Abstract

Castor is an important oilseed crop. The castor bean contains about 50-55% oil. Among vegetable oils, castor oil is distinguished by its high content (over 85%) of ricinoleic acid. No other vegetable oil contains so high proportion of fatty hydroxy acids. Castor oil’s unsaturated bond, high molecular weight (298), low melting point (5°C) and very low solidification point (-12°C to -18°C) makes it industrially useful, most of all for the highest and most stable viscosity of any vegetable oil. The castor plant has a substantial taproot with many lateral branches which can reach a great depth enabling them to withstand drought and most harsh weather conditions. Leaves of castor plants are large, glossy and green with pointed lobes and prominent veins; each develops on a long stalk often used as feed for livestock and others animals, especially the economy booster, eri-silk worm. However, the castor leaf for many years has often been attacked by the leafhopper and in most cases leads to the destruction of the plant. The leafhopper causes hopperburn which renders the attacked leaves dry, uneven, curl downward in the shape of an inverted boat, margins turn brown and eventually death of the plant. The study of the makeup, life cycle and characteristics of this insect is of much importance to castor farmers, breeders and geneticists.

Introduction

Castor (Ricinus communis) from the family Euphorbiaceae is an important industrially valued nonedible oilseed crop [1]. It is widely distributed and adapted throughout the tropics, subtropics and temperate areas due to its low demand on soil fertility, requirement of moderate rainfall, less competition with other food crops and food grade oils. 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 [2]. Castor is grown for its seeds, which is extracted for the non-edible oil mainly used in the manufacturing of paints, lubricants, soaps, hydraulic brake fluids, polymers and perfumery products, among others; several derivatives of castor oil are used in a variety of industries [3]. Castor oil is the only vegetable oil that contains up to 85% of the unique hydroxy fatty acid, ricinoleic acid, which confers distinctive industrial properties to the oil [4,5]. Castor oil has more than 700 industrial uses, and its global demand is constantly rising at 3-5% per annum [6,7].

India is the world leader in castor, producing nearly two-thirds of the total global production followed by Brazil and China [1,8]. The instabilities in the productivity of castor in India are generally caused by two main reasons: first, it is grown as a rain-fed crop, and as a long-duration crop is subject to the vagaries of the monsoon; second, it attracts a large number of pests [9]. Castor is attacked by insect pests right from sowing to harvesting. More than 60 species of insects and mites have been reported to cause damage to the castor crop and their related yield loss has been estimated to be about 40-89% [10-12]. The seed yield losses in castor due to insect pests varied with the season, the severity of the pest and the hybrid variety of the plant [13]. The sucking pests such as leafhoppers (Empoasca flavescens), whiteflies and thrips have been known to be the most important pests attacking castor resulting in excessive loss of grain yield [14]. 14-15% of yield loss caused by sucking pests was recorded in Guajarat in India [15]. The nymphs and adults of the leafhopper suck sap from leaves and characteristic symptoms of hopperburn appear owing to the toxigenic nature of leafhopper [16].

The Leafhopper (About the insect) (Empoasca flavescens Fabricius)

Taxonomy

Phylum - Arthropoda
Class - Insecta
Sub-Order - Hemiptera
Family - Homoptera
Genus - *Empoasca*
Species - *Flavescens*

Green leafhopper, *Empoasca flavescens* Fab., which appears as light green or greenish yellow nymphs and adults (Figure 1) is one of the severe sucking pests that suck sap from on and the under surface of leaves causing hopper burn. *Cicada flavescens*, as previously called, was first described by Fabricius in Germany in 1974 [17]. Later it was reported by other investigators as generally occurring throughout Europe and northern Africa on *Atriplex*, *Chenopodium*, *Clematis*, hop, potato, raspberry, sugar beet, and vines, and on many herbaceous plants and deciduous and coniferous trees [18]. This pest has been reported to be much injurious to young plants, sucking the juices to such an extent that the plants fade, curl and eventually die.

![Figure 1: An image of the leafhopper (Empoasca flavescens).](image1)

Currently, this pest is widely distributed in the whole of Palearctic regions, United States of America, East Africa, Brazil, Ceylon, India, Great Britain and China. In India, it is supposed major pest of tea in the North-Eastern parts and affects castor mostly in the Northern areas. It has been accused of producing a stunted growth on the plants attacked in India though there is not much work to prove that.

Leafhoppers also called jassids are small and less than ¼ inches in length as adults. The adults are small, wedge-shaped and pale green. The nymphs are yellowish green in color. They have a prolonged head with a smooth, flat, triangular structure with an antenna possessing the sensorial parts. The thorax is simple and abdomen is a narrowing posterior. There are two parallel rows of spines which extend all along the tibiae at the hind legs.

### The Life Cycle of the Insect

The females scratch the leaf tissues and young stems and lay the eggs inside the veins and midribs of the leaves. A female can lay 15 to 37 eggs with an oviposition period of five to seven days. The egg hatches into nymph within 6 to 13 days (Figure 2), depending on the temperature. Compared to winter, the period of hatching in summer is longer. The nymph undergoes five instars and becomes adult in 8 to 22 days. The complete life cycle lasts for about 19 to 42 days. The average longevity of male adult is 9 days, whereas the female lives for 17 days. However, it has been recorded that an adult leafhopper may live up to 102 days. The insect remains active throughout the year, but maximum population growth occurs during November to January, that is mostly within the winter season. The life cycle of the leafhopper is described below in figure 2 from http://www.yourarticlelibrary.com/zooology/tea-green-fly-empoasca-flavescens-distribution-life-cycle-and-control/24048 [19].

![Figure 2: The life cycle of the leafhopper.](image2)

Although initially considered to be a minor or occasionally serious pest of tea, *Empoasca flavescens* has now been established as a regular and serious pest in tea plantations of sub-Himalayan North Bengal in India [20]. The leafhopper is also considered as a severe pest of castor, tea, okra, mulberry and many other crops [3,20-22].

### Hopperburn or Rim Blight

Nymphs and adults of *E. flavescens* damage the plant by sucking the sap of young leaves and tender shoots.ATTACKED LEAVES BECOME DRY, UNEVEN, CURLS DOWNWARD IN THE SHAPE OF AN INVERTED BOAT AND THEIR MARGINS TURN BROWN. This characteristic symptom is known as ‘Rim Blight’ or ‘Hopperburn’ (Figure 3).

The ‘hopperburn’ and other symptoms are caused mainly by interference with the translocation of food materials and water due to the physical plugging of the xylem and the destruction of the phloem cell [23].

![Figure 3: Image showing a castor leaf exhibiting the hopperburn symptom.](image3)

### Influence of Weather on the Incidence of Leafhopper

In an experiment by Patel et al., in analyzing the population dynamics of sucking pests with relation to the weather conditions, it was observed that the population of leafhopper increases as
temperature and evening relative humidity decreases (Figure 4) [14]. This is to say that an increase in bright sunshine hours and morning relative humidity has a positive effect on the population.

These observations in the experiment above confirm work done by Akashe et al., Jayaraj and Basheer, Jayraj and APR castor [27-29].

The activity and multiplication of the leafhopper is enhanced in the cold and humid weather of the winter season. Mounica et al., also experimented in 2018 and indicated that the correlation studies on leafhopper population with abiotic factors showed that maximum temperature, minimum temperature, rainfall, number of rainy days and evaporation were negatively correlated but relative humidity and sunshine hours were positively correlated with leafhopper population [30-32].

Too much rain or dry weather is not favorable for the development of the insect [33,34]. *Empoasca* is most damaging during the period between the dry and rainy seasons [35].

A leafhopper population on castor had a significant positive correlation with the maximum temperature and a significant negative correlation with the morning Relative Humidity (RH) in an experiment conducted by Gaur [36]. Their findings conform to the reports of Jayasimha et al., [21] who reported that leafhopper population on okra exhibited positive correlation with the maximum temperature and negative correlation with RH. Srinivasan et al., also had similar observations in okra whereby within the environmental factors maximum temperature had a positive correlation with the density of leafhopper present [22].

**Waxy Bloom Presence in Castor**

Morphological characters of host plant serve as a non-preference mechanism for feeding and oviposition by insects [37]. Among the different morphological attributes, bloom character has been reported to be the most important in imparting resistance against the sucking pests [38]. Presence of wax bloom on the surface of plant parts could act as barriers to feeding by phytophagous insects [32]. The bloom character of castor is the presence of a wax coating on the plant (Figure 6), wholly or partially. Castor plants with wax coating on all parts of the plant are classified as triple bloom, the ones with bloom on the stem, fruits, on the lower (dorsal) side of the leaf, but not the upper surface (ventral) of the leaf are called double bloom and the ones with the wax coating on only the stem and not the leaves or fruits are described as single bloom. Studies have proven that the higher the bloom, the higher the resistance to pests [39,40]. Castor varieties with heavy, waxy bloom are more resistant to leaflhoppers than bloomless types [41,42]. In Palem, Andhra Pradesh (India), castor plants with green stem and triple bloom were utterly free from leaflhoppers [13]. No-bloom and single-bloom types are reported to be less resistant to leaflhopper than double and triple-bloom types in castor [43-45].

Among 28 castor genotypes screened against leaflhopper by Mounica et al., in 2018, castor cultivars, GCH-7, PCH-254 and SKI-336 had the lowest leaflhopper population and hopper burn scores while the genotypes DPC-9, DCH-177 recorded the highest leaflhopper population with higher hopper burn scores [32]. This could be supported by the fact that GCH-7, PCH-254 and SKI-336 were triple bloom genotypes imparting resistance to the leaflhopper by antixenotic mechanism while DPC-9, DCH-177 and PCH-111 were zero and single bloom genotypes respectively with no wax bloom on their leaf lamina making them susceptible to the leaflhopper. In a similar experiment by, among the eight genotypes of castor experimented on, DCH-177 (single bloom) and DPC-9 were more preferred by the
pests, while GCH-4 (triple bloom) and PCH-111 were least preferred [46]. The genotypes with zero and single bloom were susceptible to leafhopper and thrips. None of the genotypes with double and triple bloom character recorded high infestation of leafhopper and thrips. This research confirms most work done by earlier cited in this review. The bloom of castor is an essential trait in pest resistance (Figure 7).

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Sakthivel et al., juxtaposed the effects of the commonly used chemical dichlorvos (DDVP-76EC) to some botanicals against leafhopper Empoasca flavescens F. infesting mulberry as well as their bio-safety to natural enemies (Table 1) [51]. Among the botanicals, a single application of neem oil (3%), FORS (2%) and Pongamia oil (3%) recorded 48.73, 46.88 and 42.49% reduction in leafhopper population respectively, whereas the NSKE (5%) exhibited least among all (33.59% at 1DAS).

The synergistic effect of neem oil and FORS recorded the best, 72.64% reduction followed by Pongamia oil + FORS (62.81%) and neem oil + Pongamia oil (60.16%). Though dichlorvos proved active than all treatments (88.57% reduction), the chemical also eliminated more than 90% population of predatory Coccinellids and spiders, but the botanicals found relatively safer. Hence, the combination of neem oil (3%) with fish oil rosin soap (2%) could be used as an alternate to dichlorvos to manage leafhopper menace in mulberry as well as to conserve the natural enemies.

Anjani et al., stated that although insecticide application is effective in controlling leafhoppers, the length of effective protection varies with an additional requirement of foliar insecticide sprays to control the pest, which eventually increases the cost of production [52].

Intercropping as a Control Measure

To control pests, farmers often use insecticides that are costly and detrimental to the environment. However, intercropping is an alternative pest management strategy, which can reduce herbivorous pests by making the host-plants difficult to locate, or by increasing the effectiveness of the natural enemies [53]. Intercropping is an essential cultural practice in pest management which is based on the principle of reducing insect pests by increasing the diversity of an ecosystem [54]. Most studies indicated that diversification practices such as intercropping in pigeon pea and other crops are beneficial because these practices reduce pest damage [55,56]. The excessive branching property of castor gives a unique plant structure and makes it easy to manipulate the environment and intercrop castor with different crops for a potential reduction in the incidence of insect pests [9].

It is quite difficult for farmers who solely rely on rain-fed agriculture and without much financial support to adopt capital-intensive measures in plant protection. In this regard, intercropping becomes the most likely method to be chosen. That is why there is a strong need to develop pest management practices that are less expensive for resource-poor farmers. Hence, there is a significant need to develop a system that is diverse and less prone to pests and diseases.

Rao et al., in 2012, experimented on an intercropping system for controlling pests. From their experiment, it was seen that there was a diversity created by introducing cluster bean, cowpea, black gram, or groundnut as intercrops in castor which resulted in a buildup of natural enemies (Microplitis, coccinellids and spiders) of the major pests of castor [9]. Furthermore, suitable conditions for the growth of the pests were reduced.

As a result of the buildup of natural enemies, there was much less pest incidence and damage in castor intercropped with cluster bean, cowpea and groundnut compared to the castor monocrop. These intercropping systems by Rao et al., proved much more efficient with

Chemical Control of Empoasca flavescens and Its Side Effects

Dichlorvos (DDVP), which has been banned since the 1980s in China, is a well-known chemical used in the combat of pests of mulberry like Empoasca flavescens [47-49]. The chemical, however, has been recorded to be highly toxic to the natural enemies of insect pests and aids the elimination of their entire population [50].

Recently an outbreak on mulberry by some sucking pests revealed that the most of the pests had developed resistance to the dichlorvos and apparent destruction of the natural enemies by the chemical [51].
regards to equivalent yield and land equivalent ratio [9]. Economic analysis also showed that these intercropping systems were more profitable than planting castor alone. In conclusion, these systems, aside protecting the plant from pest attacks, resulted in high yields of all intercrops and higher economic returns.

In another experiment by Faselt (2014) to control the potato leafhopper (a key pest in alfalfa) in the Northeast United States, two crop treatments (alfalfa monocrop, alfalfa intercropped with orchard grass) were crossed with three predator treatments (no predator control, Nabis americoferus and Coleomegilla maculata) [53]. There was no effect of C. maculata on leafhopper abundance. By the end of the first week, N. americoferus significantly reduced leafhopper abundance, but only in the intercropped alfalfa. These results indicated that intercropping alfalfa with orchard grass enhanced the biological control of the potato leafhopper by N. americoferus.

In 2015, Rosmana et al., conducted an experiment on how intercropping can reduce the infestation of green leafhopper (Nephotettix viridescens) by the potato leafhopper (Empoasca flavescens) [57] intercropped tea with non-host plant Catsia tora (Fabaceae) as a cover crop. The intercropping of C. tora in the tea field markedly reduced the E. vitis population levels and promoted an increase in the natural enemies of this pest, such as spiders, coccinelids and lacewings.

In 2013, Rosmana et al., conducted an experiment on how intercropping can reduce the infestation of green leafhopper (Nephotettix viridescens) Distant and white stem borers (Scirpophaga innotata Wlk.) on rice varieties in Indonesia [58]. The results of the experiment showed a lower incidence of the pests on rice in the intercropped systems than the monocropped plants. This indicated that intercropping had a positive effect on pest infestation and at the same time conserving farm traditional varieties that may be important for sustainable production, which deserves further experiment in castor.

Resistant Cultivars

Identification and use of resistant genotypes in breeding programme for the development of resistant varieties against the insect pests and their use in IPM (Integrated Pest Management) programmes is the most economical approach and would be inexpensive in long run because it minimizes the number of insecticides application, lessens the expenses involved in plant protection and conserves the natural enemies besides preserving the environmental safety [32]. Host-plant resistance is the most reliable, economical and eco-friendly measure to control leafhopper [52]. Seventeen Indian collections have been identified as stable sources of resistance against leafhopper [38,59].

In an experiment conducted at the Guangdong Ocean University, China (yet to be published), during winter, a whole farm was infested with the leafhopper pest. Many materials were susceptible but Heyuan 1 and Heyuan 2, wild materials collected from the Guangdong Province, remained resistant. In that experiment, they were observed as very resistant and subsequent tests supported this finding.

It has however been seen that most of the plants resistant to this particular kind of pest have the waxy bloom. The use of resistant varieties in the IPM programmes is economical and eventually inexpensive as it reduces the application of insecticides, lessens the expenses involved in plant protection and conserves the natural enemies while keeping the safety of the environment [40]. The resistance to leafhopper is heritable and can be used in pest resistance breeding (Figure 8).

Conclusion

A healthy castor plant is of much importance in castor production. Many industries rely on castor as the raw material. Thus the demand for castor keeps rising. To meet the rising demands, every hindrance to the optimum production of castor must be dealt with accordingly. Empoasca flavescens is an obstacle to the growth of the castor plant and adversely affecting the secondary consumers of castor like the eri silkworm.

Much research has been done on these pests, and favorable methods and conditions have been assessed. Since most methods have proved beneficial, it is expedient that measures that are less harmful to the natural enemies and consumers are employed. However, research regarding the castor plant is limited, and castor research scientists are entreated to help in the fight against the leafhopper.
Figure 8: Image showing the resistance segregation in an F2 population derived from the resistance-susceptible combination in Guangdong Ocean University (China).

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