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Papilio demoleus– A potential pest of citrus plant

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Abstract
The lime butterfly (*Papilio demoleus*) is one of the most commercially important pests in the developing citrus industries in India along with different regions of the world, causing nursery destruction, but it is typically perceived to be a minor pest of mature plants. Rutaceae family members for the invasive outer Australian subspecies and Fabaceae family members for the Australian subspecies are its primary natural host plants. The abundance of eaten food is greatest on the same varieties of *Citrus aurantium* and *Citrus limon*. According to the previous research report, the amount of damage is observed to range from 21-54% on newly growing plants to 8-19% on nursery plants and 3-11% on tree branches. 4-6 larvae can defoliate citrus plant of 1-2 ft height during their development and can also be responsible for dropping off trees. Pyrethroid, deltamethrin endosulfan, carbaryl, dichlorvos chemical pesticides are strongly effective in the management of larvae of *Papilio demoleus*. Several biological control methods and mechanical methods are used to control the *Papilio demoleus* through integrated pest management techniques, which is the best alternative to chemical pesticides.

Keywords: *Papilio demoleus*, lemon butterfly, larvae, defoliate, citrus plant

Introduction

Citrus is among the world's major economic crop plants and is planted extensively throughout the tropical and subtropical areas. It is cultivated in over 52 countries worldwide. The citrus fruit, after mango and banana, is the third biggest in the world. Sweet orange produced over 204.1 lakh hectares in the Andhra Pradesh and Telangana states with both a yearly output of 30.61 lakh tonnes of fruit and a yield of 15 MT/Ha (Mistry, Singh and Gandhi, 2013) [29]. In India, more than 250 species of insect pests have been found targeting and spoiling various citrus tree and nurseries but 165 of these species are economically important insect pests which causing up to 30 per cent yield loss by infesting citrus crop (Pruthi and Mani, 1945) [34]. In general, numerous insect pests cause significant economic losses to citrus species and nurseries, including some important citrus plants pest species like *P. demoleus Linnaeus*, *Diaphorina citri Kuwayama* (citrus psylla), *Dialeurodes citri Ashmead* (citrus whitefly), *Aonidiella aurantii Maskell*, *Phylloncistis citrella Stainton* (citrus leaf miner) *and Papilio polytes Linnaeus* (citrus caterpillar) (Guerrero *et al*., 2004) [12]. Most of the insects act like plant pests, which sucking the plant juices and affecting trunks, roots, leaves, fruits parts of plants and finally the yellowing leaves of plants becoming pale in appearance, resulting in the falling off trees and causing substantial yield losses. High population and the extreme invasion of economically important insect pests lead to retarding of plant growth and decrease the fruit production and finally allow the trees to defoliate (Dunn, 1999) [9].

The genus *Papilio* is found in several regions of the world, like India, Australia, New Guinea, Pakistan, Japan, China, Indonesia, Iran, Formosa (Ganguli & Ghosh, 1967) [11]. Butterflies adapt rapidly to climatic changes, strong vision, odour behaviours, and this agricultural ecosystem are the favourable habitat for their successful survival and also useful for pollination of plants (Asokan, 1997) [2]. For many butterflies, the most favourable climatic conditions are 25-26°C of an average temperature, 80-100% relative humidity, and 50 mm of daily rainfall (Mathew, 2001) [24].

The lemon butterfly, *Papilio demoleus Linnaeus*, popularly referred to as the lime or citrus swallowtails, is one of the most common and frequent pests in nurseries, youthful seedlings, as well as on fresh flushes of adult trees in Asia even amongst the numerous insect pests that target citrus. It is one of the major defoliating pests leading substantial harm to citrus leaves during the development of the plant. *Papilio demoleus* caterpillar feeds on mild and semi-mature leaves, causing further damage to nursery plants as well as to mature trees. Only the midrib sections of the leaves remain left over. The larvae consume rapaciously and destroy nurseries and growing plants severely. Extreme infestation of citrus leaves by *Papilio demoleus* larvae leads to plant defoliation and also lead to retarding growth of plants and reduces the product yields (Vattikonda and Sangam, 2016) [47]. The dual position of the lemon butterfly, *Papilio demoleus* pest, and pollinator and growth relies on the accessibility of the host plants (Pathak & Rizvi, 2003) [20]. Different types of plant species belonging to the family Rutaceae are reported as the host plants of *P. demoleus*. This butterfly has natural frequency ability, allowing it to survive and successfully invade in a wide range of climatic circumstances. *P. demoleus* is known as a major citrus plant pest in Bangladesh and has the capacity for massive population growth in a favourable climate (Rafi *et al.*, 1999) [36]. Proper control of *Papilio demoleus* may theoretically provide a considerable commercial influence on the development and quantity for citrus crops. Through its growth, a single caterpillar can eat 9 foliage (Badawi,1981) [3] and four to six larvae of *P. demoleus* can defoliate a citrus tree about 1-2 ft tall (Yunus and Munir, 1972) [51]. This poses a major challenge to the rising local citrus industry.

Status and Habitat

The abundance of *Papilio demoleus* shows the resilience of the butterfly and its adaptability to different environments. It is widely distributed in the ground, fallow lands, and gardens of savannahs, evergreen forests, and semi-evergreen forests. This species is present in the tropical and subtropical areas of southern Asia, varying from India, Nepal, southern China, Taiwan, and Japan to Saudi Arabia, Iran, and the Middle East. It is typically located on the plains, but it may be observed on the hills of peninsular India and in the Himalayas at up to 7,000 feet (2,100 m) (Kunte and Krushnamegh, 2000) [16]. Meenakshi *et al.* (2019) [25] reported the peak population of *P. demoleus* during the months of April and July to October.

Classification

- Domain: Eukaryota
- Kingdom: Metazoa
- Phylum: Arthropoda
- Class: Insecta
- Order: Lepidoptera
- Family: Papilionidae
- Genus*: Papilio*
- Species: *demoleus*

Fig 1: *Papilio demoleus* (Adult)

Life cycle (Fig. 2)

Papilio demoleus' life cycle includes multiple stages, i.e., egg, larva, pupa, and adult. In fifteen days (summer) and nearly forty seven days (winter), its life cycle is accomplished. The life expectancy of an adult male is approximately 135 days, whereas even of a female is approximately 145 days. The length of their stages of life varies with the place and can be eight generations each year (Samiksha, 2014) [39].

Developmental stages of lime swallowtail butterfly

Egg- After mating, the female adult lays eggs separately near the tip of the leaves of the host plant. The eggs are light yellowish, almost globular, approximately 1.5 mm, wide at the base, and smooth. In order to develop, the eggs take three to four days, and blacken as the larva grows inside, and after 5 to 9 days they hatch. A single female lays 15 to 22 eggs on the surface of tender leaves and also on thin twigs (Khan, Molla and Rahman, 2019) [23]. The incubation period of egg is influenced by temperature and relative humidity of environment, usually an average incubation period of egg is 2.75–3 days (Jahnavi *et al.*, 2018; Rao, 2015) [15, 37].

Larva

Five instars larvae are observed during the time of the larval stage. The first instar is black with just a blackhead, with small spongy spines on two sub-dorsal rows. A blackish-brown, shiny head capsule has second, third, and fourth instars. The anterior, middle and posterior sections provide broad pale yellow spinal lines, providing a camouflage to resemble bird dropping to the larvae. The fifth instars are a cylindrical tube formed and anteriorly curved. The first through fifth instars had an average period of 2.20, 2.15, 2.35, 2.25, and 2.35 days, respectively (Jahnavi, Rao and Sarada, 2018) [15].

Pupa

The pupae are flabby, tough, and around 30 mm long. These are bound only to host plant's bold branches or nearby point twigs. The pupa is primarily green but at the time of adult emergence, it turned pale brown to brown (Lewis, 2009) [7]. The pupa gets darker following 8 days of development as the formation inside and then pupal case finally comes to an end. The next day, mature butterfly develops from the pupal case. The average period of the pupal stage is 13.50 days, (Khan *et al.*, 2019) [23], and the appearance of pupal stage is sensitive to temperature. During the summer (mean temperature of 30 ± 4°C), the period of the pupal stage is an average of 10.8 ± 1.4 days. In contrast, at the temperature of 25.5–27°C, the period of pupal stage is extended by 6.8 times (around 73 days) (Islam *et al.*, 2019) [14].

Adult (Fig. 1)

Adult butterflies are big and pretty with a large spread of wings. The anterior part of the forewing is black with a series of irregular yellow spots on the outer wing margin. The body is coated with fur which is black and yellow in colour. Their hind wings are curved; the fore wings are trigonal in design. The wings, with yellow markings, appeared black. The adult females survived longer than that of the male ones. The average size of male butterfly measured 24.00, 4.00, and 2.50 mm, respectively, whereas the female butterfly size measured 25.75, 5.75 and 3.00 mm, respectively (Resham *et al.*, 1986; Maheswarababu, 1988) [38, 19].

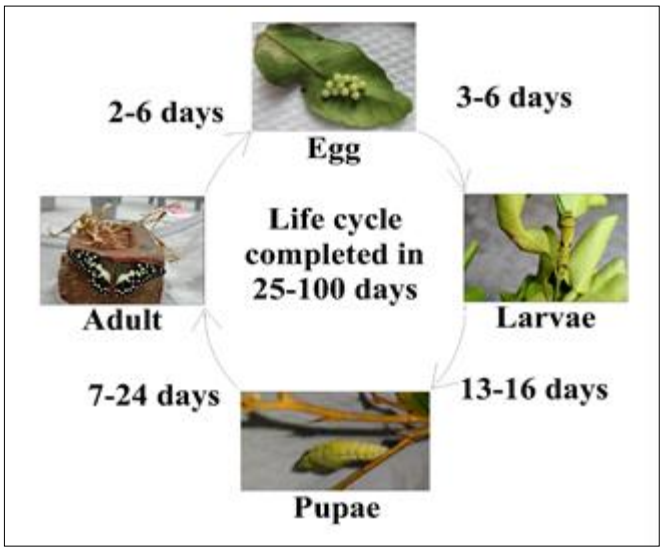

Fig 2: Life cycle of *Papilio demoleus*

Host plants

The preference of the host plant by the herbivorous insect requires not only the selection of the correct plant species but also the selection of that plant species which is suitable for the consumption, survival, and growth of immature stages. Attack of the insect pests on the growth stage of plant and at the time of fruit formation stage reduces the quality and productivity of the fruits from those trees. Among the species of the Papilionidae family, the citrus butterfly is the most economically important pest whose larval stage induced significant harm by consuming enormous quantities of the leaves of citrus plant of family Rutaceae, Rhamnaceae, Anacordiaceae, Apiaceae, Sapindaceae and family Fabaceae, with particular selection as well wild species and cultivated citrus species during the subsequent phase of its growth (Patel *et al*., 2017) [31].

Yunus and Munir (1972) [51] have reported that the leaves of at least18 citrus species are eaten by the *Papilio demoleus* larvae, while they also noted the variations in the food intake frequency, growth time, and death rates. *Papilio demoleus* has the fastest growth period and highest food intake on *Citrus aurantium* (sour orange) and *Citrus limon* (lemon), assisted with *Citrus* and *grandis* (shaddock) *Citrus sinensis* (sweet orange). The most preferred and the most suitable host plant for the development of *Papilio demolues* is lemon (Mahesh *et al*., 2003) [20].

In Saudi Arabia and Iran, and also in India, it is reported that *P. demoleus* is identified as plague of citrus grove (Badawi, 1981) [3]. In Andra Pradesh, Narayanamma *et al.* (2001) [27] observed up to 83% infestations of mature grove plants, and Thakare and Borle (1974) [50] have also observed that the infestation by *Papilio demoleus* is enough to make skeletonised whole citrus garden.

Host plants of *Papilio demoleus* mainly belong to the following two families:-

a. Rutaceae family

In Asia, the larval food plants of *P. demoleus* are mainly from the family Rutaceae. It is known to feed on basically all species and varieties of citrus plants such as *Glycosmis pentaphylla* (Jamaica mandarin orange), *Ruta graveolens* (Rue, common rue, herb of Grace), *Aegle marmelos* (Bael fruit), *Murraya koenigii* (Indian curry-leaf tree) *Chloroxylon swietenia* (East Indian satinwood) (Lewis, 2009) [7]. *Papilio demoleus'* host preference occurs within the range of sweet orange > curry leaf > acid lime (Lakshminarayanamma, 2001) [17]. The greatest food consumptions are observed on *Citrus aurantium* (sour orange) and *Citrus limon* (lemon), followed by *Citrus grandis* (shaddock) and *Citrus sinensis* (sweet orange). According to previous study, the greatest numbers of eggs are laid by adult females on *Citrus limon*, followed by *Citrus grandis*, *Citrus aurantifolia*, *Murraya koenigii* and *Aegle marmelos* (Patel *et al*., 2017) [31].

b. Fabaceae family

The Australian and New Guinean population group feed on the host plant of family Fabaceae. They feed on species of *Cullen*: *Cullen australasicum* (tall verbena), *Cullen badocanum, Cullen balsamicum, Cullen cinereum, Cullen patens* (spreading scurf-pea, native verbena), *Cullen pustulatum, Cullen tenax* (toughscurf-pea, emu-foot, emu grass), and *Cullen leucanthum*. The larva of *Papilio demoleus* also feed on *Soralea pinnata* (fountain bush), and *Microcitrus australis* (Australian round-lime, Australian lime) (Lewis, 2009) [7].

Control of *Papilio demoleus*

Recently, lemon butterfly is being controlled through different advanced pest management strategies. Depending on the level of infestation, several prevention methods are used, such as if there is a low- level infestation, it can be controlled by the handpicking method (Cherian, 1942) [6]. But if there is a high level of infestation, then it can be controlled only by applying chemical substances and plants extract (Radke and Kandalkar, 1986) [35]. For this several pesticides have been investigated and proven successful as well. But the constant use of pesticide is causing adverse effects for human health and non-target species as well as they are also responsible for ecological damage. Pesticides should always be used in a lawful manner, consistent with the product's label. Therefore, Bio-agents, botanical compounds also should be used to control pests.

Synthetic control

Chemical insecticides

Chemical pesticides are utilized on massive scale for pests' control in agriculture all over the world. In many countries,

the utilization of chemical pesticides has been continuously increasing, mainly in developing countries. The legislation of chemical pesticides is also rising internationally leading to issues about their toxicity and environmental protection. Additionally, they can be toxic to instinctive predators of pest species (Hussain & Zahid, 2016) [13].

Radke and Kandalkar (1986) [35] reported the control of *Papilio demoleus* with permethrin, cypermethrin and fenvalerate at 0.01%, decamethrin at 0.0025%, monocrotophos and oxydemeton-methyl at 0.05% and formothion at 0.04% in a citrus nursery in Maharashtra, India. The larvae of *Papilio demoleus* exhibit almost 100 % mortality after treatment with these chemical compounds. In comparison, the treatment with organophosphates oxydemeton-methyl and formothion caused 76% and 70% mortality, respectively. Novaluron and emamectin benzoate pesticides also have ovicidal activity with 95% and 85% mortality, respectively; against *Papilio demoleus* eggs (Murthy *et al*., 2009) [26]. Nikhat *et al.* (2010) [28] also reported that the pyrethroid cypermethrin are highly toxic to *Papilio demoleus* larvae.

The effectiveness of 5 insecticides: endosulfan, carbaryl, dichlorvos, hexachlorocyclohexane, and parathion are evaluated in field testing against *Papilio demoleus* on orange, in India. All five chemical substances are efficient in reducing the infestation of citrus leaves by *Papilio demoleus* larvae. But out of these 5 insecticides dichlorvos, carbaryl, and parathion are most potent insecticides (Singh and Kumar, 1986) [42]. Quinalphos and Chlorpyriphos caused significant mortality in the population of citrus butterfly larvae (Pawandeep, Singh, and Singh 2020) [32].

Biological control

Biochemical pesticides

Generally, biochemical pesticides are based on plant-derived compounds/ extracts and essential oils. These prevent the resistance development against the insect pests (Batish *et al*., 2008) [4]. These biopesticide are less toxic and safer to environment, biodegradable in nature and also alternative to conventional synthetic pesticides. These pesticides involve a mixture of naturally occurring substances obtained from plants and essential oil (Chauhan & Srivastava, 2017) [5]. Popularity has increased of botanical pesticides throughout world. Biochemical pesticides include botanicals pesticides, insect growth regulators, and insect pheromones (Shadia, 2011) [41].

Another approach is to spray distasteful botanical pesticides onto the plant leaves with the aim of inhibiting *Papilio demoleus* larvae from eating on them. Betulinic acid (isolated from the bark of *Ziziphus jujuba* plant) showed a significant (94.04%) mortality at 200ppm concentration for the management of *Papilio demoleus* larvae. And along with this, the antifeeding activity of Forskolin (a plant extract, which was segregated from the root of *Coleus forskohlii*) is observed against all development stages of *Papilio demoleus.* This Forskolin extract is a good antifertility product for the control of *Papilio demoleus*. Solasodine demonstrated strong antifeedant activity to the fourth instars larva of *Papilio demoleus* (Vattikonda and Sangam, 2014) [46]. Andrographolide (a plant extract, which was segregated from the stem and leaves of the *Andrographis paniculata*) is the most effective inhibitor of oocyte growth of *Papilio demoleus (*Vattikond and Sangam, 2018) [48].

Solunk and Deshpande (1991) [45] reported the lime swallowtail butterfly *Papilio demoleus* larvae when nourished with citrus leaves plunged in aqueous extract of *Ficus religiosa, Parthenium hysterophonus, Azadirachta indica, Caliothropis gigantea or Datura stramonium, Parthenium hyterophorus* then these extracts caused 52.8% of the mean mortality of *Papilio demoleus* after 72 hrs. The essential oils from *Cymbopogan flexuosus, Jatropha curcas, Cymbopogan nardus, Eucalyptus citriodora, Lippia alba, Ocimum tenuiflorum, Lavandula angustifolia, Foeniculum vulgare, Mentha arvensis, Cymbopogan martinii, Geranium* species reduced weight gain of larvae and causes the larval mortality (Chauhan & Srivastava, 2017) [5]. *Bacillus thuringiensis* is the most commonly used microorganisms which is highly effective against most Lepidopteran larvae as well as it potentially disrupts the growth and development of *Papilio demoleus* and also decrease their fecundity. *Bacillus thuringiensis* var. kuristaki Berliner used at 0.5 mg/ml concentrations for the control of *Papilio demoleus* and observed 100% mortality or a highest level of control of *Papilio demoleus* (Fawzi *et al.,* 2007) [10].

Natural enemies

There are some insect species that hold the potential of biological control agents; some of these species are specific as their parasitism or parasitoidism of *P. demoleus*. Natural enemies perform a significant role in reducing hazardous insect pest species and they will be more able to persist if sustainable and environmentally friendly bio-pesticides are introduced. *Telenomus sp.* and *Trichogramma chilonis*, *Ooencyrtus papilionis* are found as egg parasitoids to the lemon butterfly *Papilio demoleus* (Singh and Singh, 1998) [44]. The exploitation of *Papilio demoleus* larval parasitoids is associated positively with rainfall and moisture content, and adversely with temperature. Some *Papilio demoleus* caterpillars are parasitized by wasps that lay hundreds of eggs inside them. The caterpillar is eaten from the inside by the parasitic wasp larvae. The crucial organs are primarily excluded, but still, the essential organs are eaten at the moment that larvae are able to pupation. The parasitoids come out from the pupa shortly just after the caterpillar pupates, thereby destroying it. As predators of the citrus butterfly *Papilio demoleus*, numerous species of *Coccinellids, Vespids* and praying mantids are described. *Distatrix papilionis* is a probable parasitoid braconid larva of citrus butterfly that induces up to 73% predation in India (Mani and Krishnamoorthy, 2000) [21]. There are three parasitoids recognised as to parasitize *Papilio demoleus* larvae in India. They are *Apanteles papilionis, Apanteles sp. and Bracon hebetor. Melalophacharops sp., Braconid, Apanteles flavipes,* and *Ichneumonid* are the prevalent larval parasitic insects and *Chalcid Pteromalus puparium,* and an *Ichneumonid Holcojoppa coelopyga* are the dominant pupal parasitoids that may be used scientifically for successful pest management. The significant lethality agents in the eggs and early larvae are spiders, while *S. dichotomus and Podisus sp*. are important in the younger larvae. The effective parasitic insects for *Papilio demoleus* eggs and pupa are *Ooencyrtus papilioni* and *Pteromalus puparum*, respectively (Suwarno, 2012) [49]. Badawii (1981) [3] has reported pupal fatalities due to the implementation of Bacillus insertion. Pupae parasitized by the wasp *Pteromalus puparum* are reported by Ackery *et al.* (1995) [1]. Lewis, (2018) [18] has reported *Erycia nymphalidophaga*

tachinid fly (Diptera: Tachinidae) parasitizing *Papilio demoleus* larvae. The *Cantheconidea furcellata* and *Proxys punctulatus* parasitic, *Pentanomide* bugs are also recorded on *Papilio demoleus* (Lewis, 2018) [18].

Mechanical Control

Hand operated elimination of eggs, larvae and pupae of *Papilio demoleus* is a potent natural method in nurseries and young citrus plantations (Doharey and Butani, 1985) [8]. Hand-picking of caterpillar may be taken out in nurseries or lots of small citrus trees, but this activity is labor exhaustive if an infestation is heavy (Schmutterer, 1969) [40].

Conclusion

Papilio demoleus is the most prevailing and harmful insect pest in aspects of its foliage-destructive efficiency around the world. The larvae consume rapaciously and do major harm to nurseries, early plants, and they are also able to defoliate the entire plants, as a consequence of which this pest is a perceived danger to the citrus fruit crops. Young trees recorded in Andra Pradesh are up to 83% defoliated. *Papilio demoleus* originates primarily from Madagascar and is native to India, spreading from Iran in the west to Japan and Australia in the east, through India and southern China. The most optimal duration of its development is July to December. Its versatility to different climatic situations, spanning from tropics to subtropics and areas of temperate regions, is the key explanation for its rapid expansion and, equally, the pest often changes its feeding habits depending on crop yields. *Papilio demoleus* sustain on Fabaceae plants in Australia and out of Australia on Rutaceae plants. *Papilio demoleus's* host choice occurs in the sequence of sweet orange > curry leaf > acid lime. It was observed that a lot of extent for advanced pest control including bioactive strategies in lemon butterfly management, which is a chemical alternative. Recent research offers too many alternatives for bio-control of both bio agents and bio-pesticides, but there is no reason to suggest that there should be an endless quest for even more effective bio-control substances. There have been only a handful of the botanicals screened against this pest. Therefore, any further analysis to focus on the use of botanicals. Another factor that stays untouched is the rises of chemical pheromones or adult colour-directed entrap that have enthralled in the coming years. There is growing interest/awareness among the citrus growers for adoption of latest technologies for commercial cultivation of citrus.

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