

Effects of Different Host Plants on the Age-Stage, Two-Sex Life Table of *Bradysia odoriphaga* (Diptera: Sciaridae)

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Abstract

The age-stage two-sex life table resolves sex-specific developmental trajectories and enables accurate quantification of pest growth, survival and reproduction. As a subterranean herbivore, *Bradysia odoriphaga* (chive maggots) has undergone long-term coevolution with host plants, generating distinct host preference and adaptive differentiation; this study further quantifies such coevolutionary differentiation via age-stage two-sex life table parameters and interprets its theoretical implications for plant-insect coevolution. Field monitoring and laboratory life table assays were conducted on seven local vegetables of four families in cold Heilongjiang. Field data show temperature and precipitation jointly regulate seasonal population fluctuations, with three annual adult occurrence peaks. Laboratory assays reveal significant variations in developmental duration, survival, fecundity and intrinsic rate of increase among the seven hosts, with *A. tuberosum*, *A. fistulosum* and *C. sativus* supporting the highest population performance, whereas *S. tuberosum* severely suppresses population growth. Stage-specific analysis identifies early-instar larvae as the key stage for population regulation. This study fills gaps in cold-region research on its host adaptability, provides quantitative evidence for pest-plant coevolution, and offers theoretical support for ecological pest management and scientific rotation in organic chive cultivation.

Introduction

The interaction between herbivorous insects and their host plants represents a classic model of long-term reciprocal coevolution (Franziska and Georg 2022, Jones et al. 2022). Host nutritional profiles and defensive secondary metabolites impose divergent selective pressures on pest growth, survival and reproduction, driving distinct host preference and adaptive differentiation across phytophagous species (V and A 2003, Lingfei et al. 2021, Farhan et al. 2026). *Bradysia odoriphaga* (chive maggots, Diptera: Sciaridae), a subterranean root-feeding sciarid pest, poses severe threats to the cultivation of *Allium tuberosum* (Zhang et al. 2014). Its larvae hide underground within root tissues and display overlapping generations, which greatly reduces the efficiency of chemical control and easily triggers pesticide residues and pest resistance problems (Yang et al. 2015, Yang et al. 2020, Xie et al. 2024).

Previous investigations have confirmed that chive maggots is capable of utilizing more than 30 vegetable species from seven plant families, with clear fitness gaps among different host types (Zhu et al. 2017). For instance, Chinese chives are the optimal hosts for oviposition and growth, while *Allium sativum* L. (garlic, Asparagales: Amaryllidaceae) exerts an inhibitory effect (Yang et al. 2020, Yan et al. 2021). The occurrence dynamics of this pest show prominent geographic variations: populations peak in spring and autumn under northern open-field conditions, whereas continuous multi-generational reproduction can be observed in greenhouses (Pineda and Marcos-García 2008, Cheng et al. 2017, Shi et al. 2018). Parameters such as generation quantity and damage duration differ remarkably across provinces including Jiangsu, Hebei and Shandong. Key environmental regulators include temperature (optimal range: 20–25°C), soil moisture (optimal range: 20%–24.7%), and host defensive compounds like allicin (Shi et al. 2020b, Xie et al. 2024), all of which exert profound influences on the developmental duration, survival and fecundity of chive maggotss (Shi et al. 2020a). At present, chemical pesticides still dominate pest control practices, while physical, agricultural and biological control methods suffer from unstable efficacy (Chen et al. 2017, Wang et al. 2021, Fu et al. 2022); a mature integrated pest management system specialized for cold-region chive plantations has not yet been established.

The age-stage two-sex life table is a robust quantitative analytical tool for arthropod population ecology (Zhu et al. 2022, Hu et al. 2024, Chen et al. 2025). This method distinguishes developmental disparities between males and females, and enables precise calculation of core demographic traits associated with pest fitness (Baral and Jha 2018, Park et al. 2021, Chi et al. 2023). Nevertheless, existing studies concerning the host adaptation of chive maggots merely rely on qualitative phenotypic observation (Chunni et al. 2021, Chunni et al. 2023, Yang et al. 2026). Few researchers have adopted complete two-sex life table datasets to quantitatively evaluate the matching degree of pest-host coevolution. In particular, systematic comparative life-table experiments targeting staple vegetables grown in cold regions such as Heilongjiang remain vacant. The hierarchical adaptive performance of chive maggotss on local dominant crops has not been quantitatively clarified, forming a theoretical bottleneck for developing region-specific ecological control strategies.

In the present research, seven widely cultivated vegetable species from four families in Heilongjiang Province were selected to construct age-stage two-sex life tables of chive maggots. Combined with a full-year field population monitoring survey at two representative chive planting sites, we systematically quantified how diverse host resources alter the pest's developmental rhythm, survival status and population reproductive potential. By synthesizing individual life-history traits and population demographic parameters, this study quantitatively unravels host adaptive differentiation shaped by cold-climate plant-insect coevolution. It provides new empirical quantitative evidence for the coevolution theory of underground sciarid pests, and offers reliable theoretical guidance for ecological regulation and scientific crop rotation in cold-region organic chive cultivation.

Materials and Methods

Test host plant

Four families and seven host plant species were selected from Heilongjiang Province, China, including *Allium tuberosum* Rottl. ex Spreng. (chive, Asparagales: Amaryllidaceae), *Allium fistulosum* L. (Welsh onions, Asparagales: Amaryllidaceae), *Allium sativum* L. (garlic, Asparagales: Amaryllidaceae), *Cucumis sativus* Linn. (cucumbers, Cucurbitales: Cucurbitaceae), *Raphanus sativus* L. (radishes, Brassicales: Brassicaceae), *Brassica pekinensis* (Lour.) Rupr. (cabbages, Brassicales: Brassicaceae), and *Solanum tuberosum* (potatoes, Solanales: Solanaceae). All these host plants are main cultivated varieties in Heilongjiang Province and were collected from the organic vegetable planting base in the campus of Heilongjiang Academy of Agricultural Sciences.

Test insect

The *Bradysia odoriphaga* used in the experiment were obtained from the Institute of Plant Protection, Tianjin Academy of Agricultural Sciences in December 2012. The population was continuously reared in the laboratory and cultured in an artificial climate incubator (Model: MLR-352H-PC) under the following conditions: temperature of 25 ± 1 °C, relative humidity of 80%, and a photoperiod of 14:10 (L:D) h (Hoffmann et al. 2001). The population of *Bradysia odoriphaga* used for the life table study had been subcultured for more than 10 generations.

Survey of Population Dynamics in the Field

Field population dynamics of the chive maggots were investigated in major Chinese chive-producing areas of Heilongjiang Province, with open-field Chinese chive fields in Hulan (126°58'E, 46°N) and Ning'an (129°47'E, 44°35'N) selected as representative survey sites. The experimental materials included dissecting microscopes, magnifying glasses, forceps, fine threads, scissors, iron wires, and 25 cm × 15 cm yellow sticky traps manufactured by Taizhou Jinnong Screen Factory. From January to December 2024, yellow sticky traps were used to monitor the population dynamics of adult chive maggotss. The yellow sticky traps were vertically fixed 20 cm above the ground, with 10 traps placed at 5 m intervals at each survey site. Observations were conducted daily at 16:00, and insect numbers were counted weekly with traps replaced, for a continuous observation period of one year to clarify the distribution and occurrence of this pest in Heilongjiang Province.

Establishment of two-sex life table

All seven tested host plant species were cut into 1.0 cm × 1.0 cm pieces, which were then placed separately into round transparent plastic boxes (19 cm in diameter, 10 cm in height) serving as adult oviposition containers. Ten pairs of newly emerged adults were introduced into each box. Egg masses were collected 12 hours later, with 60 eggs gathered for each host plant species, and the experiment was replicated three times for the life table study. The eggs were reared under the aforementioned experimental conditions, and the egg hatching rate was recorded on a daily basis. After hatching, the larvae were individually transferred to new Petri dishes for separate rearing, and their survival status was documented daily. Once pupation occurred, the pupae were moved to new Petri dishes. Upon adult emergence, the adults were paired by sex and placed into oviposition plastic containers. The number of eggs laid was monitored daily, and the adults were transferred to new containers regularly; the total fecundity of each adult was recorded until its death.

Data analysis

All raw data of individual chive maggotss were analyzed according to the principles of the age-stage, two-sex life table (Hsin and M. 1988). Parameters, means, and standard errors were calculated using the bootstrap method (Brown 1995). Parameters included intrinsic rate of increase (r_m), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T). The developmental duration, fecundity, age-specific survival rate (S_{xj}), age-specific fecundity (f_{xj}), age-stage-specific survival rate (l_x), age-stage-specific fecundity (m_x), age-specific expectation of life (e_{xj}), age-stage-specific reproductive value (v_{xj}), female preoviposition period (APOP), and female time to first oviposition (TPOP) were analyzed using the TWOSEX-MSChart program. In the analysis of variance, the Tukey-Kramer method was used to compare differences between various methods, with a P-value < 0.05 considered statistically significant (Chi 2015).

Results

Field Population Dynamics of chive maggots in Heilongjiang Province, China

Yellow sticky traps were deployed in Hulan and Ning'an to monitor adult chive maggots populations across 2024. Temporal dynamics of weekly precipitation, monthly temperature and pest density are illustrated in Fig 1a,b. Temperatures rose to mid-year peaks then declined at both sites, with precipitation peaking synchronously alongside high pest density. Correlation analysis (Fig 1c,d) showed mean temperature had a significant positive correlation with pest density (Hulan: $R = 0.614$; Ning'an: $R = 0.652$), and suitable precipitation amplified temperature's promotion of pest abundance. Adults first emerged in mid-April, forming three annual population peaks (mid-May, mid-late June, late August), while adults were nearly absent from October to early April of the next year.

These three seasonal outbreak peaks represent phenological synchrony formed by long-term coevolution between chive maggots and cold-region *Allium* hosts. April–August climatic conditions match the optimal growth requirements of both chives and maggots, where balanced root nutrients and host secondary metabolites benefit pest survival. From October to early April, host dormancy and accumulated defensive compounds drastically suppress maggots populations, demonstrating coevolutionary phenological constraints from host plants.

The Influence of Host Plants on the Developmental Calendar, Longevity, and Fecundity of the chive maggots

Analysis of the developmental duration, longevity, and fecundity of the chive maggots on seven different host plants (Chinese chives, onions, cucumbers, cabbages, radishes, and potatoes) (Table 1) revealed significant differences in its development, longevity, and fecundity across these hosts. In terms of developmental duration (TPOP), no significant differences were observed in TPOP between Chinese chives ($25.63 \pm 0.42_d$), Welsh onions ($27.87 \pm 0.94_d$), and cucumbers ($25.18 \pm 0.74_d$). However, these values were significantly shorter than those on garlic, cabbages, radishes, and potatoes, with the longest TPOP recorded on potatoes ($55.83 \pm 1.70_d$). There were noticeable differences in egg developmental duration; the shortest egg duration was on potatoes ($3.00 \pm 0.00_d$), which was significantly different from that on other hosts, while the longest was on garlic ($6.00 \pm 0.00_d$). During larval development, no significant differences were found in duration between cucumbers ($14.61 \pm 1.10_d$) and Chinese chives ($15.55 \pm 0.19_d$), and both were shorter than those on other hosts. The subsequent order was Welsh onions, garlic, and radishes, with the longest larval duration on potatoes ($46.23 \pm 1.82_d$). Pupal development exhibited an exception with cucumbers: except for cucumbers ($5.13 \pm 0.67_d$), no significant differences were observed in pupal duration across other hosts, and the pupal duration on cucumbers was the longest among all hosts. No significant differences were detected in adult longevity and APOP across the seven host plants. In terms of fecundity, the chive maggots showed the highest fecundity on Chinese chives (87.48 ± 0.94), followed by Welsh onions and cucumbers. The lowest fecundity was recorded on potatoes (28.33 ± 4.37). No significant differences were found in fecundity among garlic, radishes, and cabbages.

The faster development and higher fecundity of chive maggots feeding on *Allium* crops (Chinese chive, Welsh onion) and cucumber, alongside sharply extended developmental time and reduced reproduction on potato, reflect host-specific adaptive divergence shaped by long-term plant-insect coevolution. Significant inter-host divergence was primarily detected in egg and larval developmental durations, indicating that embryonic and juvenile growth stages undergo intense directional selection during the long-term coadaptation between chive maggots and its host vegetation.

Table 1 Developmental Duration of Each Life Stage, Adult Longevity, and Fecundity of the Chive maggots on Different Host Plants

stages	host plants						
	Chive	Onion	Cucumber	Garlic	Cabbage	Radish	Potatoes
Egg	5.00±0.00 ^b	4.24±0.28 ^{cd}	3.68±0.07 ^e	6.00±0.00 ^a	4.44±0.04 ^c	4.00±0.00 ^{de}	3.00±0.00 ^f
Larva	15.55±0.19 ^{de}	18.59±0.66 ^d	14.61±1.10 ^e	22.31±1.09 ^c	43.48±0.23 ^a	36.35±0.58 ^b	46.23±1.82 ^a
Pupa	3.31±0.36 ^b	3.24±0.17 ^b	5.13±0.67 ^a	4.45±0.55 ^{ab}	3.53±0.38 ^b	3.24±0.10 ^b	3.21±0.21 ^b
Adult	3.13±0.18 ^a	3.04±0.18 ^a	3.07±0.36 ^a	3.10±0.08 ^a	2.84±0.34 ^a	3.00±0.08 ^a	3.15±0.12 ^a
Preadult	23.91±0.47 ^d	26.14±1.04 ^d	23.36±1.08 ^d	32.84±0.75 ^c	51.95±0.43 ^a	43.77±0.76 ^b	52.98±1.95 ^a
APOP	1.70±0.23 ^a	1.58±0.07 ^a	1.94±0.39 ^a	1.34±0.12 ^a	1.52±0.23 ^a	1.56±0.08 ^a	1.67±0.47 ^a
TPOP	25.63±0.42 ^d	27.87±0.94 ^d	25.18±0.74 ^d	34.84±0.60 ^c	53.72±0.25 ^a	45.69±0.46 ^b	55.83±1.70 ^a
Fecundity	87.48±0.94 ^a	69.86±3.22 ^{ab}	73.26±2.23 ^{ab}	54.90±4.63 ^b	56.00±2.89 ^b	54.98±14.24 ^b	28.33±4.37 ^c

Note: APOP refers to the developmental duration from female adult eclosion to the first oviposition. TPOP refers to the total developmental duration from newly laid egg to the first oviposition in female adults. In the analysis of variance, the Tukey-Kramer method was used to compare differences between various methods, with a P-value < 0.05 considered statistically significant

The effects of host plants on the survival and age characteristics of the chive maggots

The S_{xj} curves (Fig 2) show that in the graphs corresponding to each host, the curves of different life stages overlap significantly, and there are differences in the survival rates of different individuals. In terms of host selection, the survival curves of male and female adults overlap synchronously in the curves corresponding to Chinese chives, Welsh onions, and cucumbers. However, on garlic, radishes, cabbages, and potatoes, the survival curve of males appears earlier than that of females, and males have a longer lifespan. In terms of overall survival rate, the chive maggots shows relatively high survival rates on Chinese chives, Welsh onions, and cucumbers, reaching 57.78%, 55.56%, and 51.11% respectively, which are significantly higher than those on garlic (35.56%), cabbages (32.22%), and radishes (28.89%). The lowest survival rate was recorded on potatoes, at only 21.11%. Meanwhile, the mortality rate during the larval stage is a key factor influencing the overall survival rate of the chive maggots, and its lifespan varies significantly across different host plants, being the longest on potatoes.

Analysis of the age-stage-specific survival rate (l_x), age-stage-specific fecundity (m_x), and age-stage-specific reproductive value ($l_x m_x$) of the chive maggots on different host plants (Fig 3) shows that, except for potatoes, the chive maggots can survive and reproduce on the other host plants. The m_x and $l_x m_x$ curves of the chive maggots on Chinese chives both have relatively high peaks. Female age-stage-specific fecundity (f_x) refers to the number of offspring produced per individual per day at age x and stage j . However, only females can reproduce, so only the f_x curve of females is presented. The chive maggots has a single highest f_x peak on garlic, but the other f_x peaks are relatively low. There are two relatively high f_x peaks on Chinese chives, followed by cucumbers, and the lowest peak on potatoes, with the longest oviposition period. Similarly, l_x is the curve simplified by ignoring the stage difference in the S_{xj} curve. The chive maggots has the longest developmental duration and the lowest survival rate on potatoes.

The e_{xj} curve (Fig 4) represents the expected remaining lifespan of an individual at age x and stage j . For example, the expected lifespan of eggs of chive maggotss reared on Chinese chives is 22.5 days, while the expected lifespan of 17-day-old larvae exceeds 6 days. The expected lifespan of eggs of chive maggotss is the longest on cabbages, followed by potatoes and radishes, and shortest on cucumbers. Meanwhile, the expected lifespan of chive maggots larvae reared on Chinese chives, garlic, and cabbages decreases gradually over time, while it shows an irregular change on other host plants.

Synchronous overlapping survival curves of male and female adults on optimal hosts, contrasted with earlier mortality of males on unfavorable hosts, reveal divergent resource allocation strategies forged under coevolutionary pressure. Larval mortality dominated overall population survival loss across all tested hosts; early instar juveniles may exhibit the greatest susceptibility to host nutrients and defensive phytochemicals, which likely functions as a vital survival filter throughout reciprocal plant-insect evolutionary interactions.

The Effect of Host Plants on the Breeding Value and Population Parameters of the chive maggots

Reproductive value (v_{xj}) refers to the contribution rate of an individual to future offspring from age x to stage j . Since males do not produce offspring, there is no v_{xj} curve for males (Fig 5). There were no significant differences in v_{xj} during the pre-pupal stage of the chive maggots on Chinese chives, Welsh onions, and cucumbers, while v_{xj} were similar on garlic, cabbages, radishes, and potatoes. The female had a single highest v_{xj} peak on garlic, while the other peaks were relatively small. There were two relatively high v_{xj} peaks on Chinese chives, which were higher than those on other host plants, followed by Welsh onions and cucumbers.

Analysis of the population parameters of the chive maggots on different host plants (Table 2) shows that the intrinsic rate of increase (r_m), net reproductive rate (R_0), and finite rate of increase (λ) of the chive maggots on Chinese chives were the highest, reaching 0.12 ± 0.00 , 26.24 ± 0.28 , and 1.13 ± 0.00 , respectively. All values were significantly different from those on other host plants, except for the λ value, which was the same as that on cucumbers. Similarly, the chive maggots reared on potatoes had the smallest r_m (0.01 ± 0.00), R_0 (1.89 ± 0.29), and λ (1.01 ± 0.00). The mean generation time (T) is the time required for a population to reach an R_0 -fold size in a stable age distribution. The longest T value was recorded on potatoes (56.93 ± 1.05), followed by cabbages (54.52 ± 0.24). The shortest T values were on cucumbers (25.73 ± 0.63) and Chinese chives (26.55 ± 0.52), followed by Welsh onions (28.50 ± 0.69). There were no significant differences in the gross reproductive rate (GRR).

Gradients in the intrinsic rate of increase (r_m) and net reproductive rate (R_0) serve as core quantitative metrics to measure the coevolutionary compatibility between chive maggots and its hosts. Higher coevolutionary matching corresponds to stronger population growth potential. The gradient difference of core population growth indices further verified that early larval development serves as the decisive bottleneck determining the final coevolutionary compatibility between this sciarid pest and different host lineages.

Table 2 Effects of Different Host Plants on the Population Parameters of the Chive maggots

Parameter	Host plants						
	Chive	Onion	Cucumber	Garlic	Cabbage	Radish	Potatoes
r_m	0.12 ± 0.00^a	0.11 ± 0.00^b	0.11 ± 0.00^b	0.06 ± 0.01^c	0.04 ± 0.00^d	0.04 ± 0.00^d	0.01 ± 0.00^e
R_0	26.24 ± 0.28^a	23.20 ± 0.86^b	21.98 ± 0.67^b	8.69 ± 0.78^c	9.33 ± 0.48^c	5.28 ± 0.27^d	1.89 ± 0.29^e
λ	1.13 ± 0.00^a	1.12 ± 0.00^b	1.13 ± 0.00^a	1.06 ± 0.00^c	1.04 ± 0.00^d	1.04 ± 0.00^d	1.01 ± 0.00^e
T	26.55 ± 0.52^{de}	28.50 ± 0.69^d	25.73 ± 0.63^e	35.58 ± 1.11^c	54.52 ± 0.24^a	46.99 ± 0.71^b	56.93 ± 1.05^a
GRR	80.99 ± 2.55^a	74.23 ± 14.32^{ab}	72.26 ± 6.23^{ab}	45.33 ± 16.79^{abc}	48.76 ± 10.50^{abc}	37.63 ± 13.55^{bc}	19.18 ± 3.43^c

Note: In the analysis of variance, the Tukey-Kramer method was used to compare differences between various methods, with a P-value < 0.05 considered statistically significant

Discussion

Quantitative Metrics for Quantifying Pest-Host Coevolutionary Compatibility

This study utilized a multi-scale indicator system to quantitatively characterize the coevolutionary matching degree between chive maggots and different host plants, covering individual, population and stage-specific metrics. At the individual level, we recorded developmental duration of each life stage, stage survival rate, female fecundity, adult longevity, adult preoviposition period (APOP) and total preoviposition period (TPOP)(Abbes et al. 2024, Zhai et al. 2025). These phenotypic traits directly mirror the evolutionary selective pressure imposed by host plants on insect growth and reproductive performance. At the population level, three core demographic parameters served as key quantitative proxies for coevolutionary adaptation: the intrinsic rate of increase (r_m) reflects the long-term evolutionary expansion potential of pest populations; the net reproductive rate (R_0) represents generational reproductive fitness; the mean generation time (T) quantifies the degree of phenological synchrony formed via plant-insect coevolution. For stage-specific assessment, the age-stage-specific survival rate (S_{xj}) and age-stage reproductive value (V_{xj}) were applied to identify developmental stages exposed to the strongest coevolutionary selection. Our results confirmed that early-instar larvae undergo the most intense filtering pressure during plant-insect coevolution(Zhu et al. 2022, Maryam et al. 2023).

Conventional research on chive maggots host preference mostly relies on qualitative observation of biological phenotypes and fails to quantify coevolutionary adaptation. In contrast, the age-stage, two-sex life table method used in this study differentiates male and

female performance and covers the full complete life cycle of the pest, enabling accurate quantitative evaluation of coevolutionary compatibility(Zhu et al. 2022). This analytical framework fills the research gap in quantitative assessment of coevolutionary interactions between chive maggots and cold-region vegetable hosts.

The Influence of Host Plants on the Biological Characteristics and Adaptive Differences of the Chive maggots

The age-stage two-sex life table data revealed clear differentiation in pre-reproductive schedules of chive maggots across tested hosts (Table 1). The female adult preoviposition period (APOP) remained statistically consistent among all seven vegetable species, suggesting that short-term post-eclosion physiological status of adult females is barely affected by larval feeding substrates. In contrast, total preoviposition period (TPOP), an integrated index covering the full immature developmental cycle, varied drastically between host groups (Table 1). Statistical correlation analysis further indicated that the intrinsic rate of increase (r_m) was closely linked to mean generation time (T) (Table 2), rather than APOP alone. This partially explains the apparent inconsistency with Lewontin's classic theory on reproductive timing, as the framework of age-at-first reproduction fails to incorporate the lengthy pre-adult growth process of subterranean phytophages. Such findings highlight that pre-adult developmental duration acts as a dominant factor shaping population expansion potential for root-feeding sciarids(R et al. 2005, Diseases et al. 2018, Pan et al. 2024).

Host plant chemical compositions create divergent physiological barriers for larval development. Brassicaceous vegetables accumulate glucosinolates(E et al. 2000, Vanda et al. 2023), while potato produces steroidal alkaloids(Visser , Akiyama et al. 2025); these two defensive phytochemicals impose strong growth suppression effects on chive maggotss(Zeci et al. 2021). Unlike Allium crops that generate tolerable allicin, the above toxic compounds cannot be efficiently metabolized by this pest, which may underpin the extended larval developmental duration observed on unfavorable hosts(Zhu et al. 2017, Chunni et al. 2023). Meanwhile, larval mortality served as the primary limiting factor for overall population survival across all tested hosts (Fig. 2). Early instar juveniles may exhibit the greatest susceptibility to host nutrients and defensive phytochemicals, which likely functions as a vital survival filter throughout reciprocal plant-insect evolutionary interactions(Yan et al. 2019, Guodong et al. 2022).

Phylogenetic differences among host plants lead to hierarchical differentiation of pest population fitness (Table 2). As long-term co-evolved partners, Allium vegetables provide matched nutrients and mild chemical stress, supporting superior population performance. Cucumber lacks deep co-adaptive linkage with this pest and only delivers moderate fitness outcomes, whereas Solanaceae and Brassicaceae form evolutionarily inhibitory habitats(He et al. 2026, Saw et al. 2026). The descending gradient of (r_m) and (R_0) fully reflects such adaptive divergence, with potato showing near-zero intrinsic population growth capacity (Table 2), representing the weakest pest-host matching among all test plants.

Distinct inter-host adaptive discrepancies provide baseline evidence for standardized lab rearing and field population forecasting (Fig. 3, Fig. 5). Allium tuberosum supported balanced development, survival and oviposition performance, making it the most suitable substrate for indoor mass rearing. The obvious fitness gap between host groups also interprets the field preference of chive maggotss for Allium plots, and theoretically supports the use of inhibitory crops as intercropped barriers. Overall, the life-history traits quantified in this work establish a phenotypic foundation for uncovering host-selection mechanisms of underground herbivores, and supply reference parameters for regional pest early-warning systems.

Hierarchical Coevolutionary Adaptation Patterns Between Chive maggots and Its Host Plants

We classified the seven tested hosts into three functional groups according to life table demographic parameters to unpack the coevolutionary interplay between chive maggotss and different plant hosts. Optimal coevolved hosts included Chinese chive and Welsh onion (Alliaceae), which formed bilateral adaptive matching through long-term reciprocal coevolution. While Allium plants continuously synthesize allicin as defensive metabolites, chive maggotss have formed physiological adaptation to withstand this chemical stress; concurrently, root nutrients such as amino acids and soluble sugars of Allium crops precisely match the nutritional requirements of larval development. This mutually beneficial co-adaptation was manifested as the shortest generation time, highest survival rate, maximum single-female fecundity, as well as the greatest (r_m) and (R_0), which stands for a typical stable coexistence phenotype driven by plant-insect coevolution. Cucumber (Cucurbitaceae) was defined as a suboptimal temporary host, as it shares no long coevolutionary association with chive maggotss. Its root tissues feature low levels of defensive secondary metabolites and abundant watery nutrients that can temporarily support pest population proliferation, yet its significantly lower (R_0) relative to Allium hosts confirms it merely serves as a transitional suitable host without stable coevolutionary compatibility. Potato (Solanaceae), Chinese cabbage and radish (Brassicaceae) fell into the category of evolutionarily inhibitory hosts, since glucosinolates from Brassicaceae and steroidal alkaloids from Solanaceae are defensive substances that chive maggotss have not evolved matched detoxification pathways

to tolerate (Madhusudana et al. 2021, Thompson et al. 2025). No stable co-adaptive linkage was built between the pest and these plant groups; larvae reared on these hosts suffered drastically extended developmental duration, sharply declined survival and fecundity, plus nearly stagnant population growth, which fully illustrates the evolutionary antagonism triggered by host chemical defenses. Across all host treatments, larval mortality acted as the core limiting factor of overall population survival, and early-instar larvae represented the developmental stage most sensitive to host nutrition and secondary metabolites. This immature phase bears the strongest natural selective pressure during plant-insect coevolution and constitutes the critical window of evolutionary trade-offs between chive maggotss and its host plants.

Coevolutionary Interactions of chive maggotss with Host Plants and Supporting Integrated Pest Management Strategies

The hierarchical coadaptation relationship and cold-climate phenological synchrony clarified above provide a theoretical basis for breaking the reciprocal matching between chive maggotss and optimal *Allium* hosts via ecological regulation. Field monitoring data (Fig.1) confirmed three annual adult outbreak peaks formed by co-evolved seasonal synchronization of pest and *Allium* vegetation, while low winter temperatures create unique cold-region phenological constraints that can be artificially utilized for pest suppression (Zhanxia et al. 2015, Han et al. 2021). Targeted field management strategies are proposed accordingly: First, implement a three-year rotation mode of Chinese chive–potato–Chinese cabbage to disrupt long-term pest-host coevolution cycles (Saxena et al. 1992, Jinhao et al. 2022). The evolutionarily inhibitory effect of potato can drastically reduce overwinter pest populations compared with continuous chive monocropping, and interplanting *Allium* with cucumber should be avoided to block cross-host migration. Second, deploy yellow sticky traps for regular population surveillance aligned with the three pest occurrence peaks, and carry out biological root irrigation with *Bacillus thuringiensis* and entomopathogenic nematodes during spring regreening and autumn seedling stages (Noga et al. 2022, He et al. 2026), targeting the selection-sensitive early larval window shaped by plant chemical defense. Third, deep ploughing over 20 cm in winter can take advantage of subzero cold to kill diapausing pupae and late larvae; garlic and radish can be planted as peripheral buffer strips, where released secondary metabolites interfere with larval detoxification and weaken pest co-adaptive contact with host plants (Mendesil 2014, He et al. 2026). Integrated application of the above ecological tactics can lower dependence on synthetic agrochemicals and sustain stable pest control effects, supporting the sustainable development of organic chive cultivation in cold temperate agricultural regions.

Declarations

Author Contributions Statement

H.M. and Y.L.C. drafted the main manuscript text. Z.H.X., J.Y.C., S.W.P., T.Q.L., X.R.W., J.Q.C. and P.M. collected data and organized relevant materials. F.S.Y. and H.Y.F. supervised the whole research work and revised the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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Figures

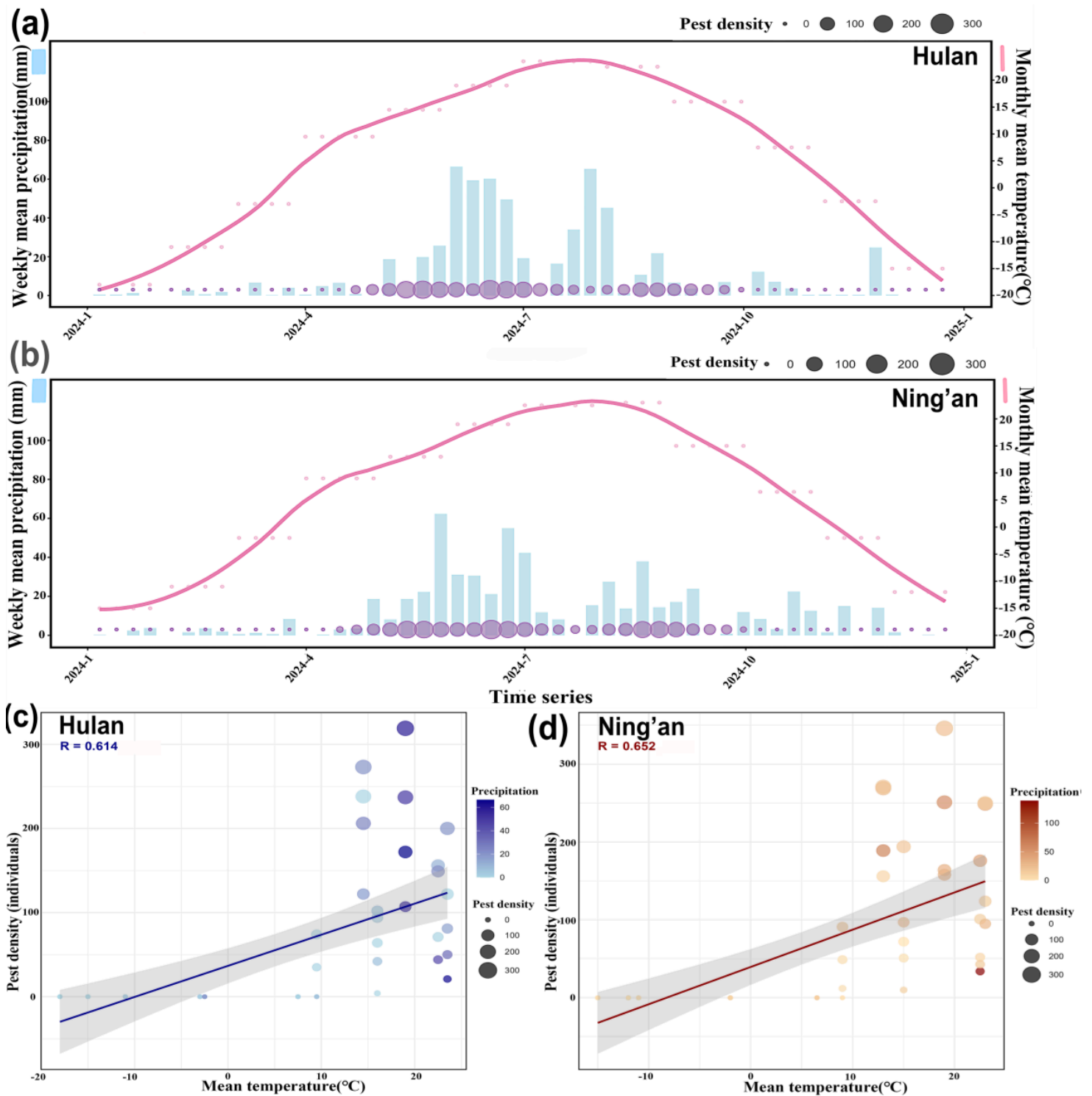


Figure 1

Temporal dynamics and correlation analysis of chive maggots population density and meteorological factors in Hulan and Ning'an. a, b Temporal series of weekly average precipitation (blue columns), monthly average temperature (pink line), and pest density (purple dots with different shades representing density levels: 0, 100, 200, 320 individuals) in Hulan and Ning'an in 2024; c, d Correlation between average temperature and pest density in Hulan and Ning'an, with precipitation represented by the color gradient of dots

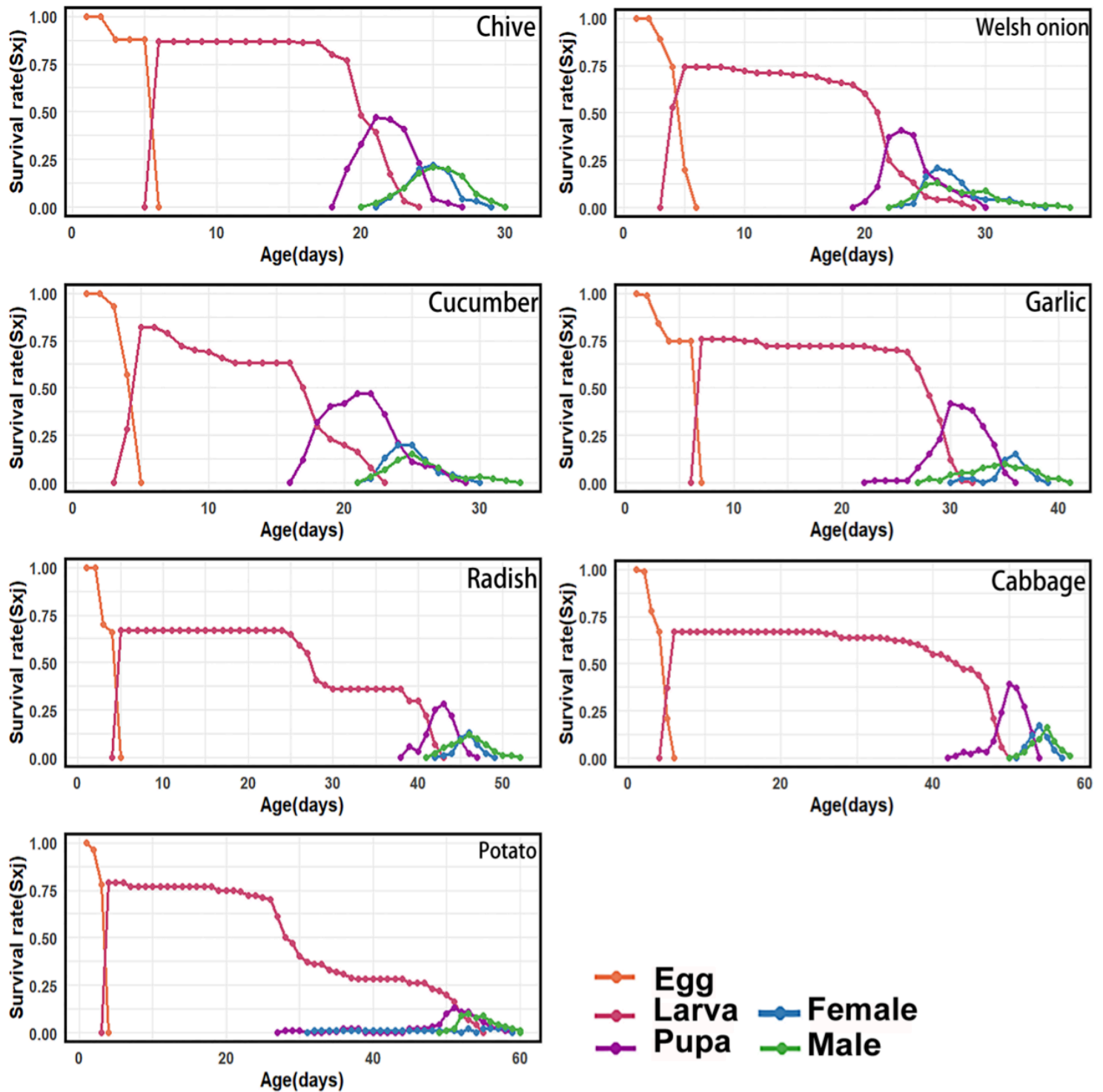


Figure 2

Effects of Different Host Plants on the Age-specific Survival Rate (S_{xj}) of the Chive maggots

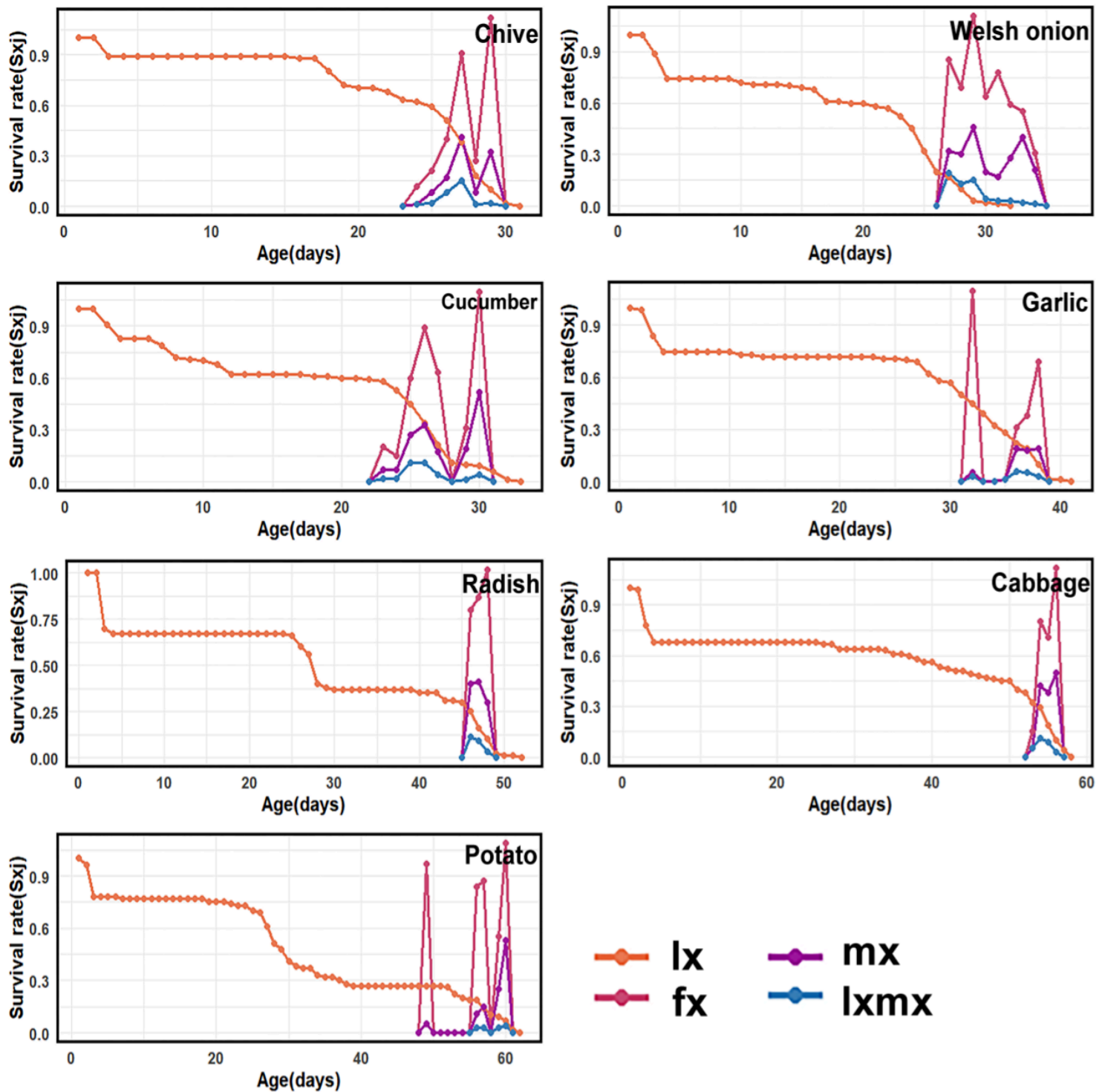


Figure 3

Effects of Different Host Plants on the Age-stage-specific Survival Rate (l_x), Female Age-stage-specific Fecundity (f_x), Age-stage-specific Fecundity (m_x), and Age-stage-specific Reproductive Value ($l_x m_x$) of the Chive maggots

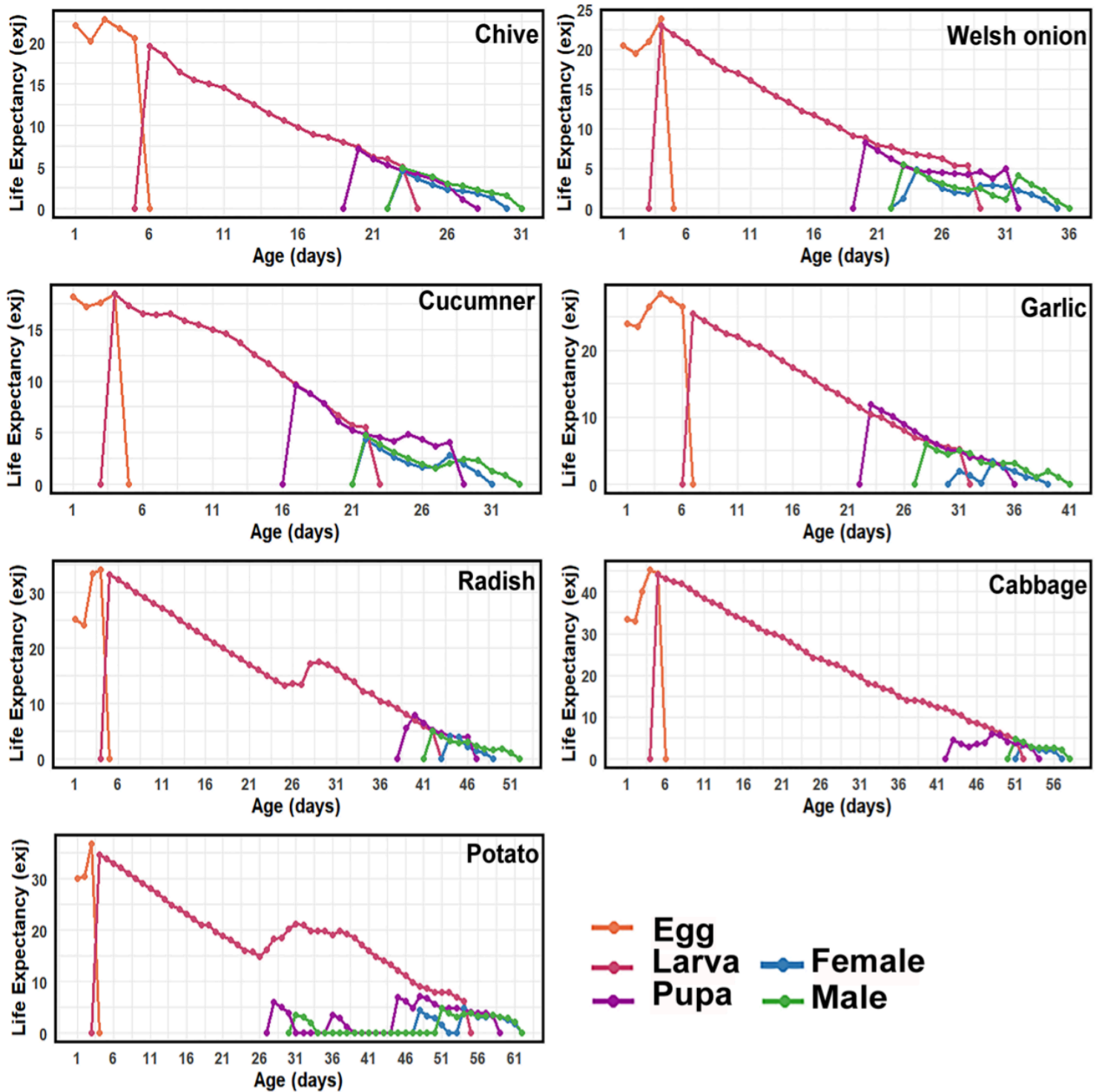


Figure 4

Age-stage-specific Life Expectancy (e_{xj}) of the Chive maggots on Different Host Plants