

## MAGNETS ON WING DIMORPHISM AND HOST NUTRIENTS ALLOCATION OF *MYZUS PERSICAE* (HEMIPTERA: APHIDIDAE)

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**Abstract.** Wing polymorphism is commonly observed in many insects, green peach aphid *Myzus persicae* (Hemiptera: Aphididae) exhibit wing polyphenism in response to poor habitat quality. Here, we focus on the effects of magnets on wing dimorphism and host nutrients allocation of green peach aphid. The proportion of winged female progeny increased logarithmically with magnets between 0.065 T to 0.5 T. The first and second instar period of winged progeny was significantly lower than that wingless progeny with the exception of the 0.5 T magnets exposure; the third instar period of winged progeny was significantly lower than that wingless progeny except the 0.28 T magnets exposure. The fecundity of winged female *M. persicae* progeny decreased exponentially compared with wingless female *M. persicae* between 0.065 T to 0.5 T. The effects of magnets on the intrinsic rates of increase ( $r$ ), finite rates of increase ( $\lambda$ ), net reproductive rates ( $R_0$ ), and gross reproductive rate (GRR) of winged progeny decreased logarithmically compared with wingless ones accompanied with the magnets increase. 0.065 T wingless progeny had the highest increase in flavonoid content (1.815 mg<sup>-1</sup> g) while 0.28 T winged progeny had the lowest flavonoid accumulation (0.543 mg<sup>-1</sup> g). Our findings highlight the wing morphology and development under varied magnet intensities and reveal that the accumulation of total phenol and flavonoid content correlated positively with the life history parameters, such as the total preoviposition period, female longevity, and the intrinsic rates of increase ( $r$ ). It is thus possible to increase winged female production for the purposes of biological control by manipulation magnets conditions.

**Keywords:** magnets, wing dimorphism, life history parameters, phenol, flavonoid, *Myzus persicae*

### Introduction

Phenotypic plasticity is the phenomenon that organisms flexibly alter their phenotypes in response to external stimuli, granting the ability to adapt to their surrounding environments (Brisson and Davis, 2016; Chen et al., 2019). This adaptive strategy can affect critical life-history traits, including physiology, behaviour, morphology and host-plant nutrients allocation (Martel et al., 2011; Wei et al., 2014; Wang et al., 2015). Wing dimorphism is the morph differentiation of an organism associated with phenotypic plasticity (Simpson et al., 2011). Wing dimorphism commonly observed in many insect species, particularly in the aphid. Aphid can develop different morphs of phenotypic plasticity despite having the same genotype in response to specific environments, as a strategy to balance trade-offs in ecological systems between flight capability and fecundity (Grantham and Brisson, 2018). For instance, the morphological and physiological characteristics of winged aphids enable them to have the chance to disperse and survive in harsh environment conditions (Simon and Peccoud, 2018); aphid

individuals invest self-energy in reproduction over dispersal under relatively stable or predictable conditions; compared to the apterous phenotype, the alate aphids display a longer nymph development period, lower offspring production, and higher longevity (Islamoglu and Alkan, 2019). Moreover, during embryogenesis and postembryonic development in aphid morphs, the total number of embryos and the maximum embryo volume of winged individuals were significantly smaller than those of wingless individuals at the same development stage, and this differentiation occurred at the early postembryonic instars of winged or wingless morphs. Environmental factors probably could affect wing polyphenism and development in parthenogenesis and viviparous females during the embryonic period (Ohde et al., 2022). Therefore, wing and wingless variation is a trade-off strategy that has evolved in aphids for coping with complex and uncertain environments.

Numerous studies have addressed the expression of aphid wing polyphenism, including crowding, host quality, interspecific interactions, natural enemies, alarm pheromone, maternal, temperature, photoperiod, precipitation, etc. For example, *Myzus persicae* and *Lipaphis erysimi* produced more winged individuals under extreme temperature conditions (Mehrparvar et al., 2013); more winged cabbage aphid would be produced under long photoperiod and high intensity light conditions (Brisson, 2010); higher aphid densities lead to more tactile stimulations triggering wing induction of *M. persicae* and *Aphis glycines* (Grantham, 2016; Martínez and Costamagna, 2018); the prenatal crowding of mothers and postnatal crowding of larvae were both influence the production of *M. persicae* winged forms (Hu et al., 2019), etc. Particularly, the magnets had already been a new factor influencing development and further vital stages in insect life cycles. The impact of extreme high magnets in the context of magnetic pollution should be investigated more precisely considering individual developmental stage for direct effects but also for further adult morph induction.

Nowadays, compared with geomagnetic field (GMF), much larger magnetic field are emitted by miscellaneous electric infrastructure components, people have access to much stronger static magnetic fields (SMFs), such as magnetic resonance imaging (MRI) and national high magnetic field laboratories (Migdal et al., 2022). Taking advantage of these large equipment, biological scientists have regarding strong SMF impact on living organisms from multiple aspects, including growth development, mortality, physiology and behavior, orientation, antioxidant defense, mutations, replication and transcription mechanisms. For example, 9.4 T exposure delayed hatching in mosquito eggs (Pan and Liu, 2004); SMF of 2.4 T prolongs the postembryonic development of *Drosophila subobscura* (Todorović et al., 2015); 8.5 T exposure exert developmental abnormality in *Caenorhabditis elegans* (Wang et al., 2015); 7 T for 75 min did not influence the mice during the entire pregnancy (Zahedi et al., 2014); 1T SMFs induce abnormal mitotic spindles and increase mitotic index (Luo et al., 2016); moderate magnetic field (1mT-1T) exposure retarded development of microorganisms, plants and animals (Zhang et al., 2017). Though little is known regarding the impact of stronger static magnetic fields on wing polyphenism of the aphid.

Previous research only investigated the long-term effects of SMFs on the aphid viability. it is vital for expanding the knowledge for a wider spectrum of electromagnetic radiation of the short-term impacts exposure on wing polyphenism and host nutrients allocation. *Myzus persicae* (Hemiptera: Aphididae) has caused damage to hundreds of agricultural crops in more than 66 families. This aphid mainly exists in young plant tissues, causes delayed plant growth and sucks plant sap leading to yellowing of

cruciferous crops. Additionally, aphid secretion of honeydew influences plant photosynthesis and encourages fungal growth (Ahmed et al., 2019; Qasim et al., 2022). Cabbages are commonly attacked by this aphid species. They have developed some sophisticated defensive strategies to thwart and escape aphid attacks (Mithöfer and Boland, 2012). In response to aphid feeding, plant can induce signal transduction to activate the corresponding physiological and biochemical reactions. Secondary metabolites in plants are natural defense mechanisms against insect attacks (Jan et al., 2021). Previous researches have elucidated that flavonoid and phenol are dominant plant secondary metabolites that protect plants from insect pest attack (Pan et al., 2016). For example, high phenol and flavonoid content in alfalfa could influence the nymph development, reproduction period, and fecundity of pea aphid (*Acyrtosiphon pisum*) (Goławska and Łukasik, 2009). Much research has been performed on the relationship between secondary substances and environmental stimuli. To date, research of magnets on wing polyphenism is extremely scarce. This study was conducted to determine wing morph differentiation of *M. persicae* and elucidate the mechanisms responsible for wing polymorphism in order to understand the roles of magnets driving wing polymorphism.

## Materials and methods

### *Plant and insect*

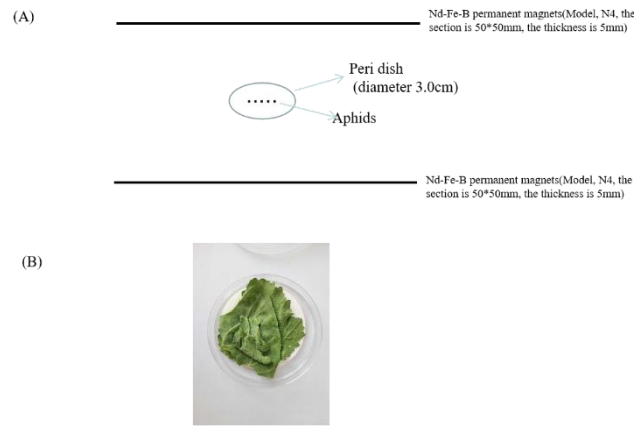
The cabbage (*Brassica oleracea* L. var. capitata) seeds were initiated from the Seed and Plant Research Improvement Institute (Shanxi Agricultural University, China). Plants were grown in plastic pots in a greenhouse for two weeks under  $25 \pm 1$  °C,  $65 \pm 5\%$  RH, and a 16:8 h light: dark photoperiod. The potted plants grown up to the 7–9 leaves stage was used for aphid feeding.

The aphid *M. persicae* (Hemiptera: Aphididae) was initiated from the Insect Ecology and Integrated Pest Management Laboratory (Shanxi Normal University, China). The aphids were reared on cabbage leaves in a greenhouse under conditions given above. To ensure the experiments remained uniform, a single colony was reared on cabbages stated above for five generations. Then, the sixth-generation colony was used for quantifying life table parameters and secondary metabolites. The nymphs born within 24 were considered instar zero. Subsequently, the first time of *M. persicae* molting was recorded to first instar, followed by the second, third and fourth instar.

### *Experimental procedure of magnetic field*

To determine the effects of magnets on wing morph of *M. persicae*, three magnets regimes (0.065 T, 0.28 T and 0.5 T) exposure 4 min were established according to our previous studies (He et al., 2013). The static magnetic field was generated by three Nd-Fe-B permanent magnets obtained from the Shenzhen Magnetic Research Technology Corporation. The experimental *M. persicae* reared in Glass Petri dishes (diameter: height= 3.0 cm: 3.0 cm) were exposed to the center of the magnet's surface (*Fig. 1*). Each glass petri dishes were covered by a piece of 40-mesh nylon gauze to prevent the escape of aphid. After exposure, each treatment comprised of 30 nymphs were individually fixed to the cabbage leaf using a clip cap (0.6 cm in diameter, 0.3 in height). One potted cabbage was placed with 12 replicates covered by a anti-insect white mesh external dimensions of  $35 \times 35 \times 28$  cm. After progeny emergence was completed, numbers of winged and wingless females were counted for winged female progeny analysis. At this time, the

winged and wingless female's progeny born within 24 hrs were used for the life history experiments and secondary metabolites qualifications. Oviposition and developmental progress of progeny were observed daily. There is no shielding against the natural variation of terrestrial MF, because their intensity (0.03- 0.06 mT) was insignificant compared to the experimental SMF.



**Figure 1.** Static magnetic field exposure of the green peach aphid *Myzus persicae* (A) Setup of magnetic field treatment. Thirty aphids were randomly selected as a group placed in one Petri dish for magnetic field exposure. (B) A Petri dish showing the enclosed aphids

### Effects of magnets on wing morph and progeny development

The biological parameters of magnets on development of winged and wingless progeny were analyzed using TWOSEX- MSChart software (Chi, 2020; Chi et al., 2020), including immature developmental duration, TPOP (total preoviposition period counted the time from the nymph birth); APOP (adult preoviposition period counted the time from the adult emergence); the age-specific survival rate ( $l_x$ , described the change in survival rate of the population with age as equation (1) ); the age-specific fecundity ( $m_x$ , described the start times and duration of the reproductive phase as equation (2)) the start times and duration of the reproductive phase), age-specific maternity ( $l_x m_x$ ), reproductive value ( $v_{xj}$  described the expected contribution of an individual of age  $x$  and stage  $j$  to the future population), the net reproductive rate ( $R_0$ ) as equation (3), intrinsic rate of increase ( $r$ ) as equation (4), finite rate of increase ( $\lambda$ ) as equation (5), mean generation time ( $T$ ) as equation (6). The formulas of above-mentioned parameters were calculated as follows (Chi, 2020; Chi et al., 2020):

$$l_x = \sum_{j=1}^k S_{xj} \quad (\text{Eq.1})$$

where  $k$  means the number of stages, and  $j$  means the ages.  $S_{xj}$  the age-stage-specific survival rate

The parameter of age-specific fecundity ( $m_x$ ) was defined as:

$$m_x = \frac{\sum_{j=1}^k S_{xj} f_{xj}}{\sum_{j=1}^k S_{xj}} \quad (\text{Eq.2})$$

where  $k$  means the number of stages, and  $j$  means the ages.  $S_{xj}$  the age-stage-specific survival rate,  $f_{xj}$  age-stage specific fecundity.

The value of net reproduction rate calculated the mean number of offspring that an individual can produce during its lifetime:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad (\text{Eq.3})$$

where  $x$  means the number of stages,  $l_x$  means age-specific survival rate,  $m_x$  means age-specific fecundity.

The parameter of the intrinsic rate of increase calculated from the Euler-Lotka formula using the methodology of iterative bisection with the age indexed from 0:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad (\text{Eq.4})$$

where  $x$  means the number of stages,  $l_x$  means age-specific survival rate,  $m_x$  means age-specific fecundity,  $r$  means the intrinsic rate of increase.

The finite rate ( $\lambda$ ) was estimated as:

$$\lambda = e^r \quad (\text{Eq.5})$$

where  $r$  means the intrinsic rate of increase.

The mean generation time means that the time length a population needs to increase to  $R_0$ -fold of its size when the population achieves the stable age-stage distribution:

$$T = \frac{\ln R_0}{r} \quad (\text{Eq.6})$$

where  $r$  means the intrinsic rate of increase,  $R_0$  means the net reproductive rate.

The GRR was calculated as  $GRR = \sum m_x$ . Where  $m_x$  means age-specific fecundity.

### **Total phenol compounds content assay**

After aphid inoculating 14 days, cabbage leaves were collected for secondary metabolites qualifications. 0.5 g fresh leaves from each treatment were used to prepare extracts. The leaves accurately weighed, added a small amount of quartz sand and 2 mL deionized water. Subsequently, the leaves ground in an ice bath and transferred to a 10 mL test tube, added 5 mL of deionized water. These samples homogenized in a glass homogenizer and filtered through four layers of gauze. The filtrate was aspirated and kept at 4 °C until phenol compounds content assays were performed.

The total phenol content of cabbage was assayed as previously described by Chlopicka et al. (2012), the colorimetric Folin–Ciocalteu reagent method were utilized with minor modifications. In brief, 0.3 mL extracts diluted with 2.7 mL of deionized water were oxidized by adding 0.15 mL Folin-Ciocalteu reagent. This solution neutralized with 0.3 mL of 10% sodium carbonate after 3 min. The samples absorption was read at 700 nm using gallic acid as a standard. One unit of the total phenol compound content was defined as the micromoles of gallic acid equivalent (GAE) per gram of grain. Assays were carried out three replicates.

### Total flavonoid content assay

The total flavonoid content was determined utilizing the method described by Chlopicka et al. with appropriate modifications (2012). Briefly, the dilutions of sample extract reacted with 5% sodium nitrite ( $\text{NaNO}_2$ ) were stand for 5 min before adding the solution of 10%  $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ . This mixture added 1 mol/L NaOH in a fixed volume of distilled water after 6min. The absorption was immediately measured at 700 nm using known concentration of catechin concentration as a standard. Flavonoid content was expressed as milligrams of catechin equivalents per 100 g dry weight. All experiments were performed three replications.

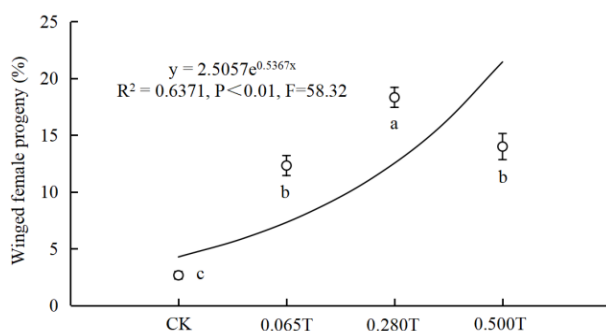
### Statistical analyses

A nominal logistic regression model was used to analyse the effects of magnets on wing dimorphism. The biological parameters, total phenol, and flavonoid content of each magnets on *M. persicae* progeny were tested by one-way ANOVA followed by Tukey's test ( $p < 0.05$ ). Linear (PROC REG) or nonlinear regression (PROC GLM) analyses were used to compare the difference of development days, fecundity and population parameters ( $r$ ,  $T$ ,  $R_0$ ,  $\lambda$ ,  $GRR$ ) between winged and wingless female *M. persicae* progeny. ANOVA were also used to compare the difference of fecundity between winged and wingless female *M. persicae* progeny. All statistical analyses were conducted with SAS software version 10.0.0 (SAS Institute Inc. 2012, Cary, NC, USA). Scientific graphs of magnets on *M. persicae* progeny parameters were plotted using Sigmaplot 12.3 software (SigmaPlot Version 12.3 (2013) Systat Software, Inc., San Jose, California). Values of  $p < 0.05$  were considered significant among the magnets treatment.

## Results

### Effects of magnets on progeny wing dimorphism

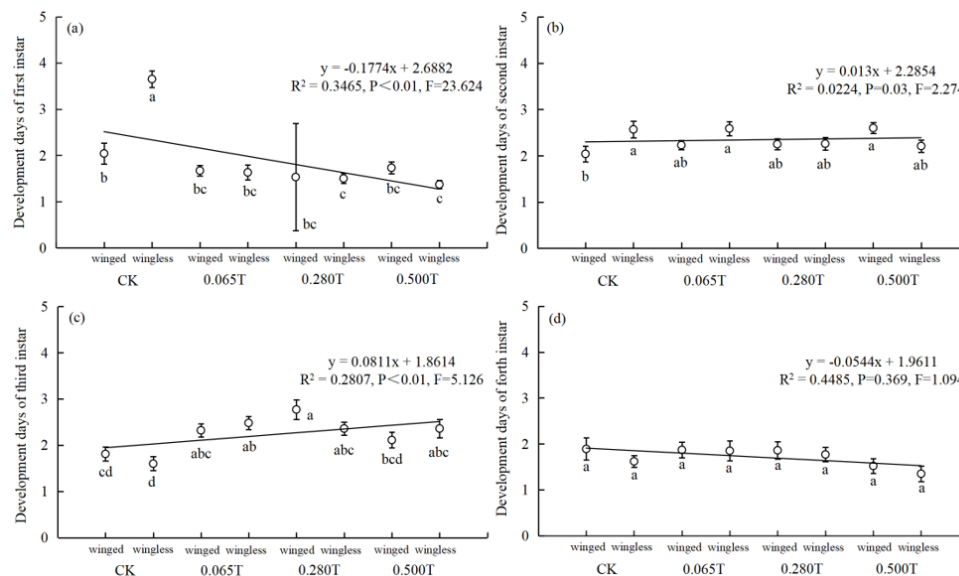
It indicated that magnets significantly affected the production of wings compared with the control groups. Percentage of winged female progeny showed a marked logarithmic relationship with magnets ( $F = 35.916$ ,  $P < 0.01$ ) (Fig. 2), the percentage of winged progeny in the 0.065 T treatment ( $0.13 \pm 0.01$ ) was significantly lower than that of treatments at 0.28 T ( $0.18 \pm 0.01$ ) and 0.5 T ( $0.14 \pm 0.01$ ). These results revealed that magnets had a notable impact on the rate of reproduction of winged progeny, and that higher magnets contribute to wing development in *M. persicae*.



**Figure 2.** Effects of magnets on progeny wing dimorphism. Percentages of winged female progeny with different letters show significant differences among treatments according to Tukey test at  $\alpha = 0.05$ . Data in the figures are means  $\pm$  SE

### Effects of magnets on wing morph and progeny development

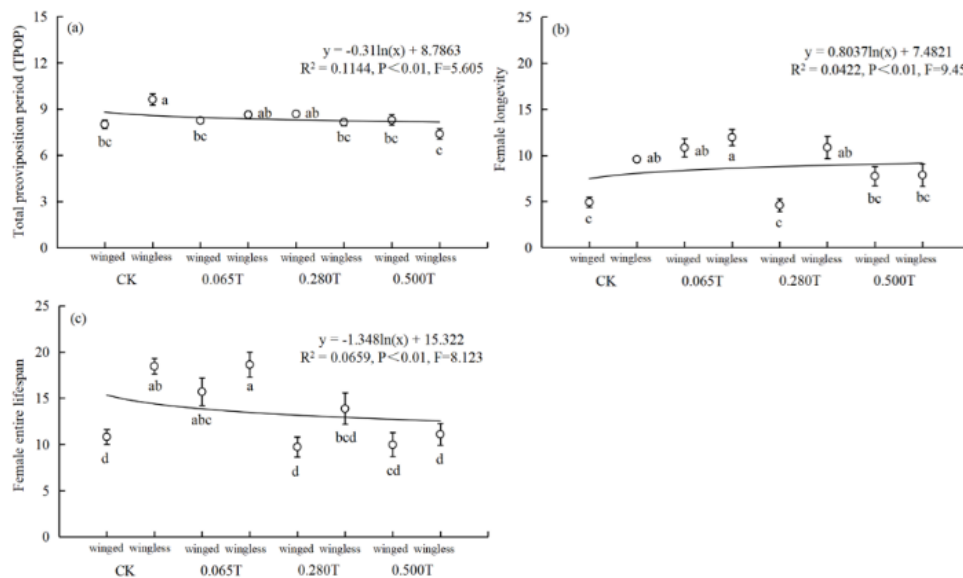
Magnets significantly impacted the immature developmental duration of *M. persicae* progeny, with a pronounced general linear relationship between the two variables (Fig. 3). Within the same magnets, the first instar period of winged progeny was significantly lower than that wingless progeny with the exception of the 0.5 T magnets exposure ( $F = 23.624$ ,  $p < 0.01$ ); furthermore, there was a statistical trend toward in the second instar, which is similar but is clearly inferior to first instar. ( $F = 2.274$ ,  $p = 0.03$ ), the developmental duration of these two instar were higher than that of control; the third instar period of winged progeny was significantly lower than that wingless progeny except the 0.28 T magnets exposure ( $F = 5.126$ ,  $p < 0.01$ ), and these two morphs progeny was significantly lower than that of the control; however, the fourth instar period of these two morphs progeny showed no significant change ( $F = 1.094$ ,  $p = 0.369$ ). In the first and second instar, 0.065 T wingless progeny had the highest increase value, while 0.065 T winged progeny had the lowest value; in the third instar, the highest value was observed in the 0.28 T winged progeny while the lowest parameters was found in the 0.5 T winged population.



**Figure 3.** Effects of magnets on progeny developmental days of immature stages. See Fig. 2 legend for interpretation

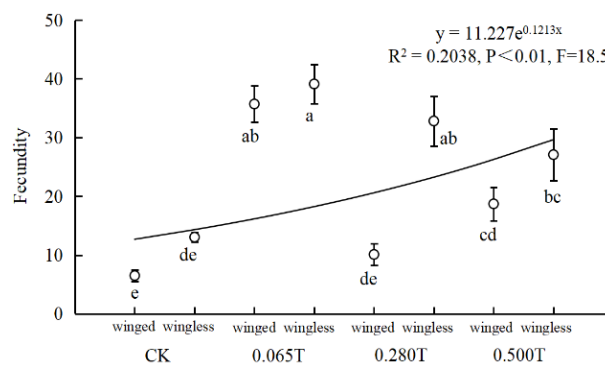
Results from logarithmic relationship analyses also indicated that magnets significantly affected the total preoviposition period, female longevity and female entire lifespan of two morphs progeny (Fig. 4). Within the same magnets, the total preoviposition period of winged progeny was significantly higher than that of the wingless morphs except the 0.065 T magnets exposure, and all wingless progeny were significantly higher than the control, while all the winged progeny showed no significant difference compared with the control ( $F = 5.605$ ,  $p < 0.01$ ). Female longevity and female entire lifespan of winged progeny was significantly lower than that of the wingless morphs accompanied with the magnets increase, female longevity of all winged progeny was higher than the control while all wingless progeny was not significantly influenced by magnets ( $F = 9.45$ ,  $p < 0.01$ ), female entire lifespan of wingless progeny was

statistically lower than that of the control except the 0.065 T magnets while all winged progeny was higher than the control ( $F = 8.123$ ,  $p < 0.01$ ). 0.28 T winged progeny had the highest the total preoviposition period while 0.28 T wingless ones had the lowest values; 0.065 T wingless progeny had the highest increase in female longevity while 0.28 T winged ones own the lowest parameter; the highest female entire lifespan was observed in the 0.065 T winged progeny while the lowest parameters was found in the 0.28 T winged ones.



**Figure 4.** Effects of magnets on progeny TPOP, female longevity and female entire lifespan. See Fig. 1 legend for interpretation

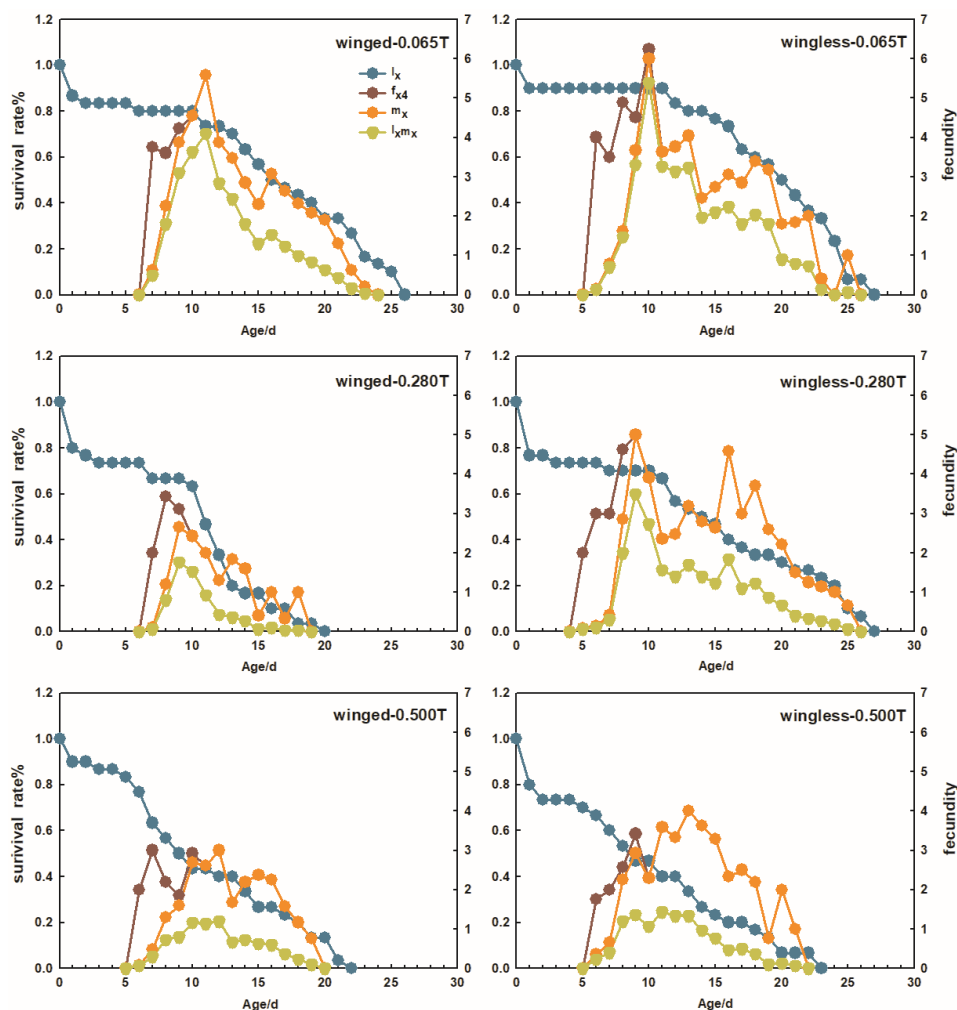
The fecundity of these two morphs progeny showed a marked exponential relationship with magnets ( $F = 18.5$ ,  $P < 0.01$ ) (Fig. 5). Generally, the fecundity of winged female *M. persicae* decreased significantly compared with wingless female *M. persicae* at the same magnets exposure, and the wingless progeny were statistically higher than the winged ones, both of these two morphs fecundity were statistically higher than that of the control groups. 0.065 T wingless progeny had the highest fecundity while 0.28 T winged had the lowest value.



**Figure 5.** Effects of magnets on progeny fecundity. See Fig. 1 legend for interpretation



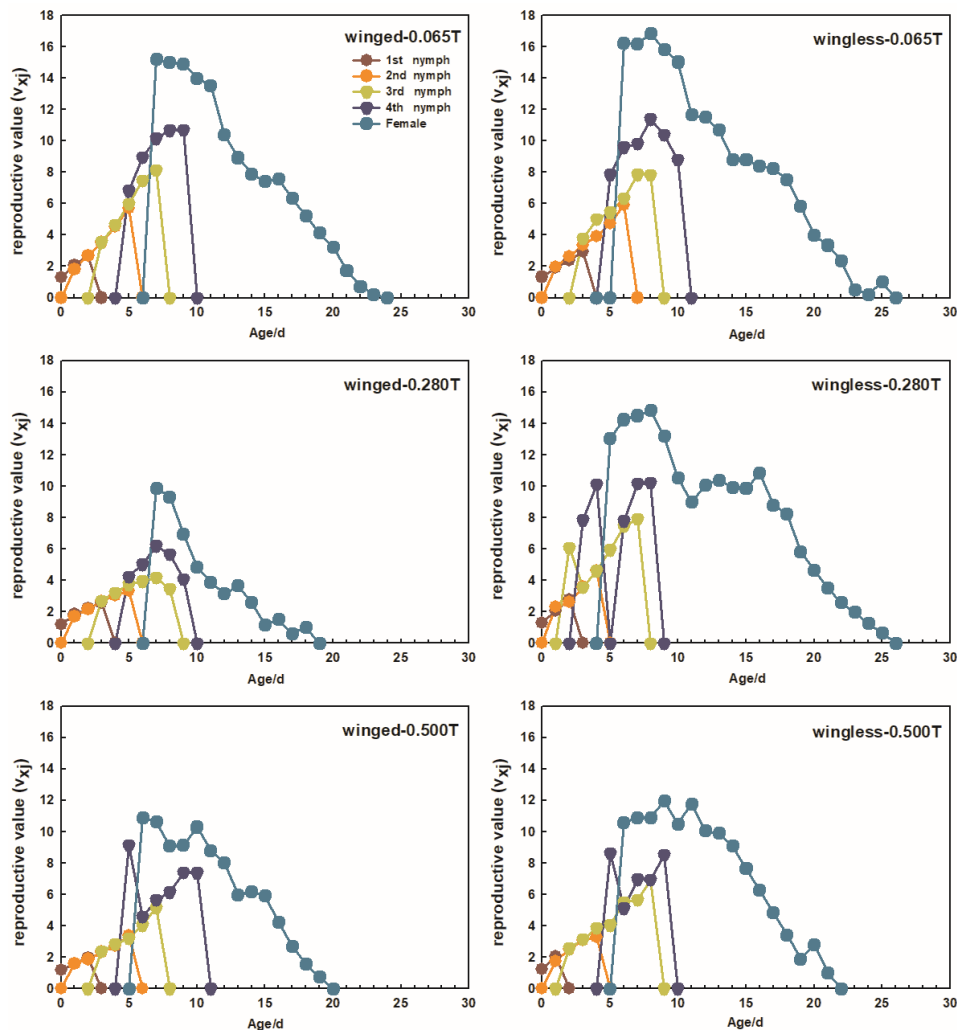
The  $l_x$  curve showed that winged morphs exposure at 0.065 T, 0.28 T and 0.5 T was significantly decreased from age 12, 10, 7 d, while the wingless morphs decreased from age 13, 13, 4 d, respectively. The highest peak of  $f_x$  was observed for winged and wingless populations of 0.065 T, 0.28 T and 0.5 T were 4.8 and 6.6 nymphs, 3.8 and 5.0 nymphs, 3.0 and 3.8 nymphs, respectively. Based on the curve  $m_x$ , the highest peaks of winged phenotype exposure at 0.065 T, 0.28 T and 0.5 T occurred at age 10 d with 5.8 offspring, age 13 d with 2.88 offspring, age 12 d with 3.04 offspring, whereas the wingless phenotype observed at age 10 d with 6.8 offspring, age 9 d with 5.2 offspring, age 13 d with 4.4 offspring. The maximum  $l_x$   $m_x$  value of winged and wingless phenotype recorded at 0.065 T at age 10.5 d with 4.4 offspring and age 10 d with 5.6 offspring, at 0.28 T at age 8 d with 1.8 offspring and age 8 d with 3.2 offspring, at 0.5 T at age 12 d with 1.2 offspring and age 11 d with 1.3 offspring, respectively (Fig. 6).



**Figure 6.** Effects of magnets on *M. persicae* progeny age-specific survival rate, age-stage-specific fecundity and age-specific fecundity

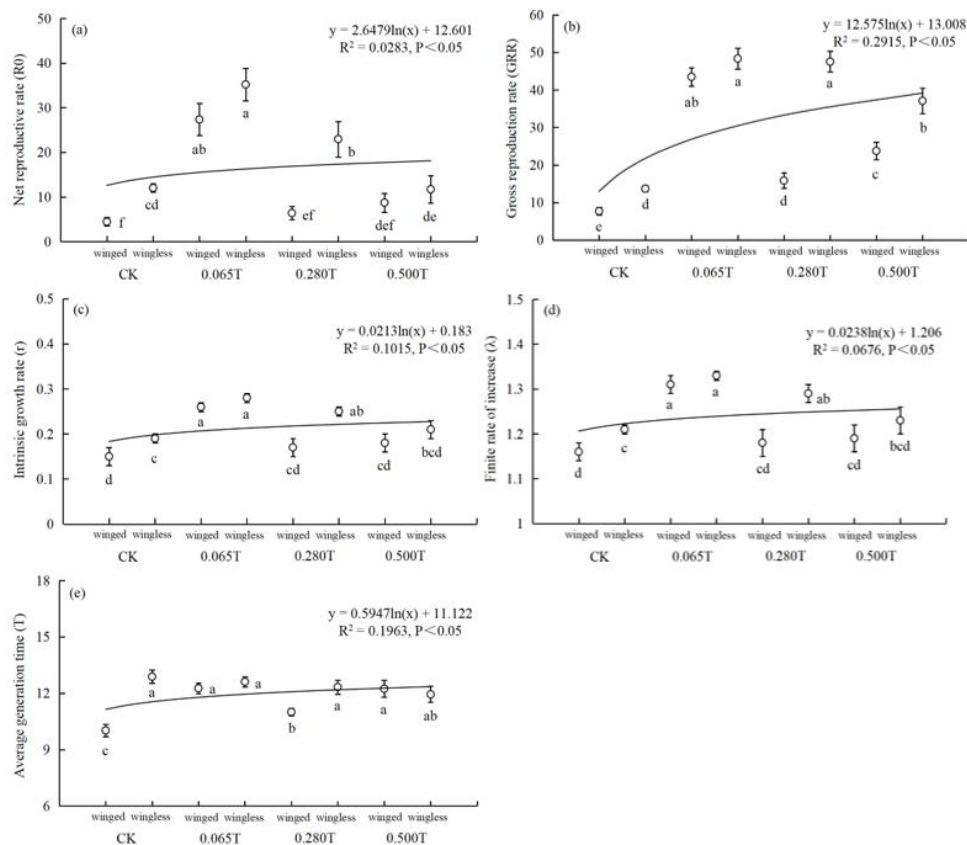
The reproductive value ( $v_{xj}$ ) of the winged and wingless morphs exposure at 0.065 T, 0.28 T and 0.5 T gradually increased with an increase in age and stage, whereas the reproductive value of the female stage significantly increased when they began to oviposit. The value  $v_{xj}$  of winged were all lower than the wingless morphs at the same

magnets exposure. The highest reproductive values for winged and wingless populations exposure were recorded at 0.065 T at 15 d<sup>-1</sup> and 17.8 d<sup>-1</sup>, at 0.28 T at 11 d<sup>-1</sup> and 15 d<sup>-1</sup>, at 0.5 T at 11.8 d<sup>-1</sup> and 11.8 d<sup>-1</sup>, respectively (Fig. 7).



**Figure 7.** Effects of magnets on *M. persicae* progeny age-stage-specific reproductive value ( $v_{xj}$ )

The population parameters of these two morphs progeny had a significant logarithmic relationship with magnets intensities (Fig. 8). The effects of magnets on the intrinsic rates of increase ( $r$ ), finite rates of increase ( $\lambda$ ), net reproductive rates ( $R_0$ ), and gross reproductive rate (GRR) of winged progeny decreased significantly compared with wingless ones at the same magnets, and the wingless progeny were statistically higher than the winged ones, but all of them were statistically higher than that controls ( $P < 0.01$ ). The effects of magnets on mean generation times ( $T$ ) wingless progeny were stronger than winged ones except 0.5 T, and winged progeny was statistically higher than that of the control while wingless progeny exhibited no significance compared with the control ( $P < 0.01$ ) (Fig. 8). 0.065 T wingless progeny had the highest values of intrinsic rates of increase ( $r$ ), finite rates of increase ( $\lambda$ ), net reproductive rates ( $R_0$ ), and gross reproductive rate (GRR), while 0.28 T winged morph had the lowest values of these parameter.



**Figure 8.** Effects of magnets on progeny population parameters

### Total phenol and flavonoid content

We focused on variation in total phenol and flavonoid content of plants to investigate the effects of *M. persicae* on secondary metabolite accumulation. The total phenol content accumulated varied across all magnets. After 14 days of infestation, total phenol content of wingless progeny was higher than winged ones at the same magnets. The highest total phenol content was found 0.065 T wingless ones ( $0.932 \text{ mg}^{-1} \text{ g}$ ), while 0.28 T winged progeny showed a significantly lower accumulation of total phenol content ( $0.301 \text{ mg}^{-1} \text{ g}$ ), total phenol content of the wingless morphs were higher than that of controls of ( $0.410 \text{ mg}^{-1} \text{ g}$ ) and while winged ones was lower than the control of ( $0.342 \text{ mg}^{-1} \text{ g}$ ) (Table 1).

Considering the difference in content of total phenol in infested plants across all the magnets, changes in flavonoid content were also determined to observe its response to *M. persicae* infestation. Changes in flavonoid content in each magnets were assessed 14 days after infestation. There was a significant difference between the winged and wingless progeny within the same time magnets. 0.065 T wingless progeny had the highest increase in flavonoid content ( $1.815 \text{ mg}^{-1} \text{ g}$ ) while 0.5 T winged progeny had the lowest flavonoid accumulation ( $0.573 \text{ mg}^{-1} \text{ g}$ ). Both of these two morphs were higher than that of controls of wingless ( $0.845 \text{ mg}^{-1} \text{ g}$ ) and winged ( $0.499 \text{ mg}^{-1} \text{ g}$ ). Interestingly, we noticed that the trend in flavonoid content change was very similar to that previously observed in the total phenol content (Table 1).

**Table 1.** The accumulation effect of *M. persicae* exposure magnets feeding on cabbage on the (A) total phenol content ( $\text{mg}^{-1} \text{g}$ ) and (B) flavonoid content ( $\text{mg}^{-1} \text{g}$ )

Magnets	wing type	Total phenol	P	Total flavonoid	P
CK	winged	0.342±0.018d	p<0.05	0.499±0.015c	p<0.05
	wingless	0.410±0.031c		0.845±0.220bc	
0.065T	winged	0.852±0.029a		1.602±0.146a	
	wingless	0.932±0.061a		1.815±0.193a	
0.280T	winged	0.301±0.021cd		0.592±0.014c	
	wingless	0.706±0.022b		1.003±0.079b	
0.500T	winged	0.321±0.032cd		0.573±0.131c	
	wingless	0.652±0.036b		0.937±0.243b	

The data represented are the mean ± standard deviation (SD). Different lowercase letters in the columns indicate significant differences among different magnets at the 0.05 level (Tukey's test)

## Discussion

Numerous environmental cues affect the production of insect alatae forms. Temperature, photoperiod and humidity may all influence the production of winged forms. Our results confirmed that magnets probably had a vital catalytic role in the development of insect alatae forms. Moreover, the effect of magnets pressure on two morph progeny varied significantly in terms of the immature developmental duration, longevity, fecundity, population parameters; two morphs *M. persicae* progeny in total phenol and flavonoid content of cabbages were also significantly different. This study was important for understanding adaptation and evolution of insect polyphenism under high magnets intensities with short time exposure.

Winged morph production has been considered a driver of magnets regulation in insect. Previously, Wan et al. (2014), reported the phenotypic of the magnetic field effects on development and physiology in small brown planthopper *Nilaparvata lugens* female adults of the macropterous and brachypterous; Wan et al. (2015, 2020), observed wing dimorphism, flight duration, fecundity and longevity of the macropterous and brachypterous of the white-backed planthopper *Sogatella furcifera* female adults were significantly affected by the near-zero magnetic field and geomagnetic field; Hsu and Weng (2021), studied that the superparamagnetic magnetite prevented bee's mortality and wing deformity; Pan et al. (2016), studied that the amount of magnetic particles associated with the developmental stage and the wing form of macropterous versus brachypterous insects; Migdal et al. (2022), elucidated that 1 mT and 1.7 mT of magnetic field exposure caused changes in honeybee wingbeat frequency and wing movement. Our results confirmed earlier studies and clearly showed that aphids wing polyphenism are responsive to magnets, the proportion of winged progeny in 0.28 T treatment was significantly higher than that of treatments at 0.065 T and 0.5 T. It has been indicated that magnets stimulated the production of winged progeny probably related to the change of juvenile hormone. Previous studies have reported that juvenile hormone was related with the wing dimorphism and the development of brachypterous wings in *Sogatella furcifera* under the near-zero magnetic field (Wan et al., 2014). Moreover, the gene expression levels of juvenile hormone epoxidehydrolase in 5th instar nymphs of *S. furcifera* and

juvenile hormone methyltransferase in *S. furcifera* macropterous virgin female adults consisted with an up-regulation of juvenile hormone (Van Ekert et al., 2014; Wan et al., 2020), which further indicated that the juvenile hormone involved in the regulation of wing dimorphism under the magnetic field exposure.

The 20-Hydroxyecdysone and juvenile hormone may coordinately orchestrate aphid growth development (Meelkop et al., 2011; Zhang et al., 2017). Firstly, previous findings suggested that change patterns of 20-Hydroxyecdysone and juvenile hormone in *S. furcifera* involved with prolonging the nymphal development under the near-zero magnetic field and geomagnetic field (Van Ekert et al., 2014; Wan et al., 2015). Many experiments have also shown that juvenile hormone reduced fecundity or sterility and extended longevity in grasshoppers, butterflies, hemipterans, and fruit flies<sup>41</sup>. Secondly, juvenile hormone was responsible for the significantly shorter life span of macropterous virgin female adults under the NZMF compared to the GMF in *S. furcifera* (Wan et al., 2015, 2020); some research has also reported that juvenile hormone involved with the regulation of wing dimorphism and the development of brachypterous wings in *N. lugens* (Meelkop et al., 2011; Wan et al., 2014). Our research confirmed that the immature total preoviposition period, female longevity and female entire lifespan of two morphs progeny were significantly different under magnets.

The reproductive adaptive strategies of magnets on two morph *M. persicae* progeny probably contributed to the embryonic development. Several studies have elucidated a potential effect of magnets on embryogenesis development. *Drosophila* larvae showed abnormalities in embryogenesis during exposures to 2.4 T magnets (Todorović et al., 2015); 14.1 T SMF delayed hatching rate in mosquito eggs (Pan and Liu, 2004); 9.0 T SMF temporarily delayed pharyngeal development of zebrafish embryos (Ge et al., 2019); 8 T induced the embryonic development differentiation of the early zebrafish embryo (Civelekoglu-Scholey et al., 2006). *M. persicae* is typically parthenogenesis and viviparous, the embryogenesis had already developed completely within the mothers' ovarioles before the offspring's gave birth (Hu et al., 2019). A physical mutagenic agent could affect wing polyphenism during the embryonic period of insects, which thereby achieving the reproduction difference of these two progeny. For example, in comparison to the controls, 0.065 T wingless progeny had the highest fecundity while 0.28 T winged had the lowest value. Indeed, there are a trade-off between dispersion and reproduction traits (Chang et al., 2021). Previous researches on aphid female wing polyphenism addressed that the first-instar nymphs of wingless viviparous females possess wing and flight-muscle primordia. However, this wing characteristics subsequently degenerate during postembryonic development, the wingless nymphs subsequently probably shunted the energy derived from muscle degeneration to reproductive organs of postembryonic development (Zhang et al., 2019; Ohde et al., 2022). The energetic and material costs required developing wings and flight apparatus according to the 'fitness costs' theory. Flight-capable species consume the energy to develop and maintain the flight muscles at the expense of reproduction. Flight-incapable species lack the capability fly but possess a greater reproductive output (Guerra, 2011).

Plants, inevitably, are attacked by diverse phytophagous insects in agricultural. Accordingly, plants have evolved a plethora of chemical defenses, such as secondary metabolites, to reduce the damage caused by arthropod herbivores (Mithöfer and Boland, 2012). Phenol and flavonoid are dominant plant secondary metabolites compounds that probably affected the weight, developmental rate, and survivorship of insect herbivores through their toxicity (Rani and Pratyusha, 2013; Moctezuma et al., 2014; Jamwal et al.,

2018). Meanwhile, the accumulation of phenol substances is the most visible secondary metabolites protecting plants from insect pest attack (Wang et al., 2019). Nonetheless, the link between total phenol compounds and insect performance remains controversial. We here addressed the effects of magnets on two morph progeny infestation on total phenol and flavonoid content in different cabbages after 0.065 T, 0.28 T, and 0.5 T of magnets infestation *M. persicae*. Total phenol and flavonoid content accumulation varied across all magnets in this study. Change in phenol and flavonoid content is a dynamic process as aphid exposure intensities increases. For example, in comparison with the controls, the effect of magnets pressure on two morph progeny varied significantly in terms of total phenol and flavonoid content in cabbages, the total phenol and flavonoid content of 0.065 T wingless progeny had the highest increase while 0.28 T winged progeny had the lowest accumulation. Plant phenol and flavonoid contents often change in response to insect herbivore attacks (Treutter, 2006; Zhang et al., 2017). Previous research has shown that higher levels of phenol in plants can prevent pests from feeding. In comparison to the other treatment, this suggests that 0.065 T wingless progeny appears to be able to accumulate sufficient phenol and flavonoid content in response to peach aphid attack. In accordance with the current findings, Zhu et al. (2011) observed that the total phenol content of resistant varieties was significantly increased with the length of infested time (Zhu et al., 2011); Julkunen-Tiitto et al. (2015) also discovered that various plant organ, tissue and developmental-stage dependent changes in flavonoid and phenol due to intensity of UV-exposure. Moreover, The accumulation of total phenol and flavonoid content correlated positively with the immature developmental duration, longevity, fecundity, population parameters. This suggests that the high accumulation of total phenol and flavonoid contents hampered the performance of the *M. persicae* by delaying its development.

## Conclusion

In summary, our findings reveal that the accumulation of total phenol and flavonoid content correlated positively with the life history parameters, for example, 0.065 T wingless progeny had the highest values of intrinsic rates of increase ( $r$ ), finite rates of increase ( $\lambda$ ), net reproductive rates ( $R_0$ ), and gross reproductive rate (GRR), while 0.28 T winged morph had the lowest values of these parameter; 0.065 T wingless progeny had the highest increase in flavonoid content ( $1.815 \text{ mg}^{-1} \text{ g}$ ) while 0.28 T winged progeny had the lowest flavonoid accumulation ( $0.543 \text{ mg}^{-1} \text{ g}$ ). However, the seasonal fluctuations and other physical factors in the field would likewise probably contribute to the outputs of phenotypic plasticity. Furthermore, juvenile hormones have been depicted to influence wing polymorphism and physiology in insect *S. furcifera*. Thus, further researches would focus on the impacts of juvenile hormones of magnets on aphid wing morph differentiation combined with other environmental factors.

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