggs laid during reproductive time) were quantified for each of the five wheat cultivars.

### *Life table analysis*

The life history data was analyzed using the age-stage, two-sex life table theory with the software TWOSEX- MSChart (Huang et al., 2012; Elpidina et al., 2001). The age-stage specific survival rate ($s_{xj}$) defined as the survivorship to age x and stage j; the age-specific survival rate (l x) described the change in survival rate of the population with age); the age-specific fecundity (mx) described the start times and duration of the reproductive phase, age-specific maternity (lxmx), the age-stage life expectancy ($e_{xj}$) defined the length of time an individual of age x and stage j expected to survive, the reproductive value ($v_{xj}$) described the expected contribution of an individual of age x and stage j to the future population. The formulas of above-mentioned parameters were calculated as follows (Huang et al., 2012; Elpidina et al., 2001).

$$lx = \sum_{j=1}^{k} Sxj \qquad \text{(Eq.1)}$$


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$$\mathrm{mx} = \sum_{j=1}^{k} \mathrm{sxj} f_{xj} / \sum_{j=1}^{k} s_{xj} \quad \text{(Eq.2)}$$

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s_{iy} \quad \text{(Eq.3)}$$

$$\mathrm{V_{xj}} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{a} e^{-r(i+1)} \sum_{y=j}^{k} s'_{iy} f_{ij} \quad \text{(Eq.4)}$$

The population parameters of intrinsic rate of increase (r), mean generation time (T), the net reproductive rate ($R_0$), finite rate of increase (λ), and GRR were also calculated according to the age-stage, two-sex life table approach. The formulas were calculated as follows (Huang et al., 2012; Elpidina et al., 2001):

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad \text{(Eq.5)}$$

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad \text{(Eq.6)}$$

$$\lambda = e^r \quad \text{(Eq.7)}$$

$$T = \frac{\ln R_0}{r} \quad \text{(Eq.8)}$$

$$\mathrm{GRR} = \sum \mathrm{m\ x} \quad \text{(Eq.9)}$$

### *Preparation of midgut extracts*

Nymphs were reared on each of the tested wheat cultivars until the fourth instar. The nymph were cut the head and incapacitated by chilling on ice. Subsequently, the aphid quickly dissected under a stereomicroscope to release the tissues of hemolymph, midguts were extracted and homogenized in a glass homogenizer on ice. The homogenates were centrifuged at 11,000 × *g* for 20 min at 4°C. The clear supernatants were aspirated and kept at −20°C for enzyme assays. There were 20 nymphs collected randomly from 25 plants per cultivar.

### *Determination of proteolytic activity of S. avenae on various wheat cultivars*

Digestive proteolytic activity of midgut extracts was assessed through incubating at 37°C for 50 min using a reaction mixture. The reaction mixture contained a substrate of 2% (w/v) azocasein solution, a universal buffer system of 50 mM sodium phosphateborate over a pH range of 7–12, 50 μL of the midgut extract, 80 μL of the substrate in 50 mM universal buffer. Proteolysis added 100 μL of 30% trichloroacetic acid (TCA) was cooled at 4°C for 30 min and centrifuged at 11,000 × *g* for 20 min. The proteolysis supernatant added an equal volume of 2 M NaOH was available for measuring


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the absorbance at 440 nm. One unit of proteolytic activity was used to determine as the quantity of enzyme (mg), and the optical density was increased by 0.1 per minute in 1 mL of the reaction mixture under the assay conditions (Bradford, 1976). All proteolytic activity assay were measured three replicates using appropriate controls. Furthermore, protein concentrations were determined according to the Bradford (1976) protein assay (Bernfeld, 1955), and the standard curve generated through the known amounts of bovine serum albumin (BSA) (2, 1.5, 1, 0.5, 0.25, 0.125, and 0.063 mg $mL^{-1}$).

### *Determination of amylolytic activity of S. avenae on various wheat cultivars*

General amylolytic activity of midgut extracts was determined by utilizing the dinitrosali cylic acid (DNS) procedure. The reaction mixture added in sequence with a substrate of 1% starch, 10 mM succinate-glycine-2, morpholinoethan sulfunic acid of the universal buffer system over a pH range of 5–12, and midgut extracts. The reaction mixture was incubated at 37°C for 30 min. Then, the reaction added 50 μL of DNS and heated in boiling water for 10 min (Hu et al., 2015). This mixture was cooled on ice and then used to record absorbance at 540 nm. A unit of amylase enzyme activity needed to generate one mg of maltose in 30 min at 37°C under the assay conditions. All experimental assays were conducted three replicates using appropriate controls.

### *Statistical analysis*

Firstly, the life history traits and population parameters were conducted according to the approach of age-stage, two-sex life table by the TWOSEX-MSChart software. Then, a nominal logistic regression model was used to analyze the effects of five wheat cultivars against *S. avenae*. Analyses of variance (ANOVA) using linear regression, followed by Tukey's separation of means test, were used to compare the immature developmental days, longevity and fecundity. Enzyme activity were first tested for normality, and subsequently analyzed using one-way analysis of variance (ANOVA). The variances of population growth parameters (R0, r, T, λ and GRR) were calculated via the bootstrap method and the bootstrap values were compared by paired bootstrap tests (Chi, 2018). All scientific graphs were plotted using Sigmaplot 12.3 software. All comparison of means was carried out using Turkey's post hoc Honestly Significant Difference (HSD) test with ($\alpha = 0.01$) by the statistical software SPSS v. 22.0.

## Results

### *Evaluation of wheat resistance to S. avenae*

AQR parameter was available for assessing the level of resistance to *S. avenae* in five wheat varieties. AQR means the average number of aphids on per plant divided by the average number of aphids for all observed wheat cultivars. Classification criterion of five wheat cultivars resistance to the aphid S. avenae were showed in *Table 2* and *Figure 1*. Changmai No.6878 had a significantly higher AQR than Jinmai No. 105, Zhongmai No. 175, Linhan No.9 and Pinyu No. 8012. Pinyu No. 8012 had a higher AQR than Jinmai No. 105, Zhongmai No. 175, Linhan No.9 cultivars ($p < 0.05$). Changmai No.6878 had the highest AQR of the five cultivars (1.380). Jinmai No. 105 had the lowest AQR (0.714). No statistically significant difference was found between Zhongmai No. 175, Linhan No. 9 and Pinyu No. 8012 ($p > 0.05$). The findings revealed that the wheat varieties had a discernible effect on the AQR, Jinmai No. 105 and Linhan


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No.9 exhibited low resistance (LR) to *S. avenae*; the Zhongmai No. 175 and Pinyu No. 8012 were low susceptible (LS), and Changmai No.6878 was moderately susceptible (MS). Highly susceptible (HS), moderately resistant (MR), and highly resistant (HR) cultivars were not observed among the five cultivars in the current research.

***Table 2.*** *Classification criterion of five wheat cultivars resistance to the aphid S. avenae*

| Wheat varieties | Resistance Level | AQR |
|---|---|---|
| Jinmai 105 | LR | 0.714 ± 0.221c |
| Linhan 9 | LR | 0.891 ± 0.035bc |
| Pinyu 8012 | LS | 1.1215 ± 0.018b |
| Zhongmai 175 | LS | 1.013 ± 0.021b |
| Changmai 6878 | MS | 1.381 ± 0.065a |

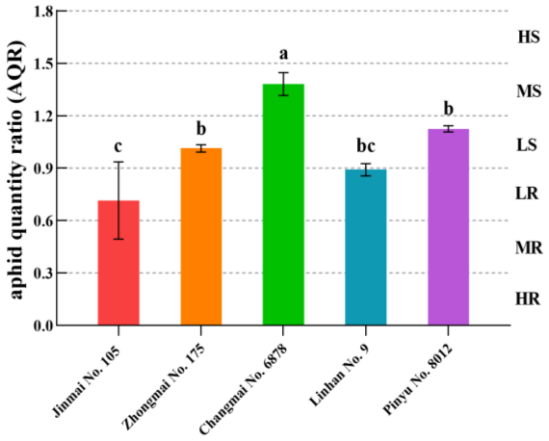


***Figure 1.*** *The aphid quantity ratio (AQR) and resistance level of S. avenae on five wheat varieties. Values represent the mean ± SD (n = 3). HR stands for highly resistant; MR stands for moderately resistant; LR stands for low resistance; LS stands for low susceptible; MS stands for moderately susceptible; HS stands for highly susceptible. Different lowercase letters above the columns indicate significant differences among different cultivars at the 0.05 level (Tukey's test)*

### *Life history parameters*

Different wheat varieties had an effect on the biological parameters of *S. avenae*. More specifically, developmental duration of immature stages and survival of *S. avenae* on five wheat cultivars exponentially presented in *Figure 2*. Durations of four instars *S. avenae* varied significantly among the five wheat cultivars ($p < 0.01$). The highest and lowest first instar periods were obtained on Pinyu no. 8012 (8.65 day) and Jinmai No. 105 (1.56 day) cultivars, respectively ($F = 5.178$, $p < 0.01$) (*Fig. 2a*). Nymphs fed with Zhongmai No. 175 (2.34 day) cultivars exhibited the longest second instar periods, while those fed with and Jinmai No. 105 (1.55 day) had the shortest periods ($F = 3.684$, $p = 0.007$) (*Fig. 2b*). The third time of wheat cultivars Jinmai No. 105 (2.34 day) were significantly different from Linhan No. 9 (1.78 day) and Pinyu 8012 (1.80 day) ($F = 2.327$, $p = 0.060$) (*Fig. 2c*). Larvae fed with Jinmai No. 05 (2.16 day) cultivars exhibited the longest fourth instar period, while those fed with Zhongmai No. 175 (1.90 day) had the shortest periods ($F = 0.332$, $p = 0.856$) (*Fig. 2d*).


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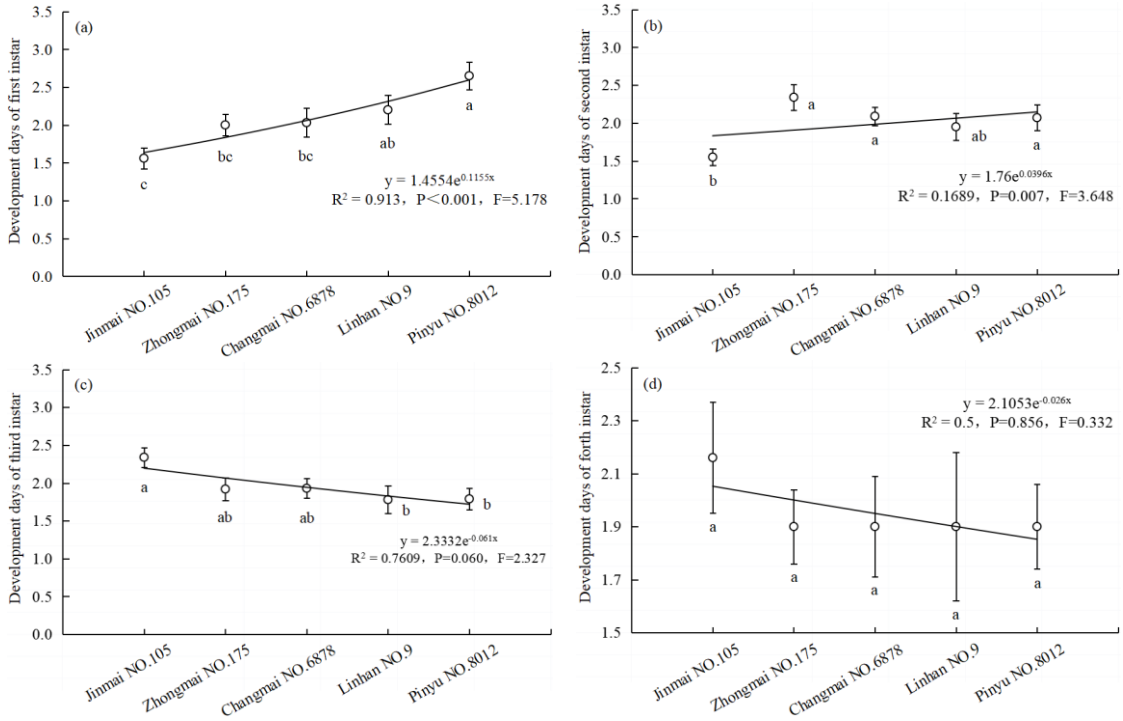


***Figure 2.*** *Immature developmental duration of S. avenae reared on five wheat cultivars with different letters show significant differences among treatments according to Tukey test at* $\alpha = 0.05$. *Data in the figures are means* $\pm$ *SE*

The life table analysis rates of *S. avenae* fed on five wheat cultivars are plotted in *Figure 3*. The lowest age-stage specific survival rate ($s_{xj}$) of the wheat cultivar occurred on Linhan No.9 and the highest occurred on Zhongmai No.175 (*Fig. 3a*). The age-stage life expectancy ($e_{xj}$) of the five wheat cultivars were similar among the tested cultivars, and *S. avenae* successfully reproduced and developed on each of the tested cultivars (*Fig. 3b*). The greatest and lowest the reproductive value ($v_{xj}$) occurred on the Changmai No. 6878 and Jinmai No. 105, respectively (*Fig. 3c*). The age-specific survival rate (l x) curves were similar among the tested cultivars, and *S. avenae* successfully reproduced and developed on each of the cultivars investigated. The greatest and lowest value of age-specific maternity (lxmx) occurred on Changmai No. 6878 and Jinmai N0. 105 cultivars, respectively (*Fig. 3d*).

### *Adult life table variables*

Adult longevity and reproductive performance of *S. avenae* reared on the five wheat cultivars logarithmically presented in *Figure 4*. Female *S. avenae* reared on the Linhan No. 9 (9.11 day) were significantly different from Changmai 6878 (7.65 day) and Jinmai No. 105 (7.80 day) cultivars ($F = 3.153$, $p = 0.018$) (*Fig. 4a*). The female longevity of Jinmai No.105 was significantly different from the wheat cultivars of Linhan No. 9and Changmai No. 6878($F = 3.087$, $p = 0.018$) (*Fig. 4b*). Female entire lifespan was highest when reared on Changmai No. 6878 (11.45 day) and lowest when reared on the Linhan No. 9 (8.41 day) ($F = 2.623$, $p = 0.041$) (*Fig. 4c*). The fecundity was highest on Linhan No. 9 (7.63) while was lowest on Jinmai No. 105 (2.50), respectively ($F = 4.517$, $p = 0.02$) (*Fig. 4d*).


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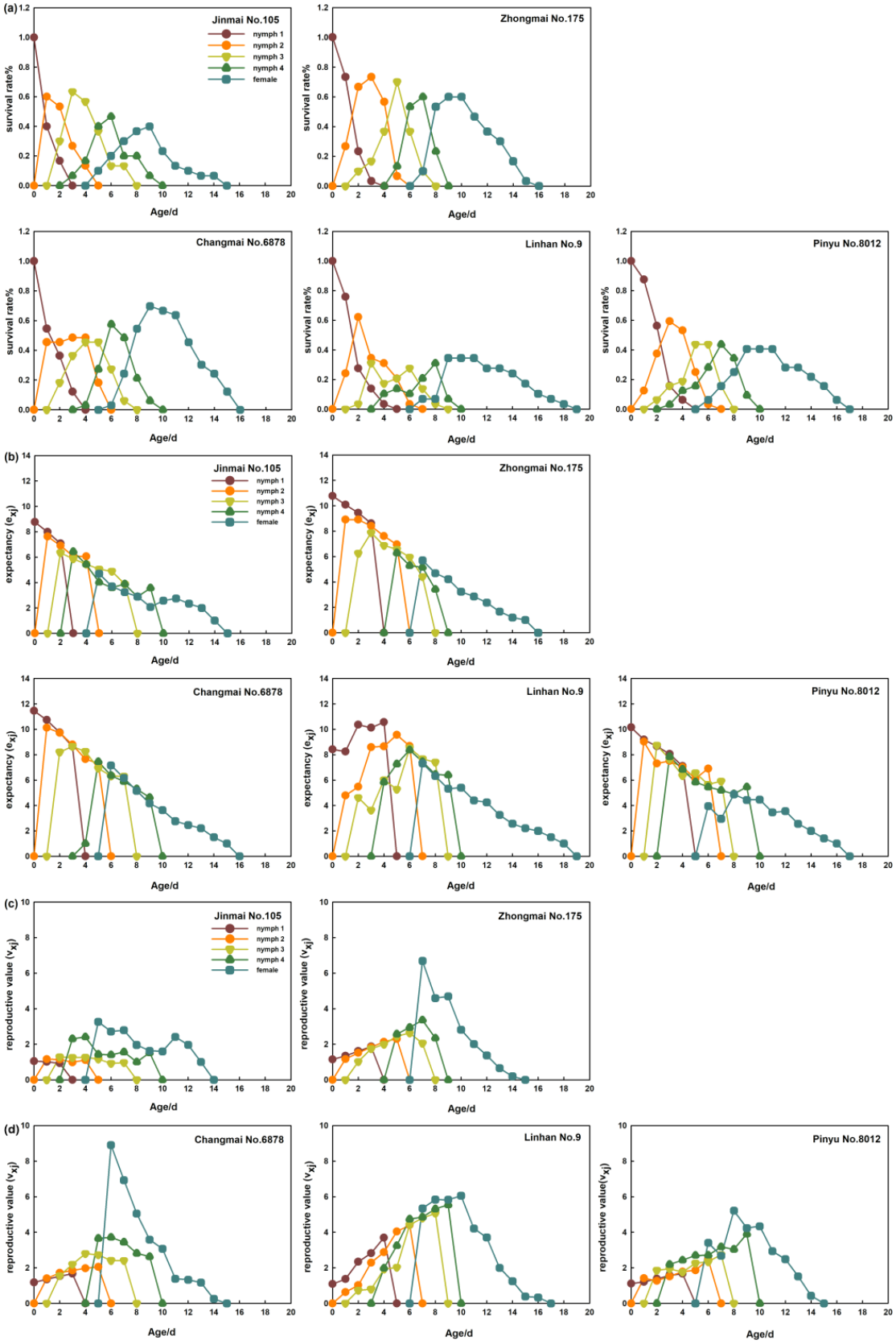


***Figure 3.*** *Age-stage-specific survival rate ($s_{xj}$), age-specific survival rate, age-stage-specific fecundity and age-specific fecundity, age-stage specific life expectancies ($e_{xj}$), age-stage-specific reproductive value ($v_{xj}$) of S. avenae reared on five wheat cultivars*


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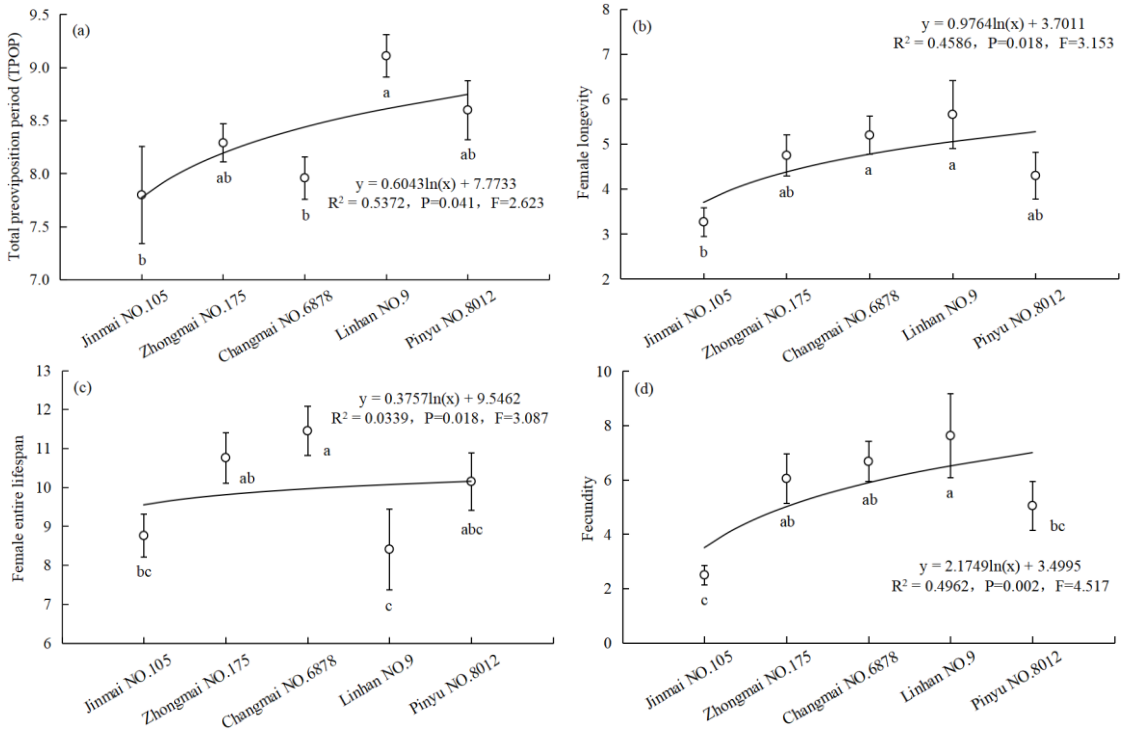


***Figure 4.*** *Total preoviposition period (TPOP), female longevity and female entire longevity of S. avenae reared on five wheat cultivars with different letters show significant differences among treatments according to Tukey test at α = 0.05. Data in the figures are means ± SE*

There were significant differences among all population growth parameters of *S. avenae* reared on the five wheat cultivars (*Table 3*) ($p < 0.01$). The net reproductive rate (R0) value of Jinmai No. 105 (1.56 offspring) was significant different from Changmai 6878 (5.06 offspring), Zhongmai No. 175 (4.03 offspring) and Pinyu 8012 (3.15 offspring). The gross reproductive rate (GRR) of Linhan No. 9 (9.36 offspring) was significant different from Jinmai No. 105 (5.66 offspring) cultivars. The intrinsic rate of increase (r) reared on Changmai No. 6878 (0.16 $day^{-1}$) was significant different from Jinmai No. 105 (0.04 $day^{-1}$). The generation time (T) reared on Linhan No. 9 (11.97 day) was statistically different from the Jinmai No. 105 (9.54 day) (*Table 3*).

***Table 3.*** *Life table parameters of S. avenae reared on various wheat cultivars*

| Statistics | R0 | GRR | r | λ | T |
|---|---|---|---|---|---|
| Jinmai No.105 | 1.56 ± 0.32b | 5.66 ± 1.20b | 0.04 ± 0.02c | 1.04 ± 0.02c | 9.54 ± 0.65c |
| Zhongmai No. 175 | 4.03 ± 0.78a | 7.43 ± 0.74ab | 0.13 ± 0.01ab | 1.14 ± 0.02ab | 10.50 ± 0.20bc |
| Changmai No. 6878 | 5.06 ± 0.74a | 7.99 ± 0.69ab | 0.16 ± 0.01a | 1.17 ± 0.01a | 10.12 ± 0.25bc |
| Linhan No. 9 | 2.89 ± 0.88ab | 9.36 ± 1.14a | 0.08 ± 0.02bc | 1.09 ± 0.03bc | 11.97 ± 0.27a |
| Pinyu No. 8012 | 3.15 ± 0.70a | 7.87 ± 0.87ab | 0.10 ± 0.02bc | 1.11 ± 0.02bc | 10.99 ± 0.35b |

Means followed by different letters in each column are significantly different (paired bootstrap test, $p < 0.01$). R0, net reproductive rate; GRR, gross reproductive rate; r, intrinsic rate of increase; λ, finite rate of increase; T, mean generation time


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### *The activity of digestive enzymes*

Proteases and amylases activity in the larval midgut of S. littoralis reared on five wheat cultivars until the fourth instar are shown in *Table 4*. The findings concluded that the activities of digestive proteases and amylases in the larval midgut were significantly affected by the wheat cultivar consumed by *S. avenae*. Larvae fed on Changmai No. 6878 (2.11 U $mg^{-1}$) and Jinmai No. 105 (0.36 U $mg^{-1}$) cultivars exhibited the highest and lowest levels of proteolytic activity, respectively ($p < 0.05$). The highest amylolytic activities were detected in larvae reared on the cultivars Zhongmai No. 175 (0.86 U $mg^{-1}$), in contrast, the lowest amylolytic activities were observed in larvae fed on the cultivars Linhan No. 9 (0.42 U $mg^{-1}$) ($p < 0.05$).

***Table 4.*** *General proteolytic and amylolytic activity of midgut extracts from Sitibion avenae larvae reared on five wheat cultivars*

| Wheat varieties | Protease | Amylase |
|---|---|---|
| Jinmai No.105 | 0.36 ± 0.09c | 0.54 ± 0.20bc |
| Zhongmai No. 175 | 1.43 ± 0.51ab | 0.86 ± 0.3a |
| Changmai No. 6878 | 2.11 ± 0.32a | 0.65 ± 0.05b |
| LinhanNo. 9 | 0.62 ± 0.19c | 0.42 ± 0.02c |
| Pinyu No. 8012 | 1.71 ± 0.22b | 0.79 ± 0.26ab |

Each column represents the mean of four independent estimations ± standard error (SE). Different letters indicate statistically significant differences (Tukey, $p < 0.01$)

## Discussion

Screening natural resistance wheat cultivars with higher yield and pest management has emerged as a major goal of scientific investigation. The current economic and environmentally friendly strategy to control cereal aphids confronting Chinese wheat farmers make insecticidal control as a less viable option; thus, given the importance of selecting the resistant wheat cultivars is necessary. This potentially valuable resources significantly contribute to food security and alleviate poverty in vulnerable agricultural environments. This will also help to reduce the escalation of problems that aim to reduce chemical inputs, including insecticide resistance, market demand, and environmental contamination. Our results indicate that performance and population growth parameters of *S. avenae* significantly affected among five wheat cultivars. Developmental duration, nymph survival rate, fertility (F), and intrinsic rate of increase (rm) are available for evaluating and understanding insect population dynamics (Hu et al., 2015). Indeed, many published studies favored using these basic biological parameters to assess the plant resistance to insect attack (Hu et al., 2015; Hong et al., 2019).

We identified the wheat resistance/susceptibility level to *S. avenae* by observing AQR and biological parameters of *S. avenae*. In this study, Changmai No.6878 had the longest *S. avenae* female entire lifespan and lowest AQR, whereas Jinmai No. 105 No.6878 had the shortest female entire lifespan and the lowest AQR. Antibiosis primarily hampers target pest's life cycle, including reduced viability and growth development, retarded the reproduction capacity and survivability (Abbas et al., 2012). This recommends that the Jinmai No. 105 cultivar probably have possessed a stronger antibiosis characterization that hampered the growth of S. avenae. This recommendation


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was confirmed by positive correlation of AQR with female entire lifespan, which inhibited the development of *S. avenae*. Changmai No. 6878's susceptibility to *S. avenae* is demonstrated by the absence of the antibiosis test. This result is consistent with previous observations that the longevity of susceptible varieties on *S. avenae* was longer than the resistant ones (Lan et al., 2021; Shishehbor et al., 2021). Compared to the other wheat cultivars, Linhan No.9 had the lowest fecundity, TPOP and adult longevity. The positive correlation of AQR with the fecundity, TPOP and adult longevity supported this. Performance of *S. avenae* rearing on other resistant/susceptible wheat cultivars showed a similar result (Shishehbor et al., 2021).

The life table traits revealed that *S. avenae* successfully develops from nymphs to adult on all of the tested wheat cultivars. However, there were significant differences in the nutritional potential and growth rates of *S. avenae* among five wheat cultivars. The Jinmai No. 105 appeared least suitable as sources of nutrition and supported the lowest growth rate of developing larvae. Variation in the period from nymph to adult emergence of *S. avenae* among the five cultivars probably was related to the difference in biochemical characteristics. The shortest developmental time of TPOP occurred on the Jinmai No.105 was related to the high protease content (Naseri et al., 2022). Furthermore, adult reproductive potential primarily depends on the nutrition acquired during the immature stage and therefore developmental period of immature stages influences the fecundity and longevity of adults. Accordingly, there were significant differences in life table parameters of *S. avenae* on the 5 cultivars evaluated; Changmai No. 6878 and Jinmai No. 105 cultivars supported the highest and the lowest reproductive potential of adults, respectively.

There were significant correlations between growth and reproduction potential of *S. avenae*. The intrinsic rate of increase (r) of *S. avenae* was positively correlated with protease and amylase content that developed on five wheat cultivars. Furthermore, these findings are consistent with the previous researches that related biochemical traits of various plants to herbivore performance (Huang et al., 2012). The value of r is related to life table analyses, such as developmental period, survivability, and reproductive capacity. Therefore, r could be a valuable indicator to evaluate the susceptibility/resistance level of plants to herbivores (Elpidina et al., 2001).

The protease and amylase activities measured in the midgut of *S. avenae* that fed on wheat cultivars. Generally, plants protect themselves against herbivores by producing various digestion inhibitors. In order to compensate, insect herbivores increase production of digestive enzymes in the midgut (Karimi et al., 2014). Polyphagous insects can rapidly modify their digestive enzyme profiles in response to digestion inhibitors. Our results revealed that both proteolytic and amylolytic activities differed among *S. avenae* larvae reared on different wheat cultivars. Among the investigated wheat cultivars, the highest general proteolytic activity was observed in on the Changmai No.6878. This high protease activity could be a response to the high protein content characterizing this cultivar. These hypotheses require further investigation. The current results also indicate that the Jinmai No. 105 is a poor host for *S. avenae* (Smith et al., 2012). These investigations suggest that the Jinmai No. 105 cultivar was probably contribute to the poor performance of *S. avenae* reared on this cultivar. Further research is needed to identify potential specific compound associated with this cultivar that may delay growth and development cultivars. Molecular analysis of midgut proteases probably contributed to the adaptive responses of nymph feeding on wheat cultivars.


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## Conclusions

Our results suggest that the Changmai No. 6878 cultivar was probable the most suitable host for population growth of *S. avenae*. In contrast, *S. avenae* performed worst on the Jinmai No. 105 cultivar. Furthermore, our results revealed primary metabolite contents of protein and amylase among the five wheat cultivars. The metabolite contents could be associated with differences in reproductive and population growth in *S. avenae*. Overall, our results suggest that the Jinmai No. 105 cultivar may be a useful selection for cultivation in areas or breeding efforts that involve *S. avenae* management, such as insecticides, may be more limited.

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