

Research Paper

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Comparative performance and digestive physiology of *Diaphania indica* (Lepidoptera: Crambidae) on *Trichosanthes anguina* (Cucurbitaceae) cultivars

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Abstract

Diaphania indica (Saunders) (Lepidoptera: Crambidae) is an important phytophagous pest of *Trichosanthes anguina* L. in India. We studied life table parameters by age-stage, two-sex, amyolytic and proteolytic activities, and food utilization parameters of *D. indica* on the leaves of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1). Further, nutrients (total carbohydrates, proteins, lipids, amino acids and nitrogen) and antinutrients (total phenols, flavonols and tannins) in leaves were determined. The development time (egg to adult emergence) was the shortest on MNSR-1 (19.79 d) and the longest on Polo No. 1 (25.72 d). Fecundity was the highest and lowest on MNSR-1 (259 eggs) and Polo No. 1 (151.22 eggs), respectively. The lowest intrinsic rate of increase (r_m) and net reproductive rate (R_0) of *D. indica* on Polo No. 1 were 0.1112 d^{-1} and 27.22 offspring individual $^{-1}$, respectively. The mean generation time (T) was the shortest on MNSR-1 (23.99 days) and the longest on Polo No. 1 (29.70 d). The larvae of *D. indica* fed with MNSR-1 had the highest level of amyolytic and proteolytic activities, and the lowest activities were in the larvae fed with Polo No. 1. The fifth-instar larvae fed with Polo No. 1 had the lowest consumption index and growth rate. The higher larval development time and lower fecundity of *D. indica* on Polo No. 1 were due to the lower level of nutrients and a higher level of antinutrients than other cultivars. Our results concluded that Polo No. 1 cultivar could be suggested for cultivation.

Introduction

The genus, *Trichosanthes* L. belongs to Cucurbitaceae and consists of ca. 100 species. The genus is of Asiatic origin and is grown at an altitude from 1200 to 2300 m (Saboo *et al.*, 2012). *Trichosanthes anguina* L., commonly known as snake gourd or serpent gourd, is a widely cultivated vegetable in India, Bangladesh, Nepal, Pakistan, China, Myanmar, Sri Lanka, Malaysia, Vietnam, Indonesia, Philippines and Australia (Peter and David, 1991; Devi, 2017; Singh *et al.*, 2017). The fruit is a rich source of vitamins A, B and C. In traditional medicine, the plant is used as an appetizer, laxative, aphrodisiac, blood purifier (Sivarajan and Balachandran, 1994) and for treatment of wounds including boils, sores, skin eruptions such as eczema and dermatitis (Pullaiah, 2006). The whole plant has an immense medicinal value such as antidiabetic (Arawwawala *et al.*, 2009), gastro-protective (Arawwawala *et al.*, 2010a), anti-inflammatory (Arawwawala *et al.*, 2010b) and antimicrobial activity (Ali *et al.*, 2011; Patil and Kannapan, 2014). The whole plant is also a good source of antioxidants (Arawwawala *et al.*, 2011).

The caterpillar, *Diaphania indica* (Saunders) (Lepidoptera: Crambidae) is one of the major insect pests of *T. anguina* in India and Sri Lanka (Roopa *et al.*, 2014). The insect is also a serious pest of cucumber, melon, gherkin, bottle gourd, bitter gourd, snake gourd, luffa, little cucumber and cotton (Tripathi and Pandey, 1973; Pandey, 1977; Clavijo *et al.*, 1995; Hosseinzade *et al.*, 2014). The first to third-instar larvae feed on the lower surface of leaves, while fourth and fifth-instar larvae gregariously consume leaves. After defoliating, the caterpillar also attacks flowers and fruits of the plant and finally, results in loss of crop yield (Patel and Kulkarny, 1956). The yield loss of different cucurbit fruits varies from 14 to 30%, which depends on the infestation by this caterpillar on crop species (Jhala *et al.*, 2005; Singh and Naik, 2006). The insect is abundant in India, Sri Lanka, Burma, Fiji, Indo-china, Japan, Australia, Netherlands, Samoa, Mauritius, Tonga Island, French West Africa, French Equatorial Africa, French Sudan and USA (Patel and Kulkarny, 1956; Peter and David, 1991; Nagaraju *et al.*, 2018). However, we did not find literature on the biology of *D. indica* on *T. anguina*.

Synthetic insecticides such as carbaryl, dimethoate, dihydroxycarb and methomyl are commonly applied to control the insect pest, *D. indica* (Butani, 1975; Schreiner, 1991; Wang and Huang, 1999; Roopa *et al.*, 2014). But, applications of chemical insecticides are not safe for environmental-health and non-target organisms. Several biopesticides such as *Beauveria bassina*, *Nomurea rileyi*, Dipel (a commercial product of *Bacillus thuringiensis*) and *Helicoverpa armigera* nucleopolyhedrovirus (*HaNPV*) are fruitful for control of this insect pest in laboratory conditions (Roopa *et al.*, 2014). But, till date, commercial biopesticides are not available in the market. Therefore, a host-plant resistant program is of considerable interest to achieve an efficient and safe control. Different cultivars of a host plant can differ in physiological and morphological characteristics including wax content, nutritional content as well as secondary metabolites (Golizadeh *et al.*, 2017a, 2017b; Mobarak *et al.*, 2020), which can affect the development, survival, longevity of adults, reproduction and fecundity of an insect pest.

Construction of life table is very useful to observe the development, survival and reproductive potential of an insect population, which is a popular method to measure various parameters of an insect and this, is necessary for the control of an insect pest (Chi and Getz, 1988; Southwood and Henderson, 2000; Zheng *et al.*, 2017). However, the traditional life table does not consider both sexes of an insect, while using age-stage, two-sex life table we can precisely determine the characteristics of an insect population such as stage differentiation, individual differences and male population (Chi, 1990; Chi and Su, 2006; Huang and Chi, 2011; Mobarak *et al.*, 2020).

Therefore, the objectives of the present study were to (i) construct age-stage, two-sex life table of *D. indica* to record the development, longevity and reproductive potential of *D. indica* on the leaves of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1 are currently grown in West Bengal, India due to high yielding potential), (ii) explore the food utilization efficiency measures of *D. indica* by feeding on the leaves of three *T. anguina* cultivars, (iii) determine the amyolytic and proteolytic activities of the fifth-instar larvae of *D. indica* by feeding on the leaves of three *T. anguina* cultivars, and (iv) understand the probable effect of various nutrients (total carbohydrates, proteins, lipids, amino acids and nitrogen) and antinutrients (total phenols, flavonols and tannins) present in the leaves of three *T. anguina* cultivars on the development, survival and reproductive potential of *D. indica*. The findings of this study could be useful in the selection of partially resistant *T. anguina* cultivar, which can contribute useful data for further *T. anguina* breeding program and effective management of *D. indica*.

Materials and methods

Host plants

Seeds of three *T. anguina* cultivars [Baruipur Long, Polo No. 1 and MNSR-1 {Baruipur Long and MNSR-1 were originated from India, while Polo No. 1 (F1 Hybrid) was originated from Thailand}] were separately cultivated at the Crop Research Farm (CRF), University of Burdwan (23°16' N, 87°54' E), West Bengal, India. Each *T. anguina* cultivar was attacked by the larvae of *D. indica* during early May 2018 in the field.

To get leaves from uninfested plants of each *T. anguina* cultivar, seeds of plants in earthen pots containing ca. 1500 cm³ of soil were grown in the CRF, The University of Burdwan between May

and August 2018 under a natural photoregime of 13L: 11 D at 30–37°C. Each plant with the pot was covered by a fine mesh nylon net [100 cm (height) × 60 cm (diameter)] to protect plants from insect damage and unintentional infection. Insecticides were not applied to these plants.

Insect culture

Fifth-instar larvae of *D. indica* were collected from each cultivar of *T. anguina* plants growing at the CRF of the University of Burdwan during mid-June 2018. Larvae were taken into the laboratory and transferred on same leaves in glass jars (20 cm diameter × 30 cm height) from which cultivar they were collected. A pair of newly emerged male and female was transferred in a glass jar (20 cm diameter × 30 cm height) for mating and egg-laying ($n = 5$ pairs of male and female for each cultivar of *T. anguina*), containing leaves of the same cultivar from which fifth-instar larvae were collected. Eggs (50) laid by females on the fourth day were collected from the leaves of each *T. anguina* cultivar (Baruipur Long, Polo No. 1 and MNSR-1). The eggs were separately used for culture in the leaves of each *T. anguina* cultivar for three generations.

Life table study

Newly emerged fourth-generation adults raised from caterpillars (the sexes were separated by the presence of a tuft of light brown hairs on the tip of the abdomen, which are bushier in female than that of male), which were fed with three generations on the leaves of the same cultivar, were used for the construction of life table. Newly emerged adults (male and female) were placed in fine-mesh nylon net cages (25 × 25 × 25 cm³) for mating and egg-laying (newly emerged males and females mate on the second day of emergence), and same-aged eggs were collected on the fourth day. Groups of 100 eggs collected from females, on which cultivar they were maintained, were employed to construct age-stage, two-sex life table of *D. indica* on the leaves of each *T. anguina* cultivar. Each egg was used as a replicate on the leaves of a particular cultivar. Leaves were changed at 24 h interval. To prevent moisture loss from leaves, a moist piece of cotton was placed around the petiole of each fresh mature leaf, which was covered by an aluminium foil to prevent moisture loss. Each larva was transferred into a glass jar (3 cm diameter × 5 cm length) with leaves from a particular *T. anguina* cultivar until pupation. Each pupa was transferred into a separate glass jar (8 cm diameter × 10 cm length). Development stages, the fate of each larva (dead or alive), larval moulting, pupation time and the emergence of each adult were recorded at 24 h interval. The length and breadth of eggs, and larval instars by feeding on the leaves of a particular cultivar (Baruipur Long, Polo No. 1 and MNSR-1) were measured to observe the growth of *D. indica* (egg and first instar were measured by microscope fitted with an objective lens of 10X attached with oculometer ERMA Japan, while from second to fifth instars were measured on millimetre graph paper) ($n = 10$). Further, the length and breadth of the pupa and newly emerged adults were measured on millimetre graph paper ($n = 10$). The longevity of each adult (emergence to death) was noted at 24 h interval.

Fecundity of *D. indica* through lifetime was recorded on the leaves of each *T. anguina* cultivar, on which larvae were reared. The adult pre-oviposition period (APOP: the period between the emergence of an adult female and her first oviposition),

total pre-oviposition period (TPOP: the time interval from birth to the beginning of oviposition), oviposition days, daily fecundity and total fecundity (number of eggs produced during the reproductive period) were recorded on the leaves of each cultivar (Chi, 1988; Chi and Su, 2006).

Raw data on the survival, development and oviposition of all individuals were analysed based on age-stage, two-sex life table theory (Chi and Liu, 1985; Chi, 1988) using the computer program TWSEX-MSChart (Chi, 2017a). The parameters calculated were: age-stage-specific survival rate (s_{xj} , x : age and j : stage), age-specific survival rate (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x), age-stage life expectancy (e_{xj}), age-stage reproductive value (v_{xj}).

The potential population growth of *D. indica* on three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1) was projected according to Chi and Liu (1985) & Chi (1990) to forecast the future population size and age-stage structure by using the TIMING-MSChart program (<http://140.120.197.173/Ecology/Download/Timing-MSChart.rar>) (Chi, 2017b).

Food utilization indices

Newly emerged fourth-generation first-instar larvae that had been fed with the leaves of a particular *T. anguina* cultivar (Baruipur Long, Polo No. 1 and MNSR-1) were used for this experiment. Before placing larvae on the leaves of a particular cultivar, larvae and leaves were weighed. Larvae were allowed to feed for 24 h and leaves remained after 24 h of feeding were reweighed. Sample leaves from each cultivar prior to larval feeding and after 24 h of feeding were weighed, oven dried for 72 h at $50 \pm 1^\circ\text{C}$ and reweighed to determine the dry weight of the diet supplied to the larvae. The amount of food consumed by larvae was determined by recording the difference between the total dry weight of diet supplied initially and dry weight of diet remained after 24 h interval. Five replicates (each replicate contained ten larvae, $n = 10$) were conducted on the leaves of a particular cultivar. The fresh weight gain of larvae on the leaves of a particular cultivar during the period of study was determined by recording the differences in the weight of larvae at 24 h interval. Faeces were collected at 24 h interval and weighed, and then placed in a hot air oven and reweighed to find the dry weight of excreta.

The parameters of food utilization indices, i.e., growth rate (GR), consumption rate (CR), relative growth rate (RGR), consumption index (CI), egestion rate (ER), host consumption rate (HCR), approximate digestibility (AD), the efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD) all based on dry weight were determined by the formulas of Waldbauer (1968) (Supplementary material S1).

Enzymatic activity of larvae

Fourth-generation fifth instar *D. indica* larvae that were fed with the leaves of a particular *T. anguina* cultivar for three generations were used to determine enzymatic activity. For each cultivar, fifth-instar larvae (second day) were placed in ice for paralysis, and after that larvae ($n = 5$) were rapidly dissected under a stereomicroscope. The haemolymph was cleaned with precooled distilled water, and the extraneous tissues were removed from midguts. Midguts including contents were homogenized in 1 ml of 10 mM NaCl by a glass homogenizer. The solution was centrifuged at 12,000 g at 4°C for 15 min. The supernatant was collected for enzymatic assays and stored at -20°C until use.

Non-specific amylolytic activity of midgut extracts was determined according to Bernfeld (1955) with some modifications by Mohammadzadeh *et al.* (2013). The optimum pH on α -amylase activity in the midgut extracts of *D. indica* larvae was determined by incubation of the reaction mixture with pH set at 7–12. Soluble starch (1% w/v) as a substrate was added in 20 mM glycine–NaOH buffer (pH 11.5). One-hundred μl of the enzyme extract was added with glycine–NaOH buffer (500 μl ; pH 11.5) at 37°C . The reaction began when 200 μl of 1% soluble starch was added and stopped 30 min later by the addition of 300 μl of dinitrosalicylic acid (DNS) and heating in boiling water for 10 min. Each treatment was replicated five times including blanks in which substrate was added after DNS, and the absorbance was measured at 540 nm in the UV-visible spectrophotometer (Shimadzu, UV-1800240V). The result was expressed as mg maltose per min (one unit of α -amylase activity was defined as the quantity of enzyme required to produce 1 mg maltose at 37°C per min).

Total general proteolytic activity from enzyme extracts was estimated by the protocol of Elpidina *et al.* (2001) using azocasein as a substrate at the pH optimum. The buffer (20 mM glycine–NaOH buffer) was used to determine the pH optimum of proteolytic activity over a pH range of 7–12. Azocasein (1.5% w/v) as a substrate was mixed in 20 mM glycine–NaOH buffer (pH 9.0). Enzyme extracts (100 μl) were added with 200 μl azocasein and 300 μl of 20 mM glycine–NaOH buffer (pH 9.0). The enzymatic reactions were stopped by addition of 30% of 300 μl trichloroacetic acid (TCA). The solution was centrifuged at 12,000 g for 15 min and the supernatant monitored spectrophotometrically at 440 nm. The absorbance from the supernatant was measured at 440 nm in the UV-visible spectrophotometer (Shimadzu, UV-1800240V). Each treatment was replicated five times including blanks in which substrate was added after TCA, and the result was expressed as mU min^{-1} (one unit is defined as the amount of enzyme that is required to hydrolyse azocasein to give 1 μg of tyrosine in 1 min at 37°C at certain pH).

Biochemical analysis of leaves

The nutritional parameters from the leaves of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1) were estimated by using 1 g fresh leaves of respective type to various biochemical analysis such as total carbohydrates (Dubois *et al.*, 1956), total proteins (Lowry *et al.*, 1951), total lipids (Folch *et al.*, 1957), total amino acids (Moore and Stein, 1948), total phenols (Bray and Thorpe, 1954) and total flavonols (Howell *et al.*, 1976). Dried leaves were used for determination of total tannins (Scalbert, 1992) and total nitrogen (Vogel, 1958) as the water content in fresh leaves may interfere with satisfactory estimations. Each biochemical analysis was replicated five times.

Estimation of moisture content

One gram fresh leaves from each *T. anguina* cultivar (Baruipur Long, Polo No. 1 and MNSR-1) was placed in a hot-air oven for 72 h at $50 \pm 1^\circ\text{C}$ and the dried leaves were weighed in a balance (± 0.01 mg). The water content was determined by recording the difference between fresh and dry weights of leaves ($n = 5$). The moisture content for leaves of three cultivars was replicated five times.

Statistical analysis

The means and standard errors of life table parameters were estimated by bootstrap technique (Efron and Tibshirani, 1993) with

Table 1. Development time and adult longevity (mean \pm SE) of *Diaphania indica* on three *Trichosanthes anguina* cultivars

Parameters	Baruipur Long		Polo No. 1		MNSR-1	
	<i>n</i>	Duration (day)	<i>n</i>	Duration (day)	<i>n</i>	Duration (day)
Egg	91	3.60 \pm 0.08a	92	3.99 \pm 0.08b	95	3.09 \pm 0.06c
First instar	85	2.56 \pm 0.07a	82	2.83 \pm 0.07b	87	2.38 \pm 0.06c
Second instar	77	2.23 \pm 0.05a	71	2.37 \pm 0.06a	76	1.79 \pm 0.05b
Third instar	70	2.0 \pm 0.09a	63	2.41 \pm 0.07b	72	1.53 \pm 0.06c
Fourth instar	64	2.05 \pm 0.07a	55	2.20 \pm 0.05b	67	1.76 \pm 0.05c
Fifth instar	59	2.05 \pm 0.06a	49	2.65 \pm 0.09b	62	1.85 \pm 0.06c
Pupal duration	53	8.53 \pm 0.14a	43	9.28 \pm 0.15b	57	7.40 \pm 0.09c
Preadult duration	53	23.08 \pm 0.25a	43	25.72 \pm 0.28b	57	19.79 \pm 0.21c
Adult longevity						
Female	25	8.84 \pm 0.15a	18	8.33 \pm 0.14b	32	9.03 \pm 0.20c
Male	28	6.50 \pm 0.20a	25	5.96 \pm 0.17b	25	7.40 \pm 0.21c

Standard errors were estimated using 100,000 bootstrap resampling. Data followed by different lower-case letter within the row were significantly different based on a paired bootstrap test at 5% level of significance.

100,000 replications, which is present in the TWOSEX-MS Chart program containing whether the data are normally distributed (Chi, 2017a). The paired bootstrap (Chi, 2017a, 2017b) was used to evaluate the differences at the 5% significance level in the development time, adult longevity, adult preoviposition period (APOP), total preoviposition period (TPOP), oviposition period and fecundity, and life table parameters (r , λ , R_0 and T) among three *T. anguina* cultivars. Data on different feeding indices of *D. indica* and enzymatic activity of the fifth-instar larvae among treatments and the biochemical properties of three *T. anguina* cultivars were subjected to one-way analysis of variance (ANOVA) followed by Tukey's test (HSD) (Zar, 1999). The Pearson correlation coefficient analysis was applied to observe the relationship between the life table parameters of *D. indica* and chemical properties (nutrient and antinutrients metabolites) of the leaves of three *T. anguina* cultivars. All the statistical analyses were performed by using SPSS (version 13.0) software.

Results

Development, survival and oviposition of *D. indica*

Effect of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1) on the development time of five larval instars, pupal duration and longevity of *D. indica* adults were presented in table 1. The incubation time of eggs was the longest on Polo No. 1 followed by Baruipur Long and the shortest on MNSR-1. Except for second instar, where larval duration was longer on Baruipur Long and Polo No. 1 than MNSR-1, the development time of first, third, fourth and fifth instars were the longest on Polo No. 1 followed by Baruipur Long and the shortest on MNSR-1. The pupal duration was the longest on Polo No. 1, intermediate on Baruipur Long and the shortest on MNSR-1. The preadult duration (from egg to adult emergence) was completed earliest on MNSR-1 followed by Baruipur Long and the slowest on Polo No. 1. The longevities of adult males and females were the longest on MNSR-1, intermediate on Baruipur Long and the shortest on Polo No. 1.

Table 2 shows different morphological features of *D. indica* fed with three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1). The length and breadth of eggs, and first instar of *D. indica* were higher on MNSR-1 than Polo No. 1. The length of third instar was the highest on MNSR-1 followed by Baruipur Long and the shortest on Polo No. 1, but there were no significant differences in the breadth of insects fed with three *T. anguina* cultivars. The length and breadth of last two instars (fourth and fifth) were the highest on MNSR-1 followed by Baruipur Long and the shortest on Polo No. 1. The data on head capsule width from first to fifth instar of *D. indica* fed with three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1) are presented in Supplementary table 1. The head capsule width of the fifth instar was greater on MNSR-1 than Baruipur Long and Polo No. 1. The length and breadth of pupa, and newly emerged adults (male and female) were smaller on Polo No. 1 than MNSR-1 (table 2).

The APOP, TPOP, oviposition days and fecundity of adult *D. indica* emerged from larvae fed with three *T. anguina* cultivars are presented in table 3. The APOP was higher on Polo No. 1 than Baruipur Long and MNSR-1, while oviposition days were higher on Baruipur Long and MNSR-1 than Polo No. 1. The TPOP was the longest on Polo No. 1 followed by Baruipur Long and the shortest on MNSR-1. Fecundity was the highest on MNSR-1 followed by Baruipur Long and the lowest on Polo No. 1.

The s_{xj} (an individual will survive to age x and stage j) curves of *D. indica* on three *T. anguina* cultivars were overall similar (Supplementary fig. 1). The female curves emerged at age 20 d, 22 d and 18 d on Baruipur Long, Polo No. 1 and MNSR-1, respectively; whereas male curves emerged at age 21 d, 23 d and 17 d on Baruipur Long, Polo No. 1 and MNSR-1, respectively (Supplementary fig. 1a–c).

The curves of age-stage specific fecundity (f_{xj}) demonstrated variation in the egg-laying performance of *D. indica* on three *T. anguina* cultivars (Supplementary fig. 2). The f_{xj} and age-specific fecundity (m_x) on Baruipur Long, Polo No. 1 and MNSR-1 started at 21, 24 and 20 d, respectively (Supplementary fig. 2a–c). The maximum daily oviposition rates were the highest on MNSR-1, intermediate on Baruipur Long and the lowest on Polo

No. 1. The females started to oviposit on 21 d and continued up to 33 d on Baruipur Long, while females started to oviposit on 24 d and ended at 34 d on Polo No. 1, but females began to oviposit on 20 d and ended on 29 d on MNSR-1. The highest f_{xj} and m_x peaks of *D. indica* on Baruipur Long were 25 and 26 d, respectively, while the highest f_{xj} and m_x peaks on Polo No. 1 were recorded on 30 d, and the highest f_{xj} and m_x peaks on MNSR-1 were 23 d (Supplementary fig. 2a–c). We recorded the highest age-specific maternity ($l_x m_x$) on 25, 29 and 23 on Baruipur Long, Polo No. 1 and MNSR-1, respectively (Supplementary fig. 2a–c).

The age-stage specific life expectancy is the probability that an individual of age x and stage j is expected to live. The life expectancies of *D. indica* at age zero (e_{01}) were 20.80, 20.05 and 19.75 d on Baruipur Long, Polo No. 1 and MNSR-1, respectively, which are due to individuals of the same age can develop to different stages, and these individuals will show different life expectancies (Supplementary fig. 3). The maximum life expectancies of female and male *D. indica* on Baruipur Long were 36 d and 34 d, respectively (Supplementary fig. 3a). The maximum life expectancies of female and male on Polo No. 1 were 36 d (Supplementary fig. 3b), while the maximum life expectancies of female and male were 32d when fed with MNSR-1 (Supplementary fig. 3c).

The age-stage reproductive value (v_{xj}) represents the contribution of age x and stage j to the future population. The reproductive value of a new-born individual (v_{01}), finite rate of increase, on Baruipur Long, Polo No. 1 and MNSR-1 were 1.157, 1.118 and 1.202 day^{-1} , respectively (Supplementary fig. 4a–c). Females began to emerge at age 20, 22 and 18 days on Baruipur Long, Polo No. 1 and MNSR-1, respectively, and subsequently, reached its peak values to 149.65, 109.85 and 166.70 d^{-1} at 24, 25 and 21 d on Baruipur Long, Polo No. 1 and MNSR-1, respectively. The reproductive values were zero at age 34, 35 and 30 days on Baruipur Long, Polo No. 1 and MNSR-1, respectively, as the aged adults did not produce eggs.

The gross reproductive rate (GRR) was higher on MNSR-1 than Polo No. 1 (table 4). The intrinsic rate of increase (r_m) of *D. indica* was the highest on MNSR-1 followed by Baruipur Long and the lowest on Polo No. 1, while the finite rate of increase (λ) was the highest on Baruipur Long, intermediate on MNSR-1 and the lowest on Polo No. 1 (table 4). The net reproductive rate (R_0) of *D. indica* was the highest on MNSR-1 followed by Baruipur Long and the lowest on Polo No. 1, suggesting that more offspring of *D. indica* would be available within one generation on MNSR-1 (table 4). The mean generation time (T , time needed for an insect population to enhance to R_0 fold of its population size at the constant age distribution) of *D. indica* was the longest on Polo No. 1, intermediate on Baruipur Long and the shortest on MNSR-1, indicating that the population of *D. indica* will enhance quicker on MNSR-1 followed by Baruipur Long and Polo No. 1 (table 4).

Population projection

The stage structures of *D. indica* are projected with an initial population of ten eggs using the TIMING-MSChart program (Supplementary fig. 5). After 80 days of simulation, the population growth was the highest on MNSR-1 followed by Baruipur Long and the slowest on Polo No. 1. There are 527,539 preadults and 10,401 adults (5508 females and 4893 males) on Baruipur Long, while the numbers of preadults on Polo No. 1 were 4982 and adults were 273 (147 females and 126 males). The numbers

Table 2. Morphological features of *Diaphania indica* [$n = 10$, mean (mm) \pm SE] reared on three *Trichosanthes anguina* cultivars under laboratory conditions (27 \pm 1°C, 65 \pm 5% r.h. and 12L:12D)

	Length				Breadth					
	Baruipur Long	Polo No. 1	MNSR-1	F _{2,27}	P value	Baruipur Long	Polo No. 1	MNSR-1	F _{2,27}	P value
Egg	0.81 \pm 0.02a	0.76 \pm 0.01a	0.85 \pm 0.02b	7.748	0.002	0.39 \pm 0.01a	0.37 \pm 0.01a	0.45 \pm 0.02b	9.595	0.001
First instar	3.78 \pm 0.19ab	3.45 \pm 0.17a	4.33 \pm 0.25b	5.762	0.008	0.55 \pm 0.02ab	0.51 \pm 0.03a	0.60 \pm 0.03b	4.561	0.02
Second instar	8.06 \pm 0.14a	7.65 \pm 0.17b	8.73 \pm 0.16c	14.499	0.0001	0.84 \pm 0.03ab	0.77 \pm 0.01a	0.87 \pm 0.04b	4.086	0.028
Third instar	10.99 \pm 0.17a	10.25 \pm 0.18b	12.52 \pm 0.15c	59.356	0.0001	1.57 \pm 0.07	1.45 \pm 0.06	1.62 \pm 0.07	2.101	0.142
Fourth instar	14.21 \pm 0.13a	13.80 \pm 0.15b	15.40 \pm 0.19c	35.073	0.0001	2.17 \pm 0.08a	1.94 \pm 0.08b	2.63 \pm 0.08c	23.03	0.0001
Fifth instar	19.20 \pm 0.14a	18.47 \pm 0.15b	20.89 \pm 0.44c	23.166	0.0001	2.90 \pm 0.08a	2.60 \pm 0.13b	3.52 \pm 0.08b	30.131	0.0001
Pupa	13.72 \pm 0.21ab	13.28 \pm 0.21a	14.20 \pm 0.22b	5.933	0.007	2.84 \pm 0.13a	2.70 \pm 0.10a	3.22 \pm 0.09b	7.229	0.003
Male ^a	12.78 \pm 0.15ab	12.30 \pm 0.15a	13.23 \pm 0.29b	6.367	0.005	3.15 \pm 0.11a	3.09 \pm 0.13a	3.63 \pm 0.19b	4.789	0.017
Female ^a	13.87 \pm 0.24ab	13.26 \pm 0.25a	14.49 \pm 0.18b	8.623	0.001	3.36 \pm 0.09a	3.24 \pm 0.15a	3.83 \pm 0.19b	5.205	0.012

Means followed by different letters for length or breadths of *D. indica* within the rows are significantly different by Tukey's test at 5% level of significance.
^aNewly emerged.

Table 3. Mean (\pm SE) of adult preoviposition period (APOP), total preoviposition period (TPOP), oviposition period and fecundity of *Diaphania indica* emerging from larvae reared on three *Trichosanthes anguina* cultivars

Parameters	Baruipur Long	Polo No. 1	MNSR-1
APOP (days)	2.29 \pm 0.17a	2.94 \pm 0.13b	2.26 \pm 0.09a
TPOP (days)	24.67 \pm 0.40a	28.18 \pm 0.59b	21.68 \pm 0.26c
Oviposition period (days)	4.17 \pm 0.15a	3.59 \pm 0.23b	4.52 \pm 0.09a
Fecundity (eggs)	203.68 \pm 10.43a	151.22 \pm 12.07b	259.00 \pm 9.66c

Standard errors were estimated using 100,000 bootstrap resampling. Data followed by different lower-case letter within the row were significantly different based on a paired bootstrap test at 5% level of significance.

Table 4. Mean (\pm SE) of gross reproductive rate (GRR), intrinsic rate of increase (r_m), finite rate of increase (λ), net reproductive rate (R_0 : offspring/individual) and mean generation time (T) of *Diaphania indica* reared on three *Trichosanthes anguina* cultivars

Parameters	Baruipur Long	Polo No. 1	MNSR-1
GRR (offspring/individual)	121.19 \pm 24.62ab	83.41 \pm 15.80a	159.78 \pm 19.33b
r_m (d^{-1})	0.1461 \pm 0.0072a	0.1112 \pm 0.0085b	0.1841 \pm 0.0067c
λ (d^{-1})	1.1573 \pm 0.0084a	1.1177 \pm 0.0095b	1.1202 \pm 0.0081c
R_0 (offspring/individual)	50.92 \pm 9.19a	27.22 \pm 6.18b	82.88 \pm 12.46c
T (d)	26.90 \pm 0.28a	29.70 \pm 0.54b	23.99 \pm 0.22c

Standard errors were estimated using 100,000 bootstrap resampling. Data followed by different lower-case letter within the row were significantly different based on a paired bootstrap test at 5% level of significance.

of preadults on MNSR-1 were 44,93,595 and adults were 5135 (3166 females and 1969 males).

(0.41 \pm 0.01 mU min⁻¹) and the lowest on Polo No. 1 (0.34 \pm 0.01 mU min⁻¹).

Food utilization efficiency measurement

Table 5 presents food utilization efficiency measures for the fifth-instar larvae of *D. indica* that fed with the leaves of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1) (food utilization efficiency measures for the first to fourth-instar larvae were provided in Supplementary tables 2–5). The GR and RGR values were the highest in insects fed with MNSR-1 than Baruipur Long and Polo No. 1; whereas CR, CI and HCR values were the highest on MNSR-1 followed by Baruipur Long and the lowest on Polo No. 1 (table 5). The value of ER was the highest on MNSR-1 followed by Polo No. 1 and the lowest on Baruipur Long (table 5). Higher values of AD were recorded on MNSR-1 and Baruipur Long than Polo No. 1 (table 5). Both ECI and ECD values were the highest on Polo No. 1, intermediate on Baruipur Long and the lowest on MNSR-1 (table 5). We recorded higher value of HUE on Baruipur Long and MNSR-1 than Polo No. 1 (table 5).

Enzymatic activity of larvae

The results for non-specific amylolytic activity in the fifth-instar larvae of *D. indica* were significantly different among treatments ($F_{2,12} = 99.33$, $P < 0.0001$), which was the highest in larvae fed with MNSR-1 (0.60 \pm 0.02 mg maltose min⁻¹) followed by Baruipur Long (0.43 \pm 0.01 mg maltose min⁻¹) and the lowest on Polo No. 1 (0.31 \pm 0.01 mg maltose min⁻¹) (fig. 1).

General proteolytic activity in the fifth-instar larvae of *D. indica* was significantly affected in response to feeding on the leaves of three *T. anguina* cultivars ($F_{2,12} = 26.5$, $P < 0.0001$) (fig. 2). Proteolytic activity was the highest in larvae fed with MNSR-1 (0.49 \pm 0.02 mU min⁻¹) followed by Baruipur Long

Biochemical properties of leaves

Total carbohydrates, proteins, lipids and amino acids were the highest in MNSR-1, intermediate in Baruipur Long and the lowest in Polo No. 1 (table 6). The nitrogen content was the highest in MNSR-1 than Baruipur Long and Polo No. 1 (table 6). Total phenols, flavonols and tannins were the highest in Polo No. 1, intermediate in Baruipur Long and the lowest in MNSR-1 (table 6). The highest water content was recorded in MNSR-1 and Baruipur Long than Polo No. 1 (table 6).

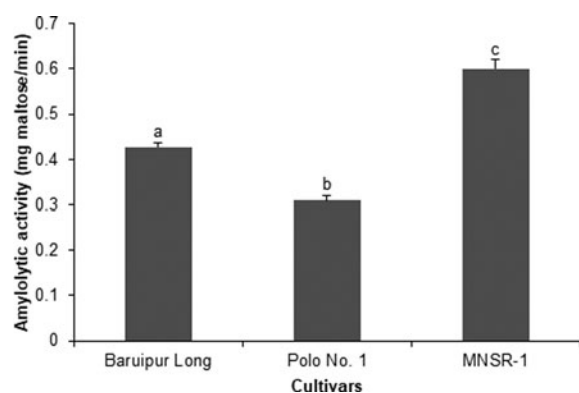
Correlation analysis

The analysis of correlation coefficients between life table parameters of *D. indica* fed with three *T. anguina* cultivars and biochemical properties of the leaves of three tested cultivars are presented in table 7. Duration of immature stages of *D. indica* fed with the leaves of three cultivars showed negative correlations with nutrients (total carbohydrates, proteins, lipids, amino acids and nitrogen) and moisture content, while positive correlations were observed with antinutrients (total phenols, flavonols and tannins). A positive correlation was observed between fecundity and nutrients (total carbohydrates, proteins, lipids, nitrogen and amino acids) as well as moisture content, while a negative correlation was observed between fecundity and antinutrients (total phenols, flavonols and tannins) (table 7). Positive correlations were observed for GRR, r_m , λ and R_0 with nutrients (total carbohydrates, proteins, lipids, nitrogen and amino acids) and moisture content, while negative correlations were observed with antinutrients (total phenols, flavonols and tannins) (table 7). The T was negatively and positively correlated with nutrients (total carbohydrates, proteins, lipids, nitrogen and amino acids) and antinutrients (total

Table 5. Measurement of food utilization efficiency (Mean \pm SE) of the fifth-instar larvae ($n = 10$) of *Diaphania indica* reared on three *Trichosanthes anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1)

Parameters	Baruipur Long	Polo No. 1	MNSR-1	$F_{2,27}$	P
GR (mg d ⁻¹)	2.71 \pm 0.08a	2.75 \pm 0.06a	2.99 \pm 0.06b	4.69	0.018
CR (mg d ⁻¹)	36.60 \pm 0.78a	32.43 \pm 0.63b	44.80 \pm 1.01c	59.02	0.0001
RGR (mg d ⁻¹)	0.23 \pm 0.01a	0.23 \pm 0.005a	0.288 \pm 0.01b	11.25	0.0001
CI (mg d ⁻¹)	3.20 \pm 0.09a	2.55 \pm 0.06b	4.69 \pm 0.17c	92.63	0.0001
ER (mg d ⁻¹)	0.72 \pm 0.01a	0.87 \pm 0.03b	0.97 \pm 0.02c	23.85	0.0001
HCR (mg d ⁻¹)	3.92 \pm 0.09a	3.42 \pm 0.08b	5.66 \pm 0.19c	81.5	0.0001
AD (%)	77.32 \pm 0.60a	65.84 \pm 1.0b	79.13 \pm 0.40a	102.23	0.0001
ECl (%)	7.42 \pm 0.23a	9.25 \pm 0.22b	6.17 \pm 0.15c	55.27	0.0001
ECD (%)	9.60 \pm 0.32a	14.07 \pm 0.37b	7.80 \pm 0.21c	109.45	0.0001
HUE (%)	81.53 \pm 0.40a	74.58 \pm 0.55b	82.74 \pm 0.28a	106.47	0.0001

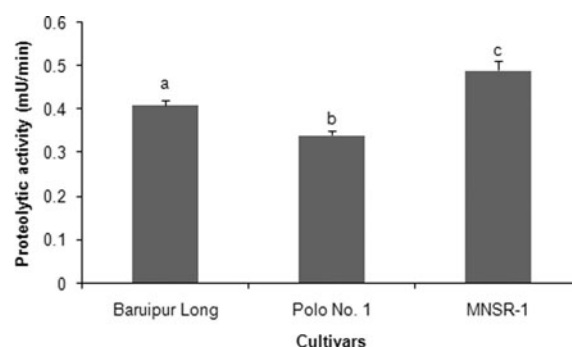
Food utilization efficiency measures: GR, growth rate; CR, consumption rate; RGR, relative growth rate; CI, consumption index; ER, egestion rate; HCR, host consumption rate; AD, approximate digestibility; ECl, efficiency of conversion of ingested food; ECD, efficiency of conversion of digested food; HUE, host utilization efficiency. Within the row means followed by same letter(s) are not significantly different by Tukey's test.

**Figure 1.** Non-specific amylolytic activity of the fifth-instar larvae of *Diaphania indica* ($n = 5$) fed with three cultivars of *Trichosanthes anguina*. Means followed by different letters are significantly different by Tukey's test at 5% level of significance.

phenols, flavonols and tannins), respectively (table 7). General proteolytic activity was positively correlated with nutrients (total carbohydrates, proteins, lipids, nitrogen and amino acids) and moisture content, while negative correlations were observed with antinutrients (total phenols, flavonols and tannins) (table 7). Non-specific amylolytic activity was positively correlated with total carbohydrates, proteins, lipids, nitrogen and moisture content, while non-specific amylolytic activity was negatively correlated with total amino acids, phenols, flavonols and tannins (table 7).

Discussion

Different cultivars of a host plant play a crucial role in population growth and food utilization of insects (Golizadeh and Razmjou, 2010; Alami et al., 2014; Nemati-Kalkhoran et al., 2018; Mobarak et al., 2020). Till date, no reports are available on *D. indica* using age-stage, two-sex life table, and further, the biology of *D. indica* on *T. anguina* is reported for the first time. In the present study, the longest preadult duration (egg to adult emergence) was recorded on Polo No. 1 (25.72 d) followed by Baruipur Long (23.08 d) and the shortest on MNSR-1 (19.79 d), suggesting that the variation in the nutritional quality of the

**Figure 2.** General proteolytic activity of the fifth-instar larvae of *Diaphania indica* ($n = 5$) fed with three cultivars of *Trichosanthes anguina*. Means followed by different letters are significantly different by Tukey's test at 5% level of significance.

leaves of three *T. anguina* cultivars influenced the development of *D. indica*. Total larval development of *D. indica* was 8–10 d on snake gourd (Ganehiarachchi, 1997), 15.22 d on gherkins (*Cucumis anguria* L.) (Roopa et al., 2014), 13.5 d on *C. sativus* L. (Fitriyana et al., 2015) and 9.50 d on bitter melon (*Momordica charantia* L.) (Nagaraju et al., 2018). The variation in the nutrient and antinutrient metabolites including leaf structure of different host plants might influence the development time of *D. indica* on different host plants. In this study, immature stages of *D. indica* showed positive correlations with the antinutrients of leaves (total phenols, flavonols and tannins), suggesting that antinutrients caused a delayed growth of *D. indica* to reach the adult stage. Koner et al. (2019) showed positive correlations between immature stages of *Galerucella placida* Baly (Coleoptera: Chrysomelidae) and antinutrients of *Rumex dentatus* L. and *Polygonum glabrum* Willd. (Polygonaceae) leaves.

The fecundity of *D. indica* on snake gourd, gherkin and cucumber was 267, 116.5 and 250.21 eggs during lifetime, respectively (Ganehiarachchi, 1997; Roopa et al., 2014; Nagaraju et al., 2018); whereas in this study, the fecundity of *D. indica* was the highest on MNSR-1 (259 eggs), intermediate on Baruipur Long (203.68 eggs) and the lowest on Polo No. 1 (151.22 eggs), implicating that variations in fecundity among host plants as well as different cultivars of a host plant could be due to differences in

Table 6. Biochemical analyses (mean \pm SE) of the leaves of three *Trichosanthes anguina* cultivars

Parameters	Baruipur Long	Polo No. 1	MNSR-1	$F_{2,12}$	<i>P</i> value
Carbohydrate (mg g ⁻¹ DWL)	16.59 \pm 0.94a	12.94 \pm 0.59b	20.58 \pm 0.98c	19.97	0.0001
Protein (mg g ⁻¹ DWL)	41.30 \pm 1.89a	31.06 \pm 1.64b	51.90 \pm 3.04c	20.95	0.0001
Lipid (mg g ⁻¹ DWL)	44.05 \pm 1.70a	35.67 \pm 1.53b	61.40 \pm 2.11c	53.22	0.0001
Amino acid (mg g ⁻¹ DWL)	1.19 \pm 0.07a	0.79 \pm 0.03b	1.62 \pm 0.07c	45.90	0.0001
Nitrogen (% DWL)	3.60 \pm 0.16a	3.27 \pm 0.13a	4.14 \pm 0.18b	7.63	0.007
Phenol (mg g ⁻¹ DWL)	1.66 \pm 0.07a	2.50 \pm 0.13b	1.26 \pm 0.07c	44.40	0.0001
Flavonol (mg g ⁻¹ DWL)	0.37 \pm 0.01a	0.61 \pm 0.03b	0.25 \pm 0.02c	69.14	0.0001
Tanin (mg g ⁻¹ DWL)	2.31 \pm 0.07a	2.73 \pm 0.06b	1.94 \pm 0.14c	16.29	0.0001
Moisture content (% FWL)	77.80 \pm 1.94a	71.40 \pm 1.78b	80.10 \pm 2.08a	5.43	0.021

DWL, dry weight of leaves; FWL, fresh weight of leaves.

Means followed by different letters within the rows are significantly different by Tukey's test at 5% level of significance.

quality and quantity of food consumed by the larvae of *D. indica* during larval stages (Razmjou *et al.*, 2014). In the current study, there is a negative correlation between the fecundity of *D. indica* and antinutrients of three *T. anguina* cultivars, suggesting that antinutrients of leaves played an inhibitory role which influenced the egg-laying performance of *D. indica*. The lowest fecundity of *D. indica* on Polo No. 1 suggested that the poor nutritional quality of Polo No. 1 than the other two cultivars of *T. anguina* determines the least performance of *D. indica* on Polo No. 1.

The intrinsic rate of increase (r_m) and finite rate of increase (λ) can exactly predict the overall population growth, development and fecundity of an insect population, and are considered as important parameters in measuring population growth potential (Karimi-Pormehr *et al.*, 2018; Nemati-Kalkhoran *et al.*, 2018; Das *et al.*, 2019; Mobarak *et al.*, 2020). The r_m was the lowest on Polo No. 1 (0.1112 d⁻¹) and the highest on MNSR-1 (0.1841 d⁻¹), suggesting that poor nutritional quality of Polo No. 1 are the effective factor for delayed development of *D. indica*. The r_m of *D. indica* on *C. sativus* is 0.1 individual female⁻¹ d⁻¹, while the net reproductive rate (R_0) is 51 individuals female⁻¹ (Fitriyana *et al.*, 2015). The R_0 indicates fecundity as well as survival characters, which was the highest on MNSR-1 (82.88 offspring/individual) and the lowest on Polo No. 1 (27.22 offspring/individual). The T indicates as the period that a population needed to enhance R_0 fold of its size when time at infinity and the population approaches a stable age distribution, which was the fastest on MNSR-1 (23.99 days) and the slowest on Polo No. 1 (29.70 days). This study revealed that T of *D. indica* fed with three *T. anguina* cultivars was positively correlated with the antinutrients of leaves (total phenols, flavonols and tannins), implicating that the antinutrients of leaves influenced prolonged generation time of *D. indica* (Koner *et al.*, 2019). Here, the finite rate of increase (λ) of *D. indica* was the lowest on Polo No. 1 (1.1177 d⁻¹) than the other two cultivars tested in this study, indicating that *D. indica* fed with Polo No. 1 exhibited a slower growth rate and longer generation time among three *T. anguina* cultivars. The above results suggested that Polo No. 1 is the least suitable cultivar for the development and reproduction of *D. indica* due to lower amount of nutrients and a higher amount of antinutrients.

Phenols serve as defensive agents against feeding by herbivores and attack by nematodes including fungal and bacterial pathogens (Harborne, 2003). Tannins, an anti-herbivore component, reduce the digestibility of substances (Harborne, 2003), while flavonols help to protect plants from insect attack by influencing behaviour

as well as growth and development of insect herbivore (Treutter, 2006; War *et al.*, 2012). Our findings on the biochemical properties of leaves of three *T. anguina* cultivars suggested that Polo No. 1 is of poor nutritional quality than MNSR-1 and Baruipur Long because nutrients such as total carbohydrates, proteins, lipids, amino acids and nitrogen content were the lowest in Polo No. 1 than the other two cultivars used in this study; whereas antinutrients or secondary metabolites such as total phenols, flavonols and tannins were the highest in Polo No. 1 than the other two cultivars. This could be the probable explanation for lower growth and development including fecundity of *D. indica* feeding on Polo No. 1 than MNSR-1 and Baruipur Long. Low water content in the leaves of host plants reduces survivability of insect herbivores. The lowest water content in the leaves of Polo No. 1 than MNSR-1 and Baruipur Long could be another explanation for lower survivability of *D. indica* on Polo No. 1 (Mattson and Scriber, 1987; Roy and Barik, 2012, 2013; Mobarak *et al.*, 2020). The food consumed by the larvae of Lepidoptera could influence the reproductive potential of adults (Razmjou *et al.*, 2014). Therefore, this study suggests that the differences in the fecundity of *D. indica* on three *T. anguina* cultivars might be due to variations in nutritional quality and quantity as well as secondary metabolites in host cultivars (Sarfriz *et al.*, 2007; Golizadeh *et al.*, 2017a, 2017b).

The ability of an insect herbivore to utilize host cultivars depends on the conversion of food by ingestion and assimilation into body tissues, which influences development, fecundity and survival of adults (Awmack and Leather, 2002; Genc, 2006). Therefore, quality of host plant plays an important role in the growth and reproductive performance of an insect herbivore (Awmack and Leather, 2002; Razmjou *et al.*, 2014; Mukherjee *et al.*, 2017; Malik *et al.*, 2018). The midgut amyolytic activity of *D. indica* fed with three *T. anguina* cultivars was positively correlated with total carbohydrates, proteins, lipids and nitrogen, while proteolytic activity was positively correlated with total carbohydrates, proteins, lipids, amino acids and nitrogen, suggesting that the nutritional quality of leaves played an important role in the synthesis and secretion of enzymes as well as digestion of consumed foods. The amyolytic and proteolytic activities of the larvae of *D. indica* were the highest on MNSR-1 and lowest on Polo No. 1, suggesting that *D. indica* had a high ability to utilize the leaves of MNSR-1 than Polo No. 1. This observation indicated that digestive performance of insects fed with MNSR-1 would lead to higher survival and increased biological fitness (Srinivasan *et al.*, 2005;

Table 7. Correlation coefficients (r) of the life table parameters of *Diaphania indica* reared on three *Trichosanthes anguina* cultivars with the nutrients, moisture content and antinutrients.

Parameters	Carbohydrate		Protein		Lipid		Amino acid		Nitrogen		Phenol		Flavonol		Tannin		Moisture	
	r	P value	r	P value	r	P value	r	P value	r	P value	r	P value	r	P value	r	P value	r	P value
Immature stages	-0.826	0.0001	-0.869	0.0001	-0.917	0.0001	-0.900	0.0001	-0.786	0.001	0.899	0.0001	0.895	0.0001	0.801	0.0001	-0.674	0.006
Fecundity	0.797	0.0001	0.822	0.0001	0.893	0.0001	0.926	0.0001	0.621	0.013	-0.710	0.0001	-0.943	0.0001	-0.822	0.0001	0.634	0.011
GRR	0.800	0.0001	0.759	0.001	0.805	0.0001	0.889	0.0001	0.590	0.02	-0.748	0.0001	-0.797	0.0001	-0.742	0.002	0.566	0.028
r_m	0.855	0.0001	0.858	0.0001	0.927	0.0001	0.934	0.0001	0.730	0.002	-0.843	0.0001	0.911	0.0001	-0.851	0.0001	0.674	0.006
λ	0.793	0.0001	0.791	0.0001	0.859	0.0001	0.907	0.0001	0.624	0.013	-0.858	0.0001	-0.955	0.0001	-0.778	0.001	0.719	0.003
R_0	0.638	0.005	0.701	0.004	0.865	0.0001	0.888	0.0001	0.580	0.023	-0.711	0.003	-0.819	0.0001	-0.741	0.002	0.582	0.023
T	-0.858	0.0001	-0.860	0.0001	-0.886	0.0001	-0.889	0.0001	-0.792	0.0001	0.936	0.0001	0.898	0.0001	0.793	0.0001	-0.700	0.004
Proteolytic activity ^a	0.752	0.001	0.685	0.005	0.859	0.0001	0.865	0.0001	0.687	0.005	-0.887	0.0001	-0.878	0.0001	-0.756	0.0001	0.616	0.014
Amylolytic activity ^b	0.885	0.0001	0.896	0.0001	0.944	0.0001	-0.911	0.0001	0.792	0.0001	-0.836	0.0001	-0.853	0.0001	-0.891	0.0001	0.531	0.042

^aGeneral.^bNon-specific.

Bouayad *et al.*, 2008; Naseri *et al.*, 2010; Borzoui and Bandani, 2013; Kaur *et al.*, 2014; Borzoui and Naseri, 2016). In the present study, variations in the parameters of nutritional indices of *D. indica* were recorded when the insects were fed with the leaves of three *T. anguina* cultivars (Baruipur Long, Polo No. 1 and MNSR-1). The approximate digestibility (AD) influences the growth rate (GR) of an insect (Shobana *et al.*, 2010; Xue *et al.*, 2010; Sarkar *et al.*, 2016). Fifth-instar larvae of *D. indica* showed higher AD and GR when fed with MNSR-1 than Polo No. 1, suggesting that better suitability of MNSR-1 resulted shorter development time and higher fecundity of *D. indica*.

In conclusion, the development, longevity and reproduction of *D. indica* were influenced by the nutritional quality in terms of primary essential nutrients and secondary metabolites present in the leaves of three *T. anguina* cultivars. Our study showed that the prolonged development time and lowest fecundity of *D. indica* caused the lower intrinsic rate of increase and net reproductive rate of *D. indica* on Polo No. 1, suggesting that the lower population growth of *D. indica* could result in lower subsequent infestations. Therefore, the use of partially resistant Polo No. 1 cultivar could be recommended for cultivation. Further research into the potential of using Polo No. 1 cultivar with other control strategies in the integrated pest management programme (IPM) of *D. indica* in field conditions is necessary.

Supplementary material. The supplementary material for this article can be found at <https://doi.org/10.1017/S0007485320000255>.

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