ORIGINAL PAPER

Wheat as a new host for potato aphid *Macrosiphum euphorbiae* Thomas (Hemiptera: Aphididae) and construction of its age-stage two-sex life tables

Y. N. Venkatesh[1] · S. Rajna[1] · Sachin S. Suroshe[1] · Sunil Joshi[3] · Subhash Chander[2]

Abstract

Wheat (*Triticum aestivum* L.) is the major global staple food crop that meets the food security demands of various nations across the continents. The recent reduction in wheat production is attributed to several biotic and abiotic factors especially, temperature and rainfall patterns, and pest occurrence. Among insect pests, aphid species are emerging as new pests of economic importance in India and elsewhere. The present investigation identified a new association of *Macrosiphum euphorbiae* Thomas with the wheat crop. Life table parameters were studied for *M. euphorbiae* and *Rhopalosiphum padi* fed on wheat foliage. The total nymphal duration and life cycle duration, respectively, of *R. padi* (4.76 ± 0.54 and 9.71 ± 1.38 days) and *M. euphorbiae* (5.84 ± 0.69 and 9.96 ± 1.31 days) were significantly different for these species. The fecundity of the two aphid species was 23.95 ± 8.67 and 11.6 ± 4.10 progeny/female, respectively. Age-specific survival rate (l_x), age-specific fecundity (f_x), and population age-specific fecundity (m_x) were higher in *R. Padi* compared to *M. euphorbiae*. Reproductive value (V_{xj}) was high in *R. padi* and the duration of reproduction was less, while these parameters showed an opposite trend in *M. euphorbiae*. The gross reproduction rate (GRR) was found higher in *R. Padi* (29.17 offspring/adult lifetime) compared to *M. euphorbiae* (19.58 offspring/adult lifetime). The *M. euphorbiae* being a pest of solanaceous crops seems to have shifted to a new host, i.e., wheat. This new adaptation strategy to survive for long periods on a wheat crop might pose a serious threat to wheat crop cultivation in near future.

Introduction

Of late, agricultural production is facing continuous challenges by ever-increasing adverse environmental instability and abiotic and biotic stresses. Wheat (*Triticum aestivum* L.) domestication is closely associated with the efforts of humans to protect themselves from hunger and to gain

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✉ Subhash Chander
schanderthakur@gmail.com

1   Division of Entomology, ICAR-Indian Agricultural Research Institute, Pusa, New Delhi, India

2   ICAR-National Research Centre for Integrated Pest Management, New Delhi, India

3   Division of Germplasm Collection and Characterization, ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, India

control over their food supply. Wheat is cultivated worldwide, and it is the second most important cereal source of food and essential nutrients. Wheat has the advantage of requiring less water for cultivation than other similar crops. Presently, China and India are the top two wheat-producing countries, where it serves as a staple food along with rice (Igrejas and Branlard 2020). In India, despite unfavorable weather conditions and limited availability of farm workers due to COVID-19 restrictions, 32.0 million hectares (mha) of wheat was harvested in 2021 with a yield average of 3.38 tons per hectare (t/ha), and the production is estimated at a record 108 million metric tons. However, the wheat yield is almost 2 percent lower than the previous year because of warmer-than-average temperatures, dry conditions, and biotic stress factors across the Indian wheat belt (Commodity Intelligence Report, USDA 2021). An increase in temperature may affect the grain filling duration and sterility of grains and ultimately reduce the productivity of yield (Hatfield et al. 2011). Several insect pests, viz. aphids; termites,

Odontotermes obesus (Ramb); shoot fly, *Atherigona naqvii* (Steyskal); brown wheat mite, *Petrobia latens* (Muller); armyworm, *Mythimna separata* Walker and cutworms, *Agrotis ipsilon* (Hufnagel), are important pest attacking the wheat crop. Among them, aphid species (Wains et al. 2010) heavily infect the wheat crop. In India, aphids pose a serious threat to wheat cultivation due to the advent of the rice–wheat cropping system (Aggarwal et al. 2000). Aphids are phloem-feeding insect pests that use their piercing and sucking mouthparts to feed on plant sap. Also, aphids are "r-strategists," indicating that their simple bodies enable them to consume and reproduce quickly, with the majority of the energy going toward the production of nymphs (Rabasse and Steenis 1999). They can cause 35–40% yield loss directly by sucking sap and 20–80% indirectly by the transmission of viral diseases like barley yellow dwarf virus (BYDV) and cereal yellow dwarf virus (CYDV) (Rossing et al. 1994; Bukvayova et al. 2006). The climatic variability became an advantage for the aphids which are emerging as an important pest of wheat in the recent past, and more than 11 aphid species have been reported on wheat. The bird cherry-oat aphid, *Rhopalosiphum padi* (L.) and English grain aphid, *Sitobion avenae* (F.) are more dominant, destructive, and commonly occurring pest species responsible for significant yield and quality losses in the wheat crop in many parts of the world and India (Blackman and Eastop 1984; Oerke et al. 1996; Liu et al. 2012; Dhadwal et al. 2014; Alawi et al. 2021).

In the present investigation during 2021–2022, for the first time potato aphid, *Macrosiphum euphorbiae,* infestation was observed on wheat crop in New Delhi, India, along with the bird cherry-oat aphid, *Rhopalosiphum padi* (L.). *M. euphorbiae* feeds on more than 200 plant species from 20 distinct families, with a wide host range, including herbaceous crops, solanaceous plants, and ornamental crops. *M. euphorbiae* can also infest tomato globally, occasionally reported as a major pest in California, which resulted in crop losses of one ton per acre approx. (Zalom 2007). *M. euphorbiae* is a potential virus vector and spreads plant viruses such as potato leafroll virus (PLRV) and potato virus Y (PVY) (Moeller 1973; Singh and Boiteau 1986; Millar 1990; Chan et al. 1991; Radcliffe and Ragsdale 2002; Blackman and Eastop 2007). *M. euphorbiae* is significant in viral epidemiology studies due to its abundance and tendency to generate alatae forms. It is a concern that *M. euphorbiae* can feed on wheat, and this sends a warning signal to all wheat-growing areas as this aphid species was originally reported from North America and has now spread throughout the globe (Starý et al. 1993; Finlayson et al. 2009; Valenzuela et al. 2009; Raboudi et al. 2011; Le Guigo et al. 2012). In the course of biological evolution, the environment acts as a selective force on any species, influencing its genetic potential to respond to its survival (Harrington et al. 2001). Therefore, this research aims to understand the age-specific

mortality and survival rate in each developmental stage or age interval and the measurement of population density at several points in the life cycle during each generation of *R. padi* and *M. euphorbiae* infesting on wheat crop. This information forms a basis and is highly needed for further studies of aphid pest control in wheat crop.

Materials and methods

The study was conducted at ICAR-Indian Agricultural Research Institute (IARI), Pusa, New Delhi, India (28°38'N latitude, 77°09'E longitude, 228.61 m altitude), during 2021–2022.

Aphid culture

The initial cultures of *R. Padi* and *M. euphorbiae* aphids were collected from a wheat (HD-3086) field in ICAR-IARI, Pusa, New Delhi, India. The field-collected aphids were transferred individually to Petri plates (90 mm dia.) for nymphoposition. Each plate was facilitated with air holes on the lid and sterile filter paper at the bottom of the plate for holding moisture on which a wheat leaf was placed to keep the leaves turgid and fresh. Every day, leaves were replaced with fresh ones from each Petri plate. The Petri plates were placed at a normal room temperature of $25° \pm 1$ °C and 65–70% RH with 12 h each of a dark and light phase. Both the aphid species were allowed to lay nymphs for 24 h, and after 24 h offspring were separated and kept individually in separate Petri plates to record daily observations, viz. instar-wise developmental duration, reproductive period, reproductive rate, adult mortality, and longevity. The offspring were removed daily to record the fecundity of each adult aphid until its death. The mortality and survival of the aphids and nymphs were recorded at 24 h of intervals at approximately the same time each day and the longevity and percentage of survival were further calculated. A total of 40 ($n=40$) replicates were maintained for this study.

Morphological and molecular identification of the aphid species

Aphids collected from wheat fields were stored in 70% ethanol and used for morphological and molecular identification. The morphological identification was undertaken at the Division of Germplasm Collection and Characterization, ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, India. The aphids were identified based on the keys developed by Blackman and Eastop (2000). For molecular identification, total genomic DNA was extracted from single adult aphids using a DNeasy Blood and Tissue kit (Qiagen™). The extracted DNA

was used as a template in PCR-based detection following quality and quantity checks using nanodrop 2000 (Thermoscientific™). The mitochondrial cytochrome oxidase I (*MtCO1*) gene was targeted to amplify with the forward LCO(F) 5'-GGTCAACAAATCATAAAGATATTGG-3' and reverse HCO(R) 5'-TAACTTCAGGGTGACCAA AAAATCA-3' primers. The PCR comprised an initial denaturing step at 94 °C for 4 min and 35 amplification cycles (94 °C for 1 min., 48 °C optimal annealing temperature for 1 min, 72 °C for 1 min), followed by a final extension step at 72 °C for 5 min. The amplified products were resolved on 1% gel electrophoresis and further used for Sanger sequencing. The *MtCO1* gene sequences obtained were curated and aligned with the help of reference sequences obtained from the Basic Local Alignment Search Tool (nBLAST) of the National Centre for Biotechnology Information (NCBI) database (http://blast.ncbi.nlm.nih.gov/Blast.cgi) using BioEdit v 72 program. The final sequences with identity checks were submitted to NCBI to get the accession number and aligned.

Life table construction

The life table studies were carried out by rearing aphids separately on wheat leaves. According to the age-stage, two-sex life table principle and method (Tuan et al. 2014), the following parameters were calculated and the age-stage, two-sex life tables of *R. padi* and *M. euphorbiae* on the wheat were established.

1. Age-stage-specific survival rates (S_{xj}): It is the probability that a newly laid nymph will survive to age x and stage j.

$$S_{XJ} = \frac{n_{xj}}{n_{01}}$$

   where n_{01} is the number of nymphs used at the beginning of the life table study and n_{xj} is the number of individuals surviving to age x and stage j (Chang et al. 2016).

2. Age-specific survival rate (l_x): It is the probability that a newly laid nymph will survive to age

$$l_x = \sum_{j=1}^{m} S_{xj}$$

   where, m is the number of stages.

3. Age-stage-specific fecundity (f_{xj}): It is the number of hatched nymphs produced by the adult female at age x and j is the life stage number.

4. Age-specific fecundity (m_x): The number of nymphs per individual at age x

$$m_x = \frac{\sum_{j=1}^{m} S_{xj} f_{xj}}{\sum_{j=1}^{m} S_{xj}}$$

5. Age-specific maternity ($l_x * m_x$): The product of l_x and m_x.

6. Age-stage-specific life expectancy (e_{xj}): It is the time that an individual of age x and stage y is expected to live

$$e_{xj} = \sum_{j=i}^{m} \sum_{j=1}^{m} S_{ij}$$

   where S_{ij} is the probability that an individual of age x and stage y will survive to age and stage j.

7. Age-stage-specific reproductive value (V_{xj}): It is the contribution of individuals of age x and stage y to the future population

$$v_{xj} = \frac{e^{-r(x+1)}}{S_{xj}} \sum_{i=x}^{n} e^{-r(i+1)} \sum_{j=y}^{m} S_{ij} f_{ij}$$

8. Intrinsic rate of increase (r): It is the population growth rate as the time approaches infinity and the population reaches the stable age-stage distribution. The population size will increase at the rate of e^r per time unit.

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

9. Finite rate of increase (λ): The finite rate is the population growth rate as the time approaches infinity and the population reaches the stable age-stage distribution. The population size will increase at the rate of λ per time unit.

    Simply the proportional change in population size from one time period to the next.

$$\lambda = e^r$$

10. Net reproductive rate (R_0): It is referred to as the "carrying capacity" of the average insect under defined environmental conditions. It is the mean number of female offspring produced by a female during her entire lifetime (i.e., the replacement rate). It is also $R_o < 1$ indicates the members of the population are not replacing themselves (i.e., the population is declining): $R_o > 1$ denotes an increasing population and $R_o = 1$ indicates a stationary population. Its unit is females/female/generation.

$$R_o = \sum_{x=0}^{\infty} l_x m_x$$

11. Mean generation time (T): It is the period that a population requires to increase to R_0-fold of its size as the time approaches infinity and the population settles down to a stable age-stage distribution (SASD), i.e., stable age distribution SAD, too. A shorter generation time does not mean a faster growth rate.

   Simply, the average interval between the birth of an individual and the birth of its offspring.

$$T = \frac{1_n R_o}{r}$$

Statistical analysis

The life-history data of *R. padi* and *M. euphorbiae* were used separately to calculate each population parameter and analyzed using TWOSEX-MSChart software (http://140.120.197.173/Ecology/prod02.htm) (Chi 1988; Huang and Chi 2012). The means, standard errors and variances of the population parameters were arrived at by the bootstrap technique (100,000 repetitions) (Efron and Tibshirani 1993). Sigma plot 14.5 (https://systatsoftware.com/sigmaplot/) was used to create graphs.

Results

Morphological and molecular identification of the aphid species

Morphological characteristics of the two different aphid morphotypes revealed the features of *R. padi* as apterous pale green to dark green adults which had a rust-red shade around the base of each cornicle and abdominal end. The body length of the apterae ranged between 1.2 and 2.4 mm. The terminal process of the sixth antennal segment of the apterae was 4–5 times longer than its base. The apical ends of the cornicles were slightly swollen and ended with a strong flange preceded by a distinct construction, and the cauda was shorter than the cornicles. Similarly, morphological characteristics of *M. euphorbiae* are; apterae either green with a darker green longitudinal stripe, their eyes noticeably red, and the antennae darker toward their tips.

Molecular identification of the two different aphid morphotypes collected from wheat was performed by targeting the mitochondrial cytochrome oxidase I (*MtCO1*) gene. In nucleotide BLAST analysis, the bird cherry morphotype RP-IARI-DL-1 showed 100% similarity with other aphid species of *R. padi* (bird cherry-oat aphid), and interestingly the green morphotype, ME-IARI-DL-1 showed 99% similarity with *M. euphorbiae* (potato aphid). This has confirmed the infestation and damage caused by two aphid species *R.*

padi RP-IARI-DL-1 and *M. euphorbiae* ME-IARI-DL-1 on wheat crops. The two sequences were submitted to the NCBI database using GenBank, and accession numbers have been received for *R. Padi,* RP-IARI-DL-1 (OP380251) and *M. euphorbiae,* ME-IARI-DL-1 (OP373188). However, to further analyze their phylogenetic relationship with other aphid species, a dendrogram was constructed using the neighborhood joining method. In the phylogenetic analysis, *R. padi* (RP-IARI-DL-1) closely clustered with other strains of *R. Padi* (MF958485, MF958483, MN320354, MN320341) with 100% bootstrap value and 100% nucleotide identity (Fig. 1). Similarly, *M. euphorbiae* (ME-IARI-DL-1) showed close clustering with other strains of *M. euphorbiae* infesting potato crop (EU701726, KC008068, KY613938, ON929001) with 100% bootstrap value and 99.85% nucleotide identity. Lastly, both the aphid species were distantly clustered with *Rhalosiphum maidis* (Fitch)*, Rhalosiphum rufiabdominalis* (Sasaki)*, Schizaphis graminum* (Rondani)*, Hyperomyzus carduellinus* (Theobald)*, Hysteroneura setariae* (Thomas)*, Macrosiphum parvifolii* (Richards)*, Macrosiphum occidentalis* (Essig)*, Macrosiphum insularis* (Pergande)*, Sitobion miscanthi* (Takahashi)*, Diuraphis noxia* (Kurdjumov)*, Aphis craccivora* Koch*, Aphis gossypii* Glover and *Thrips tabaci* Lindeman (Fig. 1).

Biological aspects of *R. padi* and *M. euphorbiae* reared on wheat

The total nymphal duration of 4.76 ± 0.54 days for *R. padi* and of 5.84 ± 0.69 days for *M. euphorbiae* were significantly different. The first nymphal instar duration for both *R. padi* and *M. euphorbiae* was recorded as 1 ± 0.00 days, while the respective second nymphal instar duration was 1.33 ± 0.48 and 1.52 ± 0.51 days, which, however, did not differ significantly. The third and fourth nymphal instar durations, respectively, were 1.19 ± 0.40 and 1.24 ± 0.44 days for *R. padi* and 1.64 ± 0.49 and 1.68 ± 0.48 days for *M. euphorbiae* differed significantly. The adult aphid duration was recorded as 4.95 ± 1.50 days for *R. padi* and 4.12 ± 1.17 days for *M. euphorbiae*. The total life cycle duration was recorded as 9.71 ± 1.38 and 9.96 ± 1.31 days for *R. padi* and *M. euphorbiae,* respectively. The fecundity was 23.95 ± 8.67 and 11.6 ± 4.10 (progeny/female), respectively, in *R. padi* and *M. euphorbiae* and there was no pre-viviposition period in both the species. However, the post-viviposition period was 0.43 ± 0.51 and 0.16 ± 0.37, and the viviposition period was 4.52 ± 1.47 and 3.96 ± 1.10 days, respectively, for *R. padi* and *M. euphorbiae* (Table 1).
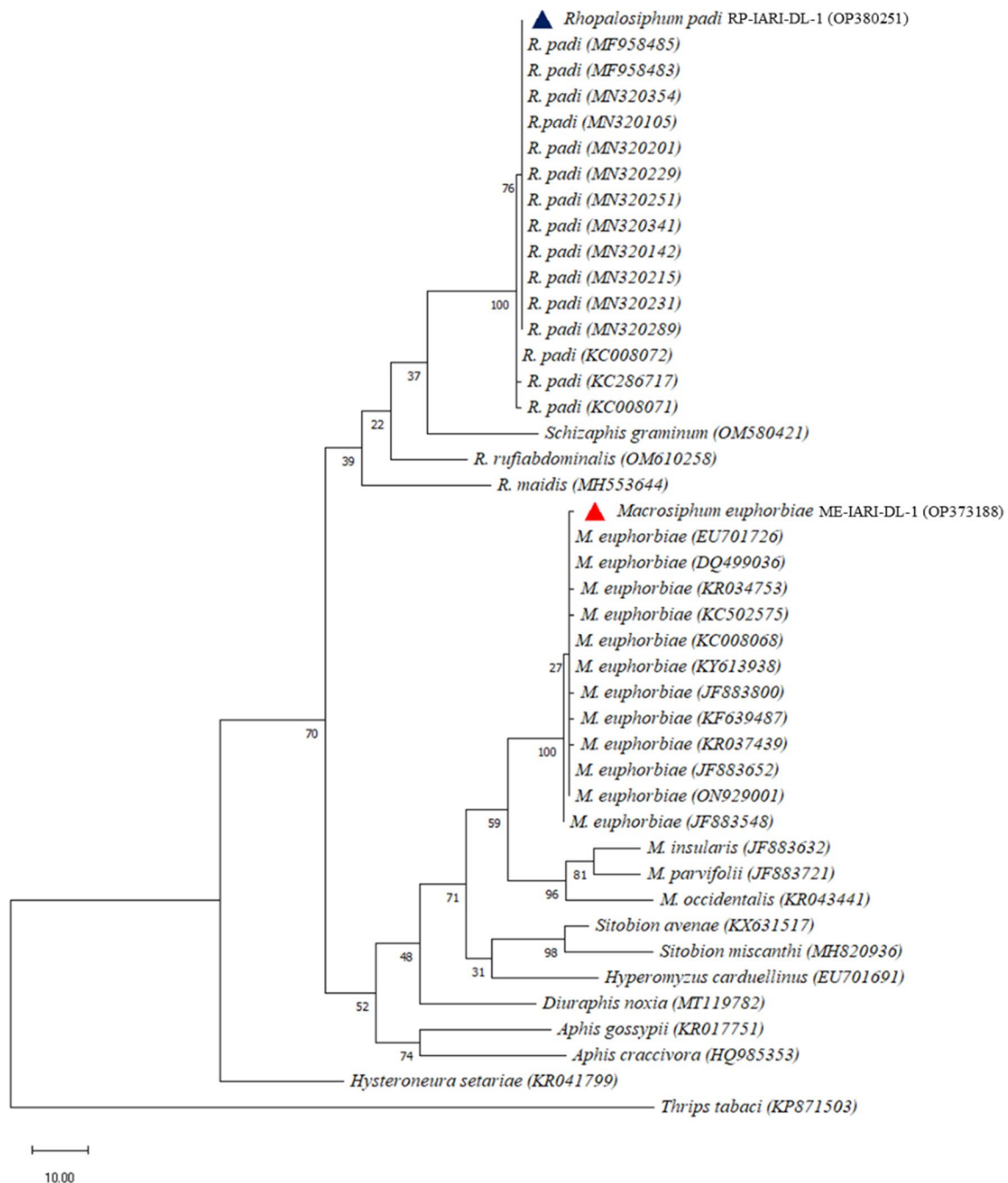
Fig.1 Phylogenetic analysis of aphid, *R. padi* RP-IARI-DL-1 and *M. euphorbiae* ME-IARI-DL-1 on wheat by neighborhood joining method

Life table parameters of wheat aphids *R. padi* and *M. euphorbiae*

The relation of Age-stage survival rate (S_{xj}), survival rate (l_x), life expectancy (E_{xj}), and reproductive value (V_{xj}) between *R. Padi* and *M. euphorbiae* on wheat was studied and results showed that the age-stage survival rate (S_{xj}) duration was higher in *M. euphorbiae* as compared to *R. padi* during all the stages of the life cycle (Fig. 2). Age-specific

survival rate (l_x), age-specific fecundity (f_x), and population age-specific fecundity (m_x) were higher in *R. padi* compared to *M. euphorbiae* (Fig. 3). Further, life expectancy (E_{xj}) was higher in *M. euphorbiae* as compared to *R. padi* (Fig. 4). Reproductive value (V_{xj}) was higher in *R. padi* but the duration of reproduction was lower, while in *M. euphorbiae* the opposite trend was observed (Fig. 5). Finally, the comparison between the reproductive value $v(x)$ and life expectancy (e_x) of both the aphids showed that reproductive

Table 1 Biological and reproductive parameters of *R. padi* and *M. euphorbiae* (Mean ± SD) on wheat under laboratory conditions

Statistics	*R. padi*	*M. euphorbiae*	t- value
First instar (days)	1.00 ± 0	1 ± 0.00	NS
Second instar (days)	1.33 ± 0.48	1.52 ± 0.51	-1.267
Third instar (days)	1.19 ± 0.40	1.64 ± 0.49	-3.358^{**}
Fourth instar (days)	1.24 ± 0.44	1.68 ± 0.48	-3.265^{**}
Nymphal duration (days)	4.76 ± 0.54	5.84 ± 0.69	-5.830^{**}
Adult duration (Days)	4.95 ± 1.50	4.12 ± 1.17	2.118^{**}
Total life cycle (days)	9.71 ± 1.38	9.96 ± 1.31	-0.619
Fecundity (progeny/ female)	23.95 ± 8.67	11.6 ± 4.10	6.335^{**}
Pre-reproductive period	0 ± 0	0 ± 0	NS
Post- reproductive period	0.43 ± 0.51	0.16 ± 0.37	2.064^{**}
Reproductive period (days)	4.52 ± 1.47	3.96 ± 1.10	1.487
Biotic potential (r)	7.05×10^{51}	1.02×10^{39}	–

** Samples are significantly different at both 5% and 1% levels of significance

capacity was higher in *R. padi* with less duration but reproducing capacity was lower with higher life expectancy in *M. euphorbiae* (Fig. 6).

In the present study, the intrinsic rate of population increase (r_m) was recorded as 0.37 (*R. padi*) and 0.24 (*M. euphorbiae*). Similarly, the information about population multiplication in a unit of time represented as the finite rate of increase (λ) was 1.45 in *R. padi* and slightly lower at 1.28 in *M. euphorbiae*. Further, the net reproductive rate (R_0) that signifies the total number of offspring that an average individual can produce during their lifetime was 14.37 (*R. padi*) and 7.25 (*M. euphorbiae*) females/adult. The

mean generation time (*T*) which is the time lapse between the birth of the parents and the birth of the offspring was 7.15 days (*R. padi*) and 7.99 days (*M. euphorbiae*). Further, the time required for the aphid population to double (DT) was 1.86 days (*R. padi*) and 2.79 days (*M. euphorbiae*). The gross reproduction rate (GRR) that characterizes the average number of offspring/adult/generations was found to be higher in *R. Padi* (29.17) compared to *M. euphorbiae* (19.58). Also, all the population parameters were found significantly different for the two aphid species in the present study (Table 2).

Discussion

Wheat, a staple food for millions, is now extremely vulnerable to climate change, especially to temperature, rainfall, humidity, and other weather vagaries. Minor pests and diseases are becoming major and unpredicted genetic mutations are expected in already known major biotic agents. In this scenario, many insect species are forced to shift toward unconventional host plants for their survival. In the present study, we observed two different aphid morphotypes (bird cherry and green aphid) infesting wheat during 2021–2022 in the fields of ICAR-IARI, Pusa, New Delhi, India. Morphological and molecular characterization based on the mitochondrial cytochrome oxidase (*MtCO1*) gene sequences showed that the bird cherry morphotype of *R. padi* showed greater similarity to other strains of *R. padi* infecting wheat, maize, and other cereals. *R. padi* is known for its broad host range comprising 20 plant families, particularly grasses, and cereals like rice, wheat, and rosaceous, aquatic, and semi-aquatic plants (Blackman and Eastop 2006; Holman 2009).
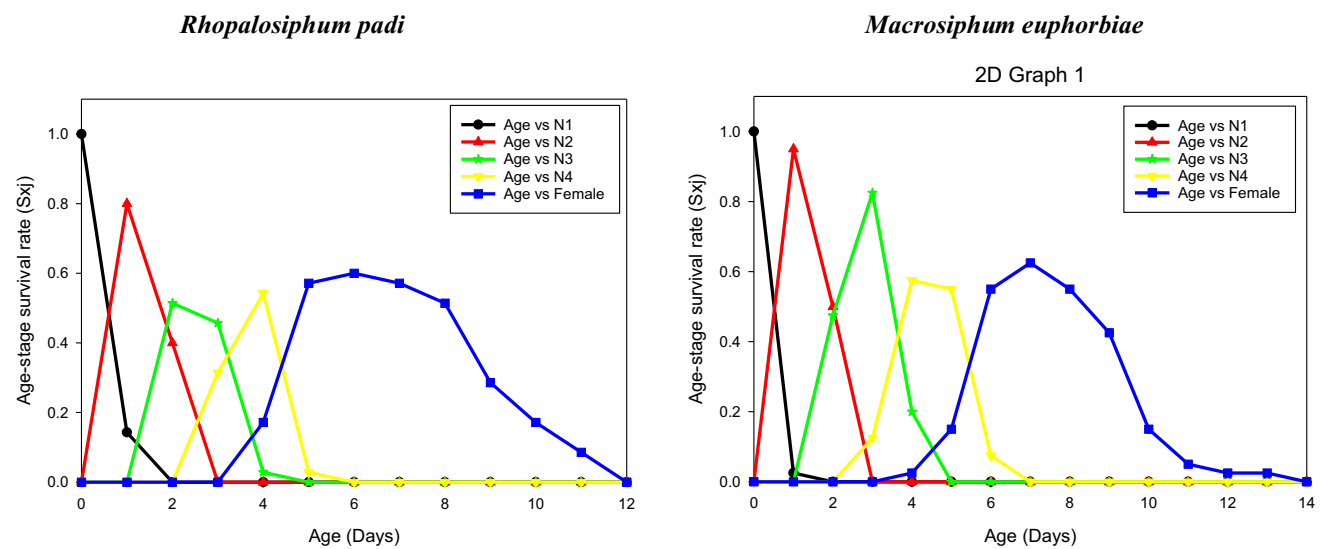

Fig. 2 Age-stage survival rate (S_{xj}) of *R. Padi* and *M. euphorbiae* on wheat under laboratory conditions
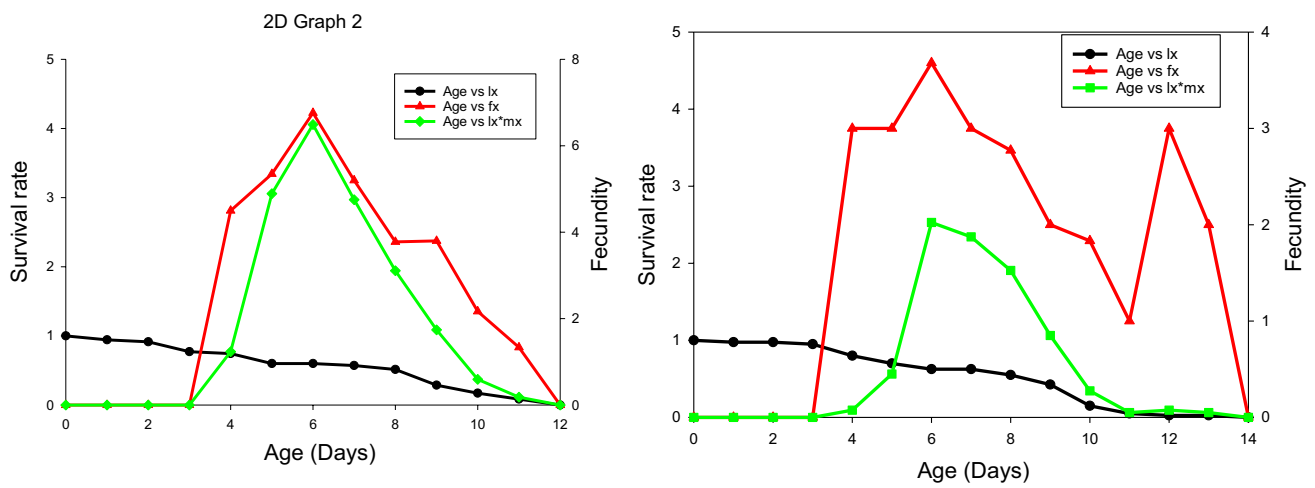
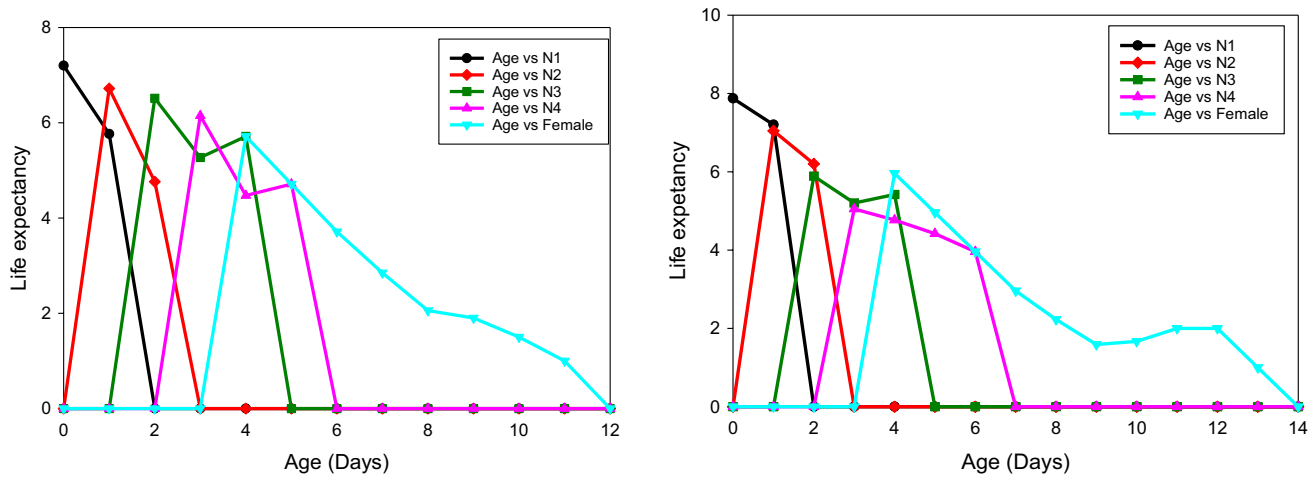**Fig. 3** Survival rate *l*(*x*) of *R. Padi* and *M. euphorbiae* on wheat under laboratory conditions

Fig. 4 Life expectancy (*E*xj) of *R. Padi* and *M. euphorbiae* on wheat under laboratory conditions
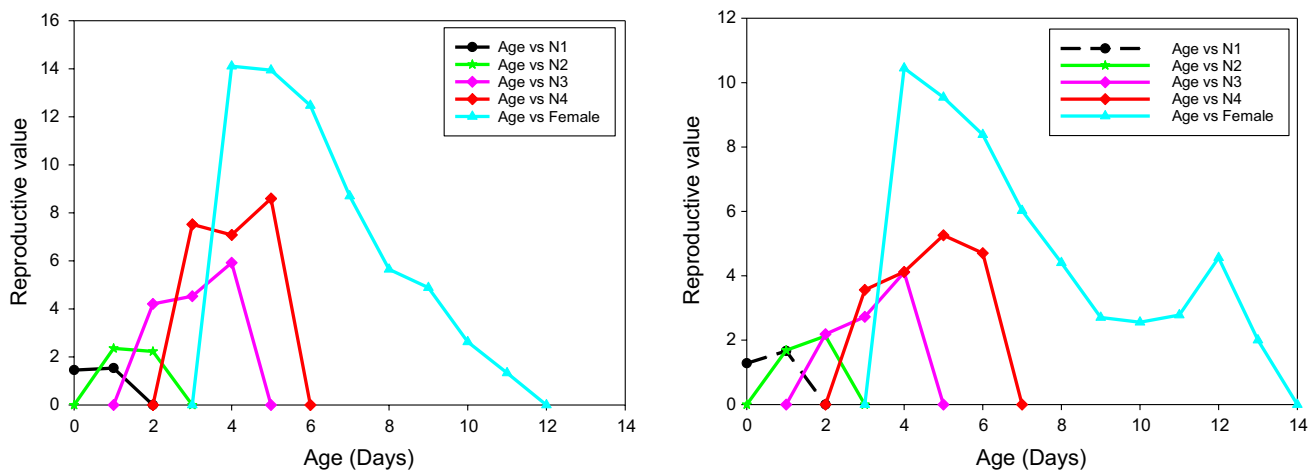

Fig. 5 Reproductive value (*V*xj) of *R. Padi* and *M. euphorbiae* on wheat under laboratory conditions
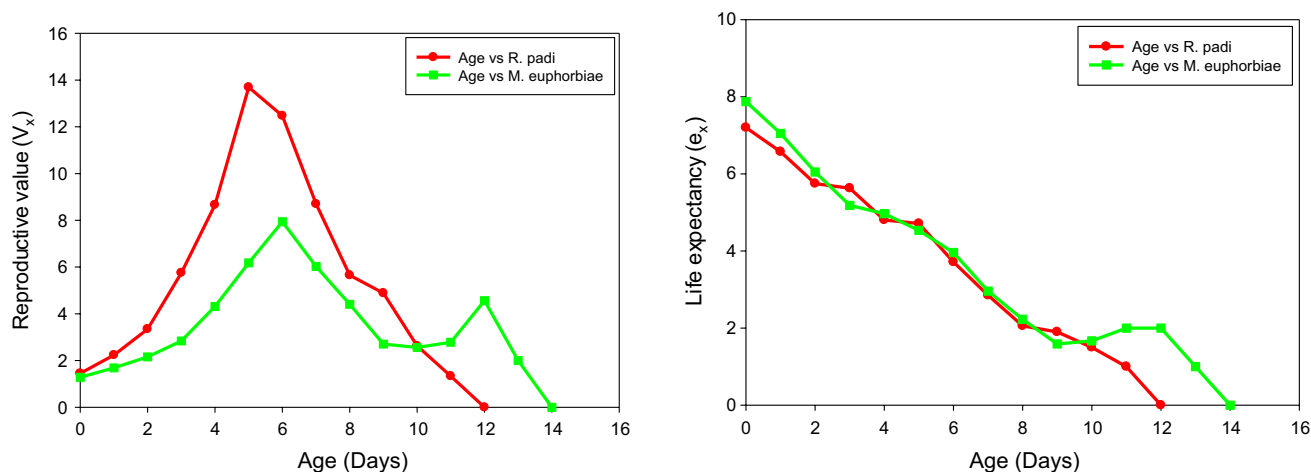
Fig. 6 Reproductive value $v(x)$ and life expectancy (e_x) of *R. Padi* and *M. euphorbiae* on wheat under laboratory conditions

Table 2 Population parameters of *R. padi* and *M. euphorbiae* on wheat under laboratory conditions

Aphid species	Intrinsic rate of increase (r_m)	Finite rate of increase (λ)	Net reproductive rate (R_0)	Mean generation time (T)	Doubling time (DT)	Gross reproduction rate (GRR)
R. padi	0.37 ± 0.003[a]	1.45 ± 0.004[a]	14.37 ± 0.226[a]	7.15 ± 0.018[a]	1.86 ± 0.014[a]	29.17 ± 0.207[a]
M. euphorbiae	0.24 ± 0.002[b]	1.28 ± 0.002[b]	7.25 ± 0.094[b]	7.99 ± 0.018[b]	2.79 ± 0.020[b]	19.58 ± 0.358[b]
P value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means followed by different letters in the same row are significantly different by using paired bootstrap test based on the CI of difference. Standard errors were estimated by using 100,000 bootstrap resampling

The green morphotype was identified as *M. euphorbiae* and showed a close clustering with other potato infecting aphid morphotypes of *M. euphorbiae*, thus revealing wheat as its new host plant. This demonstrates that monocot wheat is a new host plant species for *M. euphorbiae* ME-IARI-DL-1 which is otherwise well known for infesting dicot plant species including rose, potato, and verveine. However, other *Macrosiphum* species such as *M. pachysiphon, M. dirhodum, M. scabripes, M. longicaudatum*, and *M. miscanthi* have been already reported as pests in the *Triticum* genus (Singh and Singh 2017).

A life table is a collection of extensive datasets on a population's survival and development and fertility of a population. Understanding the different parameters of a pest's population growth would make it much easier to design a holistic pest management program for its host crop. For the development of effective pest management measures, a better understanding of the biology and life cycle features of aphids on the wheat crop is required. The population growth rate of aphids in the given generation can be predicted by these parameters. Hence, regional studies on aphid biology and life table in the wheat crop are necessary to provide knowledge to develop aphid management measures related to particular environmental conditions.

The mean duration of the *R. padi* nymphal instars reared on wheat leaves at 25 to 26 °C in the present study was 1.00 ± 0, 1.33 ± 0.48, 1.19 ± 0.40, and 1.24 ± 0.44 days for 1st, the 2nd, 3rd, and 4th instars, respectively, and the total life cycle was 9.71 ± 1.38 days, which is in accordance with the earlier studies (Auad et al. 2009) on Signal grass, *Brachiaria ruziziensis* (Prosea) at 28 °C with a life cycle duration of 7.30 ± 0.44 days and on barley (Park et al. 2017) The pre-viviposition was absent in *R. padi*, and viviposition and post-viviposition periods in the present study were found to be 4.52 ± 1.47 and 0.43 ± 0.51, respectively. However, Park et al. (2017) found the pre-oviposition period (0.40 ± 0.06), oviposition period (9.35 ± 0.37), and post-oviposition period (4.07 ± 0.51) days with 12.92 ± 0.86 days longevity and 70.32 ± 2.1 nymphs/female. The net reproductive rate shows the carrying capacity of the mean insect population under different environmental conditions. The net reproductive rate (R_0) of *R. padi* was 14.37 in our study, while the R_0 value in other studies varied from 9.85 to 66.67 (Sengonca et al. 1994), Auad et al. 2009, Park et al. 2017). The differences in oviposition periods and net reproductive rates might be due to the variation in host plant species and temperatures that affect the developmental duration of *R. padi* under different environmental conditions.

The nymphal duration of *M. euphorbiae* was observed as 5.84 ± 0.69 days, with a total life cycle duration of 9.96 ± 1.31 days. However, the fecundity of *M. euphorbiae* (11.6 ± 4.10 progeny/female) was lower compared to *R. padi* in a wheat crop. Previously, Beetge and Krüger (2019) studied the life-history traits of *M. euphorbiae* at different day-night temperatures of 25–15 °C and well-watered on potato leaves and reported that total nymphal duration was 7.9 ± 0.3 days. The pre-reproductive period was 2.5 ± 0.2 days, the reproductive period was 18.0 ± 1.6 days, the post-reproductive period was 1.0 ± 0.0 days, the total life cycle duration was 21.3 ± 1.6 days, and the fecundity was 47.5 ± 4.5 (progeny/female). These variations in life history and developmental days might be due to host specificity and the prevailing environment. The life history and development of *M. euphorbiae* were also previously studied by various workers (Smith 1919; Patch 1925; MacGillivray and Anderson 1958), and most of them showed temperature-based variation in developmental phases. Life table parameters including the intrinsic rate of increase (r_m) (0.24), finite rate of increase (λ) (1.28), net reproductive rate (R_0) (7.25), mean generation time (T) (7.99), doubling time (DT) (2.79), and gross reproductive rate (GRR) (19.58) of *M. euphorbiae* were significantly different from *R. padi* when fed on wheat leaves. The earlier study on *M. euphorbiae* infesting potato revealed a gross reproductive rate (GRR) of 76.45 ± 9.81, net reproductive rate (R_0) of 48.82 ± 6.23, mean generation time (T) of 20.90 ± 1.41, intrinsic rate of increase (r_m) of 0.17 ± 0.01, finite rate of increase (λ) of 1.21 ± 0.01, and doubling time (DT) as 3.78 ± 0.20 (Beetge and Krüger 2019).

The pre-reproductive period was not observed for *M. euphorbiae* under normal room temperature on the wheat crop; however, Conti et al. 2010 recorded a pre-reproductive period of 2.8 days at 16 °C on lettuce. However, the reproductive period was 3.96 ± 1.10 days under room temperature for *M. euphorbiae*. Similarly, in our study fecundity of *M. euphorbiae* was 11.6 ± 4.10 progeny/female. However, at 25 °C Barlow 1962 reported a slightly higher fecundity of 13.8 ± 1.95 progeny/female on potato. On wheat, the net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), and mean generation time (T) of *M. euphorbiae* was 7.25 ± 0.094, 0.28 ± 0.002, 1.28 ± 0.002, and 7.99 ± 0.020, respectively. The life table parameters were reported to be different in previous studies (Cooper and Goggin 2005; Ribeiro et al. 2006; Conti et al. 2010; Jeon et al. 2019) where the net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), and mean generation time (T) of *M. euphorbiae* were 6.1 ± 1.92, 0.08 ± 0.019, 1.092 ± 0.021, and 16.60 ± 1.00, respectively.

The host plant shift of the aphid species *M. euphorbiae* was found to produce significant differences in its life table, and these can be attributed to the food source, microclimatic conditions, and environmental effects.

Conclusion

In the present investigation, two different aphid species, *R. padi* and *M. euphorbiae,* were characterized based on morpho-molecular studies. The potato aphid *M. euphorbiae* has been reported for the first time on wheat crop. The life table studies highlighted the significant differences between *R. padi* and *M. euphorbiae* which completed the total life cycle on the wheat crop. The fecundity (progeny/female), net reproductive rate (R_0), and gross reproduction rate (GRR) of *R. padi* were observed to be higher in wheat as compared to potato aphid *M. euphorbiae*. However, the potato aphid showed high fecundity and reproduction rates on the potato crop and this shift to new hosts could lead to several significant changes in growth and development and future generations according to the feeding habits. Interestingly, though the reproduction rate was low, the other survival parameters such as age-stage survival rate (S_{xj}), survival rate $l(x)$, and life expectancy (E_{xj}) were higher in *M. euphorbiae* as compared to *R. padi*. Hence, we concluded that the changing climatic conditions may have a great effect on aphid species occurrence in wheat crop, their host adoption, and growth and reproduction.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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