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Life table- parameters and morphometrics of the corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae), reared on sorghum host plant

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Abstract
Sorghum is attacked by many insect-pests which are the principal limiting factor for its productivity throughout the country. Corn leaf aphid, *Rhopalosiphum maidis* is widely distributed and one of important pest on sorghum. The study of biology is important for understanding the form and extent of its population growth. *R. maidis* on sorghum had a life cycle of 7.79±0.12 days, adult longevity of 12.27±0.27 days, life span of 16.25±0.80 days, fecundity and rate of reproduction 35.97 progenies/female, 9.15 progenies/female/day at 27 ±0.5^{0}C. Life table parameters includes net reproduction rate (R_0) 45.05, mean generation time (T_c) 9.24, intrinsic rate of natural increase (r_m) 0.44, innate capacity of increase (r_c) 0.41 and corrected mean generation time (T) 8.73 days, respectively.
Nymphs developed through four instars and transformed into adults. The length and width of different nymphal stages of *R. maidis* were: 720.57± 9.95 µm and 303.62 ± 5.59 µm (1st instar); 978.46 ± 13.51 µm and 412.83 ± 5.53 µm (2nd instar); 1399.52 ± 24.56 µm and 581.74 ± 12.33 µm (3rd instar); 1737.5 ± 20.28 µm and 733.98 ± 10.96 µm (4th instar), respectively. The adult were yellowish green to dark olive green or bluish green and measured 1833.63±15.89 µm in length and 783.26±10.82 µm in width.

Keywords: life table, Morphomatrics, *Rhopalosiphum maidis*, sorghum.

1. Introduction
Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal grain for human and animal consumption throughout the world, and world's fifth most important cereal crop after maize, rice, wheat and barley. It offers a good substitute for wheat and maize due to its availability, low price and limited human consumption [1]. Nearly 150 insect species have been reported to damage the crop worldwide, causing an estimated loss of over US$ 1000 million annually.
R. maidis shows main feeding preference on corn followed by sorghum, and barley. It also infests sugarcane, broomcorn, Sudan grass and many other wild and cultivated grasses. It nearly attacks 26 plant species and 14 weed species [2]. The adult forms of the corn leaf aphid can be found as a winged female (alate), wingless female (apterae) and extremely rare male. The wingless adult is oval, soft-bodied, 2.5-mm long and usually pale bluish-green with black antennae, legs and cornicles. Cornicles have a dark area around the base. The head is marked with two longitudinal dark bands and the abdomen with row of black spots on each side. The nymphs are similar to the wingless adult but smaller and without wings. The present work was aimed to study the life table parameters of this aphid species in addition to it's morphometric studies.

2. Materials and methods
The cohort was taken from fields of CRIDA and Hayathnagar Research Farm. For studying the biology of aphids, Petri plates (9 cm dia.) with filter paper disc lining the bottom were taken and sprinkled with water. The cut end of sorghum leaf was wrapped with wet cotton wool at one edge to keep the leaf fresh and turgid for a longer period of time. The 1st instar nymph was transferred @ one nymph/plate to the fresh leaf with the help of fine camel hair brush for its development. These Petri plates were kept in Environmental Test Chamber (SANYO Versatile Environmental Test Chamber) at temperature of 27±0.5ºC, light 4 LS and RH 65±5%. Every day readings were taken and at every two days leaves were changed with fresh one.

The 100 individuals morphometrics (length and breadth in µm) were measured by using stereo zoom microscope (OLYMPUS SZX10) (Progress caption 2.7). The change of instars was identified based on the presence of exuviae cast by the nymph. The number of instars, total duration of life span and the number of newly emerged nymphs were noted.

2.1 Calculation of life-table statistics

The data on mortality was recorded daily till all the adults died during rearing of aphids in Petri plates. The same method was used for constructing life-tables [3].

x	:	Age of the insect
l_x	:	Number of individuals that survive at the beginning of each age interval 'x' out of 100
d_x	:	Number of individuals that died during the age interval 'x' out of 100
100 q_x	:	Per cent mortality

100 $q_x = (d_x/l_x) \times 100$

The survivorship curve was drawn by plotting the number of living individuals at a given age (l_x) and mortality (d_x) against the age (x). The shape of the curve described the distribution of mortality with age [4].

2.2 Construction of life and fertility tables of *R. maidis* on sorghum

The number of nymphs laid by the female on each day was counted till the death of the adults. The life table for female was constructed from column l_x as described [5, 6].

x	:	Pivotal age of female in days
l_x	:	Number of females alive at the beginning of each age interval 'x' (as fraction of initial population of one)
m_x	:	Average number of nymphs laid per female in each age interval assuming 1 as sex ratio

2.3 Estimation of population growth attributes

2.3.1 Net reproductive rate (R_0): The values of 'x', 'l_x' and 'm_x' were calculated from the data given in life tables. The sum total of the products 'l_x x m_x' is the net reproductive rate (R_0) [7]. The 'R_0' is the rate of multiplication of population in generation measured in terms of females produced per generation was calculated by the following formula,

$$R_0 = \sum \mathrm{lx}\ x\ \mathrm{mx}$$

2.3.2 Mean generation time (T_c): The appropriate value of generation time (T_c) *i.e.,* the mean age of the mothers in a cohort at the birth of female offspring was calculated by using the following formula.

$$T_c = \frac{\sum \mathrm{lx}\ x\ \mathrm{mx}\ x\ \mathrm{x}}{R_0}$$

2.3.3 Innate capacity for increase (r_c):

$$r_c = \frac{\log_e R_0}{T}$$

Where, e = Natural log (*i.e.,* 2.71828)

The above r_c is an approximate value of intrinsic rate of natural increase (r_m) and is slightly lower than r_m value for insects with overlapping generations [8, 9].

2.3.4 Intrinsic rate of increase (r_m): The approximate value of r_c and other provisional values r_m were substituted in the following equation to obtain accurate value of intrinsic rate of increase r_m.

$$\sum e^{-r.mx}\ x\ \mathrm{lxmx} = 1$$

2.3.5 Corrected generation time (T): It was calculated by using the following formula

$$T = \frac{\log_e R_0}{r_m}$$

3. Results and discussion

Corn leaf aphid was found to pass through four nymphal instars before becoming adults. The apterous females reproduced parthenogenetically and were found to directly give birth to nymphs. The duration of various biological parameters and morphological data of different stages are given in table 1, fig 1 and table 2, fig 2 respectively.

3.1 First instar nymph

The first instar nymph was light green in colour. The tips of head, antennae and legs were slightly darker than the body. The duration of first instar on an average was 1.97±0.02 days at 27 °C. The morphometrics were recorded by using microscope and the length and width were found to be 720.57±9.95 µm and 303.62 ±5.59 µm, respectively.

3.2 Second instar nymph

The second instar nymph was found to be less active and pale green in colour. The head, abdomen and antennae were darker than the body and the legs were paler. The total duration of second instar on an average was 2±0.03 days. Body length was 978.46±13.51 µm and width was 412.83±5.53 µm.

3.3 Third instar nymph

The third instar body was still pale green, but slightly darker on the sides. Legs were darker than the body. The head was dark green in color. On an average it took 2.02±0.04 days to complete this instar. Body length was 1399.52±24.56 µm and width was 581.74±12.33 µm.

3.4 Fourth instar nymph

The fourth instar took 1.98±0.03 days to become an adult. Body length was 1737.5±20.28 µm and width 733.98 ±10.96 µm.

3.5 Adults

The total life cycle from nymphal stage to adult stage was found to be 7.79±0.12 days. The adults were either winged (alate) or wingless (apterous). The colour was yellowish green to dark olive green or bluish green and measured 1833.63±15.89 µm in length and 783.26±10.82 µm in width. The two cornicles (projections arising from the top rear of the abdomen) were dark, relatively short, and surrounded by a dark basal area. The adult longevity was 12.27±0.27 days. The life span of *R. maidis* on sorghum was found to be 16.25±0.80 days. The fecundity rate was 35.97 progenies/female and the rate of reproduction was 9.15 progenies/female/day.

Table 1: Biological parameters of *R. maidis* on sorghum

Parameters	Values Obtained*
1st instar (days)	1.97±0.02
2nd instar (days)	2.00±0.03
3rd instar (days)	2.02±0.04
4th instar (days)	1.98±0.03
Total life cycle (days)	7.79±0.12
Adult longevity (days)	12.27±0.27
Life span (days)	16.25±0.80
Fecundity rate (progeny/female)	35.97
Rate of reproduction (progeny/female/day)	9.15
N (Number of insects)	100

*(Mean ± SEM)

Table 2: Morphometrics of *R. maidis* on sorghum

Life stages	Morphological parameters*	
	Length (µm)	Width (µm)
1st instar	720.57± 9.95	303.62 ± 5.59
2nd instar	978.46 ± 13.51	412.83 ± 5.53
3rd instar	1399.52 ± 24.56	581.74 ± 12.33
4th instar	1737.5 ± 20.28	733.98 ± 10.96
Adult Female	1833.63 ± 15.89	783.26 ± 10.82

*(Mean ± SEM)

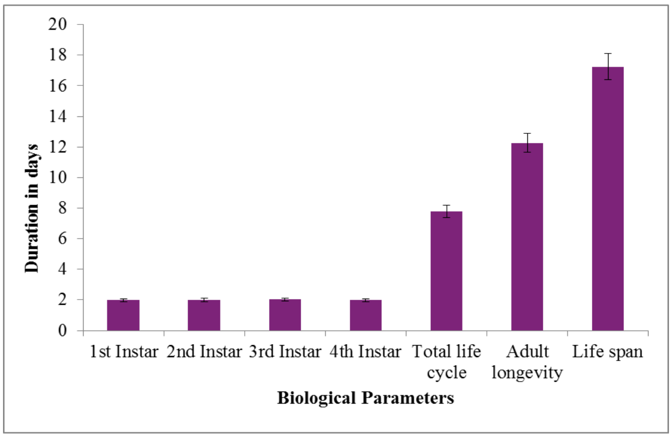

Fig 1: Duration of various parameters of *R. maidis* on sorghum leaves

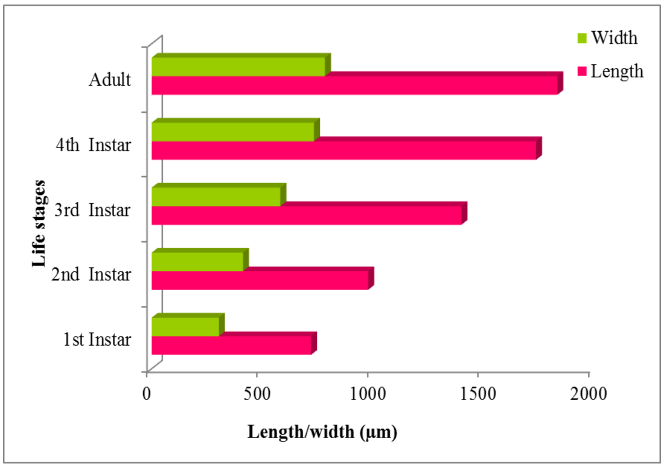

Fig 2: Morphometrics of *R. maidis* on sorghum

In the present studies, two distinct phonological were found in aphid cycle, *i.e.*, nymphs and adults. The development from nymphs to adult took 7.97±0.03 days, with the nymphs undergoing four moults to become females. The mean duration of first, second, third, and fourth instar of *R. maidis* was 1.99±0.02, 2±0.03, 2.02±0.04 and 1.98±0.03 days, respectively at 27°C. However, the total life cycle of *R. maidis* on barley was 5.0±1.6 days at 25°C with the developing period of various instars being 1.4±0.5, 1.2±0.4, 1.1±0.2 and 1.4±0.5 days, respectively [10]. Similarly, the life cycle of *R. maidis* was 5.7±0.2 days at 25°C on corn with the developmental rate of first, second, third, and fourth instar being 1.5±0.1, 1.5±0.1, 1.4±0.1 and 1.4±0.1 days, respectively was reported [11]. Thus, the duration of developmental time of various nymphal instars in the present study showed slight variation from earlier studies which could be due to difference in temperature and the host plant on which the insects were reared.

The adult longevity and life span of *R. maidis* in the present study was found to be 12.27±0.27 and 16.25±0.80 days on sorghum which was similar, the values being 12.0±0.9 and 17.7±1.1 days on corn and 11.9±3.4 and 16.9±3.2 days on barley, respectively [11, 10]. Thus, adult longevity and total life span were almost similar at 27°C and 25°C.The life cycle, adult longevity and life span of *Rhopalasiphum padi* was 7.13±0.11, 10.00±0.40 and 19.97±1.83 days on signal grass at 24°C [12]. The aphid biological parameters varied with the species, type of the host plant offered and the geographic origin of the aphid indicating that these factors can affect its development even when kept under similar heat condition [13].

The rate of reproduction was found to be 9.15 nymphs per day and average fecundity rate was 35.97 progenies/female at 27°C. The rate of reproduction and fecundity were 2.1 nymphs/female/day and 34.2 progenies/female at 19°C on wheat was observed [14]. Other researchers reported that average fecundity rates were 68.06, 69.45, 34.2 and 28.31 progenies/female respectively at 25°C and they opined that with increase in temperature the fecundity reduced [15, 16, 10, 11].

The rate of reproduction and fecundity in the other species, *R. padi* and *Aphis forbesi*, were found to be 2.73±0.14 nymphs per day and 19.97±1.83 progenies/female [12] and 1.5±0.3 nymphs per day and 8.2±1.7 progenies/female [17], respectively. The nutrional factors are also responsible for variation in fecundity, in which an increase in nitrogen content was responsible for higher fecundity of *R. padi* [18].

The length and width of different stages of *R. maidis* were: 720.57± 9.95 µm and 303.62±5.59 µm (1st instar); 978.46 ±13.51 µm and 412.83±5.53 µm (2nd instar); 1399.52±24.56 µm and 581.74±12.33 µm (3rd instar) and 1737.5±20.28 µm and 733.98±10.96 µm (4th instar), respectively (Table 3.2). The length of different stages of *Aphis gossypii* as 0.510±0.007 and 0.51±0.06 mm (1st instar); 0.790±0.014 and 0.70±0.09 mm (2nd instar); 1.140±0.012 and 0.95±0.06 mm (3rd instar) and 1.390±0.013 and 1.16±0.09 mm (4th instar) was reported respectively [19, 20] while the corresponding width was 0.38±0.005 and 0.25±0.03 mm (1st instar); 0.47±0.010 and 0.38±0.03 mm (2nd instar); 0.59±0.006 and 0.53±0.07 mm (3rd instar) and 0.71±0.008 and 0.67±0.02 mm (4th instar).

The size of *R. maidis* adult was 1833.63±15.89 µm in length and 783.26±10.82 µm in width. The adult body length of *Schizaphis graminum* was 1.87±0.261 mm. It is almost similar to *R. maidis* [21]. The adult length to be 1.60-2.30, 1.65-2.25 and 1.32-1.75 mm for *R. maidis*, *R. padi* and *S. graminum* respectively [22]. These variations were due to influence of temperature and food quality [23].

3.6 The age-specific survivorship

The age-specific life-table of the *R. maidis* was worked out by observing the survivals (l_x) and mortality (d_x) during the specific age (x). The results are given in table 3.

The survival rate (l_x) showed lower mortality during early growth. The survivals remained constant for first three days

(100 each). However, from fourth day the survivals of the population showed a steady decline (Fig. 3). The survivals of the population between 9th to 11th day remained relatively constant due to lower mortality during early adult stage. The mortality was more pronounced after 11th day. The adult mortality was observed during 12th to 16th day. Out of 100 nymphs, 72 nymphs moulted to adults successfully on 7th day. The population took 16 days to complete the life span at 27°C on sorghum leaf.

The age-specific survivorship (l_x) curves decreased more rapidly and even more sharply as the duration of different life stages increased from 4 to 16 days (Fig. 3). At 27°C, 50% mortality occurred on the 15th day, and all aphids died on the 16th day. The temperature at 35°C, 50% of mortality occurred on the 7th day, and all aphids died on the 14th day and also confirmed that, for higher temperatures, the age-specific survival curves dropped more sharply and quickly when temperatures increased from 20 to 35°C [11].

Table 3: Age-specific life table of *R. maidis* on sorghum

Age of the insects in days (x)	No. of individuals surviving at the beginning of each age interval x out of 100 (l_x)	No. of individuals dying during the age interval x out of 100 (d_x)	Per cent mortality rate at the age interval x (100 q_x)
1	100	0.00	0.00
2	100	0.00	0.00
3	100	5.00	5.00
4	95	9.00	5.26
5	90	9.00	10.00
6	81	12.00	11.11
7	72	12.00	16.66
8	60	1.00	20.00
9	48	1.00	2.08
10	47	12.00	2.13
11	46	7.00	26.08
12	34	7.00	20.58
13	27	7.00	25.93
14	20	4.00	20.00
15	16	8.00	50.00
16	8	8.00	100.00

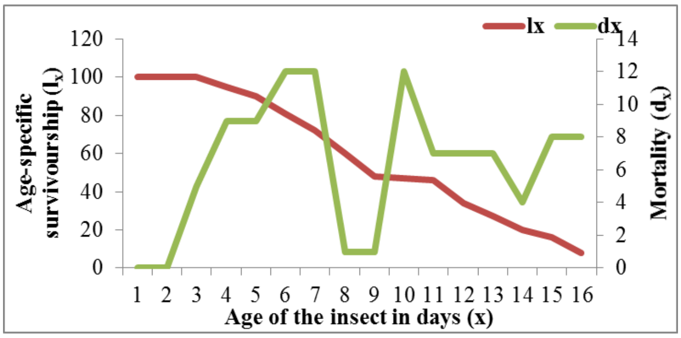

Fig 3: Age-specific survivorship (l_x) and mortality (d_x) of *R. maidis*

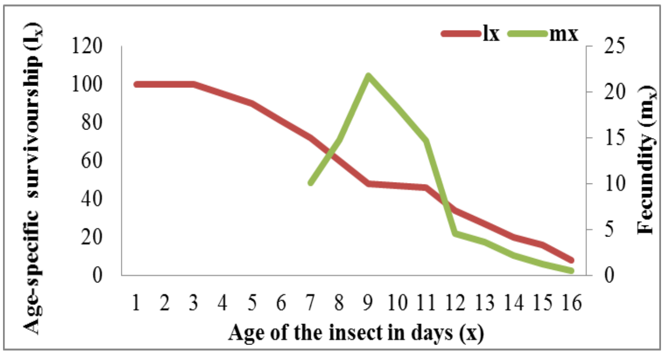

Fig 4: Age-specific survivorship (l_x) and fecundity (m_x) of *R. maidis*

Table 4: Life and fertility table of *R. maidis* on sorghum

Pivotal age of female in days (x)	No. of individuals surviving at the beginning of each age interval x out of 100 (l_x)	No. of progenies/female/day (m_x)
1	100	-
2	100	-
3	100	-
4	95	-
5	90	-
6	81	-
7	72	10.07
8	60	14.75
9	48	21.77
10	47	18.28
11	46	14.64
12	34	4.52
13	27	3.63
14	20	2.10
15	16	1.25
16	8	0.50

3.7 The life and fertility table

Life and fertility table provides the information about the longevity, fecundity, age specific survivals of adult female. In the present study, the life and fecundity table of *R. maidis* was calculated on sorghum leaves and the results obtained are given in table 4 and 5.

The 1st instar nymph took about 7 days to become adult and immediately it started producing nymphs. The number of progenies /female/day (m_x) was >10 up to 11th day and declined in the later days of the life span (Fig. 4). The female contributed to the highest number of progenies (m_x = 21.77) on the 9th day of pivotal age (x). The fecundity peak started when females were three days old. The female *R. maidis* production was 10.07 to 14.75 nymphs in a 24 h period on sorghum while, 7.5 to 11.4 nymphs by *R. padi* on transgenic wheat plants [24]. The effect of the host plant on nymph production was also reported in the *R. padi*, during 7th day of pivotal age (x) produced between 23.6 and 43.3 nymphs/female [25].

The reproduction rate (R_0) was 45.05 at 27°C (Table 5). The R_0 value was 33.50 on wheat cultivar Tajan at 25°C [26].

Earlier R_0 value of 35.09 for *S. graminum* at 24 ºC was reported [27] although the value to be 33.1 and 21.5 respectively, at 25 ºC was reported [11, 10].
The intrinsic rate of increase (r_m) relates to (R_0) and corrected mean generation time (T), indicating the biotic potential of the species [28]. The values of r_m, which reflect the overall effects of temperature on development, reproduction, and survival of a population, increased as temperature increased from 6 to 25 ºC, consistent with the trend of the developmental rate [11]. The optimum temperature for the highest population growth potential of the corn leaf aphid occurred at around 25ºC and the maximum r_m was 0.329. At 27 ºC, the value of r_m in our study was 0.44 (Table 5) while other researchers reported the values as r_m 0.32 at 25 ºC and almost similar value (0.27 and 0.28) at 20 ºC on different hosts [11, 10]. The r_m was 0.30 at 25 ºC for *S. avenae* and 0.24 at 22ºC for *Metopolophium dirhodum* (Walker), but it is much lower than the 0.52 at 27.5ºC for *R. padi* [29]. Hence, the results indicate that corn leaf aphids probably are better adapted in population growth to a wider range of high temperatures in warm regions, similar to that reported in a previous study [30].
The time interval between each generation (T) *i.e.,* 8.73 days was recorded for *R. maidis* at 27 ºC (Table 5). The T value as 9.52 days at 25 ºC for the same aphid [10]. While it was 9.62 and 11.45 days for *R. padi* and *S. graminum* on barley, respectively [31], and was 9.43 days for *R. padi* on Signal grass at 24 ºC [12]. The corn leaf aphids have short developmental times to maturation and high lifetime fecundity on some grasses at 21.1 ºC [32]. Similar to that on sorghum in the present study and on barely [33]. This confirms with the report that widely distributed grasses are good alternative host plants for the maintenance of aphid populations [34, 35].

Table 5: Life table parameters of *R. maidis* on sorghum

Parameters	Values
Net reproduction rate (R_0)	45.05
Mean generation time (T_c)	9.24
Intrinsic rate of natural increase (r_m)	0.44
Innate capacity of increase (r_c)	0.41
Corrected mean generation time (T) in days	8.73

4. Conclusion
The study of biology of aphid and life table parameters provided information regarding longer life span of adults and thereby higher food requirements leading to the visibility of the pest and symptoms, respectively, on the sorghum crop and can thus can utilized for proper assessment for the control measures in the field. Hence, this information will be helpful during the development of successful Integrated Pest Management Programme (IPM) for *R. maidis*.

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