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Biology and Role of Plant biophysical Parameters in cardamom and castor for Resistance to Shoot and capsule borers, *Conogethes sahyadriensis* sp. nov. and *Conogethes punctiferalis* Guenée (Crambidae : Lepidoptera)

B. Doddabasappa[1], Mutthuraju, G.P.[2] and A.K. Chakravarthy[3]*
[1]*Assistant Professor of Entomology, RHREC, UHS Campus, GKVK, Bengaluru -560 065, (Karnataka), India.*
[2]*Department of Entomology, College of Horticulture, Mysuru-571 130, (Karnataka), India.*
[3]*Division of Entomology and Nematology, Indian Institute of Horticultural Research, Hesaraghatta, Bangalore-560 088, (Karnataka), India.*

(Corresponding author: B. Doddabasappa)*
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ABSTRACT: Investigations were conducted on the lepidopterous borers *Conogethes sahyadriensis* sp. nov. and *Conogethes punctiferalis* Guenée infesting cardamom and castor, respectively. For a long a period, the borer on cardamom and castor were considered as *Conogethes punctiferalis* only in 2018, the cardamom borer and castor borer were identified as different species. So, it became imperative to understand the bioecology of these two sympatric borer species occurring in the same or in adjacent cultivated habitats. On respective host plants, the average fecundity was 56 eggs/female (*C. sahyadriensis*) compared to 38 eggs/ female (*C. punctiferalis*) (n=8 pairs). The borer egg viability was 69.5% on cardamom compared to 66 % on castor. The 5th instar larval weight of *C. sahyadriensis* was 73.5 mg compared to 65 mg of *C. punctiferalis*. Pupal weight of *C. sahyadriensis* was 93.5 mg compared to 46 mg of *C. punctiferalis*. The castor borer completed the life cycle on an average in 34.50 days compared to 39 days by *C. sahyadriensis*. It was found that *Conogethes* reared on cardamom when transferred on castor plant for feeding, the larvae underwent 100 % mortality and vice-versa. When the number of trichomes per cm^2 increased from 0 to 15, length of trichome increased from 0 to 7.8 mm, number of capsules/spike ranged between 31 to 43, size of capsule ranged between 1.24 to 2.21 cm and diameter of shoot ranged between 7.9 to 9.8 mm, *C. punctiferalis* oviposition also increased on different types castor. The behavioral changes in larvae were related to the shift in the host. Whenever the larvae of *Conogethes* were shifted to one host to another, larvae did not express typical orienting and feeding responses. The castor plant type with compact spiny type was maximally liked by the *Conogethes* larvae. Similarly, in cardamom the Mysore type was maximally attracted the respective species of *Conogethes*. The investigations lead to preclude that species of *Conogethes* on cardamom and castor are undergoing changes in their host selection and behavior.

Keywords: *Conogethes sahyadriensis*, *Conogethes punctiferalis,* biophysical characters, Cardamom, Castor, Biology, Resistance, South India.

INTRODUCTION

Shoot and capsule borers *viz*., *Conogethes sahyadriensis* on cardamom (*Elettaria cardamomum* (L.) Maton) and *Conogethes punctiferalis* on castor (*Ricinus communis* L.) are important pests attacking several species of wild and cultivated plants (Thyagaraj 2003, Shashank *et al*., 2018). These borers species attain importance as larvae primarily injure the reproductive parts of plant. The shoot and capsule borers are difficult-to-manage major pests in tropic and subtropics (Pena *et al.* 2002). The shoot and capsule borers, *Conogethes* spp. (Guenée) (Crambidae: Lepidoptera) are also called as yellow peach moths. Since, *Conogethes* spp. attack wide range of plants *viz.,* fruit, vegetable, plantation, root and cereals in range of habitats, publication on plant resistance is lacking (Sekiguchi, 1974), but required for developing sound management practices.

Several polyphagous borer species have higher fitness on certain host crops than on others (Kirsten and Topp, 1991). Further, the fitness of insects is mainly dependent on the host-finding abilities of the gravid females because the neonate larvae are often relatively stationary, and their proximity to damaging sites is normally determined by the judicious choice of the gravid female. Female moths have been shown to preferentially select few plant species for egg laying (Renwick and Chew, 1994; Mayhew, 1997). A prevailing hypothesis on oviposition preference is that a female will choose the hosts where caterpillars perform better (Thompson, 1988). Though species of *Conogethes* are indigenous to India, not much work on basic aspects *viz.,* identification and host plant relationships have been documented. Preliminary observations have revealed differences in larval feeding behavior of *Conogethes* infesting cardamom and castor (Honda, 1986; Noldus and van Lenteren, 1985). While few workers (Honda, 1986; Thyagaraj, 2003; Chakravarthy *et al.,* 2009) have dealt with identification of *Conogethes* populations, none have initiated efforts on utilizing host plant relationship as a means for population suppression. *Conogethes punctiferalis* is a species-complex. The species of *Conogethes* undergo overlapping generations in a season and more than one species of *Conogethes* exist or utilize a cafeteria of crops cultivated in the same or adjacent habitats. Therefore, an attempt was made to study pattern of relationships on their principal host plants (see Visser, 1988). For a long time (≈ 160 years) *C. sahyadriensis* was recognized as a *C. punctiferalis* only. It is only in 2018 that *C. sahyadriensis* was identified as a new species, different from *C. punctiferalis* (Shashank *et al.,* 2018). Similarly, Koizumi (1960), Inoue (1982) and Honda and Mitsuhashi (1989) identified two types of *C. punctiferalis* that differ in their larval and pupal morphology and adults genitalia. However, two types also differ in larval hosts; they referred to them as the angiosperm fruit-feeding type and the Pinaceae-feeding type in Japan. Further, Inoue and Yamanaka (2006) identified the two types into species, with *C. pinicolalis* Inoue and Yamanaka (2006) representing the Pinaceae-feeding type, and the revised and re-described *C. punctiferalis* as the fruit-feeding type. For the current study, two host plants *viz.,* cardamom and castor cultivated in diverse habitats were selected. Hence, the concept of integrated pest management (IPM) with an emphasis on host plant resistance (Sharma and Ortiz, 2002) is necessary. So, studies on the role of plant biophysical characters governing resistance to shoot and capsule borers, *Conogethes sahyadriensis* and *C. punctiferalis* populations infesting cardamom and castor were undertaken.

MATERIAL AND METHODS

The investigations in laboratory were conducted at the Department of Entomology, University of Agricultural Sciences, Bangalore (12°58’ N and 77°35’ E, 930 m AMSL), South India during 2010-2012.

Biology on respective hosts

Biology on cardamom

Fresh pupae /larvae of cardamom stem and capsule borer were obtained from the infested cardamom fields at and around Mudigere (13° 8' 0'' N and 75° 38' 0'' E 982 m AMSL), Chikmagalur, Karnataka, South India and maintained in laboratory for adult emergence. Just born male and female moths were differentiated based on body size *i.e.,* female moths are bigger having a brush of hairs at the tip of abdominal. A pair of moths was confined in rearing cages (76 × 36 x 36 cm) made of wood and wire mesh having young cardamom (< 3 months old) shoots in 250 ml conical flask, provided with a red light (Zero watt) (24 ± 5^{o}C; 75 ± 5 % RH; 16:8 LD). Fresh food was offered once every two days.

Each cardamom- type shoot *viz.,* Malabar, Mysore and Vazhuka were offered as food and replicated thrice in a plastic tray (15 × 25 × 35 cm). Ten moths pairs were released per replication. The life cycle was studied under semi natural (environmental chamber) conditions in laboratory.

Biology on castor: Larvae/pupae of castor shoot and capsule borer were bred on castor in plastic trays (15 × 25 × 35 cm). Emerging moths were collected daily, sexed and kept in large wooden and wire mesh cages (1 m^3) for oviposition. Swabs of cotton were dipped in 10% solution of sugar syrup were given as food for moths. Panicles of castor were used to induce oviposition in gravid moths in conical flasks (250 ml). Neonate larvae were transferred to capsules of each of castor. Plastic trays of size (15 × 25 × 35 cm) were used with Spineless, compact spikes, spiny loose spike for breeding. Field collected fruits of castor were offered as food once in four days. Each castor type was planted in three replications. Observations were made on number of eggs, egg viability (%), incubation period, larval, pupal periods, weights of life stages, adult longevity and sex ratio for both the *Conogethes* Spp.

Host shifts: The *C. sahyadriensis* larvae/pupae on castor and *C. punctiferalis* on cardamom were placed in plastic trays (15 × 25 × 35 cm). Just born 1st instar larvae were transplanted with brush on stem pieces of each cardamom types *viz.,* Malabar, Mysore and Vazhuka offered as food in a plastic tray (15 × 25 × 35 cm) and capsules of each castor type *viz.,* spineless, compact spike, spiny loose spike were bred in trays and replicated 5 times. Fresh shoot and fruits were offered as food once in four days. The study was conducted under semi natural (environmental chamber) conditions in laboratory. Observations were recorded on larval duration, survival rate and pupation for both the *Conogethes* spp. Each cardamom- type shoot *viz.,* Malabar, Mysore and Vazhuka were offered as food and replicated thrice in a plastic tray (15 × 25 × 35 cm) (Ravindran and Madhusoodanan, 2002).

Biophysical characters

Plant Morphological characters: Based on growth characteristics of the cardamom clump, Erect (Mysore), Semi-erect (Vazhuka) and Prostrate (Malabar) types were selected for the study. Fifteen capsules and shoots (five numbers per repeat, per select type) of cardamom were used to record data on the biophysical parameters of resistance/susceptibility. The fruits and shoots of test plants were examined under microscope to study the variations in morphological characteristics *viz.,* number capsules/panicle, length of the panicle (cm), number of tillers/panicle, number of panicles/plant and shoot diameter (mm) of aforementioned types of cardamom with the help of vernier calipers from different positions of each part. Number of trichomes/cm^2 were recorded under binocular microscope at 40 × magnification.

Based on the growth characteristics of the castor plant, three types were recognized *viz*., spineless, compact spike and spiny loose spike. Fifteen capsules and shoots (five per repeat, per select type) of castor (<100 days old crop) were used to record data on plant morphological characters. The capsules and shoots were observed under binocular microscope to determine the variations in morphological characteristics *viz.,* number capsules/inflorescence, trichomes numbers/cm^2, trichome length (mm), size of capsule (diameter in mm) and shoot diameter (mm).

Plant anatomical characters: The cardamom (Malabar, Mysore and Vazhuka) tender shoots and fruits (< 3 months old) and three select types of castor (spineless, compact spike and spiny loose spike) were chosen for making observations on anatomical variables. The same age (15-18 days old) plant parts were used for recording anatomical characters using Safranin and Fast green stains.

The slides were observed under microscope to determine the variations in anatomical characteristics (tissue primordial layers, lysogenous cavities numbers, shape and distance) of selected types of cardamom. In castor types, seed coat, sclerenchyma tissue, parenchyma tissue and cotyledon with seed coat were examined along with borer infestation.

Statistical analysis

The data on *Conogethes* bio ecology on cardamom, castor and vice-versa were examined through one-way ANOVA and student t-test using XLSTAT. To determine the role of plant morphological and anatomical characters, observations in the field on borer infestation were recorded. The borer infestation on cardamom was recorded on all the shoots and capsules from 20 clumps of each type. Plant parts were incised for recording plant biophysical characters in laboratory. Similarly, castor borer infestation was recorded on spikes from 20 plants. The biophysical parameters among select types of cardamom and castor under lab conditions were recorded and analyzed through one-way ANOVA.

RESULTS AND DISCUSSION

Biology on respective hosts

Biological studies brought out striking differences between the two *Conogethes* spp. (Table 1). On cardamom, the fecundity of *C. sahyadriensis* ranged between 46- 66 eggs/female with a mean of 56 eggs/female (n=10 pairs) compared to a mean of 38 eggs/female of *C. punctiferalis* with a range between 22-54 eggs/female. The egg viability varied 41-91% with a mean of 69.5% of *C. sahyadriensis* compared to 66 % with a range of 51-88% of *C. punctiferalis*. The fifth instar larval weight of *C. sahyadriensis* ranged between 72-75 mg with a mean of 73.5 mg compared to 65 mg with a range of 64-66 mg of *C. punctiferalis.* The total larval period varied between 29-34 days with a mean of 31.5 days on cardamom (*C. sahyadriensis*) compared to 29 days with a range of 26-32 days on castor (*C. punctiferalis*). Pupal weight of *C. sahyadriensis* ranged between 75-112 mg with a mean of 93.5 mg compared with 46 mg of *C. punctiferalis* with a range between 31-61 mg. There were statistical significant differences when means were subjected to t-test. *C. sahyadriensis* completed life cycle on an average in 39 days with a range of 35-43 days compared to a mean of 34.50 days with a range of 34-35 days by *C. punctiferalis*, there being statistical significant differences ($p<0.01$ at 1df).

Table 1: Striking differences biology of *Conogethes punctiferalis* on castor plant and *C. sahyadriensis* on cardamom clump.

Biological parameters	Castor types		Cardamom types		t-test @ 1 df
	Range	Mean	Range	Mean	
Fecundity	22-54	38.0	46-66	56.0	**
Egg viability (%)	51-88	66.0	41-91	69.5	*
5th instar larval weight (mg)	64-66	65.0	72-75	73.5	*
Total larval period (days)	26-32	29.0	29-34	31.5	NS
Pupal weight (mg)	31-61	46.0	75-112	93.5	**
Life cycle (days)	34-35	34.5	35-43	39.0	*

Data from this table is derived from earlier tables, so statistical analysis not indicated; ** significant at 1%; * significant at 5%

Workers in the past have studied the cardamom borer bio ecology on castor separately in the respective climatogeographic locations under the nomenclature of *C. punctiferalis*. This is the first attempt on comparative biology of the two *Conogethes* spp. under Bangalore conditions. The host phenology influenced the shape, size, life stages and development of *C. punctiferalis* (Bilapate and Talati, 1978; Jacob, 1981; Twine, 1971). There were significant differences in per cent hatching and incubation period under different temperature and relative humidity (Thyagaraj, 2003; Wang and Cai, 1997; Kondo and Miyahara, 1930; Mukerji and Gage, 1978; Rajan, 1965; Kalshoven, 1929) conditions. Fang and Zhe (2009) studied *C. punctiferalis* infesting Chinese chestnut concluded that it is difficult to control the pest because larvae remained in the capsule. Kotikal and Kulkarni (2001) screened turmeric genotypes for resistance to *C. punctiferalis* (=now *C. sahyadriensis*) and rhizome fly in comparison with a local cultivar (Arabhavi local) at two locations. Studies clearly established that *Conogethes* biology varied across different genotypes, related and wild hosts, also across different crops. In the current study, the impact of location and climate was almost eliminated as the studies were conducted under uniform laboratory conditions. Therefore, differences in biology can be mainly attributed to the effect of the plant.

Host Shift

***C. sahyadriensis* on castor**

Larval and pupal survival: The details of host shift experiments conducted in laboratory are documented by Doddabasappa (2012) and Doddabasappa *et al.* (2018). However, to ascertain the mechanism of host-shift and adaptation by the two species of *Conogethes*, salient highlights are discussed in this paper. The larvae of *Conogethes* originated from cardamom were put on the three types of castor. When eggs reared on cardamom were transplanted on castor, cent per cent hatched on the three castor types. There were significant differences in larval survival of *C. sahyadriensis* on castor. The survival of first instar larvae was 14.9±1.6, 19.0 ±2.9, 16.1± 2.1 per cent on spineless spike, compact spiny and spiny loose type of castor, respectively (Table 2). Survival of larvae of 2nd instar was 30.8±1.6, 32.6 ±2.3, 23.3± 2.4 per cent on spineless spike, compact spiny and spiny loose type of castor, respectively. Survival of third instar larvae was 15.7±2.4, 31.0 ±2.6, 17.3± 3.2 per cent on spineless spike, compact spiny and spiny loose type of castor, respectively. Larval survival of fourth instar was 41.3 ± 1.6, 51.9 ±1.4, 43.5± 0.5 per cent and of fifth instar was 48.9 ± 1.9, 54.75 ± 2.9, 52.4 ± 1.4 per cent and 13.6 ± 1.45, 23.9 ± 1.7, 18.7 ± 2.1 per cent pupation on spineless spike, compact spiny and spiny loose type of castor, respectively (Table 2). Although the first instar larvae did not suffer any mortality (14.0%), but failed to complete the life cycle. Therefore larvae of 1st instar suffer 86% mortality.

Developmental period: Statistical differences in the time required for the completion of life cycle of the cardamom borer on the three types of castor were recorded. First instar larval period was 1.00 ± 0.4, 1.35±0.4, 1.66 ±0.4 days, respectively. Second instar larval period was 2.00±0.3, 1.94±0.3, 2.14 ±0.4 days, respectively. Third instar larval period was 2.50±0.2, 2.51±0.3, 2.97 ±0.2 days, respectively. Fourth instar larval period was 2.75±0.3, 3.15±0.2, 3.06 ±0.2 days, respectively and fifth instar larval period was 3.00±0.3, 3.27±0.5, 3.38 ±0.3 days, respectively (Fig. 1).

When cardamom borer larvae were transferred to castor, larvae exhibited mortality (not shown in Table 2). Because of physiological stress the larvae were induced to complete the larval period early as result of the host-shift. In comparison, when castor capsule borer larvae were transferred on castor, larvae required about 14-16 days (Fig. 1) *i.e.,* the normal larval period. In this experiment larvae did not exhibited mortality.

Table 2: Survival of life stages of cardamom *C. sahyadriensis* on castor.

Castor plant type	Survivability (%) of larval instar					Pupation (%)
	1st	2nd	3rd	4th	5th	
Spineless spike	14.9±1.6 (22.68)^{a}	30.8±1.6 (33.72)^{bc}	15.7±2.4 (23.25)^{a}	41.3±1.6 (39.95)^{a}	48.9±1.9 (44.38)^{a}	13.6±1.45 (21.65)^{a}
Compact spiny	19.0±2.9 (25.77)^{b}	32.6±2.3 (34.79)^{c}	31.0±2.6 (33.81)^{b}	51.9±1.4 (46.09)^{c}	54.75±2.9 (47.72)^{c}	23.9±1.7 (29.26)^{c}
Spiny loose spike	16.1±2.1 (23.59)^{a}	23.3±2.4 (29.52)^{a}	17.3±3.2 (28.78)^{a}	43.5±0.5 (41.26)^{b}	52.4±1.4 (46.37)^{b}	18.7±2.1 (25.62)^{b}
S.Em±	**1.00**	**0.792**	**1.06**	**0.43**	**0.72**	**0.76**
CD@1%	**3.20**	**2.53**	**3.40**	**1.38**	**2.32**	**2.45**

Figures in bracket are arcsine transformed values; n=20; numbers followed by the same letter are not statistically significant ($p<0.001$) by LSD (Source: Doddabasappa *et al.,* 2018)

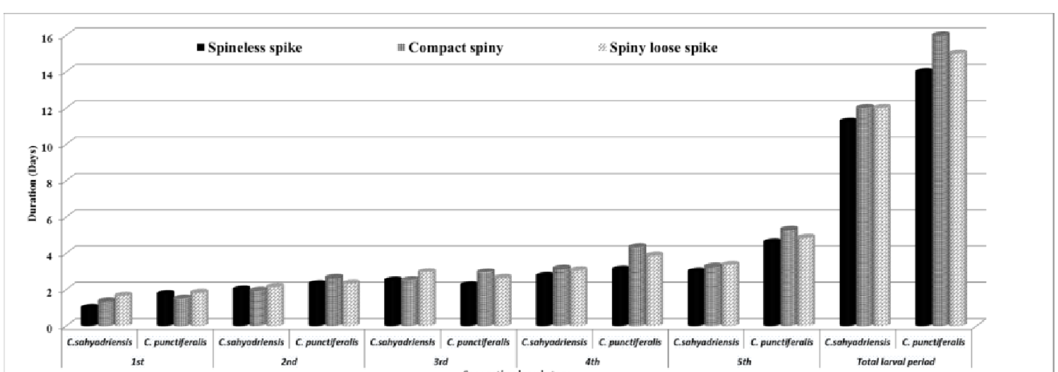


Fig. 1. Comparison of development time of *C. sahyadriensis* and *C. punctiferalis* on castor.

C. punctiferalis on cardamom

Larval and pupal survival

Statistical significant differences in the survival of larvae of *C. punctiferalis* on cardamom were observed. Survival of first instar larvae was 13.8±2.8, 19.2 ±4.4, 18.1± 2.7 per cent on Malabar, Mysore and Vazhuka cardamom types, respectively (Table 4). Survival of larvae second instar was 23.8±3.8, 29.3 ±2.69, 28.3± 3.0 per cent on Malabar, Mysore and Vazhuka types of cardamom, respectively. Survival of larvae third instar was 15.4±2.7, 29.1 ±3.0, 15.0± 2.8 per cent on Malabar, Mysore and Vazhuka type of cardamom, respectively. Survival of larvae of fourth instar was 33.83±2.5, 46.42.9 ±1.4, 43.17± 2.4 per cent and fifth instar survival was 54.58 ± 2.9, 64.42±2.6, 63.33±3.3 per cent; 15.08±2.8, 39.25±0.8, 17.73±2.7 per cent pupation on Malabar, Mysore and Vazhuka type of cardamom, respectively (Table 3). Although the first instar *C. punctiferalis* larvae survived 13.8%, but did not survived throughout the life cycle. First instar larvae (85.5%) suffered the highest larval mortality and this is critically important for the insects to survive on host plants (data not shown).

Table 3: Survival of *C. punctiferalis* on cardamom at different life stages.

Cardamom plant type	Survivability (%) of larval instar					Pupation (%)
	1st	2nd	3rd	4th	5th	
Malabar	13.8±2.8 (21.73)a	23.8±3.8 (29.09)a	15.4±2.7 (23.04)a	33.83±2.5 (35.55)a	54.58±2.9 (47.62)a	15.08±2.8 (22.77)a
Mysore	19.2±4.4 (25.83)b	29.3±2.69 (32.71)c	29.1±3.0 (32.60)b	46.42±1.4 (42.94)c	64.42±2.6 (53.62)c	39.25±0.8 (38.79)b
Vazhuka	18.1±2.7 (25.09)ab	28.3±3.0 (32.12)bc	15.0±2.8 (22.70)a	43.17±2.4 (41.06)b	63.33±3.3 (52.75)bc	17.73±2.7 (24.47)a
S.Em±	**1.49**	**1.22**	**1.20**	**0.76**	**1.01**	**1.03**
CD@1%	**4.78**	**3.19**	**3.85**	**2.42**	**3.23**	**3.30**

Figures in bracket are angular transformed values; n=20; numbers followed by the same letter are not statistically significant (p<0.001) by LSD (Source: Doddabasappa *et al.,* 2018)

Development period: Doddabasappa, (2012) and Doddabasappa *et al.* (2018) conducted detailed laboratory experiments to determine the growth and development of different life stages castor capsule borer on cardamom. In this publication briefly salient results are presented.

When the larvae were reared on Malabar, Mysore and Vazhuka types of cardamom, there were statistical significant differences in developmental time of each larval instar. First larval instar *C. punctiferalis* required 1.75±0.6, 1.50±0.5, 1.83 ±0.53 days, respectively. Second larval instar required 2.23 ± 0.3, 2.51 ± 0.2, 2.33 ± 0.2 days, respectively. Third larval instar required 3.03±0.6, 2.44±0.2 and 2.16 ±0.3 days, respectively. Fourth instar larvae required 3.43±0.7, 2.71±0.3, 2.60 ±0.4 days, respectively and fifth larval instar required 3.88±0.8, 5.06±0.7, 4.71 ±0.7 days, respectively (Fig. 2).

When *Conogethes* larvae bred on castor were transferred to cardamom, larvae suffered mortality (not shown). In addition larvae completed the period early quickly and this may due to physiological pressure (13-14 days). When cardamom larvae were transferred to cardamom, larvae took 20-22 days to complete the life cycle. This is the average larval period (Fig. 2). When *Conogethes* larvae bred on castor were transferred to cardamom, larvae met with smooth plant surface, could not establish and bore into the pseudostem. When *Conogethes* reared on cardamom were implanted on castor, the larvae met with rough surface, could not establish and bore into the capsules.

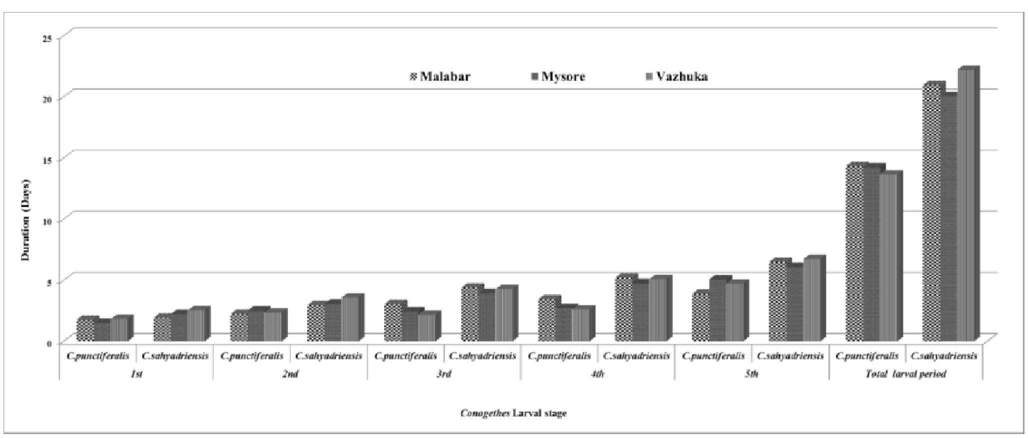


Fig. 2. Comparison of development of *C. sahyadriensis* and *C. punctiferalis* on cardamom.

***C. sahyadriensis* on three castor types:** In this test, *Conogethes* larvae were expected to have parrot green body. However, as the larvae come cross roughened surface impeding their mobility and feeding, larvae were restless and in view of the spine they were unable to continuously feed on capsules.

***C. punctiferalis* on three Cardamom types:** In this test, cardamom borer larvae normally anticipated pink or brown with rugged surface. However, the larvae come a crossed green shoot and smooth surface so as to manage inside the shoot and penetrate into the shoot. Experimental results revealed that *Conogethes* born on castor were not able to establish and continue life cycle on cardamom and vice-versa. All larvae implanted suffered mortality after host-shift whether on cardamom and castor. The decreased feeding on plant and larval survival may also be due to Hopkins' host-selection principle (HHSP). HHSP is defined as a preference for the host species on which the insects showed growth and development as larvae. Though the principle and practical utility of HHSP has been discussed often since it is first proposal in 1916 (Hopkins, 1917), in *Conogethes all the insects suffered* mortality without an exception. This suggests that there is an impact of implantation, the impact on the life cycle of insect is not only due to the HHSP, but the plant is unsuitable for the congeneric species. Similar findings were found in Dosdall and Ulmer (2004) on *Mamestra configurata* Walker infesting *Brassica napus* and *Brassica rapa.*

The antixenosis and antibiosis factors seem to impede the growth and development of larvae and pupae. Antixenosis and antibiosis in standalone or combination may have interfered in establishment of borer species on both host plants. It is noteworthy to mention here that the neonate larval death was much higher than the later instar larvae. The analogous attempt by Diegisser *et al.* (2008) on *Tephritis conura* (Loew, 1844) infested in *Cirsium oleraceum* and Calcagno *et al.* (2007) studied on species complexity of *Ostrinia nubilalis* Hubner and *Artemisia vulgaris* L. on *Zea mays* L. (corn). *O.nubilalis* damage on maize were differentiated from sympatric populations damaging on *A. vulgaris* and *Humulus lupulus* L. But these populations with varying host plants are physically undifferentiated (Bourguet *et al.* 2000; Martel *et al.* 2003; Leniaud *et al.* 2006) in France. Daves *et al.* (2007) study revealed that the larval growth was impacted negatively by the unsuitability of Southwestern corn borer, *Diatraea grandiosella* Dyar on corn (*Zea mays* L.) offered as food for the insect.

Role of biophysical characters

Plant morphological characters of cardamom on *C. sahyadriensis*

Number of capsules/panicle: The analysis of variance test revealed highly significant differences among cardamom types. The maximum number of capsules per panicle was 14.50± 1.80 in Mysore type followed by 13.6±1.6 in Malabar type and differed significantly from Vazhuka type (5.7± 1.7) (Table 4). As the number of capsules per panicle increased from 5.70 to 14.50, the number of eggs on cardamom type increased from 45 to 62 eggs among three cardamom types and larval infestation also increased from 11 to 18%. This means number of capsules per panicle was related to number of eggs laid and cardamom plant part infested by *Conogethes* larvae.

Length of the panicle (cm): The results revealed highly significant differences with respect to length of panicles (cm) among the cardamom types. The maximum length of panicle recorded was 41.90 ± 1.40 cm in Vazhuka followed by 40.7 ± 1.4 cm in Mysore type. The Malabar type possessed minimum length of panicle *i.e.*, 33.1 ± 1.5 cm (Table 4). As the length of panicle increased from 33.1 to 41.9, the number of borer eggs on cardamom type increased from 45 to 62 among three cardamom types and infestation also increased from 11 to 18%. This means length of panicle was related to number of eggs laid and cardamom plant part infested by *Conogethes* larvae.

Number of tillers/plant: Significant variations were found among cardamom types concerning number of tillers per plant (Table 4). The Mysore type possessed maximum number of tillers per plant *i.e.,* 31.70 ± 1.84 followed by 31.30 ± 1.48 in Vazhuka type. The minimum number of tillers per plant was 22.3 ± 1.84 in Malabar type. As the number of tillers per plant increased from 22.30 to 33.70, the number of eggs on cardamom type increased from 45 to 62 eggs among three cardamom types and infestation also increased from 11 to 18%. This means number of tillers per plant was related to number of eggs laid and cardamom plant part infested by *Conogethes* larvae.

Number of panicles/plant: Differences were found significant among cardamom types regarding number of panicles per plant (Table 4). The Mysore type showed maximum number of panicles per plant *i.e.,* 41.20 ± 1.47 and differed significantly from the other two types. The minimum number of panicles per plant was recorded (33.80 ± 1.77) on Malabar type followed by 35.2 ± 1.77 on Vazhuka. As the number of panicles per plant increased from 33.8 to 41.2, the number of eggs on cardamom types increased from 45 to 62 and larval infestation also increased from 11 to 18%. This means number of panicles per plant was related to number of eggs laid and cardamom plant part infested by *Conogethes* larvae.

Shoot diameter (mm): The analysis of variance test revealed highly significant differences in shoot diameter (mm) among three cardamom types. The maximum shoot diameter was recorded (17.30± 1.90 mm) in Mysore type followed by 14.20± 1.60 mm in Vazhuka type. The minimum shoot diameter (mm) was 12.60± 1.74 mm in Malabar type. As the shoot diameter increased from 12.6 to 17.3, the number of borer eggs on cardamom type increased from 45 to 62 eggs among three cardamom types. Larval infestation also increased from 11 to 18% (Table 4) suggesting that shoot diameter was related to number of eggs laid and larval infestation.

Table 4: Plant morphological parameters of cardamom types.

Cardamom plant type	Morphological characters						
	Shoot infested (%)	Number of eggs laid/ plant	Number of capsules / panicle	Length of panicle (cm)	Number of tillers /plant	Number of panicles/ plant	Shoot diameter (mm)
Malabar	11.50±1.0 (19.82)^{a}	45.0±3.49^{a}	13.6±1.6^{bc}	33.1±1.5^{a}	22.3±1.84^{a}	33.8±1.77^{a}	12.60±1.74^{a}
Mysore	19.87±1.96 (31.22)^{c}	62.45±3.87^{c}	14.5±1.8^{c}	40.7±1.4^{bc}	31.7±1.84^{c}	41.2±1.47^{b}	17.30±1.90^{b}
Vazhuka	18.12±1.49 (27.74)^{b}	53.75±5.77^{b}	5.7±1.7^{a}	41.9±1.4^{c}	31.3±1.48^{bc}	35.2±1.77^{a}	14.20±1.60^{a}
S.Em±	**0.37**	**0.41**	**0.58**	**0.47**	**0.57**	**0.55**	**0.58**
CD@1%	**1.16**	**1.83**	**1.68**	**1.38**	**1.67**	**1.60**	**1.69**

Figures in parenthesis are Days ±SD (n=20); figures in parentheses are values of arcsine transformed; numbers followed by same letters are not statistically significant (p<0.001) by LSD

Plant morphological characters on castor

Trichome number/cm^2: The statistical test of variance showed significant differences among three types of castor in having trichome density (Table 5). The maximum number of trichomes / cm^2 was 15.10 ± 1.4 in compact spiny type and differed statistically significant from spineless spike and spiny loose type (0±0 and 11.3±0.7), respectively. As the trichome number per cm^2 increased from 0 to 15, the number of eggs increased from 40 to 53 (on an average) among three castor types and larval infestation also increased from 14 to 26%, on an average.

Trichome length (mm): The data pertaining to trichome length (mm) in three select castor types are given in Table 5. The results revealed highly significant differences in the three castor types (p <0.001 df 19). The maximum trichome length was 0.81 ± 0.82 mm in compact spiny type followed by 7.21± 0.84 mm in spiny loose type and differed significantly from spineless spike (0±0). As the trichome length (mm) increased from 0 to 7.8, the number of borer eggs on castor type increased from 40 to 53 among three castor types and infestation as also increased from 14 to 26%. This means both trichome density and length are related to number of borer eggs laid and larval infestation.

Number of capsules/spike: Significant variations existed among castor types on number of capsules per spike (Table 5). The compact spiny type possessed maximum number of capsules *i.e.,* 43.2±1.6 which showed significant differences from those recorded on all other types. The minimum number of capsules 31.5 ±1.7 was recorded on spineless spike type followed by 32.8± 1.99 on spiny loose spike. As the number of capsules /spike increased from 31.5 to 43.2, the number of eggs on castor type increased from 40 to 53 among three types and infestation also increased from 14 to 26%.

Size of the capsule (cm): Statistically significant differences were found among castor types regarding capsule size (cm) (Table 5). The spineless spike type showed maximum capsule size *i.e.* 2.21±0.1 cm followed by 2.16 ±0.1 cm on compact spiny type which differed significantly from spiny loose spike (1.24±0.08 cm). As the size of the capsule (cm) increased from 1.24 to 2.21, the number of eggs on castor type increased from 40 to 53 among three castor types and infestation also increased from 14 to 26%. This means both number of capsules/spike and capsule size are related to number of eggs laid and castor plant part infested by *Conogethes* larvae.

Shoot diameter (mm): The analysis of variance revealed highly significant differences among types (p <0.001, df 19). The maximum shoot diameter was recorded (9.8 ± 0.85 mm) on compact spiny type followed by 8.90 ± 0.92, 7.90 ± 1.41 mm on spineless spike and on spiny loose spike, respectively. As the shoot diameter (mm) increased from 7.90 to 9.80, the number of eggs on castor type increased from 40 to 53 eggs among three castor types and infestation also increased from 14 to 26%. This means shoot diameter are related to number of eggs laid and castor plant part infested by *Conogethes* larvae.

Table 5: Plant morphological parameters of castor types.

Castor plant type	Morphological characters						
	Capsule infested (%)	Number of eggs laid/ spike	Trichome number/cm^2	Trichome length (mm)	Number of capsules/ spike	Capsule size (cm)	Shoot diameter (mm)
Spineless spike	15.68±2.72 (28.39)^{b}	40.0±3.13^{a}	0±0.0^{a}	0±0.0^{a}	31.5±1.7^{a}	2.21±0.10^{c}	8.9±0.92^{ab}
Compact spiny	26.17±2.45 (35.52)^{c}	53.0±5.64^{c}	15.1±1.4^{c}	7.81±0.82^{c}	43.2±1.60^{b}	2.16±0.11^{bc}	9.8±0.85^{b}
Spiny loose	14.13±1.05 (25.20)^{a}	42.45±5.58^{b}	11.3±0.7^{b}	7.21±0.84^{bc}	32.8±1.99^{a}	1.24±0.08^{a}	7.9±1.41^{a}
S.Em±	**0.29**	**0.43**	**0.30**	**0.22**	**0.60**	**0.03**	**0.37**
CD@1%	**0.94**	**1.54**	**0.88**	**0.65**	**1.75**	**0.09**	**1.08**

Figures in boxes are Days ±SD (n= 20); figures in parentheses are values of arcsine transformed; numbers followed by same letters are not statistically significant (p<0.001) by LSD

Daves *et al.* (2007) were of the view that corn plants defend against insect attack in more than one way. Defences by host plant are of either biophysical or biochemical in nature. Plants defending to attack by insects are a variety of insect pest may possess either one or both categories of resistance.

Antixenosis or non-preference is the mechanism of resistance deployed by the plant to repel away insects. Insects orientate towards plants in search of food, ovipositiona substrate and/or for safety. The characteristic of anixenotic of the plant will not allow the insect to establish (Painter, 1951). The mechanisms of repellency will influence an insect's behavioral response to the plant. The mechanism of antixenosis may be attributable to biochemical or biophysical factors or both (Panda and Kush, 1995).

Anatomical characters: Anatomical characters of cardamom shoot were observed with reference to the damage by *C. sahyadriensis* (Table 6). Borer damage was less (11.50%) when primordial layer were lower number (7-9) the infestation was less. Lysogenous cavities were circular shape, smaller size, 15-20 lysogenous cavities per layer and wider cavities. Infestation was more (18.12% and 19.87%) when the numbers of primordial layers in the shoot were higher (10-12 and 8-16). Lysogenous cavities showed rectangular shape, bigger size, 22-28 lysogenous cavities per layer and narrow distance between two cavities. The relationship of between shoot damage and primordial layers numbers of the shoot were directly correlated (Table 6).

Anatomical variations of fruits of castor were observed with a microscope to determine if *C. punctiferalis* damage is related to anatomical features of capsule (Table 7). Thickness of seed wall was indirectly associated with *Conogethes* damage. Spineless spike castor with dense seed coat, well defined sclerenchymatous tissue, thick parenchymatous cells and cotyledon with compact seed wall was recorded 15.68% capsule injury. However, compact spiny type of castor with maximum borer damage (26.17%) showed thin seed coat, not so distinct sclerenchymatous cells, thin parenchymatous cells and cotyledon with loose seed wall. The spiny loose spike type of castor had medium thick seed wall with moderate extent of damage (14%). Records of physical characteristic showed that castor and cardamom differed in anatomical and morphology features. The behaviour of borer adults and immatures changed in response to differences in biophysical characters and in the overall patterns of relationships with cardamom and castor. *C. punctiferalis* breeding on castor- trichome number/cm^2, trichome length (mm), number of capsules/ spike, capsule size (cm) and shoot diameter (mm) were related to larval damage.

C. sahyadriensis bred on cardamom- the number of fruits/panicle, length of panicle (cm), number of clumps per plant, number of inflorescence/ plant and shoot diameter, were related to egg laying and larval damage. So, the data showed that varying plant morphological and anatomical features were associated with *Conogethes* at egg and larval stages. So, *C. punctiferalis* on castor plant preferred trichome density compactness, while *C. sahyadriensis* on cardamom preferred smooth surface and parrot green colour. *C. punctiferalis* reared on castor and cardamom (*C. sahyadriensis*) plants varied in their preference for plant physical and anatomical characteristics.

The stem epidermis of cowpea influence movements and feeding of larvae inside the shoot cells (Oghiakhe *et al.,* 1991). Cells in collenchyma in old TVu 946 and IT 82D-716 shoots formed a network of well-knit interlocking cells with a few open spaces. Statistical significant differences were recorded in the distance between the epidermis and collenchyma cells of the slightly convex and concave areas of TVu 946 and IT 82D-716 shoots.

Table 6: Anatomy of cardamom shoot in relation to *C. sahyadriensis* infestation.

Anatomical character	% shoot infestation	Cardamom shoot characters*				
		No. of primordial layers	Lysogenous cavities shape	Lysogenous cavities size	Lysogenous cavities number / layer	Distance between two cavities
Malabar	11.50±1.0	7-9	Circular	Smaller	15-20	Wider
Mysore	19.87±1.9	8-16	Rectangular	Bigger	22-28	Narrow
Vazhuka	18.12±1.4	10-12	Circular	Bigger	20-26	Narrow

* In the absence of accurate measurements of the lysoginous cavities, the thickness of the lysoginous cavity was arbitrarily categorized into smaller and bigger after examining several section (atleast 12 times)

Table 7: Anatomy of castor capsule in relation to *C. punctiferalis* infestation.

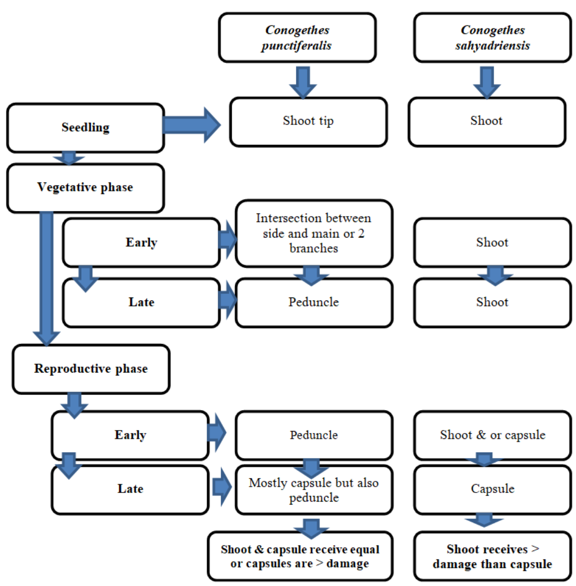
Anatomical character	Castor capsule characters*				
	% capsule infestation	Seed coat	Slerenchyamatous tissue	Parenchymatous tissue	Cotyledon with seed coat
Spineless spike	15.68±2.72	Thick	Well defined	Thick	Compact
Compact spiny	26.17±2.45	Thin	Not so distinct	Thin	Loose
Spiny loose spike	14.13±1.05	Moderate	Not so well defined	Moderate	Moderate

*In the absence of accurate measurements of the seed coat , the thickness of the seed coat was arbitrarily categorized into thick, thin and moderate after examining several section (atleast 12 times)

The studies of Kumarasinghe *et al.* (2001) found that cultivars of sugarcane resistant to *Pyrilla perpusilla* (Walker) had a thick layer of phloem fibre around the vascular bundle in leaf compared to susceptible sugarcane. The adults and nymphs of the sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner suck the sap from the leaves through the stomata. Uichanko (1928) from Philippines found that old leaves were more prone to aphid attack than young leaves. Takano (1937) reported from Japan that narrow and erect leaves of sugarcane were susceptible to sugarcane woolly aphid more than the soft, broad and drooping leaves. Pan *et al.* (1984) reported susceptibility of sugarcane cultivars in Taiwan to sugarcane woolly aphid that increased with increase in the fine vascular bundles than the compact ones.

All the above characteristics fell into antixenosis or antibiotic mechanism. Documented literature to-date has not revealed comprehensively the antixenotic and antibiotic factors contributing towards *Conogethes* resistance and/or susceptibility. Lakshminarayana (2005) found the morphological features of castor capsules related to resistance to several insect pests. Jayalaxmi (1996) mentioned that castor plants with spines and spikes that are compact had high borer *C. punctiferalis* damage compared to spineless and loose spikes of castor.

Observations recorded on the plant biophysical characteristics showed that castor and cardamom differed in the morphology of plant and even in anatomical characters. The reactions of the *Conogethes* moths and larvae changed with plant morphological characters. In view of these variations, the larvae of *Conogethes* showed differential behavioural trends with the above two plants (Flow chart 1).



A schematic representation of the patterns of borer damage on cardamom and castor plants.

It is only in 2018 that *C. sahyadriensis* was identified as a new species, different from *C. punctiferalis* (Shashank *et al.,* 2018). Further, Inoue and Yamanaka (2006) identified the two types into species, with *C. pinicolalis* Inoue and Yamanaka, 2006 representing the Pinaceae-feeding type, and the revised and re-described *C. punctiferalis* as the fruit-feeding type.

CONCLUSION

Biological studies on two *Conogethes* spp on cardamom and castor for the first have been brought out striking differences. On respective hosts, the average fecundity was 38 eggs/female (castor) compared to 56 eggs/female (cardamom). The egg viability was 66 % on castor compared to 69.5% on cardamom. The 5th instar larval weight was 65 mg on castor compared to 73.5 mg on cardamom. Pupal weight was 46 mg compared to 93.5 mg on cardamom. The castor borer completed the life cycle on an average in 34.50 days on castor compared to 39 days on cardamom. When *Conogethes* reared on cardamom were implanted on castor, larvae suffered cent per cent mortality and vice-versa. As the trichome number/cm^2 (0 to 15), trichome length (0 to 7.8 mm), capsules number/spike (31 to 43), capsule size (1.24 to 2.21 cm) and shoot diameter (7.9 to 9.8 mm) increased with the number of borer eggs on castor types. This study has brought out striking differences in the preference of borer for biophysical plant characters, hitherto not documented. Behavioral changes in larvae were also associated with the host-shift. *Conogethes* larvae when host-shifted did not exhibit normal orientating and feeding behavior. The compact spiny type was the most preferred castor type and Mysore type was the most preferred cardamom type for their respective *Conogethes* species. These investigations lead to preclude that *Conogethes* populations in India are under host-related speciation. This study has clearly established that there are genetically and chemically significant differences in the preference of host plants by the congeneric borer *Conogethes* species. Understanding the bioecology and host preference will contribute to effective management of these two major pests on economically important crops like castor and cardamom. Future investigations are desired on these two borer species in this context.

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