

Composition and Structure of Thripidae Populations in Crops of Three Geographical Regions in Colombia

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Abstract

The composition and structure of thrips populations were determined in agroecosystems of 10 crops in the Andean, Caribbean, and Orinoquia regions of Colombia. From 18,183 identified specimens, 81 species belonging to 20 genera and three families were found. The Andean region was the most diverse with 60 species ($n = 11,360$, Chao 1 = 70.5, $H' = 1.986$), followed by the Caribbean region with 42 ($n = 5,960$, Chao 1 = 57.6, $H' = 2.256$) and the Orinoquia with 24 ($n = 863$, Chao 1 = 31; $H' = 2.301$). The crop with the richest fauna was avocado (*Persea americana*) Mill. with 40 species ($n = 4,047$, Chao 1 = 55.17, $H' = 1.302$), followed by coffee (*Coffea arabica*) L. with 26 ($n = 1,395$, Chao 1 = 33; $H' = 1.026$), cassava (*Manihot esculenta*) Crantz. with 25 ($n = 1,050$, Chao 1 = 29.67, $H' = 1.635$), citrus (*Citrus* spp.) with 22 ($n = 836$, Chao 1 = 25.75, $H' = 1.748$), corn (*Zea mays*) L. with 22 ($n = 1,647$, Chao 1 = 24.5, $H' = 1.365$), mango (*Mangifera indica*) L. with 17 ($n = 1,144$, Chao 1 = 18.5, $H' = 1.303$), blackberry (*Rubus glaucus*) Benth. with 11 ($n = 545$, Chao 1 = 16, $H' = 0.886$), banana (*Musa* spp.) with 9 species ($n = 1,798$, Chao 1 = 9, $H' = 0.208$), cotton (*Gossypium hirsutum*) L. with 8 ($n = 5,621$, Chao 1 = 11, $H' = 0.913$), and rubber tree (*Hevea brasiliensis*) Müll. Arg. with 4 species ($n = 90$, Chao 1 = 4, $H' = 0.594$). Differences were found in the distribution of the species in the altitudinal gradients and in the biogeographical regions. *Frankliniella gardeniae* Moulton, was the most abundant species, with the highest presence in crops, the greatest geographic and altitudinal distribution.

Resumen

Se determinó la composición y estructura de trips en agroecosistemas de diez cultivos en las regiones Andina, Caribe y Orinoquia de Colombia. A partir de 18,183 especímenes identificados, se encontró un total de 81 especies, en 20 géneros y tres familias. La región Andina fue la más diversa con 60 especies ($n = 11,360$, Chao 1 = 70.5; $H' = 1.986$), seguido de la región Caribe con 42 ($n = 5,960$, Chao 1 = 57.6; $H' = 2.256$) y la Orinoquia con 24 ($n = 863$, Chao 1 = 30; $H' = 2.265$). El cultivo con mayor riqueza fue el aguacate (*Persea americana*) Mill. con 40 especies ($n = 4,047$; Chao 1 = 55.17; $H' = 1.302$), seguido del café (*Coffea arabica*) L. con 26 ($n = 1,395$; Chao 1 = 33; $H' = 1.026$), yuca (*Manihot esculenta*) Crantz. con 25 ($n = 1,050$; Chao 1 = 29.67; $H' = 1.635$), cítricos (*Citrus* spp.) con 22 ($n = 836$; Chao 1 = 25.75; $H' = 1.748$), maíz (*Zea mays*) L. con 22 ($n = 1,647$; Chao 1 = 24.5; $H' = 1.365$), mango (*Mangifera indica*) L. con 17 ($n = 1,144$; Chao 1 = 18.5; $H' = 1.303$), mora (*Rubus glaucus*) Benth. con 11 ($n = 545$; Chao 1 = 16; $H' = 0.886$), plátano (*Musa* spp.) con 9 especies ($n = 1,798$; Chao 1 = 9; $H' = 0.208$), algodón (*Gossypium hirsutum*) L. con 8 ($n = 5,621$; Chao 1 = 11; $H' = 0.914$) y caucho (*Hevea brasiliensis*) Müll. Arg. con 4 especies ($n = 90$; Chao 1 = 4; $H' = 0.594$). Se encontraron diferencias en la distribución de las especies de trips en los gradientes altitudinales y en las regiones biogeográficas. La especie más abundante, con mayor presencia en cultivos, mayor distribución geográfica y altitudinal, correspondió a *Frankliniella gardeniae* Moulton.

Key words: Thripidae, diversity, Andean, Caribbean, Orinoquia

Agriculture and livestock for open production systems have replaced natural forests, involving loss or alteration of biodiversity (Altieri and Nicholls 2000). Recent studies indicate that

a considerable proportion of the original biodiversity can persist within the remaining elements of the landscape and that the degree of tree cover remaining plays a fundamental role. However,

information on biodiversity in agricultural landscapes is scarce (Sanabria et al. 2008).

The cultivated areas in Colombia represent approximately 5,121,508 ha., involving 47 species of fruit trees on 364,617 ha., 33 species of vegetables planted on 220,773 ha., and 5 species of cereals on 1,010,000 ha. In the Andean, Caribbean, and Orinoquia regions the crops with greatest importance for socioeconomic, agroindustrial, and phytosanitary aspects are avocado (*Persea americana*) with 67,089 ha., cotton (*Gossypium hirsutum*) with 1,150 ha., banana (*Musa* spp.) with 52,900 ha., coffee (*Coffea arabica*) with 775,000 ha., citrus fruits (*Citrus* spp.) with 76,210 ha., maize (*Zea mays*) with 306,000 ha., mango (*Mangifera indica*) with 27,500 ha., blackberry (*Rubus glaucus*) with 12,500 ha., cassava (*Manihot esculenta*) with 270,000 ha., and rubber tree (*Hevea brasiliensis*) with 18,000 ha (Minagricultura 2011).

Colombia is ranked as the second country in the world with the greatest biodiversity, as a result of the geological processes that caused the uplift of the Andes and created new habitats and local isolations. This favored high rates of speciation and endemism in many taxa (Antonelli and Sanmartin 2011, Josse et al. 2012), particularly in the biogeographical mosaics between the Andean, Orinoquia, Guayanesa, Caribbean, Pacific, and Amazonian regions (Hernández et al. 1992). However, it is one of the countries in the Neotropical region for which there is still not a good knowledge of Thysanoptera species associated with natural systems and agroecosystems (Calixto 2005).

The order Thysanoptera comprises 6,161 known species, distributed in two suborders and nine families. The family Phlaeothripidae is traditionally considered as the only family of the suborder Tubulifera (ThripsWiki 2018). The Terebrantia suborder comprises 2,646 described species contained in the families Thripidae (2,201 species); Aeolothripidae (222 species); Melanthripidae (79 species); Stenurothripidae (=Adiheterothripidae) (24 species); Fauriellidae (5 species); Heterothripidae (93 species); Merothripidae (20 species); and Uzelothripidae (2 species) (Buckman et al. 2013). Thripidae are among the most evolved species within Thysanoptera and are the most common and well-known phytophagous thrips, with a wide range of host plants in floral and foliar structures, as well as predators (Mound 2002).

The aim of this study was to determine the composition and structure of the Thripidae assemblages that are present in agroecosystems in the Andean, Caribbean, and Orinoquia regions of Colombia, as well as the geographic and altitudinal distribution of these environments. This work constitutes the first comparative study of Thysanoptera in agroecosystems and is a contribution to the knowledge of the entomofauna of Thysanoptera in Colombia.

Materials and Methods

Study Area, Geographic Location and Sampling

Samplings were carried out from 2013 to 2016, in different agroecosystems of the Andean, Caribbean and Orinoquia regions of Colombia (IGAC 2018) (Fig. 1). Five hundred meters altitude ranges were from 0 to 3,000 meters above sea level (masl) as well as thermal floors according to the climatologic zoning of Caldas-Lang (Mejia 1982, Eslava et al. 1986, Pabon et al. 2001).

Sampling Design

The random sampling involved direct capture of thrips from five leaves, five floral structures (flowers and inflorescences), and five fruits, in 10 plants of each crop, per sampling unit. For this, brushes previously moistened with ethanol and white plastic plates were

used to collect the individuals. The Thysanoptera were deposited in 1.5 ml eppendorf tubes, with a 70% ethanol content, and each sample was assigned a unique identification code. The geographical points were recorded with the help of a GPS Garmin Etrex 30x, in each crop in the Orinoquia regions: cotton, avocado, rubber tree, citrus (*C. latifolia*; *C. sinensis*, *Citrus* sp.), corn, mango, banana, cassava; Andean: cotton, avocado, coffee, citrus (*C. latifolia*, *C. sinensis*, *C. reticulata*, *C. aurantifolia*, *Citrus* sp.), corn, mango, blackberry, banana, cassava and in the Caribbean region: cotton, avocado, coffee, citrus fruits (*C. sinensis*, *C. latifolia*, *Citrus* sp.), corn, mango, banana, and cassava.

Treatment of Samples

Immature stages were separated from the adults, the morphotypes of thrips were sorted and identified and the number of adults was recorded. The specimens were macerated with 5–10% KOH, then rinse in distilled water and dehydrate in 70% ethanol. Subsequently, the insects were mounted in Hoyers solution, and the slides were dried in an oven for 48 h at 35–40°C, according to Mound and Marullo (1996).

Taxonomic Identification

The taxonomic identification was based on morphological characters according to Moulton (1948), Sakimura and O'Neill (1979), Sakimura (1981), Mound and Nakahara (1994), Mound and Marullo (1996), Monteiro (1999), Monteiro (2002), Berzosa and Maroto (2003), Hoddle and Mound (2003), Berzosa and Maroto (2006), Mound and Ng (2009), Cavalleri and Mound (2012), and Lima and Mound (2016). A Nikon SMZ800 stereoscope and a Nikon Type-119YS2-T microscope with phase contrast and the programs for image analysis NIS elements F (v. 4.6) and ToupView-x86 were used.

Analysis of Data

The thrips identifications were sorted according to geographic region and altitudinal gradient. The quality of the Thysanoptera inventory was determined through the curve of species accumulation by region and cultivated plant (Colwell et al. 2004). The programs Past 3 (v3.21) (Hammer 2018) and InfoStat v.2008 (InfoStat 2008) were used to calculate the Shannon-Wiener diversity index (H'), Pielou's equity (J), and Simpson's dominance (D) by region and cultivated plant. We calculated the potential richness of the species with the estimator Chao 1 and the rarefaction curve by region and crop. In addition, distribution, abundance, and range-abundance curves were determined by region and crop (Colwell et al. 2004, Magurran 2004). 'T' Student's were performed to compare the diversity in each crop by region and altitudinal range (Magurran 1989).

Results

Richness and Abundance

18,183 specimens were collected from 1,358 samples, producing a total of 81 species in 20 genera. These thrips were all members of the suborder Terebrantia, and represented the Thripidae subfamilies Thripinae, Panchaethripinae, Sericothripinae, also the Heterothripidae and Aeolothripidae. Thripinae was the most frequent in terms of abundance and species richness, with 70% of the genera and 86.4% of the species, followed by Panchaethripinae with 10% of the genera and 3.7% of the species; Sericothripinae with 5% of genera and 4.9% of species. The families Heterothripidae and Aeolothripidae were each represented by 2.4% of the species collected.

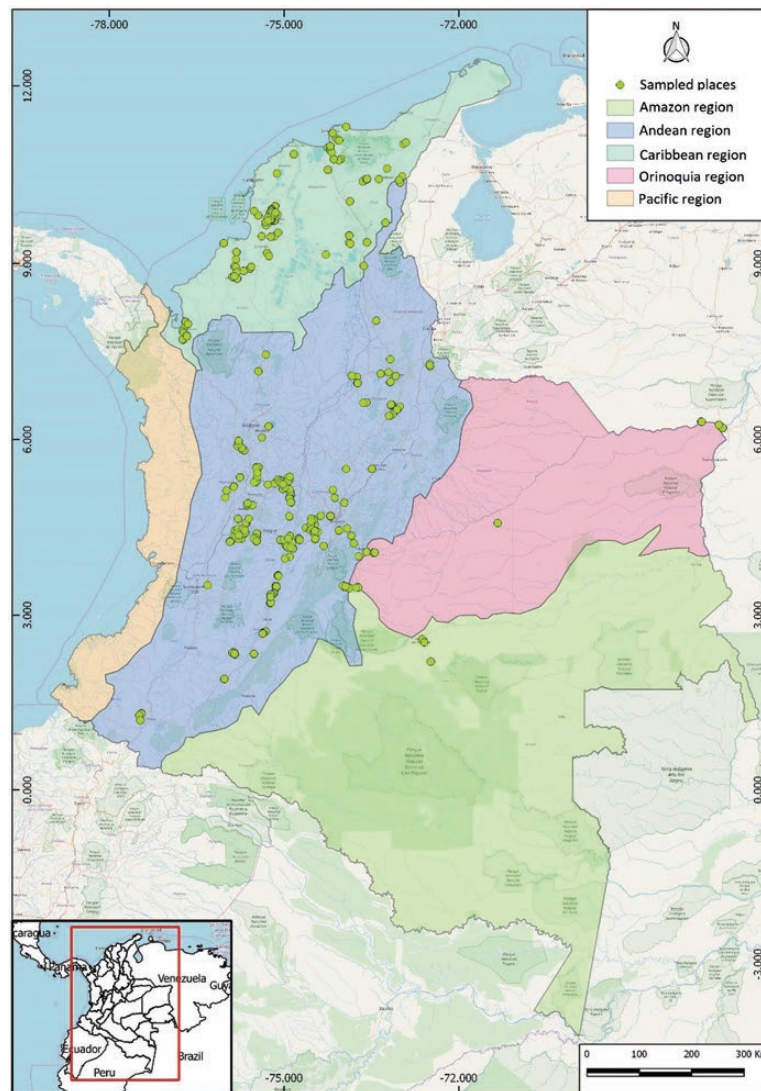


Fig. 1. Total distribution of sampling points ($n = 1,358$) and biogeographical regions in Colombia.

The most species-rich genus was *Frankliniella* Karny with 46 species representing 56.7% of the total species, followed by *Scirtothrips* Hood, with nine species (11%), *Neohydatothrips* John, with four species (4.9%) and *Thrips* Linnaeus, with three species (3.7%). The genera *Arorathrips* Bhatti, *Heliothrips* Haliday, and *Heterothrips* Hood were represented by two species each; while a single species was found for each of *Ambaeolothrips* Mound, *Baileyothis* Kono and O'Neil, *Ceratothripoides* Bagnall, *Chaetanaphothrips* Priesner, *Corynothrips* Williams, *Franklinothrips* Back, *Microcephalothrips* Bagnall, *Nexothrips* Marullo and Mound, *Psectrothrips* Hood, *Rhamphothrips* Karny, *Scirtidothrips* Hood, *Scolothrips* Hinds, and *Selenothrips* Karny (Table 1).

Species with wide geographic distribution in the Andean, Caribbean and Orinoquia regions were *Ceratothripoides brunneus* Bagnall, *Corynothrips stenopterus* Williams, *Frankliniella borinquen* Hood, *Frankliniella brevicaulis* Hood, *Frankliniella cephalica* (Crawford), *Frankliniella gardeniae* Moulton, *Frankliniella gossypiana* (Hood), *Frankliniella insularis* (Franklin), *Frankliniella melanommata* Williams, *Frankliniella parvula* Hood, *Frankliniella zeteki* Hood, *Scirtothrips dorsalis* Hood, *Scirtothrips manihoti* (Bondar), *Scirtothrips panamensis* Hood, and *Thrips palmi* Karny (Table 1).

Of 81 species, 15 (18.51%) showed wide geographical distribution and were reported in 8 crops; these were *Fr. gardeniae*, *Fr. gossypiana*, *Fr. cephalica*, *Fr. borinquen*, *Fr. brevicaulis*, *Fr. parvula*, *Fr. schultzei* (Trybom), *Fr. insularis*, *Fr. melanommata*, *Fr. zeteki*, *T. palmi*, and *S. dorsalis*. In contrast, *C. stenopterus*, *S. manihoti*, and *S. panamensis* were present only in the cassava crop. The species *C. brunneus* Bagnall, *S. dorsalis*, and *T. palmi*, are considered invasives of quarantine interest, originating from the African and Asian continent (Kumar et al. 2013). *C. brunneus* is here newly reported from Colombia where it is present in the Andean, Caribbean and Orinoquia geographical regions in avocado and coffee crops (Table 1).

Single species (singletons) were found on some crops as follows: *Baileyothis limbatus* (Hood), *Fr. cassiae* Berzosa, *Fr. fallaciosa* Priesner, *Franklinothrips orizabensis* Johansen, *Heliothrips haemorrhoidalis* (Bouche) in citrus crops; the species *Fr. bruneri* Watson, *Fr. cotobrusensis* Retana & Mound and *Fr. lorena* Mound & Marullo in coffee crops; *Microcephalothrips abdominalis* (Crawford DL) in cotton; *C. stenopterus*, *R. pandens* Sakimura, *S. lumarius* Mound & Marullo and *S. tenuipennis* zur Strassen in cassava; *S. bisbravae* Johansen and *S. multistriatus* Hood in rubber tree; *S. rubrocinctus*

Table 1. Wealth and abundance of Thripidae by geographical region (An = Andean, Ca = Caribbean, Or = Orinoquia, C = Warm, T = Temperate, F = Cold), altitudinal range and climatic zonation.

Species	An.	Ca.	Or.	Total	Altitude		Thermal Zone			Crops											
					Min	Max	C	T	F	Persea	Gossypium	Coffea	Hevea	Citrus	Zea	Mangifera	Rubus	Musa	Manihot	Total	
<i>Ambaeolothrips microstriatus</i> (Hood)	2			2	1000	1500		X		2											2
comb. n.																					
<i>Arorathrips fulvus</i> (Moulton)		1		1	1	500	X								1					1	1
<i>Arorathrips mexicanus</i>	2			2	1	500	X								2					2	2
(Crawford DL)																					
<i>Baileothrips limbatus</i> (Hood)	1			1	1	500	X									1				1	1
<i>Ceratothripoides brunneus</i> Bagnall	2	1	2	5	1	1500	X	X		3		2								5	5
<i>Chaetanaphothrips orchidii</i>		1		1	1	500	X			1										1	1
(Moulton)																					
<i>Corynothrips stenopterus</i> Williams	6	16	79	101	1	1500	X	X											101	101	101
<i>Frankliniella bicolor</i> Moulton	13			13	1000	2000		X		2		11							13	13	13
<i>Frankliniella boringuen</i> Hood	201	1403	30	1634	1	2000	X	X		1555		7		20	11	37			4	1634	1634
<i>Frankliniella brevicaulis</i> Hood	376	801	130	1307	1	1500	X	X		45	17	3		4	1082	140		5	11	1307	1307
<i>Frankliniella bruneri</i> Watson	1			1	1000	1500		X				1							1	1	1
<i>Frankliniella brunnea</i> (Priesner)	1			1	1500	2000		X		1									1	1	1
<i>Frankliniella caseariae</i> Moulton	8	12		20	1	1500	X	X		18		2								20	20
<i>Frankliniella cassiae</i> Berzosa			2	2	1	500	X													2	2
<i>Frankliniella cephalica</i> (Crawford DL)	552	357	221	1130	1	2000	X	X		46	657	53		44	209	92		7	22	1130	1130
<i>Frankliniella cotobrusensis</i> Retana & Mound	2			2	1000	1500		X				2								2	2
Mound																					
<i>Frankliniella curta</i> (Hood)	3			3	1500	2000		X		2									1	3	3
<i>Frankliniella desmodii</i> Mound & Marullo	69			69	500	1000	X			69										69	69
Marullo																					
<i>Frankliniella distinguenda</i> Bagnall		14	1	15	1	1000	X				1				6	7			1	15	15
<i>Frankliniella diversa</i> Hood		1		1	1	500	X			1									1	1	1
<i>Frankliniella fallaciosa</i> Priesner	1			1	1000	1500		X							1					1	1
<i>Frankliniella fulvipennis</i> Moulton	2			2	1000	2000		X		1		1								2	2
<i>Frankliniella gardeniae</i> Moulton	3924	315	29	4268	1	3000	X	X	X	1998		1090		384	21	754	13	2	6	4268	4268
<i>Frankliniella gemina</i> Bagnall	9			9	1000	1500		X							9					9	9
<i>Frankliniella gossypiana</i> (Hood)	42	23	1	66	1	2500	X	X	X	10	1				43	3		9		66	66
<i>Frankliniella insularis</i> (Franklin)	83	72	2	157	1	2000	X	X	X	2		20		80	52	1		2		157	157
<i>Frankliniella invasor</i> Sakimura	86	63		149	1	2500	X	X	X	66		16		33	4	28	1	1		149	149
<i>Frankliniella kelliae</i> Sakimura	38	181		219	1	2000		X	X	19		27		173						219	219
<i>Frankliniella lorena</i> Mound & Marullo	1			1	1000	1500		X				1								1	1
Marullo																					
<i>Frankliniella melanommatata</i> Williams	28	56	19	103	1	1500	X	X						9	1			93		103	103
<i>Frankliniella minuta</i> (Moulton)		4		4	1000	1500		X									4			4	4
<i>Frankliniella musaeperda</i> Hood	60	2		62	1	2000	X	X		1				5		9		2		62	62
<i>Frankliniella occidentalis</i> (Pergande)	36		1	37	1500	3000		X		3				1	16		17			37	37
<i>Frankliniella panamensis</i> Hood	482			482	1500	3000		X	X	1		1			68		412			482	482
<i>Frankliniella parvula</i> Hood	422	1541	48	2011	1	2000	X	X		42		101		58	78	1	1730	1		2011	2011
<i>Frankliniella peruviana</i> Hood	9		1	10	1	2000	X	X				9				1				10	10
<i>Frankliniella rostrata</i> Priesner	5	29		34	1	1500	X	X										34		34	34

Table 1. Continued

Species	An.	Ca.	Or.	Total	Altitude		Thermal Zone			Crops								Total																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
					Min	Max	C	T	F	Persea	Gossipium	Coffea	Hevea	Citrus	Zea	Mangifera	Rubus		Musa																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
Frankliniella schultzei (Trybom)	1	104	5	109	1	1500	X	X																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															

Table 1. Continued

Species	An.	Ca.	Or.	Total	Altitude			Thermal Zone			Crops									
					Min	Max		C	T	F	Persea	Gossypium	Coffea	Hevea	Citrus	Zea	Mangifera	Rubus	Musa	Manihot
<i>Scirtothrips panamensis</i> Hood	81	91	113	285	1	2000		X	X					14					271	285
<i>Scirtothrips perseae</i> Nakahara	12			12	1000	1500		X	X		12									12
<i>Scirtothrips</i> sp.	2			2	1000	1500		X										2		2
<i>Scolothrips tenuipennis</i> zur Strassen		2		2	1	500		X											2	2
<i>Selenothrips rubrocinctus</i> Giard	1	1		2	1	500		X									2			2
<i>Thrips palmi</i> Karny	3606	191	10	3807	1	2010		X	X	X	1	3766	23			9	5		3	3807
<i>Thrips tabaci</i> Lindeman	5			5	1500	2500		X	X	X		4						1		5
<i>Thrips</i> sp.	1			1	1500	2500		X	X	X						1				1
Total	11360	5960	853	18183							4047	5631	1395	90	836	1647	1144	545	1798	18183

Giard in mango; *Fr. minuta* (Moulton) in plantain orchards; *A. microstriatus* (Hood) comb. n., *C. orchidii* (Moulton), *Fr. brunnea* (Priesner), *Fr. desmodii* Mound & Marullo, *Fr. diversa* Hood, *Fr. tritici* (Fitch), *Fr. vargasii* Retana & Mound, *H. sericatus* Hood, *Nexothrips perseae* Marullo & Mound, *P. palmerae* Mound & Marullo, *S. hansonii* Mound & Hoddle and *S. perseae* Nakahara in avocado; the species *Fr. senckenbergiana* Berzosa & Maroto and *N. gracilipes* Hood in blackberry cultivations; and *A. fulvus* (Moulton), *A. mexicanus* (Crawford DL), *Fr. gemina* Bagnall, *Scirtidothrips* sp. and *T. sp.* in corn crops (Table 1).

Avocado orchards presented the greatest richness with 40 species, followed by coffee with 26, cassava with 25, corn and citrus with 22, mango with 17, blackberry with 11, banana with 9, cotton with 8 and 4 species in rubber tree (Tables 1 and 2). The highest abundance of thrips individuals occurred on cotton crops, with 5,621 specimens, followed by avocado with 4,049, banana with 1,759, corn with 1,647, coffee with 1,416, mango with 1,136, cassava with 1,092, citrus with 842, blackberry with 355 and rubber tree with 90 specimens (Table 1).

The species *Fr. gardeniae* was the most abundant, with 4,268 specimens in floral structures of citrus, coffee, mango, cassava, banana, avocado, blackberry and corn; followed by *Thrips palmi* with 3,797 specimens in floral and foliar structures of coffee, cotton, corn, cassava, mango and avocado (Table 1). *S. dorsalis* was found in foliar structures and fruits in cotton, while in citrus, pepper and mango crops it was associated with foliar structures.

Diversity and Structure

Regarding the distribution in the Andean, Caribbean and Orinoquia regions, the species accumulation curves formed an asymptote (Fig. 2A–C), which would indicate that the species were representative of the Thripidae community in the sampled crops. Similarly, an asymptote occurred with the species in avocado, cotton, coffee, corn, blackberry, mango, cassava, banana, and citrus crops. In the rubber tree, the results suggest the need to carry out a greater sampling effort that allows a greater representation of species (Fig. 2D–M).

The composition of Thysanoptera by crop and between geographical regions was significantly different. In citrus orchards there were no differences between all regions; in coffee crops, differences were observed between the Andean-Caribbean regions; in cotton, there were differences between the Andean-Caribbean and the Caribbean-Orinoquia regions. However, between the Andean-Orinoquia regions there were none. In mango orchards, there were differences among all regions; in cassava crops, there were no differences between the Andean-Caribbean regions; in banana crops, differences were observed in all regions; in avocado orchards, no differences were observed between the Andean-Orinoquia regions; in corn crops, there were differences in the Andean-Caribbean regions, while in the Caribbean-Orinoquia and Andean-Orinoquia there were no differences (Table 3).

The Shannon index (H') calculated for the Andean, Caribbean and Orinoquia regions showed that the values of diversity were low in all of them (Table 4); however, (H') was highest in the Orinoquia ($H' = 2.301$), followed by the Caribbean region ($H' = 2.256$) and Andina ($H' = 1.986$). When comparing them through the T test, it was determined that between the Andean-Caribbean regions ($t = -13.603$, $df = 14596$, $P = 0.000$; $P \leq 0.01$) and Andina-Orinoquia ($t = -8.3203$, $df = 1202.5$; $P = 0.000$; $P \leq 0.01$) there were significant differences in their diversities. In contrast, between the Caribbean and Orinoquia regions ($t = -0.23933$, $df = 1281.3$; $P = 0.81089$; $P \leq 0.01$) there were none (Fig. 3). The richness by region corresponded

Table 2. Observed and expected crop richness, with the Chao I estimator, Shannon-Wiener diversity index (H'), Pielou's equity (J), and Simpson's dominance (D)

Crop	Abundance	Observed reachness	Chao 1	H'	J	D
<i>P. americana</i>	4,047	40	55.17	1.302	0.353	0.393
<i>C. arabica</i>	1,395	26	33	1.026	0.315	0.618
<i>M. esculenta</i>	1,050	25	29.67	1.635	0.508	0.288
<i>Citrus</i> spp.	836	22	25.75	1.748	0.565	0.273
<i>Z. mays</i>	1,647	22	24.5	1.365	0.442	0.454
<i>M. indica</i>	1,144	17	18.5	1.303	0.460	0.459
<i>R. glaucus</i>	545	11	16	0.886	0.369	0.594
<i>Musa</i> spp.	1,798	9	9	0.208	0.095	0.926
<i>G. hirsutum</i>	5,621	8	11	0.913	0.440	0.500
<i>H. brasiliensis</i>	90	4	4	0.594	0.428	0.683

to 24 species in the Orinoquia, 42 species in the Caribbean and in the Andean region 60 species (Table 4).

Diversity reached high values in corn, cassava, and citrus; however, it was low in rubber tree, banana, blackberry and cotton (Table 2). Equity (J), showed that the richness was represented by some dominant species and the probability of finding two random individuals of the same species (dominance), took the maximum value in banana and rubber tree, which represents a low diversity of species in these crops, contrary to citrus and cassava crops, where diversity was high, with fewer dominant species (Table 2).

The richness expected by Chao 1, indicated that in rubber tree plantations no more species than those found in this study will be obtained; while in other crops there may be an increase of one to ten species if the sampling effort is increased (Table 2). The rarefaction analysis indicated that by increasing the sampling effort in the Andean region, a greater number of species and abundance of individuals will be obtained in all crops (Fig. 4A–D). In this work, cotton had the highest abundance of species present; but avocado orchards had the greatest species richness (Fig. 4B).

Association With Cultivated Plants

The distribution of abundance was not equal in each of the crops, since very few species were abundant with moderate dominance and many species represented as 'singletons' (Table 2). It is evident that the Andean region, in addition to having the greatest richness, also presented the largest number of singletons, followed by the Caribbean region (Fig. 5A). In the Orinoquia, a less steep curve was observed for most of the species, i.e., a region with low-dominance species (Fig. 5C) and with the need to carry out a greater sampling effort, which will allow a greater representation of species present in the region.

The measure of the turnover of species through the different cultivated plants, showed that 48 (59.26%) of the species were found on a single plant species, 12 species (14.81%) on two plants species and 21 species (25.93%) on three to eight cultivated plants species. The species *Fr. gardeniae*, *Fr. brevicaulis*, *Fr. cephalica*, *Fr. invasor*, *Fr. parvula*, and *T. palmi* could be considered as 'polyphagous' species due to their association with more than six cultivated plants species of different genera and botanical families, while *S. perseae*, *S. hansonii* in avocado and *S. multistriatus* in rubber tree, could be considered as monophagous species.

Out of 26 species of thrips present in coffee crops, 19 species were found in avocado, 7 in cotton, 11 in corn, 6 in blackberry, 12 in cassava but none in rubber tree. In citrus orchards, 22 species were

found of which 13 were found in avocado, 4 in cotton, 11 in corn, 6 in blackberry, 11 in cassava and none species in rubber tree. In mango orchards, 17 species were found, with 12 also found in avocado, 7 in cotton, 11 in corn, 2 in blackberry, 12 in cassava and none species in rubber tree. In plantain crops, with a richness of 9 species, 6 were found in avocado, 2 in cotton, 5 in corn, 2 in blackberry, 5 in cassava and no species in rubber tree.

Variation in Species Composition in the Altitudinal Gradient

According to Table 1, the measurement of species turnover across the altitudinal gradient showed that 45 (55.55%) of the species are shared in an altitudinal range, six species (7.4%) in two altitudinal ranges, 13 species (16.04%) in three altitudinal ranges, 11 species (13.58%) in four altitudinal ranges, five species (6.17%) in five ranges and one species (1.24%) in six altitudinal ranges. The species *Fr. gardeniae* (0–3,000 masl), *Fr. invasor* (0–2,500 masl), *Fr. kelliiae* (0–2,000 masl), *Fr. musaeperda* (0–2,000 masl), *Fr. parvula* (0–2,000 masl), *Fr. williamsi* (0–2,000 masl), *T. palmi* (0–2,000 masl) and *Fr. xanthomelaena* (0–2,500 masl), corresponding to 5.19% of the species that shared wide altitudinal ranges in the hot-tempered and cold zone in the Andean, Caribbean, and Orinoquia regions; while the species, *Fr. akaina* (2,500–3,000 masl), *Fr. occidentalis* (2,000–3,000 masl), *Fr. senckenbergiana* (2,500–3,000 masl), *Fr. panamensis* (1,500–3,500 masl), *T. tabaci* (1,500–2,500), *Thrips* sp. (2,000–2,500 masl), they shared more restricted altitudinal ranges in the cold zone of the Andean region.

The composition of Thysanoptera between 2,500 and 3,000 masl (≤ 0.15) showed a low similarity value with a representation of 1.3% of species richness. The greatest similarity (≤ 0.90) was observed in the altitudinal ranges 0–1,000 masl and 2,000–3,000 masl with 23.4 and 29.9% of the species respectively; while 45.5% of the species were found in the altitudinal range between 1,000 and 2,000 masl. The Shannon index (H') calculated for the altitudinal gradients showed that the values of diversity are relatively high in all of them; however, it was higher in 0–500 masl ($H' = 3.8286$), followed consecutively by 501–1,000 masl ($H' = 3.434$), 1,001–1,500 masl ($H' = 3.8918$), 1,501–2,000 masl ($H' = 3.3673$), 2,001–2,500 masl ($H' = 2.4849$) and 2,501–3,000 masl ($H' = 1.3863$). As shown in Fig. 6, when comparing the (H') of all the altitudinal gradients by the T test, it was determined that there are no differences between AB ($t = 2.4362$, $df = 66.748$, $P = 0.017516$, $P \leq 0.01$) and EF ($t = 3.0245$, $df = 7.5078$; $P = 0.01772$; $P \leq 0.01$); however, there were differences between BC ($t = -2.8612$, $df = 66.233$, $P = 0.005642$, $P \leq 0.01$) and CD ($t = 3.2135$, $df = 61.219$; $P = 0.0021$; $P \leq 0.01$) (Fig. 6).

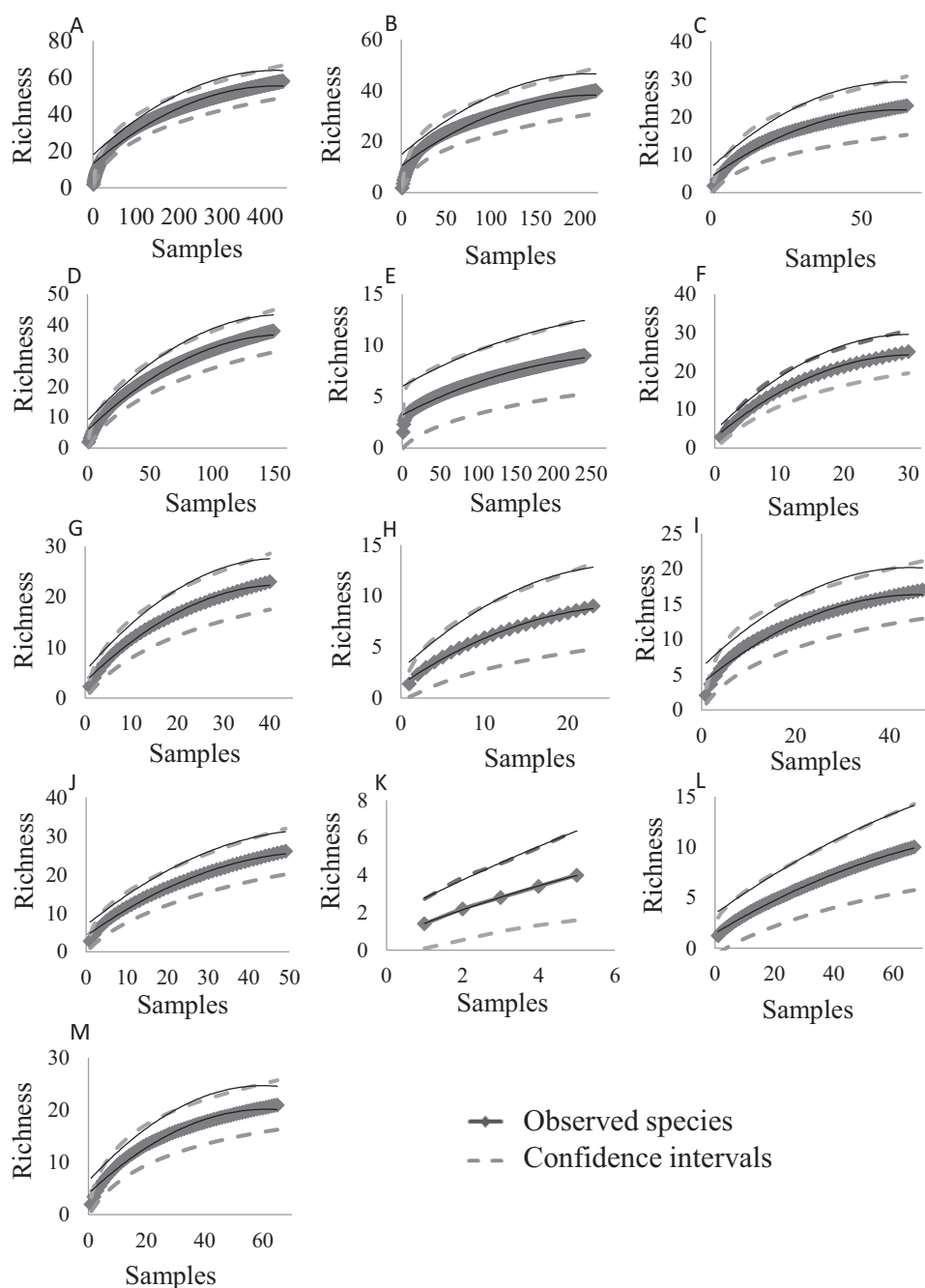


Fig. 2. Curves of species accumulation for the Thripidae sample by region and crop. (A) Andean Region, (B) Caribbean Region, (C) Orinoquia Region, (D) Avocado, (E) Cotton, (F) Coffee, (G) Corn, (H) Blackberry, (I) Mango, (J) Cassava, (K) Rubber tree, (L) Banana, and (M) Citrus.

Discussion

Composition of Thripidae Samples

Currently, there are few studies on Thysanoptera in Colombia, including the species richness, ecological function, host plants, habitats, occupied niches, and taxonomy. According to Mound (2005), the knowledge of the group in the Neotropics is dominated by works in descriptive taxonomy and pest management. As a result, there is a deficit of research that deepens our understanding of the adaptations of species to their environment, the relationships they maintain with it and how the underlying processes of diversification occur.

The diversity of thrips found was high especially in the Andean region, followed by the Caribbean region and Orinoquia, which agrees with the results of other studies carried out in other groups of invertebrates (Sanabria et al. 2008, Gutiérrez and Ulloa 2006, Sissa and Navarrete 2016). Thysanoptera is expected to be more diverse in natural systems or those less altered by the action of man. More than 2,000 species are recorded from the Neotropics, but their interactions and distributions are little known (Mound 2002, Goldaracena et al. 2012, Rocha et al. 2012, Infante et al. 2017). Therefore, knowledge of the functionality of species is a priority, particularly the interactions with cultivated and native plants. There may be positive correlations between plant richness and the diversity

Table 3. Comparison of Thripidae composition for Shannon H', between regions and crops

Crops/region	Persea		Gossypium		Coffea		Citrus		Mangifera		Zea		Musa		Manihot	
	t	P < 0.05	t	P < 0.05	t	P < 0.05	t	P < 0.05	t	P < 0.05	t	P < 0.05	t	P < 0.05	t	P < 0.05
Andean - Orinoquia	-1.615	0.108	-0.280	0.770	-	-	-0.300	0.690	2.950	0.004	1.760	0.090	10.530	0.001	1.900	0.050
Andean - Caribbean	8.254	0.001	-14.700	0.001	-8.34	0.001	-0.460	-0.140	-26.290	0.001	6.660	0.001	7.810	0.001	-1.390	0.160
Caribbean - Orinoquia	-7.230	0.001	6.480	0.001	-	-	0.250	0.790	17.900	0.001	0.310	0.750	5.240	0.001	4.000	0.001

Bold value indicates statistical significance is 0.05 = 5%.

of thrips feeding habits (such as monophagous, oligophagous, or polyphagous), also their ecosystem functions as pollinators or predators (Saxena et al. 1996, Sakai 2001, Mound 2002).

In these agroecosystems, although phytophagy is the main food habit in the Thripidae species, pollen grain consumption and predation on other arthropods could also be a food source that could affect the faunal composition (Trichilo and Leigh 1988, Saxena et al. 1996, Sakai 2001). Thrips are opportunistic insects that exhibit a wide range of life stories, most species are fungivorous and phytophagous, while a few are predators. The number of thrips present is remarkable, especially when the crops are flowering as in Infante et al. (2017).

Diversity and Structure

The Thysanoptera is a small order compared to Coleoptera or Diptera, but in part, this may due to inadequate sampling and ineffective collection methods. All this implies that production of a representative inventory of Thripidae for Colombia will be a complex and fragmented mission. It will need an exploration of natural habitats that have been little altered by man, where plant heterogeneity is likely to be related to a high thrips diversity. However, Sanabria et al. (2008), indicate that the different elements of a landscape contribute to regional or local diversity. Cultivated systems could thus benefit the diversity of the total entomofauna, as in silvopastoral systems and perennial crops that exhibit a comparable species richness with natural ecosystems.

Although the abundance observed between regions and crops is not equitable due to the low number of abundant species, the high number of singleton species and the geographical distribution of the crops plants, the highest richness was obtained in the region Andean, in contrast to the Caribbean and Orinoquia regions. This could be explained by the existence of a greater number of ecosystems with landscape heterogeneity, life zones, climatic and floristic variability in comparison with the Caribbean and Orinoquia regions. The Caribbean and Orinoquia regions have a predominance of natural savannahs, very diverse life zones and floristic landscapes of tropical dry forest (bs-T), or tropical humid forest (bh-T) fragmented, dominated by grasses and legumes (Cole 1986, Antonelli and Sanmartin 2011, Sissa and Navarrete 2016).

According to IAvH (1998), agricultural and livestock practices have fragmented and transformed the landscape of the regions in Colombia into complex mosaics of paddocks, agricultural fields, forest fragments, and other types of tree cover. Although these elements of the landscape provide a wide diversity of habitats in the Andean region, they are generally considered of little value in conservation and are scarcely included in biodiversity studies (Fajardo et al. 2006). However, Sanabria et al. (2008), Sissa and Navarrete (2016), and Gutiérrez and Ulloa (2006) indicate that a considerable proportion of the original biodiversity can persist within these elements of the landscape, and the remaining tree cover could play a fundamental role; unfortunately, information on biodiversity in agricultural landscapes remains scarce.

Association With Cultivated Plants

In this work, we do not consider whether the crops plants are breeding hosts for the collected thrips species, because we did not identify and record the immature stages. Published host-plant records are often imprecise, such that it is difficult to recognize patterns of food resource exploitation and distinguish between monophagy, oligophagy and polyphagy (Mound 2005, Marullo 2009). These are fundamental elements for the identification and delimitation of

Table 4. Observed and expected richness by region, with the Chao I estimator, Shannon-Wiener diversity index (H'), Pielou's equity (J) and Simpson's dominance (D)

Region	Observed richness	Abundance	Chao 1	H'	J	D
Orinoquia	24	863	31	2.301	0.7242	0.1328
Caribbean	42	5,960	57.6	2.256	0.6037	0.1552
Andean	60	11,360	70.5	1.986	0.485	0.2326

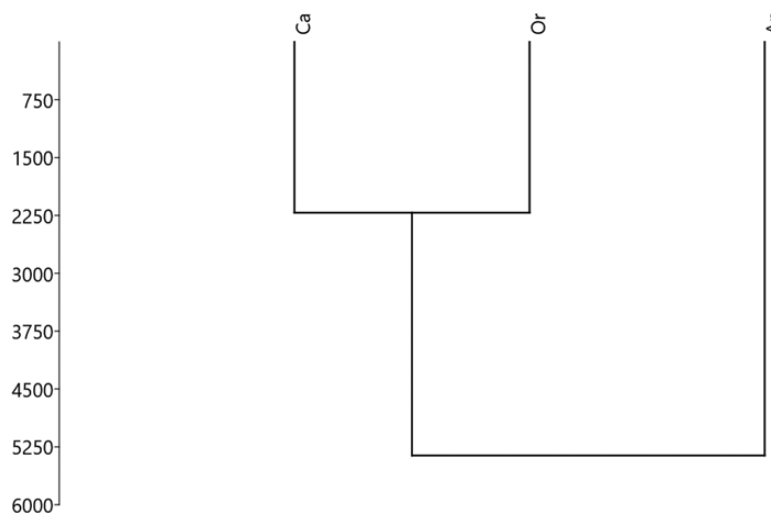


Fig. 3. Analysis of grouping by geographical region (An = Andean, Ca = Caribbean, Or = Orinoquia) with Euclidean distance for species richness ($n = 231$, Cophenetic corr = 0.99, read cases = 231, omitted cases = 0; $P < 0.01$).

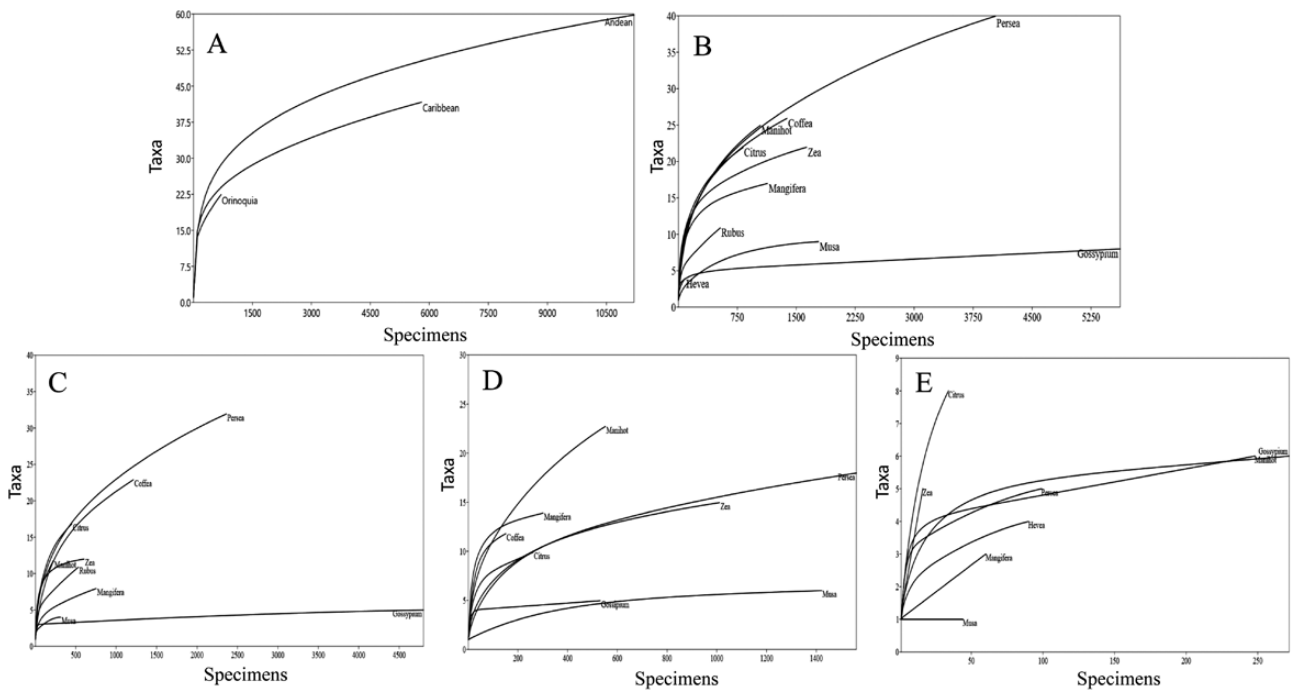


Fig. 4. Rarefaction curve for richness of Thripidae species: (A) Geographic region, (B) Crops, (C) Andean region crops, (D) Caribbean region crops, and (E) Orinoquia region crops.

species from a systematic, ecological and ethological context (Padial et al. 2010, Pante et al. 2015). Among the cultivated plants studied here, coffee, mango, citrus, and bananas are perennials native to Africa, Asia and Oceania, and

introduced to the New World in the 16th, 17th, and 18th centuries by Spanish and Portuguese conquerors (Bukasov 1981, Hernández and Córdova 2011). Many native thrips species, opportunistically pass to the introduced species from avocado, corn, cassava, and other

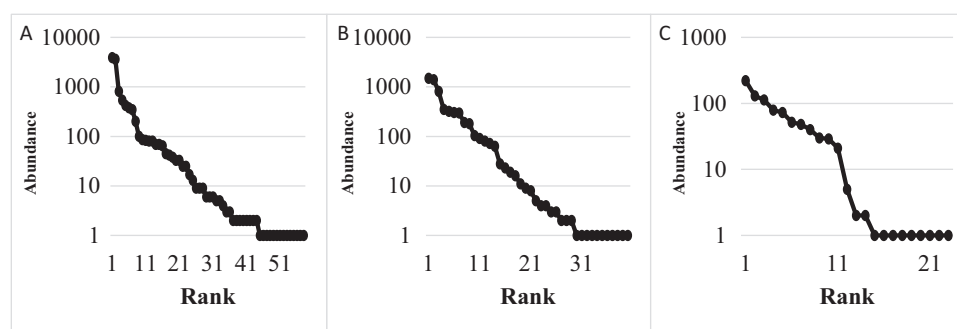


Fig. 5. Range-abundance curves of the species in Thripidae by geographic region. (A) Andean Region, (B) Caribbean Region, and (C) Orinoquia Region.

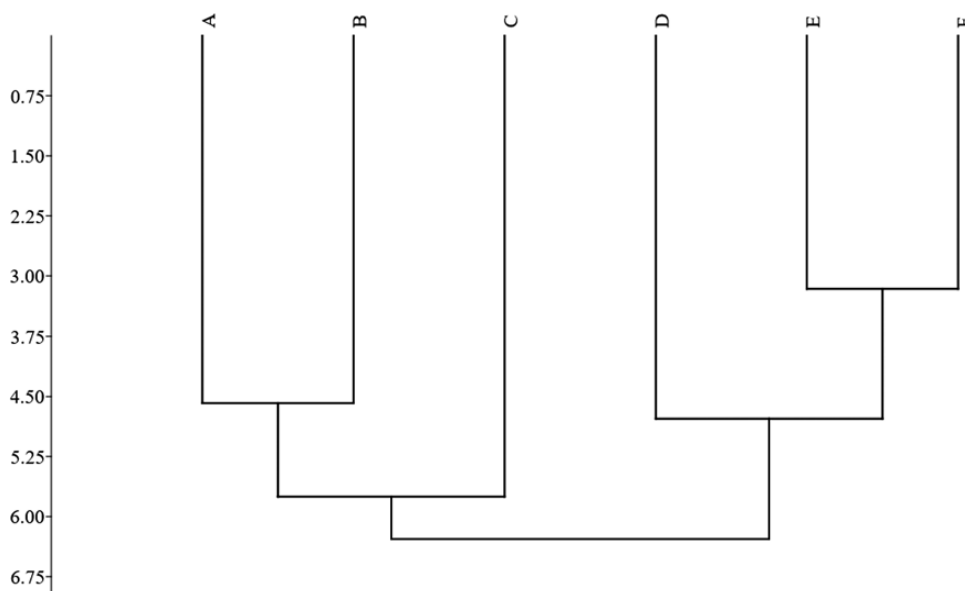


Fig. 6. Analysis of altitudinal grouping by Euclidean distance for altitudinal gradients in meters (A = 0–500; B = 501–1,000; C = 1,001–1,500; D = 1,501–2,000; E = 2,001–2,500; and F = 2,501–3,000) ($n = 486$, Cophenetic corr = 0.8389, read cases = 486, omitted cases = 0, $P < 0.01$).

wild ancestral plants of Neotropical origin (Sauer 1952, Bukasov 1981, Rocha et al. 2012), to the introduced species, possibly in response to the food supply and abundance of pollen and nectar during the flowering seasons, according to Rocha et al. (2012).

Variation in Composition of Species in the Altitudinal Gradient

In this study, we found that species richness decreases gradually as altitude increases with the correlated temperature decrease. However, it was in the altitudinal range between 1,000 and 2,000 masl, where 45.5% of the total of the species was found, possibly as a result of the presence of a greater floristic diversity, ecosystems with landscape heterogeneity, greater number of life zones and climatic variability. In such a way, the species richness is not precisely linear, with respect to the altitude-temperature gradient. These results agree with the observations obtained by Wolda (1986), Gutiérrez and Ulloa (2006), Sissa and Navarrete (2016), with different groups of tropical insects.

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