Insect Pests of Castor (*Ricinus communis* L) and their Management Strategies

M. Sujatha[1], P.S. Vimala Devi[1] and T.P. Reddy[2]

[1]Directorate of Oilseeds Research, Rajendranagar, Hyderabad 500 030, A.P., India
[2]Department of Genetics, Osmania University, Hyderabad 500 007, A.P., India
Phone: 040-24015345, Fax: 040-24017969
e-mail: mulpurisujata@yahoo.com

Abstract

Castor is an industrially important non-edible oilseed crop belonging to the family Euphorbiaceae. Development of location-specific varieties and hybrids with appropriate crop production technologies led to increased production and productivity of the crop. However, cultivation of the crop under input-intensive conditions resulted in increased vulnerability of the high yielding cultivars to a multitude of insect pests attacking the crop at all phenological stages and includes seedling pests, foliage feeders and inflorescence pests. The red hairy caterpillar in endemic areas, the defoliators, *viz.*, castor semilooper, *Spodoptera* and other hairy caterpillars, and sucking pests, such as jassid, whitefly, thrips and mites, cause huge damage to castor crop. Yield loss estimates indicate a reduction of seed yield up to 35-50% depending on the crop growth stage and the pest outbreak. Several insect pest management tactics are being developed for control of the major pests and includes cultural, biological, insecticidal and combinations of two or more methods, which are employed at three stages of prevention, observation, and intervention. In the recent past, attempts are directed towards formulation of potent microbial pesticides besides development of genetically modified castor. This chapter deals with the biology of major insects attacking castor along with the control methods being adopted, and gaps in the knowledge of pest management strategies that need to be addressed are discussed.

Key words: Castor, Insect pests, Integrated pest management, *Ricinus communis*, Transgenics

Introduction

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop of the spurge (*Euphorbiaceae*) family and is believed to have originated in Abyssinia. It is widely

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distributed throughout the tropics and subtropics due to its low demand on soil fertility, requires only moderate rainfall, do not compete with food crops and food grade oils. It is well adapted to the temperate regions of the world as well. It is high yielding and both varieties and hybrids are bred for cultivation in different agro-ecological niches with yields of around 800-1000 kg/ha under rainfed conditions and 1600-2000 kg/ha under irrigated conditions. Seeds have a very high oil content of ~50%.

Castor is grown on a total area of 1.5 m ha with an average production of 1.5 m tonnes, and productivity of 995 kg/ha during 2007 (FAOSTAT 2009). The major castor producing countries in the World are India, Brazil, USSR, China and Thailand, while the major importing countries are the USA, the USSR, the EEC and Japan. India, with an annual production of 10.5 lakh tonnes, is the leading producer of castor in the world. At current levels of production, the country accounts for 56% of area and nearly 69% of the world's output of castor. Castor oil and its derivatives, besides being used in medicine, are used in a wide range of sectors including agriculture, textile industry, paper industry, plastics engineering, rubber and pharmaceuticals (Anonymous 1972; Zimmerman 1958). Consequently, there has been a steady increase in the demand for castor oil and its products in the world market owing to their renewable nature, biodegradability and eco-friendliness. In the recent past, use of castor oil as an efficient biodiesel has been reported (www.castoroil.in).

Genetic improvement of castor has mostly been confined to the exploitation of naturally occurring genetic variability available in the base population and limited to selection for high yield, desirable branching type, non-shattering capsules and seeds with higher oil content. Extensive cultivation of the varieties and hybrids under high inputs, without proper scientific management and crop rotation, has made them vulnerable to a number of biotic and abiotic stresses. About 100 species of insect pests are recorded on castor at different phenological stages of the crop among which castor semilooper, capsule borer, *Spodoptera litura*, red hairy caterpillar, jassids and white fly cause considerable damage to castor (DOR 2005; Lakshminarayana and Raoof 2005). Yield loss estimates indicate loss in seed yield in the range of 35-50% depending on the crop growth stage and the pest attack. However, in case of severe outbreaks of castor semilooper and red hairy caterpillar during the early crop growth stage, cent percent losses have been recorded. Castor has the innate ability to tolerate leaf damage up to 25% without significant loss in seed yield while damage caused to spikes and capsules results in significant yield loss.

Fig. 7.1 Major insect pests of castor

Success in breeding of castor with yield stability is limited by a lack of exploitable genetic variability for productivity traits and sources of resistance to diseases and pests in the cultivar germplasm. Breeders have to resort to alternative approaches like intergeneric hybridization and biotechnological interventions for creation of additional genetic variability and incorporation of beneficial genes into castor plants. This chapter provides a brief account on the biology of major insect pests of castor (Fig. 7.1) as well as integrated pest management (IPM) strategies being adopted for their control.

Major Insect Pests and Their Biology

Red Hairy caterpillar - *Amsacta albistriga* Walker (Arctiidae: Lepidoptera)

The red-headed hairy caterpillar (RHC) is an important pest infesting castor crop in the Telengana region of Andhra Pradesh, particularly the districts of Ranga Reddy, Nalgonda, Warangal and Mahabubnagar. The *kharif* castor crop in Andhra Pradesh State is sown over 300,000 hectares, covering about 67% of all the land sown under this crop in India. The pest is highly polyphagous feeding on weeds and a wide range of crops such as castor, sorghum, mung bean, urd bean, sesame, soybean, pigeon pea, groundnut, etc., and

is active during June to August. RHC attacks young castor shoots and causes serious damage to the crop by completely defoliating the leaves. The pest destroys castor crop in the short period before it pupates and remains dormant for 10 months. While other crops recover, the earlier sown crop of castor is totally destroyed and farmers are compelled to sow the crop again. Farmers are also forced to delay castor sowing by a month or more, leading to withering of crop under water stress at seedling stage in the post-rainy period.

The pest has four life stages of pupa, moth, egg and larva. It is a pest when it is a larva, feeding on crops as it grows in size till it pupates and remains dormant from August till end of May. The adults emerge from the soil at the onset of south-west monsoon. Heavy rainfall wetting deeper layers of the soil triggers emergence of the adult moths from the earth. But only visual sighting of a large number of moths around lights can confirm their emergence.

Moths are medium sized and brownish white in colour with a wing span of 40-50 mm. Forewings are white with brown streaks and a yellowish streak in the anterior margin while hind wings are white with black margins, besides a.yellow band on the head. Two to five peaks of moth emergence lasting 1-3 days are observed during June-July depending on the rains. Female moths lay cream coloured eggs in masses of 200-2000 on the underside of leaves, and are covered with pale brown hairy scales. Eggs hatch within 3-5 days and larvae remain in the gregarious phase for 7-10 days feeding on the underside of the leaves. Subsequently, larvae become migratory and feed voraciously on leaf lamina leaving the petioles, midribs and main stem. Larvae are reddish in colour with long dense, reddish brown hair having broad black bands enclosing a reddish area in the middle. Duration of larval stage is around 15 days with 6 instars followed by pupation. Migratory caterpillars cause defoliation of the crop through voracious feeding and devastate whatever crops come their way. Pupation occurs in the fallow land at a depth of 2.5 to 65 cm based on soil texture and moisture – generally in the undisturbed soil of non-cropped shady areas. Pupae hibernate in the soil and adults emerge with the onset of monsoon completing only one generation in an year.

Castor semilooper - *Achoea janata* Linnaeus (Noctuidae: Lepidoptera)

Castor semilooper is a regular and serious pest on castor mainly during July - September in the Deccan Plateau and September - November in Saurashtra region of Gujarat. The pest activity starts in June in the Deccan plateau. Moths are pale brown and nocturnal in habit. The adult moth is 1 inch long with a wing span of 3.5 to 5 cm. Forewings are brownish-gray and the hind wings gray with bright black and white spots near the tips. Each female moth lays around 450 eggs singly on both the surfaces of castor leaves during the night. Eggs are round and ridged, around 1 mm in diameter and pale green in colour turning black before hatching. Eggs hatch in 3-4 days, neonate larvae are 3.5 mm in length and nibble on the outer tissues of the leaf, while the second and third instar

larvae feed on the leaves making small holes. Older larvae feed voraciously on the leaves leading to complete defoliation of the plant, leaving only bare stems and veins. Full grown larva is greyish brown in colour with red and brown lateral stripes, measuring 60-70 mm in length. Larval duration is 12-13 days during July to September with five larval stages/instars. This is followed by a short pre-pupal duration of 2-3 days leading to pupation that generally occurs in dropped leaves and loose soil. Pupal period ranges from 10 - 27 days but it normally varies from 10-14 days. One generation is completed within 28-45 days, and there are 5-6 generations of the pest in an year.

The first stage caterpillars are translucent, yellowish-brown in colour and about 0.3 cm in length, while next four caterpillar stages are variable in colour ranging from brownish orange to grayish brown. When fully grown, the caterpillars are about 6.35 cm long with grayish orange body and a broken black stripe running along the length of each side. There are white spots on the head of caterpillar as well as on the sides of the abdominal legs. A hump located on the back of caterpillar towards the rear has two bright red-orange spots.

Tobacco caterpillar - *Spodoptera litura* (Fabr) (Noctuidae: Lepidoptera)

The tobacco caterpillar is highly polyphagous and is widely distributed throughout India. It is active from August to November in Andhra Pradesh, Tamil Nadu and Gujarat. Castor is the most preferred crop by the pest. Adult moths measure between 15-20 mm in length and have a wing span of 30-38 mm. Forewings are gray to reddish-brown with a complex pattern of creamy streaks and paler lines along the veins. Hind wings are grayish-white with grayish-brown margins. Males have a blue-gray band from the apex to the inner margin of each forewing. Larvae have bright yellow stripes along the back and the sides. Larval color varies from pale green to dark green, and then finally brown for the later instars or more mature forms. Brown mature larvae appear to have three thin yellow, longitudinal lines─one on the dorsal side and one each on the lateral sides. A row of black dots runs along lateral sides, and a row of dark triangles decorates the middle and dorsal lines.

Female lays eggs in masses of 200 to 300 that are 4-7 mm in diameter and cream to golden brown in colour. Egg masses are usually covered with body hair scales and are laid on the underside of the host plant leaf. Eggs usually hatch in 3-4 days and freshly hatched larvae feed gregariously on the leaf surface for a few days and then disperse becoming migratory. Older larvae are voracious feeders and larval period lasts for 2-3 weeks with 5 instars. Larvae resort to nocturnal feeding and hide during the daytime in soil crevices and debris.

Young larvae are translucent green in colour with a dark thorax. Full grown larvae are stout, cylindrical, pale brown and possess submarginal series of narrow yellow spots with black lunules and lateral series of black spots. Feeding is initially by skeletonizing

leaving the outline of leaf veins on the plant, and as growth continues, caterpillars eat the entire leaves. Full gown caterpillars burrow into the soil several centimeters and pupate there in an earthen cocoon, thus completing 7-8 generations in an year.

Shoot and Capsule borer - *Conogethes (Dichocrosis) punctiferalis* (Pyralidae : Lepidoptera)

Conogethes punctiferalis is a major pest of castor all over India. The pest has assumed serious proportions in South India and is more serious during October- December in rainfed castor. Infestation starts from flowering stage and continues till maturity. Moths are medium sized with bright yellow wings having black dots. Female lays oval shaped eggs singly or in small groups on inflorescence, tender capsules and on tender terminal shoots. Freshly laid eggs are light greenish-yellow and turn dark-brown before hatching. Eggs hatch in 3-4 days. Freshly hatched larva is pale pink with fine hairs and dark head, and bores into the shoot if the plant is young and knits the seed capsules in older plants. The larva is seen under a cover of silk and frass that extends between capsules. Larval duration is of 12-13 days with five instars. The full grown larva is stout, reddish-brown in colour, measuring 15-25 mm in length. It pupates inside the damaged stem, peduncle or capsule in a silken cocoon. Pupal duration is 7-10 days in South India and 7-25 days in North India depending on the month of the year. The pest is found at all stages of crop growth from August to March when 4-5 overlapping generations are completed.

Leaf hopper - *Empoasca flavescens* (Fabr) (Cicadellidae : Hemiptera)

Leaf hopper occurrence is widespread in South India with peak infestation during September-December in Andhra Pradesh and November-January in Tamil Nadu. Cold and humid weather of the winter season enhances the pest activity and its multiplication. Females lay 15-20 eggs in a week's time within leaf veins on the lower surface. Nymphs emerge in 7-8 days and adults appear in 17-18 days. Longevity of adults is 9 and 18 days, respectively, in male and female hoppers. Both adults and nymphs damage the crop by sucking the sap from leaves, resulting in a burnt appearance of the leaves. Yellow patches appear on leaf margins followed by distortion of veins and leaf curling; these patches then turn brown and leaves become dry and brittle on the margins. Hopper burn, thus, lowers the vitality and plants become stunted with poor capsule formation.

Thrips – *Retithrips syriacus* (Mayet) (Thripidae : Thysanoptera)

Thrips are prevalent all over India, and of late the damage caused by thrips to castor is on the rise. Tiny pinkish nymphs and black adults with fringed wings have been found to feed on both upper and lower leaf surfaces, resulting in crinkling of the terminal leaves with a silvery appearance. Severe infestation causes stunted growth of plants, withering of emerging spikes and drying of the newly formed capsules.

Egg laying by females is preferably done inside the leaf veins. Around 40-60 eggs are laid by each female in 5-10 days. Eggs hatch in 4-5 days and emerging larvae leave circular holes leading to distortion of the attacked parts. Larvae become full grown in 7-9 days (2 instars), drop down, enter into the soil and pupate. Pupal duration lasts for 2-3 days and generation cycle is completed in 15-20 days. Hence, several overlapping generations occur during the crop season. However, rains are known to interfere with and bring down the incidence of thrips.

Whitefly - *Trialeurodes ricini* (Misra) (Aleyrodidae : Hemiptera)

Whitefly incidence on castor is high during summer months of March – June, although it prevails throughout the year. Adult flies have white wings and yellow body with pale white legs and antennae. Each female lays 80-90 shining, white long eggs in small clusters or scattered on the undersurface of tender leaves. Eggs hatch into nymphs that are yellow, oval and translucent, covered with waxy projections. Nymphs adhere to the leaves and suck the sap for a week and then pupate at the same site with a waxy margin around the pupal body. In case of severe infestation, the damaged leaves are covered with a sooty mould.

Serpentine leaf miner - *Liriomyza trifolii* Burgess (Agromyzidae: Diptera):

Widespread appearance of the pest was first reported in 1991 on castor and many other crops. Newly hatched maggots are apodous and yellowish-orange coloured. The maggots start feeding on the leaf tissue in the epidermal layer of the leaf making characteristic serpentine mines. After 6-9 days of feeding, the full grown yellow maggots come out of the mines and drop to the soil for pupation. Adult flies emerge from the brown puparia in 6-7 days. Infestation and damage starts with cotyledonary leaves and moves upward with the plant growth. Heavy infestation often results in typical drying and dropping of the leaves.

Bihar Hairy caterpillar - *Spilosoma (Diacrisia) obliqua* wlk. (Arctiidae : Lepidoptera)

Many hairy caterpillars attack castor of which Bihar hairy caterpillar (BHC), although sporadic, is a potential pest. The incidence of Spilosoma on castor occurs during October-December and in certain cases attacks July-sown crop as well. It is highly polyphagous infesting all the agriculturally important dicots. The larvae defoliate the crop and also feed on the capsules.

Adult moths are medium sized, reddish-brown with black spots. The wings are pinkish in colour and have black spots. Female lays eggs in masses on the lower leaf surface. Early stages of the larvae are gregarious and in 2-3 weeks the larvae become full grown. The larvae are pale yellow with dark yellow hair all over the body. Pupation takes place on the soil under dried foliage and debris close to the plants.

Insect Pest Management Strategies

Integrated pest management (IPM) works on six basic components which include 1) acceptable pest levels or economic threshold levels based on which control measures are imposed; 2) preventive cultural practices including host plant resistance and crop sanitation; 3) monitoring the degree days of an environment to determine the optimal time for pest outbreak; 4) mechanical control; 5) biological control; and 6) chemical control. One has to follow the appropriate combination of pest management tactics which could be individual or combinations of two or more methods depending on the pest population dynamics. Several such pest control strategies are being developed for castor as described below:

Chemical control and no cost/low cost technologies for integrated pest management

Use of chemical insecticides depends on the user requirements, ease of use, safety, economic viability and ecosystem in which the crop is raised. Castor is cultivated both under rainfed and irrigated situations and depending on the prevalent agroclimatic conditions, the following control strategies are recommended.

Red Hairy caterpillar

Bonfires must be lit in every field on the nights of mass emergence to attract and kill the moths before they mate, which they do within 48 hours. Alternately light traps can be set up using mercury lamps (200 watts) where possible, if not with petromax lights of 200 candle power. These initiatives should be undertaken with the first monsoon rains so as to attract the moths and kill them. Each mercury lamp can cover an area of ~10 ha. The egg masses (200-2000) laid in a cluster by the female moth hatch in about 72 hours, which must be collected and destroyed before the tiny larvae emerge.

Sowing of cucumber/cowpea and planting twigs of *Ipomoea*, *Jatropha* and *Calatropis* (before the main crop) along the borders of castor fields will attract the migrating larvae that can be killed mechanically. These activities must be taken up on a community basis as a village group activity. Digging trenches around the fields and dusting the furrows with methyl parathion 2%/quinalphos 1.5% can minimize threat from the migrating larvae.

Chemical control of the pest is effective when directed against early stages of the larvae. Presence of dense hairs on the body surface of older larvae coupled with their migratory nature renders them less susceptible to the insecticides. The chemical insecticides found effective against RHC include monocrotophos 0.05%, quinalphos 0.05%, endosulfan 0.07%, cypermethrin 0.05%, fenvalerate 0.02% and deltamethrin 0.003%.

In the Telangana region, the pest causes large scale economic losses in castor crop covering an area ranging from 80,000 to 1,00,000 hectares. When farmers take up late sowing of castor to avoid the period of maximum pest infestation, they lose anywhere upto 20,000 tonnes of castor valued at Rs.120 to 140 millions. RHC caterpillars cause extensive defoliation of the crop as they are voracious feeders and often migrate from one field to another devastating whatever crops come in their way.

Castor semilooper

1. Handpicking and destruction of older larvae of semilooper is beneficial for keeping defoliation at low level. 2. Semilooper eggs can be effectively controlled through weekly releases of *T. chilonis* @ 1,25,000/ha at 10-12 points in 4 split doses per acre. 3. Spraying of chemical insecticides has to be avoided when the larval parasitoids *M. maculipennis* are observed @ 1-2 per plant. 4. The pest is highly susceptible to *Bacillus thuringiensis* (Bt) which is safe to the natural enemies. Hence, Bt formulations @ 1g or 1ml/l of spray suspension are recommended. 5. Bird perches @ 10 per acre are to be provided to attract predatory birds that help reduce the larval incidence by feeding on them. 6. Chemical insecticides monocrotophos 0.05%, quinalphos 0.05% or endosulfan 0.07% are to be sprayed when defoliation exceeds 25%.

Tobacco caterpillar

1. Handpicking the gregarious stages of larvae through collection of skeletonized leaves and destroying them is an effective and practicable approach for killing the pest that helps to avoid adoption of other means of control including insecticides altogether. 2. Use of poison baits made up of monocrotophos, chlorpyriphos, rice bran, jaggery and water proved effective for control of grown up larvae. 3. Sprays of 4-5% neem seed kernel extract act as ovipositional deterrants. 4. Sprays of chlorpyriphos 0.04% or monocrotophos 0.05% are often recommended if defoliation exceeds 25%.

Capsule borer

Capsule borer is less susceptible to chemical insecticides and, hence, is difficult to be controlled. Suitable management practices other than chemical control are not available. Cultivation of castor varieties/hybrids with non-spiny capsules and non-compact/semi-compact spikes is likely to result in low capsule borer damage. If 10% of the capsules are damaged by the capsule borer, it is preferable to spray monocrotophos 0.05% or

endosulfan 0.07%. In cases of high infestation, it is advisable to spray the crop with acephate 0.075% or decamethrin 0.003% or profenophos 0.05%. If feasible, collection and destruction of infested shoots and capsules may be undertaken.

Whitefly

Damage due to white flies can be kept low by spraying the infested plants with monocrotophos 0.05%/ dimethoate 0.05%/ triazophos 0.05%, while neem oil @ 5 ml/l can be sprayed, at early stages, on the undersurface of castor leaves.

Thrips

Castor fields should be sprayed with monocrotophos 0.05%/ dimethoate 0.05%/ phosalone 0.04% when the plants exhibit initial symptoms of pest damage.

Leaf hopper

Castor may be sprayed with monocrotophos 0.05%/ dimethoate 0.05% for the control of leaf hopper. Cultivation of castor variety/hybrid bestowed with double/triple bloom and innate resistance to leaf hopper is recommended.

Serpentine leaf miner

Effective control of the pest cannot be achieved with the commonly used insecticides. However, sprays of neem-seed-kernel extract @ 4-5% can prove effective against leaf miner.

Biological and Microbial Control of Insect Pests

Insect populations are kept under check in nature by various biotic factors of which natural enemies comprising various parasites, predators and insect pathogens, *viz*., bacteria, viruses, fungi, etc., play a very important role (Fig. 7.2). Among bacteria, *B. thuringiensis* has already been commercially exploited. Seven families of viruses, *viz.*, Baculoviridae, Reoviridae, Iridoviridae, Poxviridae, Parvoviridae, Picornoviridae and Rhabdoviridae, are known to infect different insect species, and of these viruses from Baculoviridae and Reoviridae have been commercially exploited for biocontrol. Among fungi, *Nomuraea rileyi*, *Metarhizium, Verticillium* and *Baeuveria bassiana* are widely used for microbial control. Several natural enemies have been identified for controlling the insect pests of castor. Presence of egg parasitoids, *Trichogramma* spp., and *Telenomus* spp., are reported from a majority of lepidopteran pests like the red hairy caterpillar, castor semilooper and tobacco caterpillar.

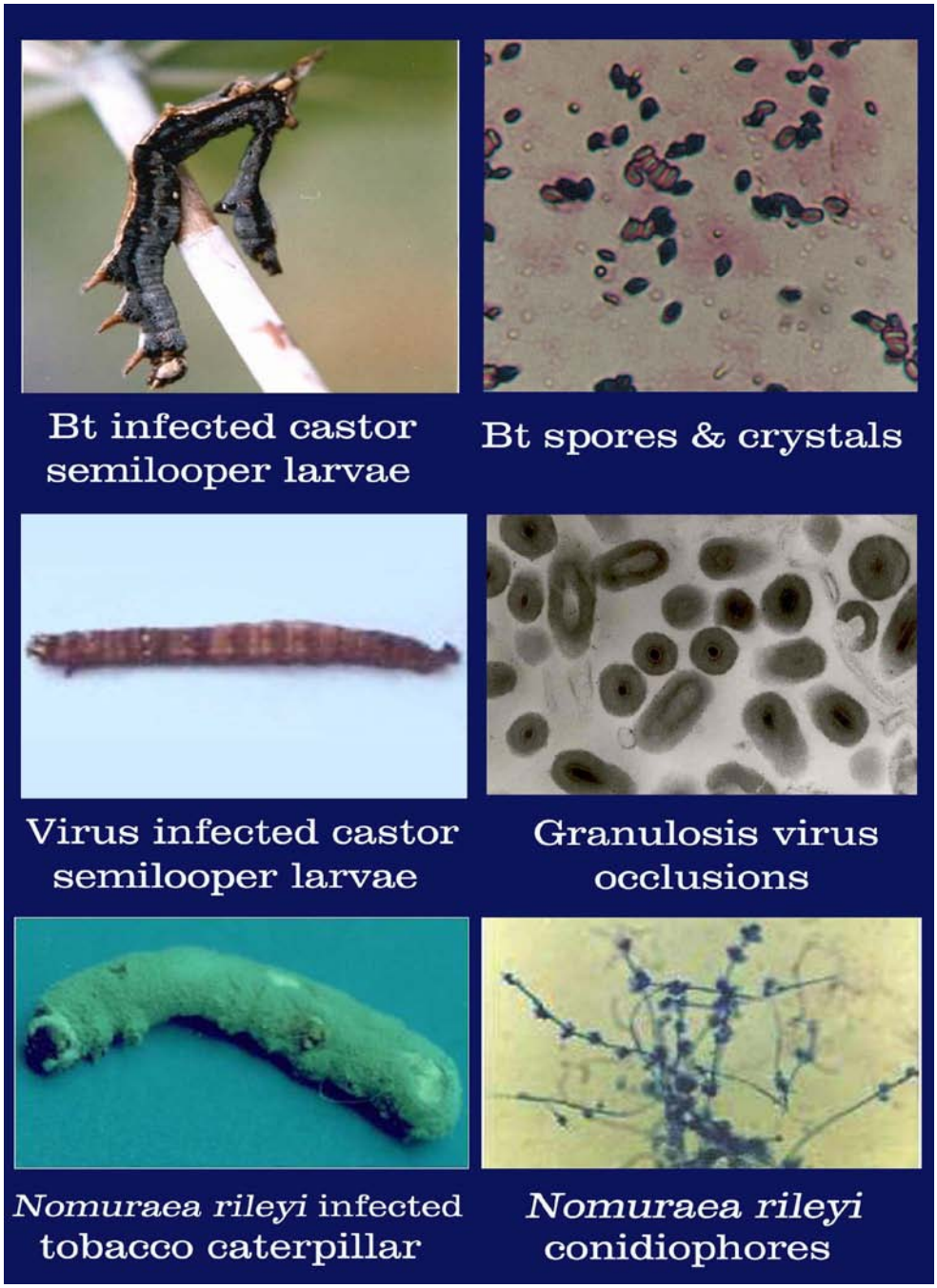

Fig. 7.2 Microbial control of some major foliage feeders

The larval parasitoid *Apanteles obliqua*, the predatory bug *Canthoconodea* spp. and the tiger beetle are shown to cause appreciable mortality of the red hairy caterpillar. The microbials reported from red hairy caterpillar include the nuclear polyhedrosis virus (NPV) and nematodes. Since it is not feasible to rear RHC under captivity, microbial control with NPV could not be exploited for its management as it can be multiplied only *in vivo*.

Most effective natural enemies on castor semilooper include the hymenopteran egg parasitoid, *Trichogramma chilonis*, parasitizing ~40% of the semilooper eggs as well as the braconid larval parasitoid, *Microplitis maculipennis*, which internally parasitizes second and third instar larvae to the tune of 60-90%. The parasitized larvae carry brown cocoon at the posterior end, which cannot feed on castor plants and die of starvation. Inundative releases of *T. chilonis* @ 1,25,000/ha is reported to be effective in increasing the rates of parasitization. Two more larval parasitoids ─ a chalicid *Euplectrus maternae* and another braconid parasite *Rhogas* spp. ─ have been identified on castor semilooper. Among the microbials, *B. thuringiensis* (Bt) var. *kurstaki* has been found to be highly effective (Vimala Devi *et al.,* 1996a). Formulation of a local isolate DOR Bt-1 is registered under the trade name KNOCK W.P. for the management of castor semilooper (Vimala Devi and Sudhakar 2006). Bt combines the twin advantages of safety to natural enemies with its rapid action and is known to cause feeding cessation of larvae within a few hours after ingestion, resulting in larval mortality within 72 h. The larvae dead due to Bt infection become scaly and black in colour. Bt formulations can be used effectively @ 1g/1ml per litre of spray suspension when directed against 2^{nd} and 3^{rd} instar larvae. Production of Bt through solid state fermentation, with less capital and low skills, enabled localized production of Bt pesticide within the reach of dryland farmers at affordable price (Vimala Devi and Rao 2005). Yet another pathogen reported on castor semilooper is the granulosus virus (GV), which can be used effectively @ 500 LE/ha at the early stages of larvae (Vimala Devi 1992). A beneficial nematode, *Mermis* sp., was reported to parasitize the castor semilooper (Chatterjee *et al.,* 1968).

Several egg, larval and pupal parasitoids are known to cause the mortality of tobacco caterpillar at different growth stages. Important agents are the egg parasitoid, *T. evanescens minutum*, larval parasitoids, *Apanteles prodenia* and *Cotesia* spp., and pupal parasitoids, *Tetrastichus ayyari* and *Trichoplusia pupivora*. The pest population is lowered by the activity of diverse predators like spiders, green lacewing *Chrysoperla* spp., bugs and birds. Among the microbials, the most important are the NPV, the entomofungal pathogen *Nomuraea rileyi*, and Bt var. *aizawai*. NPV of *S. litura* is commercially available and can be used effectively @ 250 LE/ha. Larvae infected with NPV are found hanging in inverted V shape from the plant or lying on the leaf surface with fragile cuticle. Sprays of NPV should be undertaken only during the evening hours and it proved to be most effective under conditions of >70% humidity and temperatures < 30 ^{0}C. *N. rileyi* infected larvae are identified by the malachite green colouration of

sporulating cadavers. The conidia are hydrophobic, get easily dislodged by the wind and spread into environs (Vimala Devi 1994; Vimala Devi *et al.*, 1996b).

The capsule borer is reported to be affected by several larval and pupal parasitoids. The ichneumonid parasitoids, *Diadegma ricini* and *Theronia* spp., the braconid parasitoids, *Apanteles* spp. and *Bracon hebetor*, as well as the pupal parasitoid, *Brachymeria euploeae*, are the most prevalent parasites. Studies at the Directorate of Oilseeds Research, Hyderabad (India) have revealed that capsule borer is highly susceptible to Bt var. *kurstaki*.

The lygaeid bug (*Geocoris tricolor)*, larval forms of a predatory mite belonging to Erythraeidae, and certain spiders feed on nymphs and adults of castor leaf hopper. The spider mite *Scolothrips indicus* feeds on immature stages of thrips. The aphelinid parasitoid *Encarsia* spp. parasitizes the nymphs of whitefly, the coccinellid *Menochiles sexmaculatus*, lygaeid bug *G. tricolor*, syrphid *Ischiodon scutellaris* and thrips *Taenothrips ricini* predate on whitefly, while the pupa is parasitized by a chalicid. Conservation of these natural enemies can help to check the incidence of castor pests.

Host Plant Resistance

Breeding for pest resistance

New sources of pest resistance and tolerance to stress environments are in constant demand by the breeders. Host plant resistance represents the inherent ability of crop plants to resist, retard or overcome pest infestations and thus leads to improved seed yield. Resistant cultivars represent one of the simplest and economically viable methods of insect pest control for adoption by the farmers. Unlike plant resistance for diseases, resistance to insect pests is found to be temporary and for most practical purposes partial. For disease resistance, both horizontal (polygenic) and vertical (single or few genes) resistances are reported but little evidence exists for the presence of vertical resistance with regard to host-insect interaction.

Genetic enhancement for resistance is possible if reliable sources of resistance are available in the primary, secondary or tertiary gene pools. Castor belongs to a monotypic genus, and hence resistance sources need to be tapped from the cultivar germplasm or related genera. *R. communis* is the lone species encompassing many polymorphic types known in the world collections (Weiss 1983). Several of these types were designated as species (*R. communis, R. macrocarpus, R. microcarpus*) but they are intercrossable and fertile and, therefore, are not true species as usually defined in other plants. All the castor varieties that have been investigated cytologically are diploids with a 2n number of 20 chromosomes and is reported to be a secondary balanced polyploid with a basic number of X = 5 (Singh 1976). In several crops, wild relatives have been exploited most often, as they serve as important reservoirs of genetic variability for various beneficial characters (Harlan 1976). Morphologically, the genus *Jatropha* (2n=22) resembles *Ricinus* and has

attracted interest as it possesses useful traits not found in castor. Several *Jatropha* species are grown in the greenhouse for their ornamental leaves and flowers, while other species grown in the tropics are of economic value (Anonymous 1959). Successful introgression of some of the desirable genes of *Jatropha* into castor remained virtually untapped, owing to lack of sexual cross compatibility in several castor-*Jatropha* combinations (Reddy *et al.,* 1987; Sujatha 1996).

Till date, breeding programmes aimed at introgression of resistance to the major insect pests are at infancy, and there are no varieties/hybrids being bred for insect resistance in castor. On the varietal front and parental-line development programmes, emphasis is on the development of cultivars for resistance to various diseases. Numerous reports on the resistance/tolerance of released varieties/hybrids ─ namely, TMVCH-1, DCH-519, RHC-1, DCH-32, GCH-4 to leaf hoppers; GCH-5 to jassids, white fly and capsule borer; AKC-1 to castor semilooper and capsule borer; TMV-6 to leaf hoppers, semilooper and capsule borer; and Kranti to semilooper ─ are based on field reaction to the pests. There are no systematic efforts at screening of germplasm under uniform pest-load for selection of promising genotypes except for the leaf miner. Castor germplasm has been screened against leaf miner, which resulted in the identification of RG 1930 and RG 2008 lines possessing purple morphotype and resistance to the miner with very low infestation (2-4 mines/leaf) as compared to 65 - 108 mines/leaf on control plants (Anjani 2005). Leaf miner resistance and its association with the purple colour phenotype revealed uniparental inheritance (Anjani *et al.,* 2007). Also, cultivars SKI 73 and SKI 89 were reported to be highly resistant to leaf miner infestation (Kapadia 1995).

Efficacy of Bt Cry proteins against major pests of castor

Owing to limited genetic resources conferring resistance to insect pests in castor, there is a need for exploiting the biotechnological tools for alien gene transfer. Before embarking on the programme of genetic engineering, it is imperative to identify suitable insect resistance genes, which could be deployed into castor against the major pests. Several candidate genes, such as crystal protein (*Cry*) genes of *B. thuringiensis* produced during the sporulation stage, vegetative insecticidal Bt proteins (VIPs) induced during the vegetative stage, proteinase inhibitors, lectins, α-amylase inhibitors, insect chitinases, novel genes of plant origin, etc., are deployed into crop plants for imparting protection against insect pests. However, the most commonly used and commercially exploited insect resistance genes are the Bt *Cry* genes from *B. thuringiensis.* Insecticidal δ-endotoxins of *B. thuringiensis* have acquired great significance in recent years because of their specificity to target pests, non-toxicity to humans and beneficial insects, toxicity at low concentration and environmental friendly nature. It is known that *B. thuringiensis* (Bt) var *kurstaki* strains produce several lepidopteran toxic proteins such as Cry *1A(a), Cry 1A(b), Cry 1A(c), Cry IIA* and *Cry 1B.* Information on the reaction of the major lepidopteran pests attacking castor to Cry proteins in the toxin specificity database (http://www.glfc.forestry.ca/bacillus/web98.adb) is limited. Experiments were undertaken

at the Directorate of Oilseeds Research to assess the efficacy of various purified crystal Bt proteins which are lepidopteran pest - specific against major defoliators of castor.

Ten *E. coli* clones overexpressing Bt proteins, *viz.*, Cry 1Aa, 3A, 2B, 1C, 2A, 1E, 1Ac, 1F, 9A, 1Ab, were procured from the Department of Biochemistry, Ohio State University, USA. Isolation and purification of insecticidal crystal proteins (ICPs) from *E. coli* expressing Cry toxins was carried out as per the standard procedures (Lee *et al.*, 1992). Bioassays against neonate larvae of *Achoea janata, Spodoptera litura, Spilosoma obliqua* and *Euproctis fraterna,* using Cry toxins at concentrations ranging from 4 to 1500 ng/cm^2, were done using leaf paint assay. All the proteins were tested against the target pests and data on larval mortality at 2-day intervals up to 8 days and larval weight of survivals 4 days after treatment were recorded.

Achoea janata

Bt proteins 1Aa, 1Ab, 1E and 2A were most effective, resulting in 100% mortality within 48 h, while other proteins showed no or delayed mortality at the highest concentration tested. Among the effective proteins, Cry 1Aa was found superior to other proteins in causing early mortality even at lower concentrations. Protein 1Aa gave significant mortality within 48 h at concentrations of 125 ng/cm^2 and above, while 2A, 1E and 1Ab induced delayed mortality (96 h after treatment) with concentrations < 500 ng/cm^2. Feeding cessation resulted in low larval weights as compared to the control (Sujatha and Lakshminarayana 2005).

Spodoptera litura: None of the proteins gave 100% mortality even 96 h after treatment at the highest concentration (1500 ng/cm^2) tested except for Cry 1Aa which gave 50% mortality at 1500 ng/cm^2. Increasing the concentration of proteins up to 3000 ng/cm^2 also failed to induce larval mortality. However, feeding cessation in terms of low larval weight was recorded in treatments with Cry 1Aa and 1Ab (Lakshminarayana and Sujatha 2005).

Spilosoma obliqua: Mortality of neonates at 96 h after treatment varied from 0 to 100% and maximum mortality was recorded with Cry 1Aa (100%) followed by Cry 1E (72.5%), Cry 2B (54%) and Cry 1C (46.7%) treatments. Although larval mortality occurred 96 h after treatment, yet the mortality symptoms such as low or no feeding and poor larval growth were evident at 48h after treatment.

Euproctis fraterna: The efficacy of Bt proteins has been evaluated based on larval mortality and larval weight gain recorded at 2-day intervals up to 6 days. Bt proteins, Cry 1Ac and 1Aa, proved effective against *Euproctis* causing mortality within 48 h after treatment. The LD_{50} was 62.5 ng/cm^2 for Cry 1Ac while it was 250 ng/cm^2 for Cry 1Aa.

Results obtained from various concentrations and the response at different days of treatment indicate that the Cry proteins 1Aa, 1Ab, 1E, 2B, 2A are effective against castor semilooper; 1Aa, 1E, 1Ab against Bihar hairy caterpillar*;* 1Ac, 1Aa against *E. fraterna; and* 1Aa, 2A, 1E, 1F, 1C, 9A in causing feeding cessation of *Spodoptera litura*. In view

the proven superiority of Cry 1Aa protein against all the target pests, genetic transformation of castor has been initiated using *Cry* 1 *Aa* gene with plant codon usage. Studies of Singh *et al* (2004) demonstrated the efficacy of the fusion gene *Cry1EC* against *S. litura.* However, there is an urgent need for determining the toxicity of *Bt* Cry proteins against the capsule borer.

Tissue culture

One of the strategies for genetic enhancement of resistance to insect pests is development of transgenic plants through incorporation of suitable insect resistance candidate genes (Sharma *et al.,* 2000). Transgenics are imperative for agriculturally important crops and the 74-fold hectare increase between 1996 and 2008 makes biotech crops the fastest adopted crop technology in agriculture (James, 2008). Of the global biotech area of 125 million ha under biotech crops during 2008, 15% was occupied by insect resistant crops and 22% by crops with the stacked double and triple traits. Hence, there is vast scope for genetic engineering of castor so as to mitigate the damages caused by the lepidopteran insect pests.

Availability of an efficient and highly reproducible system of tissue culture regeneration is a prerequisite for genetic transformation experiments. Castor proved to be highly recalcitrant to manipulations *in vitro* which is a major bottleneck in the development of transgenic castor (Reviewed by Sujatha *et al.,* 2008 and 2009). Earlier studies during 1960s were confined to endosperm culture which resulted in continuously growing cultures which lacked the ability for organogenic differentiation. Tissue culture studies were once again undertaken by researchers during 1980s for obtaining whole plantlet regeneration from seedling tissues of castor. Experiments were restricted to the use of young seedlings and the ability to regenerate complete plants was rather limited. Plant regeneration was mainly from the pre-existing meristematic centers (Athma and Reddy 1983; Sangduen *et al.,* 1987; Reddy and Bahadur 1989; Molina and Schobert 1995), and a maximum of 40 and 47 shoots from embryo axes and shoot tip explants, respectively, was reported (Sujatha and Reddy 1998).

Callus-mediated shoot regeneration from hypocotyl explants, young stem segments, leaves and cotyledonary leaves are reported but the morphogenic differentiation was sporadic, unreproducible with very low frequency of shoot regeneration and few shoots (1-5) per responding explants (Reddy *et al.,* 1987; Genyu 1988; Bahadur *et al.,* 1992; Sarvesh *et al.,* 1992). In the recent past, Ahn *et al* (2007), Sujatha and Reddy (2007) and Ganesh Kumari *et al* (2008) have reported relatively higher shoot induction frequencies from seedling explants with around 22 to 24 shoots per explant. Nevertheless, the reproducibility of these methods across laboratories and different genotypes has to be ascertained. Thus, despite the research efforts that have expanded over the last three decades, regeneration of whole plants with reproducible frequencies from callus cultures is a much sought after goal in castor.

Genetic transformation

Castor leaves are susceptible to crown gall disease caused by *Agrobacterium tumefaciens* (Lippincott and Haberlein 1965). However, recalcitrance *in vitro* has been a major problem for undertaking genetic transformation experiments in castor. Mc Keon *et al* (2003) obtained genetically engineered plants by employing the method of *Agrobacterium*-mediated transformation through vacuum infiltration of wounded flower buds (US Patent No 6.620.986). Genetic transformation experiments mostly relied on meristem-based shoot proliferation system. The first successful attempt to develop a stable transformation system for castor using vegetative explants has been described by Sujatha and Sailaja (2005). In this protocol, co-cultivated explants were initially subjected to expansion and proliferation on Murashige and Skoog (MS) medium with 0.5 mg/l TDZ followed by three cycles of selection on medium with 0.5 mg/l BA and increasing concentrations of hygromycin (20-40-60 mg/l). Selected shoot clusters were transferred to medium with 0.5 mg/l BA for proliferation and 0.2 mg/l BA for shoot elongation. Elongated shoots were rooted on half-strength MS medium with 2.0 mg/l NAA. With this protocol, a primary transformant can be developed within 5 months from cultured embryo axes with an overall transformation efficiency of 0.08%. As the protocol does not involve an intervening callus phase, no abnormal phenotypes are expected through this procedure. A similar regeneration method with minor modifications has been adopted for direct gene transfer using particle gun bombardment method (Sailaja *et al.,* 2008). Regardless of the method of transformation, the explants used were the decotyledonated embryo axes from mature seeds and exploitation of their excessive proliferative ability on the medium supplemented with thidiazuron (TDZ).

Transgenics for insect pest resistance

The vector-mediated and direct gene transfer methods (Sujatha and Sailaja 2005; Sailaja *et al.,* 2008) were employed for transformation of castor (cv. DCS-9) using appropriate vectors containing the Bt fusion gene *Cry 1EC* driven by enhanced 35S promoter (Sujatha *et al.,* 2009). About 81 and 12 putative transformants were regenerated following selection on hygromycin and kanamycin, respectively. The integration and inheritance of the introduced genes was demonstrated up to T_4 generation by PCR and Southern analysis. Southern analysis of two events having single and two copies showed the same pattern of integration in the subsequent generations. Field bioassays against *Spodoptera litura* and castor semilooper, conducted for eight events in T_1 to T_4 generations under net confinement, facilitated identification of promising events bestowed with resistance to the two major defoliators. Identification of transformation events bestowed with resistance to the foliage feeders is just a beginning, and there is a need to determine the toxin expression levels in different events and also changes in the level of protein expression at different developmental stages of castor.

The same procedure with minor modifications was used for production of semilooper resistant transgenic castor by incorporating a synthetic delta endotoxin *Cry1Ab* gene driven by CaMV 35S promoter (Malathi *et al.,* 2006). The construct harbouring the insect resistance gene carried the herbicide resistance gene (*bar*) for selection of putative transformants. The presence of introduced gene, its stable integration, expression and inheritance was confirmed through PCR, Southern analysis, ELISA and progeny tests. The bioassays with neonate larvae of semilooper disclosed marked feeding inhibition associated with reduced larval growth and substantial mortality (88.9 to 97.3%) on different stable (T_1) transformants as compared to the untransformed control plants (13.9%). However, characterization of transgenics harbouring the *Cry1Ab* was confined to the analysis of T_1 generation plants, and their reaction to the target pest was evaluated under laboratory conditions.

In both the studies, the genotype being subjected to transformation was DCS-9 (Jyoti) which is cultivated as a commercial variety and also used as a parental line for the hybrid, DCH-177. Both the studies relied on meristem-based proliferation of castor for genetic transformation. The frequency of transformation was extremely low and was ~0.4% (Malathi *et al.,* 2006; Sujatha *et al.,* 2009). Currently, the major biotic threats to castor cultivation in India are capsule borer and botrytis grey rot. Screening procedures are in place for botrytis grey rot, yet suitable candidate genes have to be identified against this pathogen. Whereas, for capsule borer the major challenge lies in optimizing a rearing technique prior to testing against various agents.

Conclusions and Future Perspectives

One of the problems confronting castor cultivation is the susceptibility of improved varieties and hybrids to insect pests. Integrated pest management strategies are being developed for most of the major pests and insect control is mostly through chemical insecticides or mechanical methods. In the recent past, capsule borer has increased alarmingly causing 30 to 60% yield loss in castor. The management of defoliators like semilooper and *Spodoptera* is relatively easy as the plant has the ability to tolerate certain degree of defoliation and these pests have potential natural enemies and are susceptible to a wide range of insecticides. Contrary to this, the management of capsule borer is rather difficult since the pest attacks the inflorescence and growing capsules, which directly translates into yield reduction. Considerable research gaps exist in understanding the biology of the capsule borer on different hosts, their behaviour, population dynamics and seasonal abundance, off-season survival, preference to host plants, pest-parasitoid relationships, economic thresholds and management with suitable insecticides for effective control. Efficacy of crystal protein genes from *Bt* against capsule borer has to be evaluated for which the rearing technique is an essential prerequisite. There is a need to identify reliable sources of resistance to the major pests attacking castor, and to understand the underlying mechanisms such as antixenosis, antibiosis and tolerance in the elite cultivars.

Conventional breeding methods have not made much headway due to unacceptably low levels of genetic variability for these desired traits in the cultivar germplasm of castor which belongs to a monotypic genus *Ricinus.* Hence, alternative approaches like alien gene transfer and biotechnological innovations are envisaged for genetic upgradation of this crop. Host plant resistance is the most desirable option for insect control, and recombinant DNA technology now offers breeders several ways to produce insect resistant plants. Despite the difficulties in tissue culture regeneration in castor, development of transgenics through meristem-based shoot proliferation system is quite encouraging. The protocols of genetic transformation need to be improved for enhancing the transformation frequency. Recently, certain bioagents including Bt were found effective against the major lepidopteran pests like castor semilooper and capsule borer. Molecular profiling of the potent microbial strains is expected to provide valuable leads regarding the potential candidate genes that can be introduced into castor genome for offering protection against specific target pests.

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