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Specific Determination and Evaluation of the Damage of the Tamarind Fruit Borer (*Tamarindus indica* L.) in Villaflores, Chiapas, Mexico

Fabiola Aguilar Castillo[1], Carlos Joaquin Morales Morales[1], Jesus Romero Napoles[2], Eduardo Aguilar Astudillo[1, *], Jorge Alejandro Espinosa Moreno[1]

[1]Faculty of Agronomic Sciences, Autonomous University of Chiapas, Villaflores, Mexico
[2]Phytosanity, Postgraduate College, Montecillo Campus, Texcoco, Mexico

Email address:
guerr2012@hotmail.es (E. A. Astudillo), eduardo.aguilar@unach.mx (E. A. Astudillo), oly_2345@hotmail.com (F. A. Castillo), carlosjoaquinm@yahoo.com.mx (C. J. M. Morales), jnapoles@colpos.mx (J. R. Napoles), moreno@unach.mx (J. A. E. Moreno)
[*]Corresponding author

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Abstract: The cultivation of tamarind in the producing regions of Mexico and in backyard trees is affected by insects that feed on the fruit, causing losses in yield and quality; Among the insects is the tamarind fruit and seed borer. The objective of this work was to specifically determine and evaluate the damage caused by the fruit borer. Samples were carried out in 10 tamarind trees, five trees in a backyard and five trees in a plantation established in the Álvaro Obregon community of the municipality of Villaflores, Chiapas. The collections were made directly and through the fruits with signs of the presence of the borer. For the evaluation of the damage, the total fruits of 10 trees were collected where the total number of fruits and the number of fruits infested by the borer were quantified and in this way the percentage of damaged fruits was calculated. The tamarind fruit borer was determined as the Caryedon gonagra (Coleoptera: Bruchidae) species, originally from the old world Africa, of the monophyletic group, because which is reported for the states of Colima and Morelos, this report is considered the first record for the State of Chiapas. Adults are 4 to 6 mm in length, and are characterized by presenting the prothorax in a subrectangular shape, the body slightly elongated, with golden pubescence with black or light brown spots, sometimes with small dark brown spots scattered throughout the body. differing especially in the elytra and hind legs. In the field, the initial infestation of the tamarind fruit borer in the state of Chiapas occurs at the beginning of November when the female oviposits the eggs in the middle of the tree on the tamarind pods, regardless of size. and fruit development. The damage begins when the larva penetrates the pod reaching the seed of the fruit, until reaching the adult stage, affecting 7,108 fruits, which is equivalent to 26,400 g, which represents 35.76% of the total production per tree. Regarding the weight of the tamarind fruit by C. gonagra, there is a reduction in weight of 9.341 g tree-1, that is, it affects 11.24% the production of tamarind per tree.

Keywords: Insect, Tamarin, Hurt, Evaluation

1. Introduction

Tamarind (*Tamarindus indica* L.) is an easily adapted crop with wide distribution in the national territory, with the characteristic of being a plant with resistance to drought; At a social level, it is considered of socio-economic importance since it represents an income alternative for rural producers in the region, dry trees are used as a source of fuel (firewood) and in agroforestry and silvopastoriles systems, as fodder for livestock, in the states of Oaxaca, Tabasco and Chiapas. In the family and commercial production of tamarind, the usable part is the fruits, especially the pulp that are used for the production of fresh waters, in addition, it is part of the Mexican gastronomy and industry due to its culinary qualities and product diversification such as: powder to prepare drinks, sweets, condiments, among others.

The tamarind, under the modality of backyard or areas of cultivation plantations, in 2018 the SIACON reported a planted area of 9,193.53 h; However, in some producing regions of Mexico, production is affected by insects that directly damage the fruits, causing losses in yield and pulp quality; One of the insects that seriously affects the tamarind fruit is the borer causing losses of up to 50% of the production, being the main limitation for the local marketing and export of the pulp [1]. In the state there are no studies related to insects associated with the cultivation of tamarind, especially insects that affect the growth, development and maturation of the fruit, such as the borer. Under this perspective, the present work was proposed in order to determine the species of insect and evaluate the damage it causes in the fruits of backyard tamarind trees in Villaflores, Chiapas.

2. Tamarind Tree

2.1. Origen y Distribución del Tamarindo

The tamarind tree was described for the first time by Carlos Linneo (1753), with the genus *Tamarinds* (Fabaceae), native to Africa and southern Asia [2, 3], it spread to the tropical and subtropical areas of the world [4] and is present in the American continent [5].

2.2. Características Morfológicas del Tamarindo

It is a tree of medium to large size, 10 to 25 m high, evergreen or sub-deciduous and with a rounded, scattered and dense crown, low branches, the trunk is short, thick and straight [2, 6], long-lived up to more than 200 years [7], leaves pale to dark green, alternate and paripinnate, 7 to 15 cm long, have 10 to 20 pairs of leaflets, sessile, obtuse, oblong and opposite, 1 to 2.5 cm long by 0.5 cm wide, the midrib is visible above and below [8, 9].

The flower buds of white, red or pink colors, with hermaphroditic flowers in clusters of 8 to 14 pale yellow flowers with red or orange veins, 2 to 2.5 and 5 to 10 cm in diameter and long [7], calyx with four sepals and five-petal corolla, three fertile stamens and a pistil [6, 9], cross-pollinating and self-pollinating [10], flowering occurs from March - April and in October [2]; in Mexico, it occurs from April to December [6] or from July to August [11].

The fruit is a pod, protruding, oblong, slightly curved and flattened, 7 to 20 cm long and 1 to 3 cm wide [7], light gray or brown epicarp [4], indehiscent [6], mature 10 months after flowering and remain on the tree until the next flowering period [12]. The pulp is soft, thick, blackish brown, bittersweet and with a high content of sugars and acids; with 1 to 12 seeds [6, 8]. The seeds are oval, compressed, smooth, with a lustrous brown teste, 1 cm long, with a pair of thick cotyledons, a small and straight radicle [6]. The tamarind tree supports long-term dry seasons and temperatures between -3 to 47°C, it is vulnerable to frost [8, 11], it adapts in rainfall ranges from 800 to 1500 mm per year, and soils with a pH of 6.5 to 7.5, from 40 to 600 meters above sea level [6, 9],

The tamarind is cultivated in 54 countries of the world; Thailand, Costa Rica, Mexico, Puerto Rico, Brazil, Guatemala, Belize and the United States are considered producing countries [13], the main producer is India, in 2018 it reached the production of 98,000 t of fruit [14], in 2019-2020 it exported 18,386.7 t [15]. In Mexico, tamarind is exploited under the backyard modality [4, 16], and in 12 states cultivated areas are reported, where Jalisco occupies the first place with 3,868 ha, followed by Guerrero and Colima, with 1,329 and 946.5 ha respectively. Total national production is equivalent to 38,612.9 t, with a value of 264,946.9 pesos [17].

2.3. Insects Associated with Tamarind

Tamarind production in Mexico is affected by the presence of pests, which affect the growth, development, flowering and fruiting of tamarind [1, 16, 18, 19]. The species *Perisopneumon tamarindus* (Green, 1908), *Drosicha stebbingi* Nath (1972), *Drosichiella tamarindus* Morrison (1927) (Margarodidae), *Nipaecoccus virdis* (Newstead, 1894) and *Planococcus lilacinus* (Cockerell, 1905) (Pseudococcida) have been observed. immature stages such as adults feed on the sap of the branches, flowers and fruit [18]. There are also *Aonidiella orientalis* (Newstead, 1894) and *Selenaspidus articulatus* (Morgan, 1889) (Diaspididae) [20], spot flies of the genera *Aeneolamia* Fennah 1949 and *Deois* Fennah 1949 (Cercopidae) [4], *Pteroma plagiophleps* Hampson, 1892 and *Eumeta crameri* Westwood 1854 (Psychidae), affecting young shoots [21, 22].

Virachola isocrates Fabricius, 1793 (Lycaenidae) *Paralipsa gularis* Zeller, 1877, *Phycita orthoclina* Meyrick, 1929, *Assara albicostalis* Walker, 1863 (Pyralidae) and *Cryptophlebia illepida* Butler, 1882 (Tortricidae) have been found in the fruits; [18, 23, 24] consider these species to be pests of economic importance. [25], reports the species *Sitophilus linearis* (Herbst & J. F. W., 1797) (Dryophthoridae) causing damage to the fruit; Aguilar et al. [19] indicates that the infestation of this species is continuous due to the availability of food and is considered a pest of economic importance [26, 27]. In Antioquia, Colombia, *Caryedon serratus* Oliver 1790 (Bruchidae), *S. linearis* and *Hypotenemus obscurus* Wood & Bright 1992 (Curculionidae) are reported affecting the fruit [28].

2.4. Family Bruchidae

The specimens of the Family Bruchidae present specific distinctive morphological characters, they are oval or suboval in shape, slightly cylindrical convex, some exhibit large bodies and are elongated, due to an adaptation to the type of fruits or seeds that they infest. The sizes range from 1 to 25 mm [29], they present dense pubescence throughout the body, and they adopt distinctive dispositions in the pronotum [30]. The weevils of the seeds belong to a monophyletic group, from the morphological and biological point of view, with unique distinctive morphological characteristics [31]. The head is trapezoidal, globose and widened in half; globose neck with head position and hypognant mouthpart [30, 32], large, globose and convex compound eyes; 11-segment antennae inserted between the ocular notch of filiform, serrated, pectinate, and nailed types, some species are characterized by having long antennae [33]. The thorax presents the convex proesternal, the proesternal epimeric fused to the proesternal epipleure, and the anterior cavity of the coxae closed posteriorly [32]. The prothorax of variable shape, in lateral view they are straight or arched, with the anterior part narrower than the posterior [34]. Short elytra and at rest cover the meso and metathorax, with a slightly convex and sometimes flattened disc; males suddenly show a narrowing in the posterior half and below the humerus [34]. The scutellum is rectangular with an incision in the posterior margin and the wings are functional and have a great dispersal capacity [32, 35, 36]. The coxae are oval-subglobose and small, occupying the posterior-basal part of the femur, which is elongated oblong, the rear legs have two developed carinae delimiting a groove where the internal margin of the tibia is housed, these carinae are simple in the first two pairs of legs, in the later ones they lack teeth or notches [29]. The legs are of taxonomic importance for the separation of subfamilies, tribes, genera, subgenera and species; the hind legs are longer and thicker than the middle and forelegs [30, 32], the tibia or femur may have small teeth or the last tarsomers may be slightly elongated [34-36]. The three pairs of legs consist of four visible joints, considered tetramers (4 - 4 - 4), however, they present the fourth joint with minimal development, welded to the base of the fifth joint, they are pentamers (5 - 5 - 5) or crypto-pentamer (30).

The abdomen is relatively short and convex, the last visible sternum forming the pygidium, not covered by the elytra [36] á. The last segments originate the copulatory apparatus or genitalia, and in the female the ovipositor; organs of taxonomic importance, especially males, which have unique characteristics at the species level [30]. The female genitalia consist of two very transformed abdominal segments in the dorsal and ventral part connected to each other [37]. The 0.5 and 0.2 mm long and wide egg of the bruchids, ovoid, sub-cylindrical, elongated with a convex dorsal face, hardened chorion and flat ventral face, hatch in 3 to 6 days [30, 33, 36]. The larvae have four stages, in large species they reach five stages, with a duration of two to three weeks [30, 38]. The larvae present in the first stage prenottal sclerites, in stages II and IV labial scleroma, and gouge-shaped jaws [31]; they feed specifically on seeds [32]. The pupae have a period between five and six days, the adults come out breaking the pupal chamber in a circular way, and they mate after 24 hours; each female lays between 50 to 80 eggs in seven days [36].

Among the eating habits of bruchids, there are oligophages, monophages, polyphagous, they live in stored products and naturally regulate plant populations [36]. 80% of bruchids are associated with economically important legumes [32, 39, 40].

3. Materials and Methods

The research work was carried out in the towns of Jesus M. Garza, Benito Juarez, Rivera Horizonte, Villa Hidalgo, Cristobel Obregon and September 16 of the municipality of Villaflores, Chiapas, the municipality is located at coordinates 16° 14' North latitude and 93° 17' west longitude, at 540 msnm, with mean annual temperature of 22°C and mean annual rainfall of 600 mm (INEGI[1], 2019).

The field work consisted of sampling the biological states of the tamarind pod borer, which were carried out every seven days, from the beginning of flowering (September, 2019) until harvest (April to July, 2020); 28 samplings were carried out and 168 brood chambers were placed per tree. The sample size consisted of ten tamarind trees, five in a backyard and five in an established plantation. In the search for immature stages, direct collections of flower buds, flowers, emerging fruits, green fruits and mature fruits were made, collecting 100 specimens of each biological stage per tree. In each sampling, six 6 x 20 cm wide and long organza brood chambers were placed per tree. The tree canopy was divided into three sections: upper, middle and lower zone, in order to determine the moment of oviposition and initial infestation of the fruit borer and the most attractive zone.

The collected specimens were preserved in bottles with 70% alcohol, and mounted on entomological pins according to the specifications of [41] and deposited in the Entomological Collection of the Faculty of Agronomic Sciences Campus V. The specific determination was made by morphological comparisons and through dichotomous keys of [42-44]. To corroborate the results, copies were sent to the specialist of this family, Dr. Jesus Romero Napoles, Research Professor at the Postgraduate College, Montecillo campus, Texcoco, Mexico.

To determine and quantify the damage to tamarind production, caused by the borer, 100 ripe fruits were collected per tree in each sampling community, they were separated into healthy and damaged fruits. To quantify the total production per tree, the fruits were harvested, in order to determine the percentage of damaged fruits, the formula of the percentage of infestation (IP) of Montes [5].

$$\%\,IP = \frac{Number\ of\ affected\ fruits1}{2number\ of\ total\ or\ evaluated\ fruits} * 100 \tag{1}$$

4. Results and Discussions

4.1. Specific Determination of the Tamarind Borer

At the beginning of the taxonomic studies of the seed beetles, they underwent numerous changes until they consolidated as an independent family. In the works of Crowson and Kingsolver [45, 46] unique taxonomic characteristics were established to establish this group of insects to the rank of family. However, the works of Lawrence and Newton, Borowiec and Reid [47-49], mention that the distinctive morphological characters of these

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specimens are not enough and grouped them with the taxonomic category of subfamily within the Family Chrysomelidae.

In this work, the criteria of Crowson and Kingsolver [45, 46] that consider bruquids as family were followed. In this sense, the tamarind fruit borer was determined as *Caryedon gonagra* Fabricius, 1798 (Coleoptera: Bruchidae). At the beginning of its determination and taxonomic knowledge it was determined as *C. gonagra*, later it was labeled as *Caryedon serratus* Oliver 1790 (Coleoptera: Bruchidae), [50-58]; With genitalia studies they determined that *C. gonagra* and *C. serratus* were twinned species [43]; both species feed on the fruits and seeds of tamarind, but *C. gonagra* does not naturally feed on peanut seeds (*Arachis hypogaea* L.); Therefore, it is considered as an important indicator that this species does not feed on peanuts and its main host is tamarind. On the other hand, Romero-Napoles and Segura-León [44], studied and corroborated the external morphological structures cited by Yus [59]; They also reviewed the structures of the internal morphology of the genitalia of both sexes and were related to *C. gonagra*, a species that was introduced to Mexico in 1966. In addition, they carried out molecular studies where the sequences were aligned with *C. gonagra* with coverage of 94 and 98% shared bases; presenting 21 variable nucleotides and five amino acid sites.

The species *C. gonagra* is native to the Old World especially Africa, widely distributed in the tropics [51, 60]. It was introduced to Mexico in tamarind seeds in 1966 [29], and is reported for the states of Nayarit, Guerrero, Oaxaca, Baja California Sur, Coahuila, San Luis Potosí, Durango, Chiapas, Tamaulipas, Veracruz, Michoacán, Morelos, Tabasco, Quintana Roo, and Yucatán [52]. It has currently been reported as a pest of economic importance for the states of Colima and Morelos [61]. In this sense, it is considered the first record of this species for the State of Chiapas, causing significant damage to tamarind fruits, in field conditions and in storage.

4.2. Morphological Characteristics of the Tamarind Borer

The distinctive morphological characteristics of the biological states of the tamarind pod borer are specific to the species *C. gonagra*.

The eggs are small, oval, laterally domed dorsally and flattened ventrally, they measure 0.5 to 0.6 and 0.8 to 1 mm in width and length, with an initial white color; becoming whitish and opaque as the larvae develops, until they finally become transparent, which indicates the emergence of the larva, which has penetrated the fruit in search of the seed; this agrees with Velez-Ángel [51] who indicates that newly laid *C. gonagra* eggs are white.

The larvae of *C. gonagra* are 7 to 10 mm long, with a small, dark-colored sclerosed head, a large and bulging white or creamy brown body with an arcuate "C" type, two-arm, short antennae. and conical, with a long and curved primary seta; short jaw, slightly mobile legs, thick and fleshy abdomen. When the larva reaches IV instar, it has finished weaving a transparent white silk cocoon and is no longer active; it will begin the first transformations that will give rise to the pupa. The pupa is a cocoon of soft pale yellow consistency, 5 to 7.5 ml in length, located inside the seed, on the pulp and sometimes on the outer surface of the shell [1, 28]. In this phase, they have a creamy brown or creamy yellow body, with a folded head, with the chin on the anterior tarsi, the antennas back, the elytra are not differentiated from the membranous wings, the hind legs are folded next to the sternal segments of the abdomen.

Adults of *C. gonagra* are 4 to 6 mm long, with subrectangular prothorax, light brown body, slightly elongated, with golden pubescence, small and scattered dark macules, they differ especially in the elytra and hind legs; these morphological characteristics agree with Delobel and collaborators [43] indicate that *C. gonagra* is a relatively large species, grayish brown in color, with black spots on the body, and dark markings on the legs. They present a small and short head, globose compound eyes of black color, long and serrated antennae with 12 segments, covered with a fine pubescence; they describe the adults as follows: antennal segments 1 to 4 cylindrical, 5 to 10 serrated and segment 11 oblong, the first segment is approximately twice as long. With a simple pronotum, brown elytra and they are not able to protect the last abdominal segments; similar protoraxic and mesothoraxic legs, and metathoracic legs with large, thickened developed femurs and saw-shaped edges on the ventral part, sharply curved tibiae, and four-segmented tarsi, the first elongated and the third bilobed [43].

The species *C. gonagra* differs from other species of the genus because the fourth antennal artery is the same as the second, the eyes are four times wide at the interocular distance; the pronotum with simple punctuation, pecten with 12-17 teeth and female genitalia with V-shaped indentation [43-45]. The male is distinguished from the female because the pygidium or sixth abdominal tergith is strongly curved, which seen dorsally is seen to be hidden by the elytra, unlike the female, the pygidium seen dorsally projects beyond the elytra [51].

4.3. Caryedon Gonagra Life Cycle

The initial infestation occurs in the field when the female oviposits 5 to 7 eggs individually on the surface of the pods and 1 to 3 eggs on the pulp during the months of December - April. These observations are in agreement with Oaya and collaborators; Orozco-Santos and collaborators [1, 58, 62] who indicate that *C. gonagra* females deposit their eggs in isolation on the fruit rind or on the tamarind pulp. The female selects the fruits in formation from the middle part of the tree, when the fruits are green (November-January), without considering the size and development; These results do not agree with Orozco-Santos and collaborators [61] who mention that females oviposit when the fruit has stopped growing and the pulp begins to change from green to brown. According to Oaya and davey [1, 47, 50, 62], the incubation period is 6 to 10 days and a female oviposits up to 283 eggs on average; the incubation of the eggs lasts 4 days and the larval development is 40 days and presents four larval stages

I, II, III and IV, with 15, 6, 7, and 8 days respectively, the first two stages They are creamy in color, the third creamy brown with dark brown lines and the fourth orange.

The pupation of *C. gonagra* is eight to ten days; Velez-Angel and Orozco-Santos and collaborators [1, 51] mention that the larvae of this species form cocoons that protect the pupa and serve as a shelter in the diapause period in order to preserve the survival of the species; After this period, the adults emerge, some remain inside the capsule for several months or for several generations, when the tamarind pods are available for oviposition and they consider it to be a polyvoltine species [58, 63, 64]. Adults emerge when the fruits are ready for harvest, when the pulp of the fruits turns from green to brown (May-July) or when it is in storage. In this work it was observed that adults have a life span of three to four weeks and according to Davey [50] the adults live 41 days on average; at 27.5 to 30°C and from 70 to 90% relative humidity, the shelf life is 21 days.

4.4. Caryedon Gonagra Damage Assessment on Tamarind

The presence of adults of *C. gonagra* in tamarind trees ranges from 1 to 3% at the beginning of the infestation, which is considered relatively low, with three individuals found in the towns of Cristobel Obregon, Benito Juarez and Rivera Horizonte. The infestation increases to 10%, observing in the months of February - March, a greater number of adults, with an infestation of 25%. However, in the trees that delay their production process considered intermediate (April) and late (May - July), the infestations of *C. gonagra* reach up to 35% of fruits. These data agree with Orozco-Santos and collaborators [65] who indicated that the main affectations of the fruits occur in the middle and late harvests, registering affectations of 35 to 40% of the fruits.

In the low season, a tamarind tree in the Frailesca region produces 19,876 fruits on average, of which 12,768 of them are healthy and 7,108 showed signs of *C. gonagra*, which represents 35.8% of the production. These results agree with indicated in [1, 7, 62, 65] that the immature stages of C. gonagra damage tamarind fruits during their formation and growth, reaching up to 35% damage. In addition, they recorded that in postharvest storage conditions they reach between 50 and 79% infestation of the fruits; Orozco-Santos and collaborators [58] indicate that under storage conditions the damage of tamarind fruits by *C. gonagra* reaches up to 100%.

Regarding the weight of the total production of tamarind per tree in this low production season, it reached 79,800 g tree-1; the weight per healthy and damaged fruit were 53,400 and 26,400 g $tree^{-1}$ with 4.18 and 3.71 g per fruit respectively, obtaining a reduction of 0.47 g $fruit^{-1}$, this low weight of the fruits is due to the activity and consumption of *C. gonagra*, generating a total loss of 9,341 g $tree^{-1}$, which corresponds to 11.24% of the total production per tree. When extrapolating these results per hectare, a production loss by the tamarind fruit borer of 280,230 g ha^{-1} is obtained.

In accordance with [66] recommend collecting tamarind fruits and seeds immediately after maturity to reduce losses due to direct consumption and secondary damage. Damages by predation of the seeds caused by bruchids completely deteriorate the seeds, weight losses of the seeds between 45.2 to 67.7% were reported, due to consumption by the larvae to complete their biological cycle [67].

5. Conclusions

The tamarind fruit borer was taxonomically determined as the species *C. gonagra* (Coleoptera: Bruquidae), which was corroborated by Dr. Jesus Romero Napoles, specialist in this group of insects, from the Postgraduate College, Mexico.

The tamarind tree does not present a homogeneous flowering and fruiting, since there are fruits of different sizes, from 0.5 to 11 cm in length from September to July. In addition, the tamarind tree exhibits alternating fruiting periods, a high production period, followed by a low production period; When carrying out this work from the months of September 2019 to July 2020, it coincided with the low production season, obtaining an average production of 19,876 fruits per tree, of which 12,768 were healthy and 7,108 damaged fruits, corresponding to 35.8% of the total of fruits.

Regarding the weight of the tamarind fruits, it was determined that the production of tamarind in low season is affected by 11.24% on average per tree, said loss is due to the feeding effect of the immature stages of *C. gonagra* and by decomposition of the fruit due to the effect of feces.

Considering the quality of the tamarind fruits and the magnitude of the damage caused by the pod borer, it is necessary to carry out studies on the agroecological management of *C. gonagra*; In addition, carry out cultural practices that prevent the successive proliferation and maintenance of said insect in tamarind plantations.

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