

Response of multiple generations of semilooper, *Achaea janata* feeding on castor to elevated CO₂

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Publication Info

Paper received:
17 February 2012

Revised received:
06 July 2012

Accepted:
08 August 2012

Abstract

The growth, development and consumption of four successive generations of semilooper, *Achaea janata* reared on castor (*Ricinus communis* L.) foliage grown under elevated carbon dioxide (550 and 700 parts per million) concentrations in open top chambers were estimated at Hyderabad, India. Significantly lower leaf nitrogen, higher carbon, higher relative proportion of carbon to nitrogen (C: N) and higher polyphenols expressed in terms of tannic acid equivalents were observed in castor foliage under elevated CO₂ levels. Significant influence on life history parameters of *A. janata* viz., longer larval duration, increased larval survival rates and differential pupal weights in successive four generations were observed under elevated over ambient CO₂ levels. The consumption per larva under elevated CO₂ increased from first to fourth generation. An increase in approximate digestibility and relative consumption rate, decreased efficiency of conversion of ingested food and digested food and relative growth rate of the four generations under elevated CO₂ levels was noticed. Potential population increase index was lower for successive generations under both elevated CO₂ over ambient. The present findings indicated that elevated CO₂ levels significantly alter the quality of castor foliage resulting in higher consumption and better assimilation by larvae, slower growth and longer time to pupation besides producing less fecund adults over generations.

Key words

Achaea janata, Castor, Elevated CO₂, Generations, Insect performance indices, Potential population increase index

Introduction

Climate change, especially the rise in temperature and atmospheric carbon dioxide concentrations, is the major concern of present times. The third IPCC report predicts that global average surface temperature will increase by 1.4 to 5.8°C by 2100 with atmospheric CO₂ concentrations expected to rise between 540 to 970 ppm (Houghton *et al.*, 2001). Effects of elevated atmospheric CO₂ on plants are well documented and the nutritional quality of plant changes under elevated CO₂ conditions (Hunter *et al.*, 2001) and these changes elicit responses from herbivore insects. Feeding on plants grown in elevated CO₂ conditions affects the survival, growth, development and reproduction of insect herbivores (Wu *et al.*, 2006).

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop cultivated around the world because of the commercial importance of its oil. India is the world's largest producer of castor seeds and also the biggest exporter of its derivatives contributing to 87% share of the international trade. Castor has its origin in the tropical belt of both India and Africa and is grown in arid and semi arid regions.

The castor semilooper, *Achaea janata* (Noctuidae: Lepidoptera) occurs during early growth stage of castor, feeds on the foliage and completes its life cycle on the plant. The incidence of semilooper is noticed up to early reproductive phase of castor plant (Basappa and Lingappa, 2001). During outbreaks, it causes extensive defoliation

affecting gross photosynthesis. Caterpillars also consume tender capsules. It is estimated that yield can decrease by 30-50% due to the semilooper alone.

Substantial literature is available pertaining to the responses of insect herbivores to the direct effects of elevated CO₂ through multiple generations (Chen, 2004; Wu *et al.*, 2006; Chen *et al.* 2007; Yin *et al.*, 2010). Most of the published work deals with short term or single generation studies pertaining to the insect performances under elevated CO₂ (Bezemer *et al.*, 1998). Multiple generation studies are required as they can effectively highlight the differential responses of the herbivores through successive generations, (Lindroth *et al.*, 1995). This study aimed to understand the effects of elevated atmospheric CO₂ on leaf quality of castor and to study its impact on growth characteristics of leaf feeding caterpillar over consecutive generations. In addition to the impacts, we also estimated the potential population increase index and potential population consumption of *A. janata* under elevated CO₂ conditions.

Materials and Methods

Experimental set up : Three square type open top chambers (OTC) of 4x4x4 m dimensions, were constructed at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (17.38°N ;78.47°E), two for maintaining elevated CO₂ concentrations of 550 ± 25 ppm CO₂ and 700 ± 25 ppm CO₂, and one for ambient CO₂. Carbon dioxide gas was supplied to the chambers and maintained at set levels using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump, CO₂ analyzer, PC linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA).

Castor (variety DCS 9) seeds were sown during second fortnight of June in all three OTCs during the monsoon season of 2008-2009. The soils in OTCs are typical representative alfisols with red soil type. Thus, castor plants were grown under three CO₂ conditions inside OTCs; 550 ± 25 ppm (550 CO₂-Elevated I), 700 ± 25 ppm (700 CO₂-Elevated II) and ambient CO₂ (380 ± 25 CO₂ OTC). Pure CO₂ mixed with ambient air was supplied to the chamber from seedling emergence to harvest of the crop.

Biochemical analysis of foliage : Leaf tissues from each plant used in the feeding experiment were analyzed for carbon, nitrogen and polyphenols. To determine carbon and nitrogen concentrations, samples were dried at 80°C and subsequently ground to powder. Leaf carbon and nitrogen were estimated using a CHN analyzer (Jackson, 1973). Total soluble polyphenols (hydrolysable tannins, condensed tannins and non tannin polyphenols) were determined by the Folin-Denis method (Anderson *et al.*,

1993). Leaf samples were dried at 40°C for 48 hrs. Dried leaf samples were ground to powder and phenolics were extracted with methyl alcohol. The concentration of polyphenols in the extract was determined spectrophotometrically using tannic acid as the standard, and the results were expressed as percentage tannic acid equivalents (TAE).

Insect stocks : An insect colony of *A. janata* was established using eggs obtained from the laboratory culture. Stock cultures of castor semilooper were maintained on leaves of castor plants. The cultures were maintained in a controlled chamber maintained at 20°C with a 14 hr day per 10 hr night cycle. Light intensity inside the chamber during the 14 hr day period was maintained at 550 μmol m⁻² s⁻¹. Relative humidity was maintained at 60% (day) and 70% (night).

Feeding trials : First generation experiments were initiated during the second fortnight of July 2008. Ten neonates of *A. janata* obtained from laboratory culture were placed in Petridishes of 110 mm diameter and 10 mm height forming one replication. Five such replications were kept for each of the three CO₂ conditions. Feeding trials with first to four generation larvae were conducted maintaining the treatment associations, i.e., all four generations received foliage from the same respective CO₂ growing conditions. All feeding trials were conducted as per procedure given by Srinivasa Rao *et al.* (2009). The first instar larvae of *A. janata* obtained from first generation were reared individually and separately with five replications per CO₂ treatment. The life history parameters of successive (consecutive) second, third and fourth generations of *A. janata* were measured as in the first generation described earlier.

Insect performance indices : Various insect performance indices were determined using data relating to larval weight, leaf weight consumed, and fecal matter excreted *viz.*, relative growth rate (RGR, g g⁻¹ d⁻¹), relative consumption rate (RCR, g g⁻¹ d⁻¹), efficiency of conversion of ingested food (ECI %), efficiency of conversion of digested food (ECD %) and approximate digestibility (AD %) were computed (Waldbauer, 1968; Srinivasa Rao *et al.*, 2008, 2009). The potential population increase index and potential population consumption were estimated in four step formulae as suggested by Wu *et al.* (2006).

Data analysis : The effects of CO₂ treatments on larval parameters were analyzed using one-way ANOVA. Treatment means were compared and separated using least significant difference (LSD) at p<0.05 and 0.01. The data on weight of foliage ingested, larval weight, weight of faecal matter, larval life span and pupal weight were analyzed using ANOVA with CO₂ and generations as sources of variability where CO₂ level was main factor and semilooper generation as sub

factor deployed in a split plot design.

The data on insect performance indices (ratio based) were analyzed using ANCOVA (Raubenheimer *et al.*, 1992) with initial weight as a covariate for RCR and RGR. The food consumption was taken as a covariate for ECI to correct for the effect of variation in the growth and food assimilated on intake and growth. The food assimilated was used as a covariate to analyse the ECD parameter (Hagele *et al.*, 1999). Mean values were separated using the LSD test. All statistical analyses were done using SPSS version 16.0.

Results and Discussion

Effect of CO₂ concentrations on biochemical constituents of foliage : Significantly lower leaf nitrogen content ($P < 0.01$), higher carbon ($P < 0.01$), higher relative proportion of C : N ($P < 0.01$) and higher polyphenols expressed in terms of tannic acid equivalents ($P < 0.01$) were observed in castor foliage grown under elevated CO₂ levels (Table 1). The percent variation of bio chemical constituents under two elevated CO₂ levels over ambient was significant. The percent reduction of nitrogen content (21-25) and increased percent of carbon (6-10), C: N ratio (43-45) and TAE (80 to > 100) under elevated CO₂ over ambient was observed.

The impact of elevated CO₂ on the phytochemistry of the plants was well studied (Hunter, 2001). In this study also, nitrogen concentration in castor leaves decreased by about 21-25 % when plants were grown under elevated CO₂ conditions. With increased carbon intake, the carbon content of the leaf tissues also increased (6-10%). Both of these together resulted in an increase (43-45%) of C: N ratio and these findings are similar to those reported by earlier authors (Gutierrez *et al.*, 2008). Since nitrogen is the chief constituent of proteins, this suggests that plants grown under elevated CO₂ conditions have lower protein in their tissues. Polyphenols, non-structural carbon compounds that constitute one of the defense mechanisms of plants and offer antifeedance to herbivores, are also known to increase up to 80% in leaves under elevated CO₂ conditions. In this study also, the higher concentration of polyphenols

was observed in leaves of plants grown under elevated CO₂ conditions.

Growth and development of *A. janata* in four successive generations : Significantly longer larval life span for 3rd and 4th generations ($F_{3,36} = 4.156$, $P < 0.05$) was observed under elevated CO₂ conditions ($F_{2,8} = 120.27$, $P < 0.01$) compared to ambient. The interaction between CO₂ and generations with respect to larval duration was not significant ($F_{6,36} = 1.02$, $P > 0.05$) (Table 2). The variation in pupal weights was not significant across CO₂ conditions ($F_{2,8} = 0.57$, $P > 0.01$) and generations ($F_{3,36} = 1.15$, $P > 0.05$). The pupal weights were in the range of 0.308-0.322 g (Table 2).

The survival rates of larvae did not vary significantly among CO₂ concentrations ($F_{2,8} = 1.47$, $p > 0.01$) or over generation ($F_{3,36} = 0.01$, $P > 0.05$) though these rates appeared somewhat lower in case of larvae grown under elevated CO₂ conditions. Lower survival rate was observed in the larvae in the elevated CO₂ conditions and from one generation to another generation and the effects were not significantly different for either CO₂ concentration ($F_{2,8} = 1.47$, $P > 0.01$) or semilooper generations. ($F_{3,36} = 0.01$, $P > 0.05$) (Table 2).

The fecundity of females was reduced significantly under elevated CO₂ concentrations ($F_{2,8} = 9.31$, $P < 0.01$) and was not affected significantly across all four generations ($F_{3,36} = 0.42$, $P > 0.05$). The interaction between CO₂ concentrations and generations was also found non significant (Table 2). The impact of CO₂ concentrations and generations was significant on insect species. The weight of foliage (dry) consumed by *A. janata* on castor was significantly varied among CO₂ levels ($F_{2,8} = 282.56$, $P < 0.01$) and generations ($F_{3,36} = 16.08$, $P < 0.01$). The interaction between CO₂ conditions and generations was found significant ($F_{6,36} = 3.34$, $P < 0.05$).

Larval weights of *A. janata* fed on leaves of castor grown under elevated CO₂ were not significantly different among four successive generations ($F_{3,36} = 2.41$, $P > 0.05$). Significantly higher larval weights were recorded in elevated CO₂ treatment ($F_{2,8} = 352.58$, $P < 0.01$). The interaction between

Table 1 : Effect of elevated CO₂ on bio chemical constituents of castor foliage grown under elevated and ambient CO₂

Biochemical constituents	CO ₂ concentrations			F(P)	LSD p<0.01
	550 ppm	700 ppm	380 ppm		
Nitrogen (%)	2.767±0.076 B	2.95±0.217 B	3.786±0.07 A	43.16 p<0.01	0.373
Carbon%	39.936±0.673 A	41.366±0.808 A	37.516±0.89 B	41.09p<0.01	1.439
C:N ratio	14.446±0.637 A	14.199±1.06 A	9.909±0.298 B	112.68p<0.01	1.143
TAE %	3.069±0.051 B	4.379±0.035 A	1.69±0.017 C	376.93p<0.01	0.070

Same alphabets in a row indicate that means are not statistically significant, at $P < 0.05$

Table 2 : Life history parameters of four successive generations of *A. janata* fed on castor grown under ambient and elevated CO₂ concentrations

Generation	Life history Parameters	CO ₂ concentrations		
		550 ppm	700 ppm	380 ppm
F1	Larval Lifespan (days)	16.4 ± 0.548 A b	16.4±0.548 A b	14.2±0.447 B a
	Pupal weight (g)	0.30±0.0158	0.322±0.01	0.308±0.016
	Survival rate (%)	89.6±3.578	88.8±5.21	87.2±6.57
	No. eggs laid / female / d	339.2±23.09 AB a	333.4±25.20 B ab	347.4±23.90 A bc
F2	Larval Lifespan (days)	16.6±0.548 B ab	17.2±0.837 A a	14.4±0.548 C a
	Pupal weight (g)	0.308±0.016	0.306±0.017	0.30±0.016
	Survival rate (%)	88.8±1.79	88.0±4.89	89.6±2.19
	No. eggs laid / female / d	332.0±31.21 A ab	333.4±25.21 AC ab	344.4±17.94 AB c
F3	Larval Lifespan (days)	16.8±0.447 B ab	17.4±0.548 A a	14.4±0.548 C a
	Pupal weight (g)	0.31±0.007	0.308±0.0164	0.31±0.019
	Survival rate (%)	88.0±7.48	88.0±4.89	89.6±7.26
	No. eggs laid / female / d	324.4±23.54 B b	325.4±22.88 BC b	354.0±18.84 A ab
F4	Larval Lifespan (days)	16.8±0.837 B ab	17.4±0.548 A a	14.4±0.548 C a
	Pupal weight (g)	0.314±0.0152	0.30±0.0158	0.30±0.016
	Survival rate (%)	87.2±6.57	87.2±5.93	91.2±5.215
	No. eggs laid / female / d	326.0±10.25 B b	338.0±21.09 B a	363.0±21.68 A a
LSD p<0.05		CO ₂	Generation	CO ₂ x Gen
Larval Lifespan (days)		0.444 *	0.378*	NS
Pupal weight (g)		NS	NS	NS
Survival rate (%)		NS	NS	NS
No. eggs laid / female / d		12.84*	9.24*	NS

* Significant at p = <0.01; Same upper case alphabets across CO₂ levels and lower case alphabets across generations indicate that means are not statistically significant, at P < 0.05

CO₂ conditions and generations with respect to larval weights was found to be not significant ($F_{6,36} = 1.04$, $P > 0.05$). Frass released by *A. janata* larvae was significantly more when larvae fed on castor leaves grown under elevated CO₂ concentrations ($F_{2,8} = 20.57$, $P < 0.01$) and frass produced per larva did not vary over generations ($F_{3,36} = 2.54$, $P > 0.05$). The interaction between CO₂ and generations was not significant ($F_{6,36} = 1.27$, $P > 0.05$).

Our results indicated significant influence of elevated CO₂ on life history parameters of *A. janata* over four generations. Larval duration of *A. janata* increased by 15-20% in successive four generations under elevated CO₂ compared with ambient CO₂. This increased larval life span (upto 6%) was also noticed in 4th over first generation. Differential effect of CO₂ on pupal weights and larval survival rates (4%) over four successive generations of *A. janata* was observed. Reduction in fecundity was observed over generations i.e. from 1st to 4th generations (2-4%) under each elevated CO₂ level. The significant response of insect herbivores to the effects of elevated CO₂ through multiple generations was reported in case of *H. armigera* (Chen, 2004; Wu et al, 2006; Chen et al 2007; Yin et al., 2010) and such a phenomenon holds valid for *A. janata* too.

Insect performance indices : The impact of elevated CO₂

($F_{2,8} = 17.44$, $P < 0.01$) on approximate digestibility of castor foliage by *A. janata* was significant over four generations ($F_{3,36} = 4.61$, $P < 0.01$). The results indicated that CO₂ levels adversely affected the quality of castor foliage and increased the RCR (g g⁻¹ d⁻¹) of *A. janata* larvae. The impact of elevated CO₂ on RCR ($F_{2,8} = 37.136$, $P < 0.01$) was significant over four generations ($F_{3,36} = 10.163$, $P < 0.01$). The interaction between CO₂ and generations was found significant ($F_{6,36} = 2.044$, $P < 0.05$) (Table 3). ECI % for *A. janata* larvae fed on castor foliage under elevated CO₂ concentrations was significantly reduced over generations ($F_{3,36} = 6.85$, $P < 0.05$) and also due to elevated CO₂ concentrations ($F_{2,8} = 123.0$, $P < 0.01$). The impact of elevated CO₂ ($F_{2,8} = 67.77$, $P < 0.01$) on ECD of larvae was significant over four generations ($F_{3,36} = 8.94$, $P < 0.01$). The interaction between CO₂ and generations was not significant ($F_{6,36} = .069$, $P > 0.05$). RGR of larvae decreased significantly when fed on castor foliage under elevated CO₂ ($F_{2,8} = 1711.5$, $P < 0.05$) and did not vary significantly over generations ($F_{3,36} = 0.624$, $P > 0.05$). The interaction between CO₂ and generations was found not significant ($F_{6,36} = 1.473$, $P > 0.05$) (Table 3).

The present results showed that insect performance indices of *A. janata* larvae when fed on castor foliage grown under elevated CO₂ varied in four generations than ambient. An increase of 0.32 - 12.26% of AD was observed in all

four generations under elevated CO₂ than ambient. ECI decreased in 1st and 2nd generations under elevated CO₂ compared to ambient. ECD (23-34%) and RGR (12-15%) decreased in four generations under elevated CO₂ than ambient. Increased consumption (RCR) by 6-22% was recorded under elevated CO₂ than ambient. Within each elevated CO₂ level also increased AD (about 1-6%) and RCR (13-15%) as observed in fourth generation over first generation. Larvae consumed more castor foliage grown under elevated CO₂ and assimilated better (higher values of RCR and AD) but grew slower (lower RGR) and took longer time (two days more than ambient) to pupation and similar observations were made by Wu *et al.* (2006). A reduction in nitrogen content may be accompanied by decreased efficiency of conversion to body mass and reduced growth rate (Masters *et al.*, 1998).

Potential population increase index : The population consumption and number of larval individuals were observed to be significantly lower from 2nd to 4th generations

of *A. janata* when fed on castor foliage grown under elevated CO₂ conditions when compared to the ambient. The impact of CO₂ concentrations was significant on potential number of larvae of insect species among generations. Significantly lower individuals were observed over generations ($F_{3,36}=190.04$, $P<0.05$) and across CO₂ conditions ($F_{2,8}=7.83$, $P<0.05$). The interaction between CO₂ conditions and generations was found significant ($F_{6,36}=4.74$, $P<0.05$) (Table 4). The potential larval individuals were reduced by 0.84, 12.15 %; 10.32, 29.34% and 19.82, 43.13% in 2nd, 3rd and 4th generations under two elevated CO₂ conditions, respectively. The total number of eggs laid by all females was significantly affected by CO₂ levels ($F_{2,8}=13.30$, $P<0.05$) and generation ($F_{3,36}=150.25$, $P<0.05$). The interaction between CO₂ conditions and generations was also found significant ($F_{6,36}=7.13$, $P<0.05$).

Similarly the 'potential population increase index' for successive generations was found lower in elevated CO₂ concentrations than those in the ambient. The index

Table 3 : Insect performance indices of four successive generations of *A. janata* fed on castor grown under ambient and elevated CO₂ concentration

Generation	Insect performance indices	CO ₂ concentrations		
		550 ppm	700 ppm	380 ppm
F1	AD %	80.23 ± 1.973 B cd	87.92 ± 1.51 A a	78.32 ± 8.086 B c
	ECI %	5.92 ± 0.275 B a	5.90 ± 0.416 B a	7.47 ± 0.364 A a
	ECD%	7.38 ± 0.435 B a	6.71 ± 0.529 B a	9.62 ± 1.12 A a
	RGR (g g ⁻¹ d ⁻¹)	0.116 ± 0.002 B	0.117 ± 0.002 B	0.138 ± 0.0005 A
	RCR (g g ⁻¹ d ⁻¹)	1.975 ± 0.052 A d	1.996 ± 0.141 A c	1.859 ± 0.083 B a
F2	AD %	79.42 ± 1.519 B d	87.53 ± 1.129 A a	79.16 ± 5.128 B bc
	ECI %	5.73 ± 0.416 B a	5.445 ± 0.223 B b	7.46 ± 0.411 A a
	ECD%	7.21 ± 0.529 B ab	6.222 ± 0.293 C b	9.489 ± 1.166 A ab
	RGR (g g ⁻¹ d ⁻¹)	0.119 ± 0.002 B	0.120 ± 0.001 B	0.137 ± 0.001 A
	RCR (g g ⁻¹ d ⁻¹)	2.096 ± 0.141 B c	2.206 ± 0.084 A ab	1.844 ± 0.091 C a
F3	AD %	82.71 ± 3.38 B b	87.62 ± 1.71 A a	82.24 ± 1.50 B a
	ECI %	5.47 ± 0.356 B b	5.45 ± 0.218 B b	7.49 ± 0.554 A a
	ECD%	6.62 ± 0.633 B b	6.223 ± 0.321 B b	9.12 ± 0.841 A bc
	RGR (g g ⁻¹ d ⁻¹)	0.119 ± 0.001 B	0.119 ± 0.109 B	0.136 ± 0.002 A
	RCR (g g ⁻¹ d ⁻¹)	2.18 ± 0.157 A b	2.188 ± 0.100 A b	1.816 ± 0.125 B a
F4	AD %	85.58 ± 1.83 B a	88.92 ± 0.764 A a	81.92 ± 1.11 C a
	ECI %	5.22 ± 0.221 B c	5.24 ± 0.096 B b	7.32 ± 0.551 A a
	ECD%	6.10 ± 0.21 B c	5.89 ± 0.094 B b	8.95 ± 0.763 A c
	RGR (g g ⁻¹ d ⁻¹)	0.119 ± 0.003 B	0.119 ± 0.003 B	0.136 ± 0.003 A
	RCR (g g ⁻¹ d ⁻¹)	2.282 ± 0.130 A a	2.273 ± 0.072 A a	1.861 ± 0.124 B a
LSD p<0.05		CO₂	Generation	CO₂ x Gen
	AD %	3.10	2.22*	NS
	ECI %	0.311*	0.210	NS
	ECD%	0.610*	0.410*	NS
	RGR (g g ⁻¹ d ⁻¹)	0.001	NS	NS
	RCR (g g ⁻¹ d ⁻¹)	0.095*	0.073*	0.127

* Significant at p<0.01; Same upper case alphabets across CO₂ levels and lower case alphabets across generations indicate that means are not statistically significant, at P<0.05

Table 4 : Estimation of potential population increase index and potential population consumption of *A. janata* in successive four generations fed on castor grown under elevated CO₂ concentrations

Generation	Parameter	550 ppm	700 ppm	380 ppm
F1	Initial no. of larval individuals	20 ± 0	20 ± 0	20 ± 0
	Total eggs laid by all females ¹	0.32*10 ⁴ ± 0.035*10 ⁴	0.28*10 ⁴ ± 0.042*10 ⁴	0.32*10 ⁴ ± 0.03*10 ⁴
	Total larval consumption	2.91 ± 0.10	2.906 ± 0.20	2.0908 ± 0.08
F2	Potential initial no. of larval individuals ²	2767.60 ± 292.41 A b	2451.88 ± 386.47 A b	2791.14 ± 339.43 A b
	Potential total eggs laid by all females	42.35*10 ⁴ ± 7.37*10 ⁴ A c	33.20*10 ⁴ ± 6.88*10 ⁴ B c	47.41*10 ⁴ ± 9.08*10 ⁴ A c
	Potential Population increase index ³	130.95 ± 10.42 B a	116.36 ± 9.17 C b	146.07 ± 12.92 A b
	Potential total larval consumption ⁴	7224.23 ± 929.51 b	6392.35 ± 1561.62 b	5096.52 ± 785.18 b
F3	Potential initial no. of larval individuals	38.09*10 ⁴ ± 7.12*10 ⁴ A c	30.01*10 ⁴ ± 6.17*10 ⁴ A c	42.48*10 ⁴ ± 8.15*10 ⁴ A c
	Potential total eggs laid by all females	5804.65*10 ⁴ ± 1460.0*10 ⁴ B b	4123.46*10 ⁴ ± 1290.29*10 ⁴ C b	7288.91*10 ⁴ ± 1996.33*10 ⁴ A b
	Potential Population increase index	135.57 ± 15.84 B a	125.39 ± 13.46 C ab	151.39 ± 19.84 A ab
	Potential total larval consumption	101.18*10 ⁴ ± 22.34*10 ⁴ c	84.49*10 ⁴ ± 23.40*10 ⁴ c	81.12*10 ⁴ ± 19.77*10 ⁴ c
F4	Potential initial no. of larval individuals	5266.28*10 ⁴ ± 1361.11*10 ⁴ B a	3735.07*10 ⁴ ± 1160.09*10 ⁴ Ca	6567.85*10 ⁴ ± 1780.16*10 ⁴ Aa
	Potential total eggs laid by all females	807856.3*10 ⁴ ± 284376.7*10 ⁴ Ba	524201.27*10 ⁴ ± 191796.87*10 ⁴ Ca	1146628.30*10 ⁴ ± 294374.07*10 ⁴ A a
	Potential Population increase index	136.50 ± 16.51 B a	129.75 ± 11.50 B a	158.34 ± 10.41 A a
	Potential total larval consumption	15311.8*10 ⁴ ± 14.2*10 ⁴ a	10985.17*10 ⁴ ± 3766.85*10 ⁴ a	12785.79*10 ⁴ ± 3533.10*10 ⁴ a
LSD p<0.05		CO₂	Generation	CO₂ x Generation
Potential initial no of larval individuals		415.15*10 ⁴	538.39*10 ⁴	932.52*10 ⁴
Potential total eggs laid by all females		7.01*10 ⁴	9.64*10 ⁴	16.69*10 ⁴
Potential Population increase index		8.755	9.992	NS
Potential total larval consumption		NS	1750.88*10 ⁴	NS

Same upper case alphabets across CO₂ levels and lower case alphabets across generations indicate that means are not statistically significant, at P < 0.05

values were 130.95 in 2nd generation, 135.58 in 3rd generation and 136.51 in 4th generation of *A. janata* fed on castor grown under 550 ppm CO₂ concentration. These index values were still lower under 700 ppm concentration and in the range of 116.36 to 125.39 than ambient (146.08 to 158.35). The percent reduction of index under elevated CO₂ was in the range of 10.35 - 20.54 than ambient and decrease of index was more evident in 2nd to 4th generations (Table 4).

The percent potential population increase index (PPII) decreased by 10.35 - 20.34 under elevated CO₂ than ambient and the decrease was more evident in 2nd and 3rd generations of *A. janata* fed on castor grown under 700 ppm CO₂ concentration. The potential total number of eggs laid by all females was significantly lower in two elevated CO₂ concentrations than ambient over 2nd to 4th generations. The potential total number of eggs laid by all females decreased by 10.66, 30.0 %; 20.36, 43.42% and 29.54, 54.28 % in 2nd, 3rd and 4th generations under two elevated CO₂ conditions respectively. Wu *et al.*, (2006) observed a similar reduction in PPII in cotton boll worm on wheat and attributed it to integrative effect of longer larval life span and lower fecundity and similar trend was observed in the present experimentation too. The potential larval consumption of castor foliage was found lower (-14.08%) under 700 ppm CO₂ concentration than ambient and 550 ppm CO₂ concentrations in 4th generation.

In general, host plant quality declined in elevated CO₂ with decreased leaf nitrogen and increased phenolics. The food consumption pattern and its digestibility were associated with nitrogen and phenolics in castor foliage. This assumption was well proven with *A. janata* on castor grown under elevated CO₂ (Srinivasa Rao *et al.*, 2009). Present results showed higher consumption levels of larvae under elevated CO₂ conditions over four generations. The consumption per larva of *A. janata* fed on castor foliage grown under elevated CO₂ increased by 39-57 % from 1st to 4th generation.

Acknowledgments

This work was supported by the grants from Indian Council of Agricultural Research in the form of network project on climate change (NPCC). Dr P.K. Aggarwal, Ex National Professor, IARI, New Delhi, has shown keen interest in this work and his support is thankfully acknowledged. We thank project staff for their committed involvement in data collection and analysis.

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