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BIOLOGY AND POPULATION DYNAMICS OF ADULT *Sagalassa valida* WALKER, 1856 (Lepidoptera: Brachodidae), THE OIL PALM ROOT BORER IN COLOMBIA

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ABSTRACT

Sagalassa valida *is a pest of economic importance because the larval stage feeds on the root system of the oil palm. In this investigation, the life cycle, the population dynamics of the adults, and their natural enemies were determined through biweekly samplings for 43 months in two lots of oil palm; located in the Central and Western Zone of Colombia. It was determined that the life cycle of* S. valida *is 64.1 days on average; the duration of each stage was: Egg 9.2 ± 0.5 days, larva 38.1 ± 4.9 days (five instars), prepupa 2.9 ± 1.1 days, pupa 13.9 ± 1.1 days and adult 12.3 ± 4.3 days. The adults of* S. valida *were present in the two zones during the study; using Spearman's correlation index, it was determined that in the Central Zone, the precipitation presented a direct and significant correlation with the variables: number of males (ρ = 0.24; P = 0.023) and the total number of adults (ρ = 0.21; P = 0.044). Ten natural enemies of* S. valida *and 14 weeds were identified in the study areas. This information is essential to implement an efficient management strategy for* S. valida *in plantations.*

Keywords: *Elaeis guineensis*, interspecific hybrid, life cycle, predators, weeds.

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INTRODUCTION

Colombia has 595 723 ha planted with African oil palm (*Elaeis guineensis* Jacq.) and interspecific hybrid (*Elaeis oleifera* x *Elaeis guineensis*) (*Figure 1*), the total planted is distributed in four palm zones (*Table 1*) (Fedepalma, 2022a; 2022b).

Oil palm agroecosystems are home to a great diversity of insects, some species are classified as pests of economic importance, and others are considered beneficial species in the crop (natural enemies and pollinators) (Aldana *et al.,* 2010; Bustillo-Pardey, 2014b; Montes *et al.,* 2018). Currently, five species of borer habits pest have been registered; each species affects a specific part of the oil palm, causing significant damage to the roots, the stipe, the inflorescences and the fruits (Aldana *et al.*, 2010; Barrios-Trilleras *et al.,* 2020). Among the most relevant species, the root borer, *Sagalassa valida* Walker, 1856 (Lepidoptera: Brachodidae), causes damage of economic importance in the Central and Western zones.

Sagalassa valida is a native species of South America that is present in Brazil, Colombia, Ecuador, Panama, Peru, Suriname and Venezuela. In Colombia, this borer is present in all oil palm areas. However, *S. valida* has caused significant economic loss in *E. guineensis* cultivars and the interspecific

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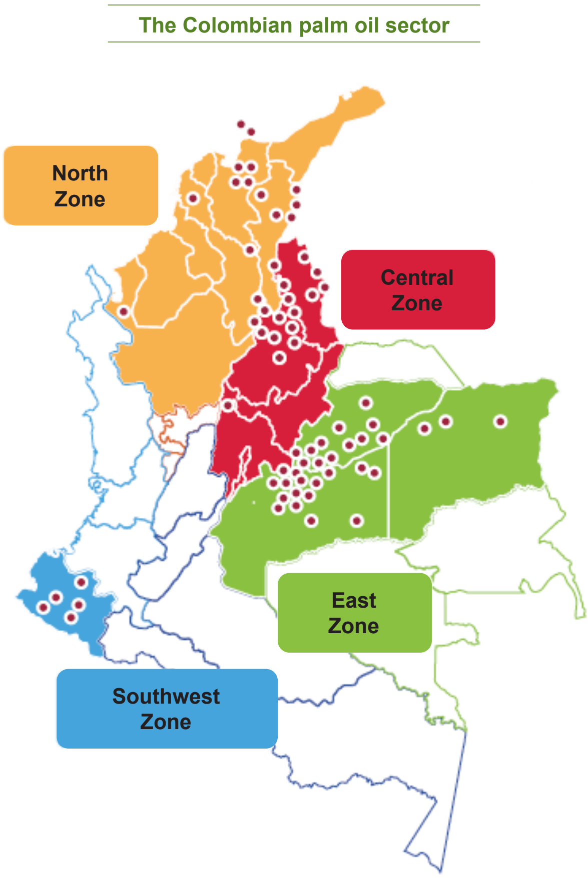


Source: Fedepalma (2022b).

Figure 1. Oil palm growing zones in Colombia.

TABLE 1. DISTRIBUTION OF OIL PALM PLANTED AREA IN COLOMBIA BY ZONE

Zone	Area planted (ha)	Production area (ha)	Growth area (ha)
Northern	111 789	101 177	10 612
Central	182 438	161 402	21 036
Eastern	278 513	216 672	61 841
Western	22 983	20 113	2 870
Total	**595 723**	**499 364**	**96 359**

Source: Fedepalma (2022a).

hybrid OxG (Coari x La Mé), in the Central and Western zones, respectively (Aldana *et al.*, 2000; Corredor *et al.*, 2016; Peña and Jiménez, 1994; Pinzón, 1995).

The larval stage of *S. valida* feeds on the root system of oil palms, feeding initially on the quaternary and tertiary roots. As it grows, pierces through the secondary and primary roots (Peña and Jiménez, 1994; Sáenz and Olivares, 2008a). While *S. valida* larvae are distributed throughout the entire root system and can be located at any distance and depth that the root system reaches, they are normally located close to the stipe in young oil palms and at 1.0-1.5 m from the base of the stipe in adult oil palms (Aldana *et al*., 2000).

Due to the damage caused by the larval stage in the roots, physiological changes occur in the palm that is reflected by poor development, slow growth, yellowing, drying of the basal leaves, continuous emission of male inflorescences, as well as a decrease in bunch size and weight, in severe attacks can overturn the palm (Aldana *et al.*, 2000; Peña and Jiménez, 1994). Chávez *et al.* (2000) determined that economic damage could occur in the crop from 5% fresh damage to the oil palm roots. Aldana *et al.* (2000) recorded losses that can exceed 50% of the root system of 6 and 10 year old palms. In 10-year-old palms, the worst damage occurred at 1.50 m from the stipe, while in 6-year-old oil palms, damage occurred at all sampling distances. Corredor *et al.* (2016) estimated decrease in yield, ranging from 50%-83% of fresh fruit bunch weight, in areas of the interspecific hybrid OxG (Coari x La Mé) infested with *S. valida*.

Sagalassa valida management is based on cultural, biological and chemical crop control practices. The cultural control consists of using available ground plant covers, such as empty fruit bunches (EFB), pruned fronds, rice husks, or crop residues, to cover the base of the oil palm and prevent direct oviposition by *S. valida* females on oil palm roots (Pinzón, 1995). Biological control can be performed using nematodes of the genera *Heterorhabditis* and *Steinernema*, native to the zones where oil palms are grown in Colombia (Bustillo, 2014b; Sáenz *et al.*, 2005). These nematodes are produced for research and are sprayed on the ground around the base of the oil palm (Sáenz *et al.*, 2006). However, these native nematodes are not commercially available due to their high production costs. In addition, the oil palm crop agroecosystem contains various weeds visited by natural enemies of *S. valida*, which control its population (Barrios *et al.*, 2018; Mexzón, 1997; Sendoya and Bustillo, 2016). Lastly, chemical control involves the application of insecticides to the base of the palm (Sáenz and Ospino, 2007); however, this measure is not very effective in controlling its population and has a negative impact on populations of natural enemies.

Some studies on the biology of *S. valida* have been published, such as Genty *et al.* (1978) and Pinzón (1995). However, considering this insect's economic impact and importance on the oil palm crop, the biology, population dynamics, habits of the adults, and the main natural enemies of *S. valida* in the oil palm crop agroecosystem, must be assessed.

MATERIALS AND METHODS

Study Area

The biological study of *S. valida* was carried out under laboratory conditions at the La Providencia experimental station of the Colombian Oil Palm Research Centre, located in the Western Oil Palm Zone of Colombia in the Municipality of Tumaco (Nariño) (1°33′3.705″N, 78°41′38.213″W, 29 m asl). The population dynamics of *S. valida* adults, their habits, and their natural enemies were studied in two agroecological oil palm zones of Colombia; the first plot was selected in the Western Zone located in the municipality of Tumaco - Nariño (1°27′54.05″N, 78°38′14.13″W, 31 m asl), planted in 2008 with the interspecific hybrid OxG cultivar Coari x La Mé in a soil with a clay loam texture (FA) and the second plot in the Central Zone, in the Palmar de la Vizcaína Experimental Station (CEPV), located in the municipality of Barrancabermeja - Santander (06°59′1.15″N, 73°41′43.5″W, 100 m asl), was planted in 2007 with *Elaeis guineensis* cultivar Deli *dura* - Patuca x Deli *dura* - Pepilla, in a soil with a clay loam texture (FA). In each area, a plot of oil palm was selected bordering wooded areas, where the presence of *S. valida* was confirmed.

Taxonomic Verification of Adults of *S. valida*

Adult collections were made with the help of an entomological sweep net (40 cm wide, with a 60 cm long handle); in the two study areas. The insects were placed in a lethal chamber with ethyl acetate, and dry mounts were made to confirm their taxonomic identification. The specimens collected were identified up to the species level and confirmed by Erika Valentina Vergara Navarro of AGROSAVIA Colombia, following the morphological key proposed by Heppner and Duckworth (1981). The extraction of the genitalia of the adult specimens was carried out following the morphological key proposed by Heppner and Duckworth (1981) for the identification and confirmation of the species.

Biology of *S. valida*

The colony was established under laboratory conditions at 25.3 ± 0.6°C and 67.6 ± 9.6% RH. *S. valida* adults were collected from 08:00 to 11:00 hr in oil palm plots near wooded areas using a sweep net (40 cm wide, with a 60 cm long handle), placed in 50 mL conical polystyrene tubes, and transferred to the laboratory. Subsequently, 20 oviposition units, consisting of five females and one male, were arranged in a 3.7 L glass jar containing a damp paper towel, *Pueraria phaseoloides* (Roxb.) Benth (Fabales: Fabaceae) leaves as an oviposition substrate (*Figure 3a*). *Melanthera aspera* (Jacq.) (Asterales: Asteraceae) flowers and a cotton ball soaked in a 1:2 solution of water and sugar as a food source. The top of the jar was covered with tulle; to prevent adults from leaving.

A cohort of 193 eggs of the colony was collected and placed in glass Petri dishes (10 cm diameter) containing a wet filter paper. The eggs were monitored daily to determine their development time and viability.

Two hundred newly emerged first instar larvae were individualised in 10 cm Petri dishes containing moist paper towels and a freshly cut primary root of the interspecific hybrid OxG (Coari x La Mé) used as a food source and changed daily. The Petri dishes were covered with Kraft paper to simulate dark environmental conditions and maintained until pre-pupation. The presence of cephalic capsules coming from the molts was the criterion taken to record the instar change (Dyar, 1890; Gaines and Campbell, 1935) (*Figure 4f*). The width of the cephalic capsules was measured using a trinocular stereoscope (Olympus SZ2-ST, Tokyo, Japan) with a 14MP 1/2.3″ digital camera (UCMOS14000KPA, Nanjing Amada Instrument Co., China) and the ToupView program (x 86, ToupTek Photonics, China).

In total, 135 pre-pupae and 127 pupae were counted in 16 oz plastic jars, covered with Kraft paper to simulate natural dark conditions, and monitored daily. The sex of the adults that emerged in each container was identified. Lastly, 18 oviposition units were established in 3.7 L glass jars following the method described above, with one pair of adults placed in each unit. The plant material was changed daily, the adult longevity was recorded, and the number of eggs oviposited per female was counted daily.

Habits of *S. valida* Adults and Associated Weeds

The behaviour of the adults of *S. valida* was determined by observations every hour for 30 min, from 07:00 to 18:00 hr; these were carried out on a 50 m transect between a forest area and the oil palm plantation. Observations were made every biweekly for 43 months.

To identify the plants visited by the adults of *S. valida*, a simple W-shaped transect samplings were carried out (five observations/sampling units), for determination of the presence or absence of these individuals on the predominant weeds in the same transect mentioned above. This sampling was made every hour for 30 min, from 07:00 to 18:00 hr, biweekly for 43 months. The plants frequently visited by adults of *S. valida* were photographed and kept in the herbarium. The plant samples were also sent to the Colombian National Herbarium (*Herbario Nacional Colombiano* – COL) for identification.

Natural Enemies of *S. valida*

The natural enemies of *S. valida*, were collected between 07:00 and 18:00 hr, at biweekly intervals for 43 months. In the weeds, the natural enemies observed preying on the adults of *S. valida* were recorded and their frequency was annotated. Roots of the oil palms close to the forest area of the study plots were sampled while the larval predators were observed. For this purpose, the method proposed by Chávez *et al*. (2000) was used, with a pit made in the area with the greatest presence of roots. For *E. guineensis*, a pit (30 × 20 × 15 cm) was dug from the base of the stipe. The size of the pit in interspecific hybrids OxG was determined after considering the distribution of the root system, as proposed by Torres *et al*. (2004). The 35 x 30 cm deep pit was dug at 50 cm from the base of the stipe. Once the position of the pit was marked, the existing vegetation was removed. Subsequently, the soil was loosened using a trenching shovel and a stake, revealing the primary and secondary roots of the oil palm, which were checked for *S. valida* larvae and their beneficial species. The collected invertebrates were taken to the laboratory for identification using taxonomic keys (Fernández and Sharkey, 2006).

Population Dynamics of *S. valida*

Simple random samplings were performed between 09:00 and 11:00 hr in the plots of the two selected oil palm zones, every fortnight for 43 months. Samplings were performed in a 50 m transect close to a wooded area. *Sagalassa valida* adults were captured by marking four transects per plot and completing 60 double passes in each transect with a sweep net (40 cm wide, with a 60 cm long handle). The captured adults were quantified and placed in 50 mL polystyrene conical tubes containing ethanol (70%). Subsequently, the species was corroborated, and the sex was determined in the laboratory. The precipitation and temperature records were retrieved from the meteorological station closest to each study area.

Statistical Analysis

Data recorded to determine the biology of *S. valida* were analysed using descriptive statistics. Information on the population behaviour of *S. valida* adults were plotted in population dynamics graphs for the two agroecological zones during the 43 months of sampling. The Spearman's rank correlation coefficient of the population of *S. valida* adults was calculated using the climatical variables to determine the relationship between meteorological factors (precipitation and average temperature) with the populations of the adults using the statistical software SAS 9.4 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Taxonomic Verification of Adults of *S. valida*

The specimens collected in the two study zones were identified as *S. valida* Walker, 1856 (Lepidoptera: Brachodidae) (*Figure 2*). Insects are present in all oil palm areas of Colombia, with economic importance in oil palm crops in the Central and Western Zone.

Biology of *S. valida*

The life cycle of *S. valida* from egg to adult emergence lasted 64.2 ± 7.6 days (average ± standard deviation), with 53.5% mortality under laboratory conditions. The egg stage lasted 9.2 ± 0.5 days with 5.7% mortality (*Table 2*). Newly oviposited eggs were white (*Figure 3b*). As these eggs developed and were close to hatching, they became dark yellow, with their chorion showing dots and forming vertical lines (*Figure 3c*).

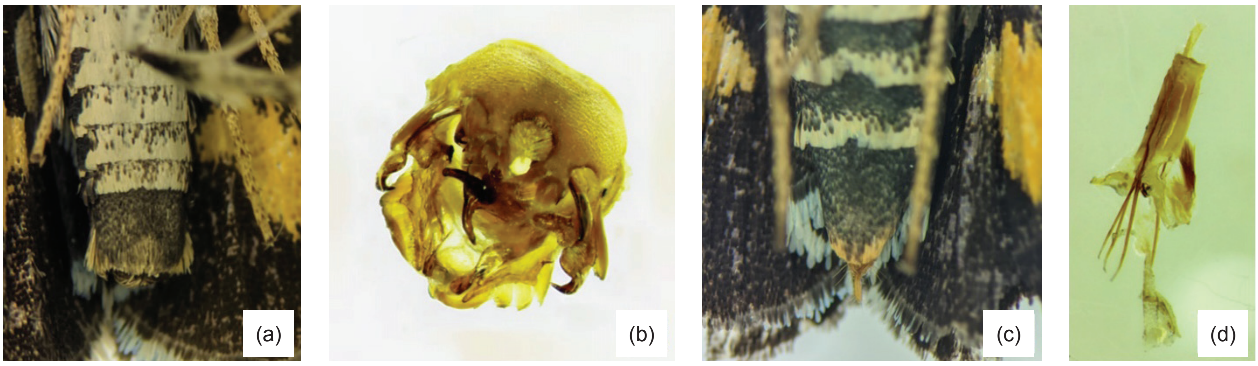


Figure 2. Sexual dimorphism and genitalia of S. valida *Walker, (a) male, last conical abdominal segment, (b) male, genitalia with aedeagus in situ, (c) female, last straight abdominal segment, and (d) female, genitalia.*

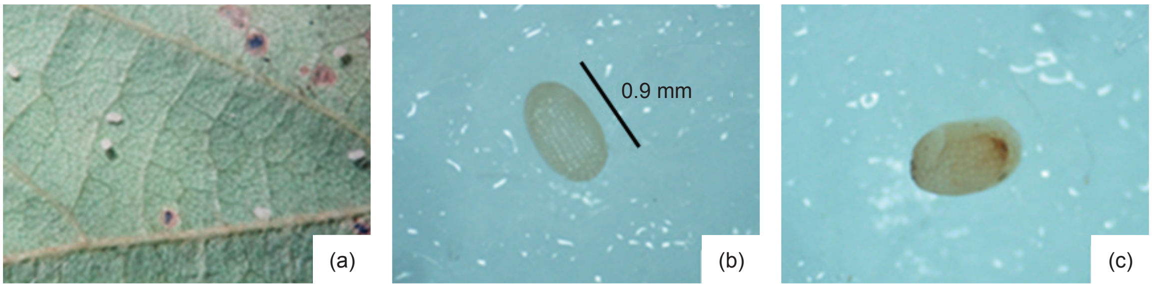


Figure 3. Sagalassa valida *eggs, (a)* S. valida *eggs on* Pueraria phaseoloides *leaves, (b) Recently oviposited* S. valida *egg on* P. phaseoloides *leaves, and (c)* S. valida *egg near hatching.*

TABLE 2. DEVELOPMENT TIME OF THE DIFFERENT STAGES OF THE OIL PALM ROOT BORER *Sagalassa valida* UNDER LABORATORY CONDITIONS (25.3 ± 0.6°C and 67.6 ± 9.6% relative humidity)

Stage		Number of repetitions	Stage duration (days)	Survival (%)
Egg		193	9.2 ± 0.5	94.3
Larva	I Instar	200	5.3 ± 0.7	82.0
	II Instar	164	4.2 ± 0.7	74.5
	III Instar	149	4.5 ± 0.9	74.0
	IV Instar	148	6.3 ± 1.1	74.0
	V Instar	135	17.9 ± 4.8	67.5
	VI Instar	26	8.7 ± 4.2	92.3
Pre-pupa		135	2.9 ± 1.1	63.5
Pupa		127	13.9 ± 1.1	46.5
Adult	Male	48	12.3 ± 4.8	
	Female	45	12.3 ± 4.3	
Total*			**76.4 ± 12.1**	

Note: * The 6th larval instar was omitted from the total.

The larval stage underwent five instars with an average development time of 38.1 ± 4.9 days (*Table 2*). Only 19.3% of the total population larvae presented six instars, with an average duration of 8.7 ± 4.2 days. Neonate larvae had a hyaline body and an amber head. As they developed, their body turned pale yellow and their head dark brown (*Figure 4*). The mortality was 32.5% and peaked in the first instar at 18.0%, followed by the second instar (7.5%). The third, fourth, and fifth stage larval were the most active and voracious.

The cephalic capsule width increased with each change in the larval instar (*Table 3*). The average cephalic capsule of the first instar larvae was 0.20 ± 0.02 mm, while the cephalic capsule of the fourth instar larvae reached 0.91 ± 0.07 mm; that is, their size was approximately four times greater than their initial measurement (*Figure 4f*). The pre-pupal period (*Figure 5a*) was 2.9 ± 1.1 days, with 4% mortality. The pupal stage lasted 13.9 ± 1.1 days, with 17% mortality. The pupa was light brown or amber (*Figure 5b*) (*Table 2*).

TABLE 3. MEAN (± SD) CEPHALIC CAPSULE WIDTH AND GROWTH RATE OF THE DIFFERENT LARVAL INSTARS OF *Sagalassa valida*

Larval instars	Width (mm)	Relationship between instars
I	0.20 ± 0.02	1.65
II	0.33 ± 0.03	1.69
III	0.56 ± 0.05	1.62
IV	0.91 ± 0.07	1.31
V	1.19 ± 0.13	1.04
VI	1.24 ± 0.06	-

Adult longevity was 12.3 ± 4.5 days, with no differences between male and female longevity (*Table 2*). Newly emerged adults were olive green, changing to ochre over time, had a black transverse band on the forewings (*Figure 5c*), and showed discrete sexual dimorphism. The last abdominal segment was conical in males (*Figure 2a*) and straight in females (*Figure 2c*). The antennae were filiform and smooth in males but contained sensory setae in females, which could be identified under a stereoscope or magnifying glass. The sex ratio was 1:1, and the females laid an average of 51.2 ± 42.5 eggs.

Habits of *S. valida* Adults and Associated Weeds

Sagalassa valida adults were found to be diurnal insects and made short and erratic flights over the nectariferous plants in the oil palm agroecosystem, on which they fed. They visited shady areas on the boundaries of the oil palm plots near the wooded areas and were also usually found near streams or pools of water that formed in the plantation while remaining hidden in low light hours during rainy periods. Between 07:00 and 09:00 hr, *S. valida* adults landed on the selected host plant species, with their antennae held along their body, but this behaviour may vary with climatic conditions. From 09:00-11:00 hr, the adults extended their antennae and flew over these plants to feed (*Figure 6a*) and copulate (*Figure 6b*). Subsequently, the females descend to the base of the palm and land on grooves in the ground, using their wings and abdomen to sweep the soil surface, later ovipositing near the tertiary and quaternary roots of the palm. In the afternoon, the activity of *S. valida* adults decreased as they sheltered within the nectariferous plants (*Figure 7*).

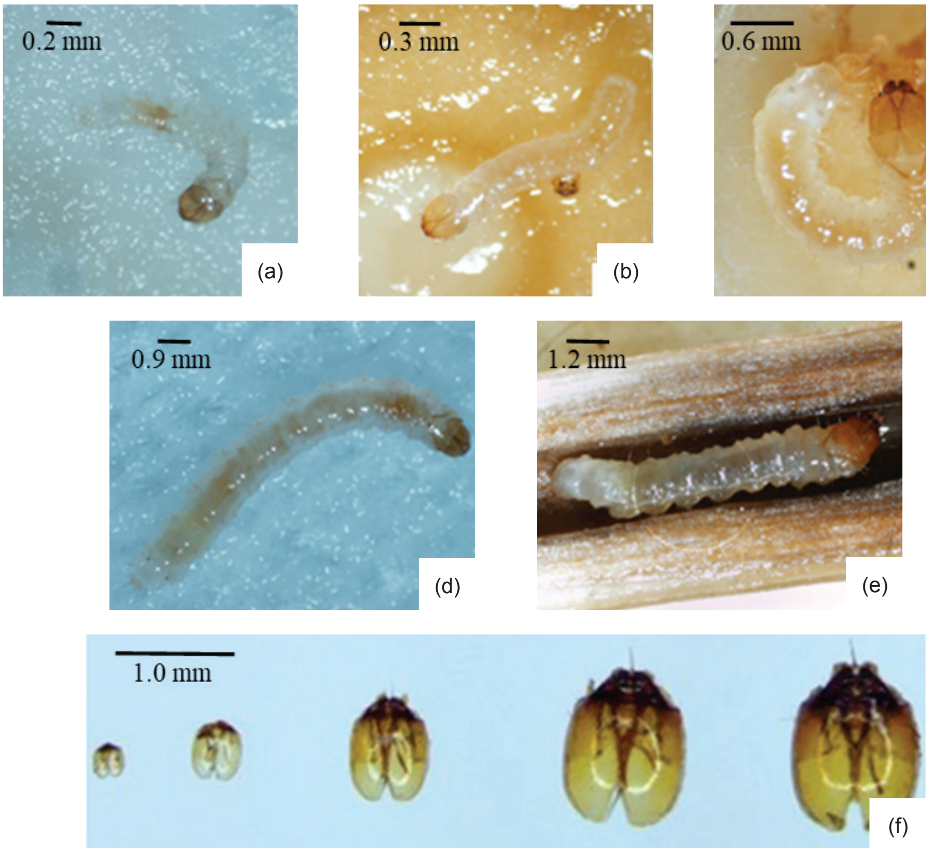


Figure 4. Larval stages of S. valida*: (a) 1st, (b) 2nd, (c) 3rd, (d) 4th, and (e) 5th instars, and (f) cephalic capsules of the different larval instars of* S. valida.

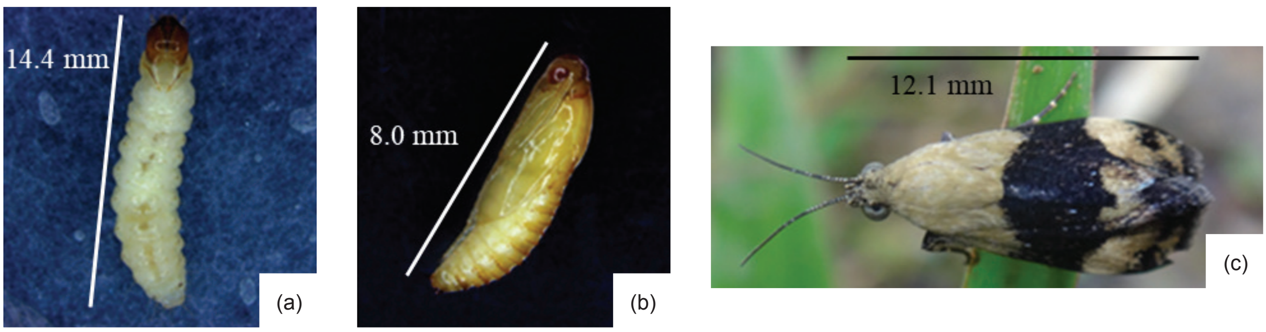


Figure 5. (a) Pre-pupa, (b) pupa, and (c) adult S. valida.

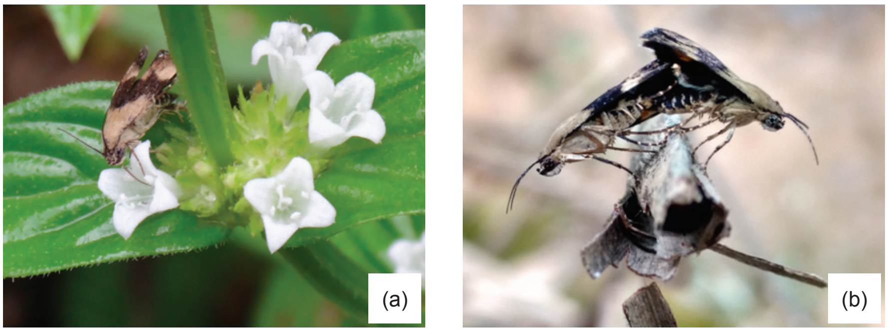
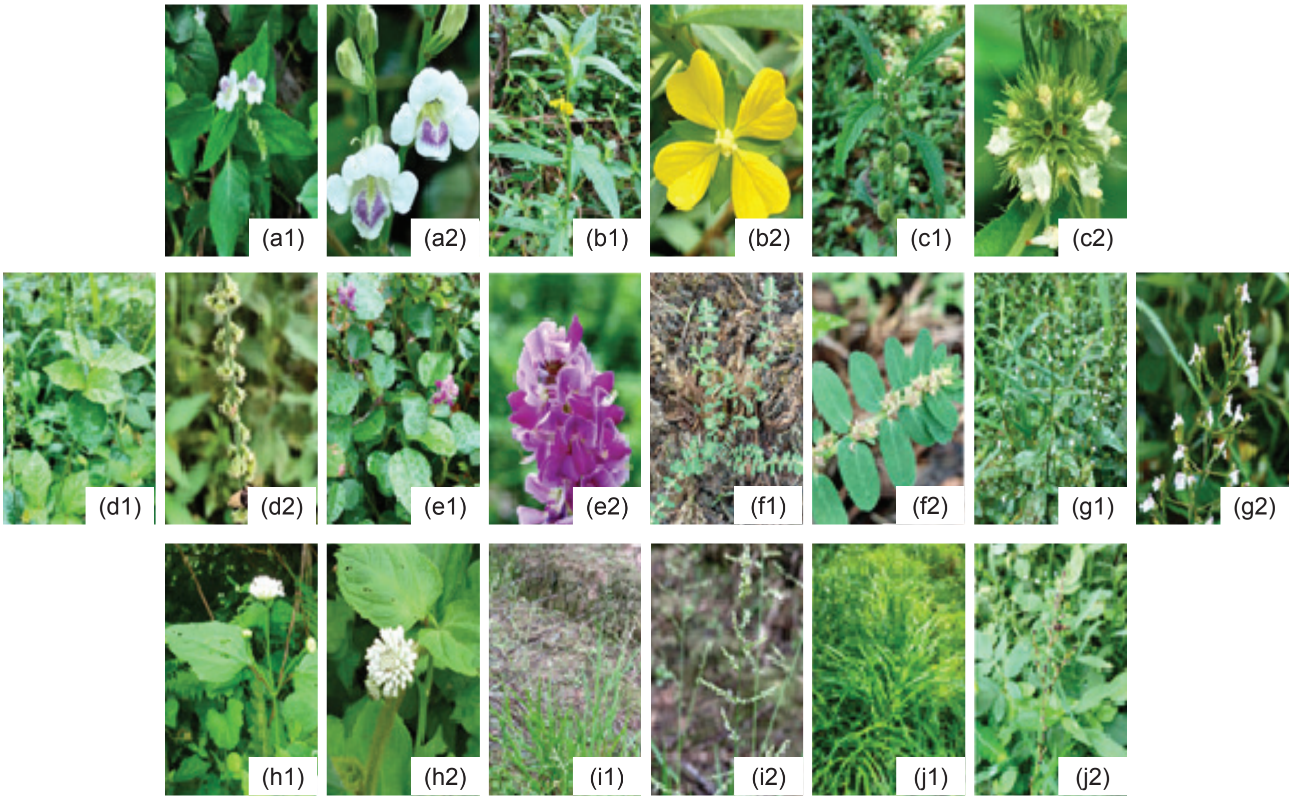


Figure 6. S. valida *adult (a) feeding on a* Spermacoce *sp. flower (09:00 to 11:00 hr), (b) copulating (between 10:00 and 12:00 hr).*



Note: 1 - Plant (full view); 2 - Flower/inflorescence (detail).

Figure 7. Weed species visited by S. valida *adults and their natural enemies: (a)* Asystasia intrusa, *(b)* Ludwigia decurrens, *(c)* Hyptis brevipes, *(d)* Cyathula prostrata, *(e)* Desmodium heterocarpon, *(f)* Chamaesyce *sp., (g)* Justicia comata, *(h)* Melanthera aspera, *(i)* Panicum laxum, *and (j)* Scleria melaleuca.

In the two agroecological zones, the weeds visited by *S. valida* adults for nectar feeding and sheltering during the day were recorded. However, this habitat was also a niche for predatory arthropods of *S. valida* and other beneficial insects of the oil palm agroecosystem. *Sagalassa valida* and their natural enemies frequently visited the nectariferous plants, such as *Asystasia intrusa* Blume (Lamiales: Acanthaceae) (*Figure 7a*), *Ludwigia decurrens* Walter (Myrtales: Onagraceae) (*Figure 7b*), *Hyptis brevipes* Poit (Lamiales: Lamiaceae) (*Figure 7c*), *Hyptis recurvata* Poit (Lamiales: Lamiaceae), *Justicia comata* (L.) Lam. (Lamiales: Acanthaceae) (*Figure 7g*), *Cyathula prostrata* L. (Caryophyllales: Amaranthaceae) (*Figure 7d*), *Desmodium heterocarpon* L. (Fabales: Fabaceae) (*Figure 7e*), *Spermacoce* sp. L. (Gentianales: Rubiaceae), *Stachytarpheta cayennensis* Vahl (Lamiales: Verbenaceae), *Chamaesyce* sp. L. (Malpighiales: Euphorbiaceae) (*Figure 7f*), *Pueraria phaseoloides* (Roxb.) Benth (Fabales: Fabaceae), and *Melanthera aspera* Rohr (Asterales: Asteraceae) (*Figure 7h*). The grass *Panicum laxum* L. (Poales: Poaceae) (*Figure 7i*) and the Cyperaceae *Scleria melaleuca* (Bergius) (Poales: Cyperaceae) (*Figure 7j*) were also identified (*Table 4*).

TABLE 4. WEED SPECIES VISITED BY *Sagalassa valida* ADULTS AND THEIR NATURAL ENEMIES IN TWO AGROECOLOGICAL ZONES OF OIL PALM IN COLOMBIA

Species	Presence in oil palm zone	
	Central	Western
Asystasia intrusa (Acanthaceae)	×	
Chamaesyce sp. (Euphorbiaceae)	×	×
Cyathula prostrata (Amaranthaceae)	×	×
Desmodium heterocarpon (Fabaceae)	×	×
Hyptis brevipes (Lamiaceae)	×	×
Hyptis recurvata (Lamiaceae)	×	×
Justicia comata (Acanthaceae)	×	
Ludwigia decurrens (Onagraceae)	×	
Melanthera aspera (Asteraceae)	×	×
Panicum laxum (Poaceae)	×	×
Pueraria phaseoloides (Fabaceae)	×	×
Scleria melaleuca (Cyperaceae)	×	×
Spermacoce sp. (Rubiaceae)		×
Stachytarpheta cayennensis (Verbenaceae)	×	×

Natural Enemies of *S. valida*

There was no evidence of parasitoids or entomopathogenic microorganisms affecting *S. valida* larvae during the sampling period in both study areas. Arachnids (Araneae) and a species of Odonata (Coenagrionidae), present within the weeds had preyed upon the *S. valida* adults (*Figure 8*). Spiders and ants were the only predators that attacked *S. valida* larvae. Among the ants (Hymenoptera: Formicidae), *Ectatomma ruidum* (Roger, 1861), *Odontomachus brunneus* (Patton, 1894), *Pachycondyla harpax* (Fabricius, 1804), *Pachycondyla obscuricornis* (Emery, 1890), and *Neoponera villosa* Fabricius (1804), were found active at the base of the palms (*Figure 9*).

Population Dynamics of Adults of *S. valida*

The abundance of *S. valida* adults was higher in the Central Zone than in the Western Zone (*Figure 10-13*). Adults were present in both zones throughout the year. The largest populations were recorded in March, April, May, August and November in the Central Zone plot (*Figure 10-11*) and in August, October and November in the Western Zone plot (*Figure 12-13*). The monthly average catches of *S. valida* adults were 121.9 ± 62.1 *S. valida* adults in the Central Zone plot and 38.4 ± 37.6 in the Western Zone plot. The male-to-female ratio of the captured adults of *S. valida* was 0.9:1.1 in the Central Zone plot and 1.2:0.8 in the Western Zone plot. There was no monthly trend of population peaks of *S. valida* in the Western Zone, in contrast to the Central Zone.

In the Central Zone plot, precipitation had significant positive correlations with the following population variables: the number of captured females ($\rho = 0.24$; $P = 0.02$) and the total number of insects captured ($\rho = 0.21$; $P = 0.04$); however, no significant correlations were found between precipitation, and the number of males captured ($\rho = 0.13$; $P = 0.22$), that is to say, that in conditions of precipitation, the activity of the females is greater in comparison to the males in this study area. No significant correlation was found between temperature and the numbers of males, females, and the total of insects captured (*Table 5*). In contrast, the Western Zone plot, recorded no significant correlations between climate and the population variables (*Table 5*).

Figure 8. Natural enemies of S. valida *adults. (a) Arachnid preying on* S. valida *on* A. intrusa, *(b)* M. aspera, *and (c)* Pueraria phaseoloides.

Source: Jhon David Cardenas.

Figure 9. Natural enemies of S. valida *larvae, (a)* Ectatomma ruidum, *(b)* Odontomachus brunneus, *and (c)* Neoponera villosa.

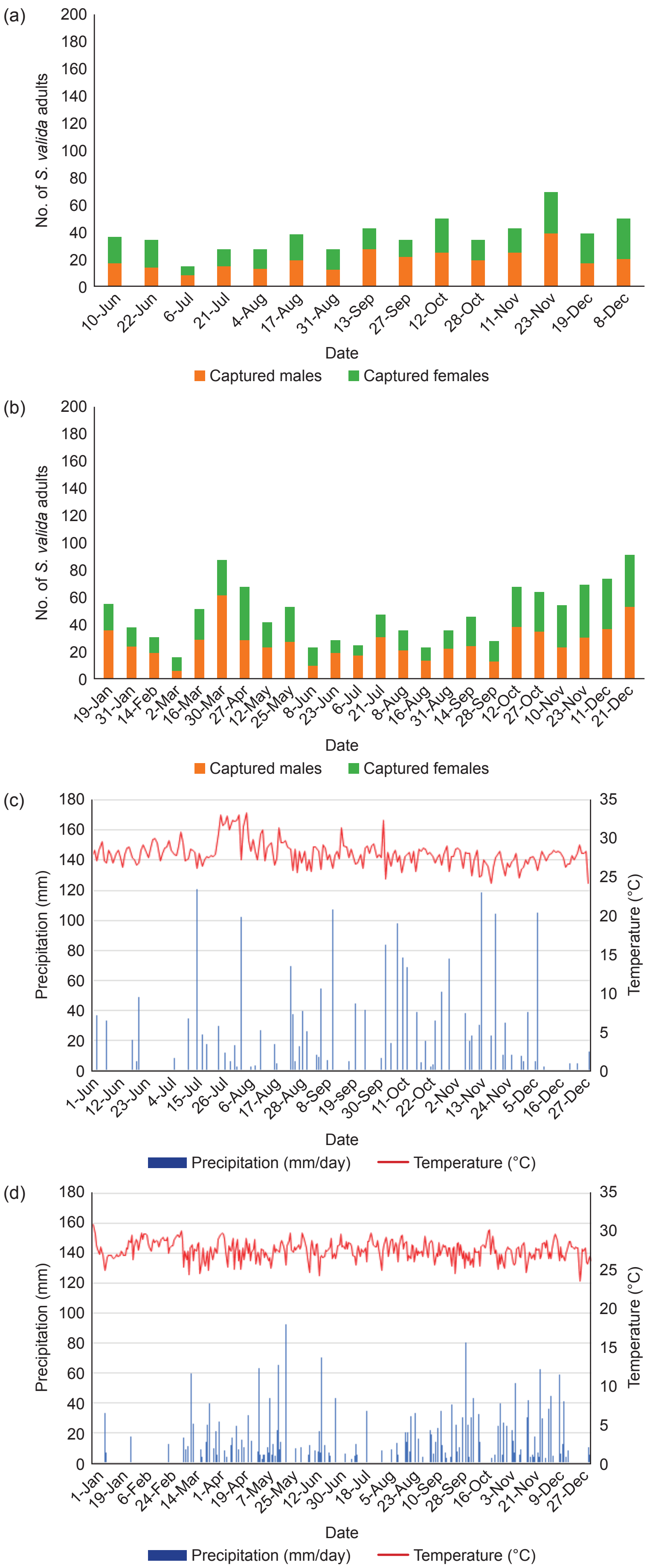


Figure 10. Population dynamics of S. valida *adults in the Central Zone in (a) year 1 and (b) year 2, and temperature and precipitation in (c) year 1, and (d) year 2.*

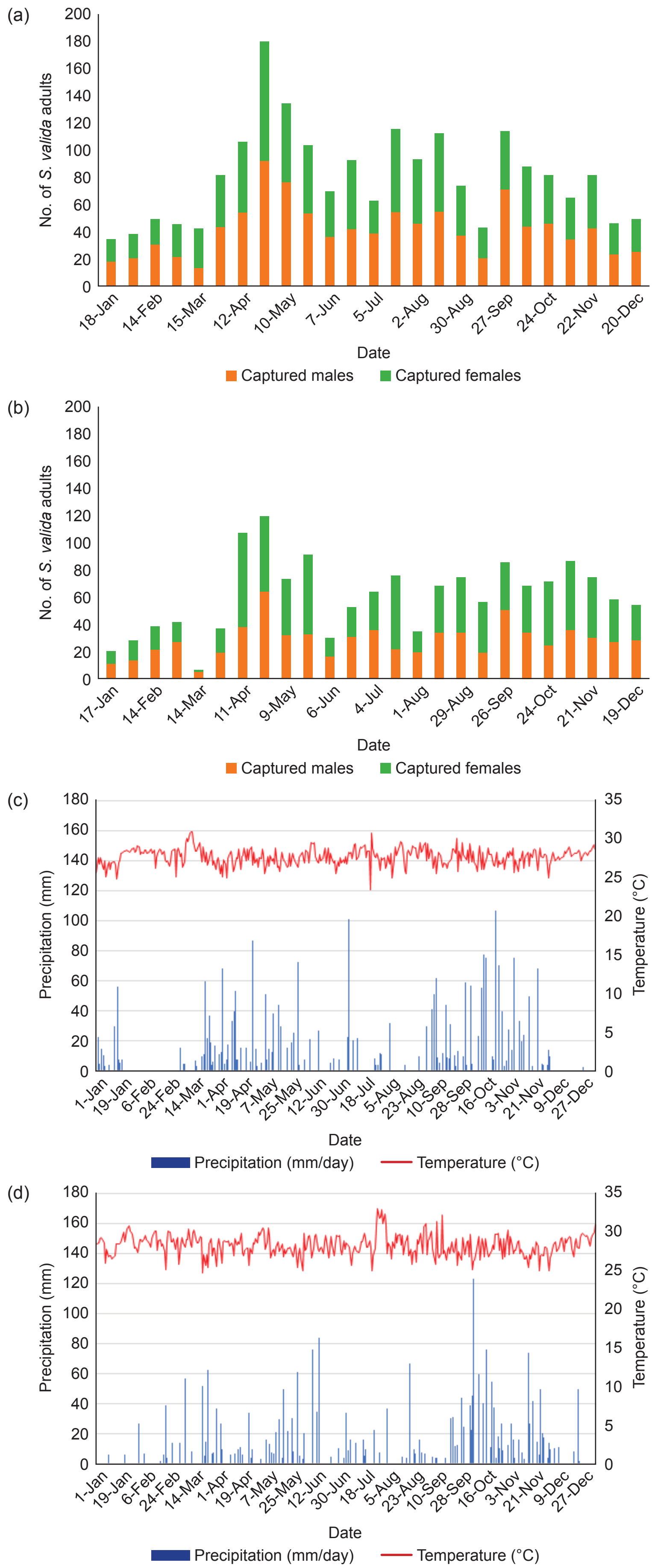


Figure 11. Population dynamics of S. valida *adults in the Central Zone in (a) year 3 and (b) year 4, and temperature and precipitation in (c) year 3, and (d) year 4.*

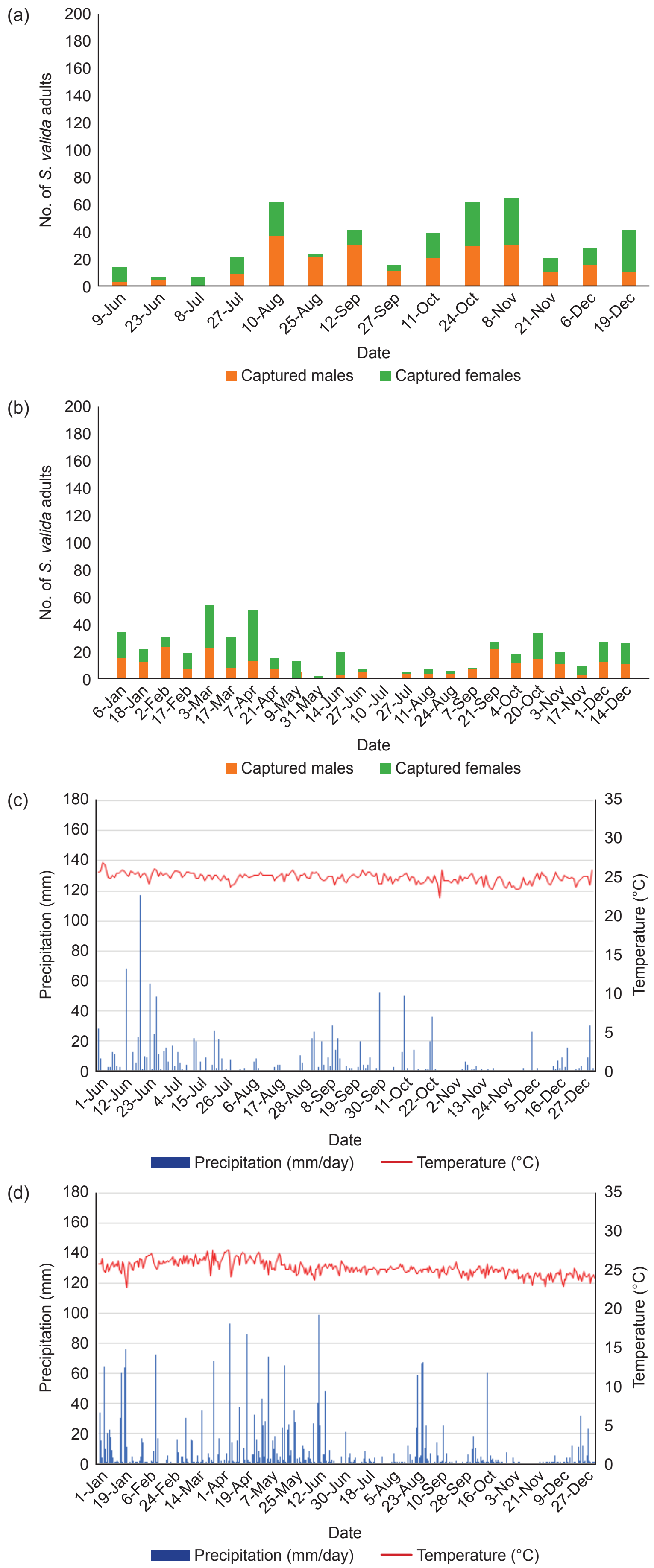


Figure 12. Population dynamics of S. valida *adults in the Western Zone in (a) year 1 and (b) year 2, and temperature and precipitation in (c) year 1, and (d) year 2.*

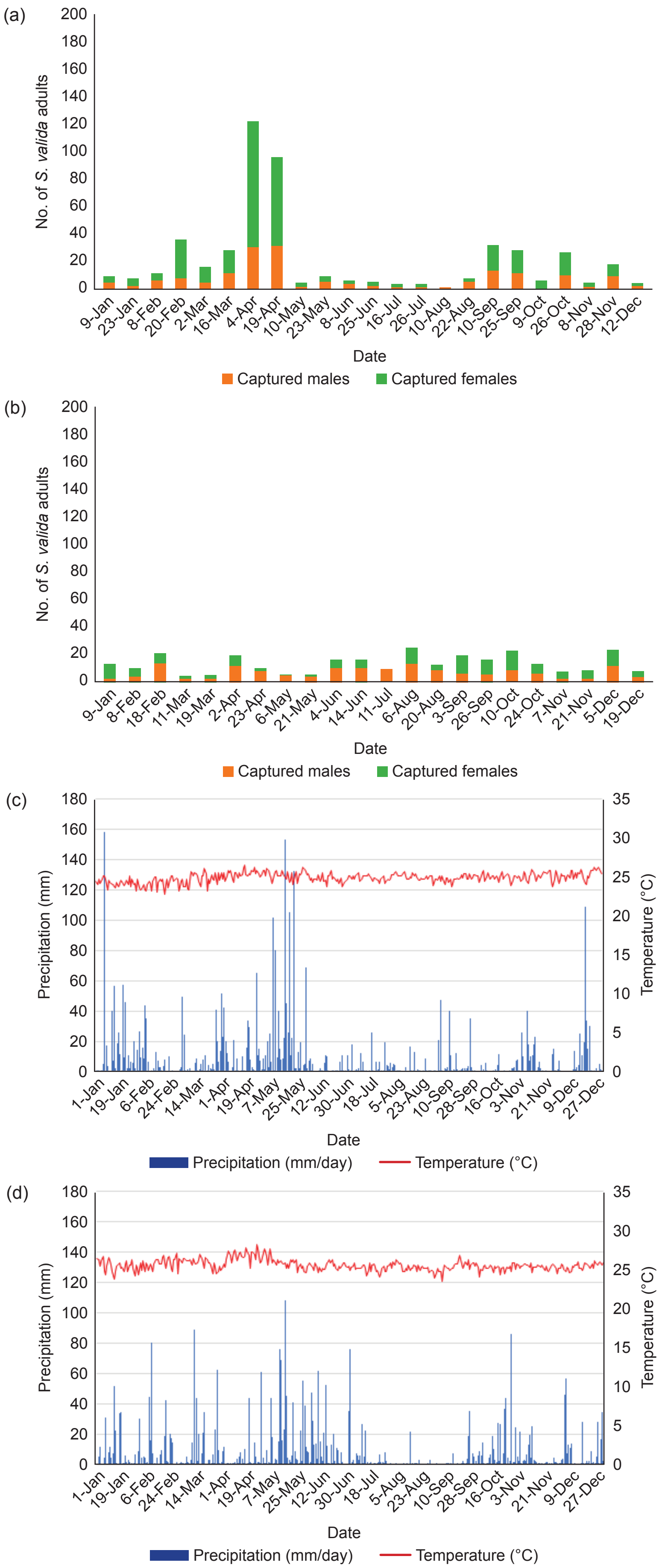


Figure 13. Population dynamics of S. valida *adults in the Western Zone in (a) year 3 and (b) year 4, and temperature and precipitation in (c) year 3, and (d) year 4.*

TABLE 5. SPEARMAN'S RANK CORRELATIONS BETWEEN ENVIRONMENTAL CONDITIONS AND POPULATION DYNAMICS OF *Sagalassa valida* ADULTS IN EACH AGROECOLOGICAL ZONE

Study area	Climate conditions	Population of *S. valida* adults		
		Females	Males	Total
Central Zone	Precipitation (mm)	*ρ:* 0.240 *P:* 0.023	*ρ:* 0.131 *P:* 0.220	*ρ:* 0.214 *P:* 0.044
	Temperature (°C)	*ρ:* -0109 *P:* 0.310	*ρ:* -0.043 *P:* 0.690	*ρ:* -0.095 *P:* 0.377
Western Zone	Precipitation (mm)	*ρ:* 0.068 *P:* 0.542	*ρ:* 0.080 *P:* 0.470	*ρ:* 0.064 *P:* 0.563
	Temperature (°C)	*ρ:* -0.029 *P:* 0.798	*ρ:* 0.066 *P:* 0.554	*ρ:* 0.009 *P:* 0.933

Note: Significant Spearman's rank correlations indicated by $P \leq 0.05$.

Discussion

The development time of the egg stage of *S. valida* is 9.2 ± 0.5 days (*Table 2*), a duration similar to that reported by Pinzón (1995); who recorded that the egg stage lasts from 8 to 9 days. The viability of the eggs was 94.3% (*Table 2*), while Pinzón (1995) reports a viability of 73%. These differences could be due to unfavourable environmental conditions related to temperature and relative humidity.

The larval stage of *S. valida* lasted 38.1 ± 4.9 days (*Table 2*) and went through five instars; however, 19.3% of the larval population presented a sixth instar. On the other hand, these results differ from those recorded by Pinzón (1995), who, under an average temperature of 29°C, recorded six larval instars with a duration of 45 to 48 days. These differences could be due to temperature variations and cultivars used as food resources. Pinzón (1995) used *E. guineensis* roots to feed larvae, whereas the interspecific hybrid OxG (Coari x La Mé) were used in the current study. Biological studies in other Lepidopteran species, such as *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), highlight differences in larval development as a function of diet, temperature, and relative humidity, with this species presenting six larval instars when fed lettuce (*Lactuca sativa* L.), while 52% of individuals showed six larval instars and the rest showing seven instars when the larvae were fed Perilla (*Perilla frutescens* L. Britton), possibly due to the differences in temperature and chemical composition of these host plants (Esperk *et al.*, 2007; Mo *et al.*, 2013).

The width of the cephalic capsules was studied using Dyar's law (1890); which means that the width of the capsule increases according to a regular geometric progression. The relationship between larval instars remained between 1.0 and 1.7 (*Table 3*); these values are within the tolerance range of Dyar's Law: 1.1 to 1.9. Through the size of the cephalic capsule, the larval instars of populations of *S. valida* can be estimated in the field.

The pupal stage lasted 13.9 ± 1.1 days, similar to those found by Pinzón (1995), who recorded developmental time from 12.0 to 18.0 days. The longevity of *S. valida* adults was recorded at 12.3 ± 4.5 days, while Pinzon (1995) reported between 5.0 to 6.0 days duration. In this study, the differences were also evident in the oviposition rate of the females, at an average of 51.2 ± 42.5 eggs per female, in contrast to Pinzon (1995), who recorded an average of eight eggs and a maximum of 30 eggs per female. These differences may be due to the place and environmental conditions in which the adults were kept; unfortunately, these factors were not reported in previous studies. The same occurs with fertility, which can be affected by the type of food consumed by the insect, as observed in *Conogethes punctiferalis* Guenée, 1854 (Esperk *et al.*, 2007) (Lepidoptera: Crambidae), where fecundity was the highest (282.3 eggs/female) when the larvae were reared on Chinese chestnut trees (*Castanea mollissima* Blume) and the lowest (19.2 eggs/female) when reared on apple trees (*Malus domestica* Miller) (Chen *et al.*, 2018).

Regarding behaviour, *S. valida* adults were active diurnally and visited the woody areas near the oil palm plantations. During the day (09:00-11:00 hr), they fed and copulated on weeds within the oil palm agroecosystem. This behaviour matched that reported by Pinzón (1995), who recorded that *S. valida* adults copulated between 10:00 and 12:00 hr, with the number of adults decreasing in hours of low light and hiding when it rained; however, in one of the study areas (Central Zone), rainfall had presented a direct and significant effect, which correlated with the number of females and the total number of adults ($r = 0.24$; $P = 0.023$ and $r = 0.21$; $P = 0.044$, respectively). This same author observed that the females were more abundant within the forest, while the males were more abundant near the forested areas at the boundary of the oil palm plots. However, in this study, there was a male and female ratio of 0.9:1.1 in the Central Zone and 1.2:0.8 in the Western Zone, between the forest and the oil palm plantation.

The weeds identified in this study (*Table 4, Figure 7*) helped to attract other beneficial invertebrates, such as parasitoids and predators, which use these plant species for food and shelter. The plant species such as *Hyptis capitata*, *Chamaesyce* sp., *C. prostrata*, and *M. aspera* attract Hymenoptera of the families Braconidae, Chalcididae, Ichneumonidae, Scelionidae, Vespidae, Evaniidae, and Formicidae, Diptera of the families Syrphidae, Tachinidae, and Asilidae, and Hemiptera of the families Pentatomidae and Reduviidae (Aldana *et al*., 1997; Mexzón, 1997; Sendoya and Bustillo, 2016), which play key roles in controlling populations of the lepidopteran oil palm pests such as *Stenoma impressella* Busck, 1914, *Stenoma cecropia* Meyrick, 1916 (Lepidoptera: Elachistidae), *Opsiphanes cassina* Felder, 1862 (Lepidoptera: Nymphalidae), *Euprosterna elaeasa* Dyar, 1906 (Lepidoptera: Limacodidae), and other defoliators that attack the oil palm crop (Aldana *et al*., 2010; Escalante, 2007; Sendoya and Bustillo, 2016).

Ants were the only predators observed that affected *S. valida* larvae in the oil palm (*Figure 11*). Löhr and Narváez (2021) determined that *E. ruidum* was the dominant ant species within the oil palm crop in the Western Zone of Colombia, with a dominance of 84.5%. Studies conducted by Coral *et al*. (2004) calculated inverse correlations of 76.7% (P = 0.0096) and 58.0% (P = 0.0786) between populations of the larval stages of *S. valida* and populations of *P. harpax* and *P. obscuricornis* present in the oil palm plantations, respectively. In contrast, Sarmiento *et al.* (2005) found that, under laboratory conditions, *P. harpax* and *P. obscuricornis* predation did not surpass 10% of the exposed population of *S. valida*. Furthermore, these biological controllers showed no preference for preying on *S. valida* larvae or eggs. Regarding entomopathogenic microorganisms, no infected insects were identified in this study; however, Pinzón (1995) demonstrated the pathogenicity of *Metarhizium anisopliae* (Metsch) Sorokin to *S. valida* larvae. Sáenz *et al.* (2005) reported observations of larvae infected with this fungus in the field. Other studies have demonstrated entomopathogenic nematodes efficacy in controlling *S. valida* larvae (Sáenz *et al*., 2005; Sáenz and Olivares, 2008b).

CONCLUSION

The life cycle and the adult longevity of *S. valida* span a total of 76.4 ± 12.1 days, which suggests that this insect pest may undergo four to five cycles a year in the oil palm crops. Due to the overlap between generations of *S. valida*, adults were found throughout the year in the two study zones. Therefore, the integrated management of *S. valida* must be based on an opportunistic diagnosis through monitoring of the adult populations, especially in lots that adjoin the wooded areas. The growth of plant species such as those recorded in this study should also be promoted to help establish and maintain populations of natural enemies that contribute to the biological control of *S. valida* and other oil palm pests.

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