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ABUNDANCE AND SPECIES RICHNESS OF LEAFHOPPERS AND PLANTHOPPERS (HEMIPTERA: CICADELLIDAE AND DELPHACIDAE) IN BRAZILIAN MAIZE CROPS

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Abstract

Insects in the Cicadellidae and Delphacidae families, common in grasses, are an important group of vectors of viruses and mollicutes, which cause diseases in several plant species. The goal of this study was to evaluate the abundance and species richness of Cicadellidae and Delphacidae and the presence of potential vectors of viruses and mollicutes in maize crops in Brazil. Insects were collected using sweep nets in maize crops in 48 counties of 8 states, distributed in 4 regions of Brazil in the yr 2005, 2006 and 2007, with a total of 198 samples. The collected material was screened, and the leafhoppers and planthoppers were identified at the species level. A total of 4233 Cicadellidae specimens, including 30 species, and 205 Delphacidae specimens, including 9 species, were collected. The most abundant species was *Dalbulus maidis* (Delong & Wolcott) representing 90.1% of leafhoppers and planthoppers. Abundance and species richness differences were observed between the northeast and center-south regions of Brazil. Eight species of leafhoppers and planthoppers were identified as vectors or potential vectors of viruses and mollicutes in maize, although some of these viruses are not reported in Brazil. Among these species, we identified the planthoppers, *Caenodelphax teapae* (Fowler), *Peregrinus maidis* Ashmed, *Pyrophagus tigrinus* Remes Lenicov & Varela and *Toya propinqua* (Fieber) are experimental vectors of *Mal de Río Cuarto virus*, which is a quarantine virus in Brazil. Two Cicadellidae species and 3 Delphacidae species were reported for the first time in Brazil.

Key Words: insect vectors, maize viruses, mollicutes, phytoplasma, spiroplasma

Resumo

Cigarrinhas das famílias Cicadellidae e Delphacidae são comuns em gramíneas e formam um grupo reconhecidamente importante de insetos vetores de vírus e molicutes, agentes causais de doenças em diversas espécies vegetais. O objetivo deste estudo foi avaliar a abundância e a riqueza se espécies de Cicadellidae e Delphacidae e a presença de vetores potenciais desses fitopatógenos na cultura do milho, em regiões produtoras desse cereal, no Brasil. Utilizando dé rede entomológica, cigarrinhas foram coletadas em lavouras de milho nos anos de 2005, 2006 e 2007 em 48 municípios de 8 estados e 4 regiões do Brasil, em um total de 198 amostras. O material coletado foi separado e identificado em nível de espécie. Foram coletados 4233 espécimes de Cicadellidae pertencentes a 30 espécies e 205 espécimes de Delphacidae de nove espécies. A espécie mais abundante foi *Dalbulus maidis* representando 90,1% das cigarrinhas. Diferenças em abundância e riqueza de species foram observadas entre as regiões nordeste e centro-sul do Brasil. Oito espécies de cigarrinhas (Cicadellidae e Delphacidae) são vetores ou vetores potenciais de vírus e mollicutes que infectam o milho, embora a ocorrência de alguns desses fitopatógenos não esteja relatada no Brasil. Dentre es-

sas espécies identificou-se as cigarrinhas *Caenodelphax teapae* (Fowler), *Peregrinus maidis* Ashmed, *Pyrophagus tigrinus* Remes Lenicov & Varela e *Toya propinqua* (Fieber), vetores em condições experimentais do *Mal de Río Cuarto virus*, que é um vírus quarentenário para o Brasil. Duas espécies de Cicadellidae e 3 de Delphacidae são registradas pela primeira vez no Brasil.

Palavras Chave: insetos vetores, viroses em milho, mollicutes, fitoplasma, spiroplasma

Species of Cicadellidae and Delphacidae families are widely distributed in the world, including the Americas, usually inhabiting grasses (Nielson 1985; O'Brien & Wilson 1985). Many species of these 2 families are vectors of phytopathogenic virus and mollicutes, which cause severe symptoms in several plant hosts, including maize (Lopes & Oliveira 2004). In Brazil, there is little information about their incidence in maize and their potential as vectors of viruses and mollicutes in this crop.

Studies about identification, biology and ecology of insect vectors of viruses and mollicutes, as well as the epidemiologic characteristics of incidence and damage by the vectored pathogens, are essential to the development of efficient management strategies to control the resulting diseases. Also, knowledge of these aspects is important to mitigate risks regarding the possible introduction of new diseases and or their insect vectors, because Brazil has approximately 15.7 thousand kilometers of frontiers with other South American countries (IBGE 2011).

More than 20 viruses and 2 maize stunting diseases caused by mollicutes have been described in maize crops around the world, and their causal agents are transmitted by insect vectors, mainly leafhoppers, planthoppers, and aphids (Nault 1980; Remes Lenicov et al. 1985; Shurtleff 1992; Thottappilly et al. 1993; Velazquez et al. 2006). In Brazil, the corn leafhopper *Dalbulus maidis* (Delong & Wolcott) (Hemiptera: Cicadellidae) is the insect vector of corn stunt spiroplasma (*Spiroplama kunkelii* Whitcomb et al.), maize bushy stunt phytoplasma and *Maize rayado fino virus*, diseases that caused severe losses in commercial maize crops (Massola Junior et al. 1999; Oliveira et al. 2002a; Oliveira et al. 2003). Other viruses reported in maize in Brazil are: *Sugarcane mosaic virus* transmitted by the aphid *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae), one the most efficient and common vector-species in maize, and *Maize mosaic virus*, transmitted by the planthopper *Peregrinus maidis* Ashmed (Hemiptera: Delphacidae) (Edwardson & Christie 1991; Waquil et al. 1996; Lopes & Oliveira 2004). Besides these phytopathogens several other important viruses transmitted by leafhoppers and planthoppers have been reported in countries of the Americas. In the USA, there are reports of *Maize chlorotic dwarf virus* and *Maize fine streak virus* transmitted mainly by the leafhopper *Graminella nigrifrons* (Forbes) (Hemiptera: Cicadellidae) (Choudhury & Rosenkranz 1983; Nault 1989; Redinbaugh et al. 2002). Also in the USA, Peru and Venezuela the occurrence of *Maize stripe virus* transmitted by the planthopper *P. maidis* was described (Gingery et al. 1981). In Argentina, severe outbreaks of *Mal de Rio Cuarto virus*, transmitted by the planthopper *Delphacodes kuscheli* Fennah (Hemiptera: Delphacidae), caused severe losses in maize crops (Remes Lenicov et al. 1985; Lenardón et al. 1998; Ornaghi et al. 1999; Truol et al. 2001).

The goal of this survey was to evaluate the abundance and species richness of the Cicadellidae and Delphacidae families in Brazilian maize crops and verify the presence of species, which can become important vectors of new viruses and mollicutes in this crop.

Material and Methods

Sampling locations

Sampling of leafhoppers and planthoppers specimens occurred in the maize experimental stations of Pioneer Seeds in the following counties: Toledo/Paraná, Passo Fundo/Rio Grande do Sul, Itumbiara/Goiás, and Balsas/Maranhão, where this cereal is cultivated all yr-long, and in maize commercial crops, in the following states and counties: Minas Gerais (Lavras, Ingaí, Três Corações, Pouso Alegre, São Gonçalo do Sapucaí, São Sebastião da Bela Vista, Pimenta, Alpinópolis, Luz, Santa Juliana, Araxá, Nova Ponte, Uberlândia); Goiás (Itumbiara); São Paulo (Altinópolis); Paraná (Lapa, São Mateus do Sul, Capanema, Cornélio Procópio, Campo Mourão, Toledo, Cafelândia, Santa Tereza do Oeste, Santo Antônio do Sudoeste, Cambe, Barracão, Santa Mariana, Mandaguari, Jurandá, Maringá, Apucarana); Santa Catarina (São José do Cedro, São Miguel do Oeste, Cunha Porã, Iraceminha, Irani, Guaraciaba, Guarujá do Sul, Nova Erechim); Rio Grande do Sul (Frederico Westphalen, Passo Fundo, Pulador, Boa Vista das Missões); Maranhão (Balsas, São Raimundo das Mangabeiras, Tasso Fragoso, Vargem Limpa), and Piauí (Baixa Grande do Ribeiro) (Fig. 1; Table 1). Sampling occurred in Jan 2005 and 2007, and in Feb 2006, except in the states of Maranhão, and Piauí, where sampling occurred in Apr 2005, 2006 and 2007. Samples were collected according to

Fig. 1. Map showing the collection localities of leafhoppers and planthoppers (Hemiptera: Cicadellidae and Delphacidae) in maize in Brazil (see Table 1 for abbreviations of names of localities).

the rainy season and to the maize growing stages in different regions of the country. The period from Oct to Mar concentrates the summer crop and the second maize crop season ("safrinha") in center-south of Brazil. The period from Apr to Aug concentrates the maize crop in northeastern part of Brazil.

Insect sampling

The insects were collected using 35cm-diam sweep nets made of voile fabric. Each sample was composed of 3 subsamples collected at 3 distinct sites in the same maize production area. Insects were collected by 30 sweeps of the sweep net between 2 maize rows around 10 m long. In the maize experimental stations 8 to 12 samples were collected (every sample consisted of 3 subsamples). In the counties belonging to the states of Maranhão and Piauí, in the large maize cultivated areas, at least 5 samples were collected. In the other commercial maize crops just 1 sample was taken. The insect samples were collected

TABLE 1. BRAZILIAN LOCALITIES WHERE LEAFHOPPERS AND PLANTHOPPERS (HEMIPTERA: CICADELLIDAE AND DELPHACIDAE) WERE SAMPLED ON MAIZE.

Region	Locality	Abbreviation	Latitude (S)	Longitude (W)	Elevation (m)
Center-south	Alpinópolis/MG	Ap	20°52'38.49"	46°22'17.61"	863
	Apucarana/PR	Ac	23°33'50.26"	51°31'55.14"	820
	Araxá/MG	Ar	19°34'31.38"	47° 0'12.06"	976
	Altinópolis/SP	At	21° 0'51.22"	47°20'13.19"	857
	Barracão/PR	Ba	26°12'32.66"	53°38'11.15"	721
	Boa Vista das Missões/RS	Bm	27°38'44.61"	53°19'41.48"	580
	Cambe/PR	Ca	23°15'31.62"	51°15'42.01"	608
	Cafelândia/PR	Cf	24°38'46.59"	53°17'55.77"	605
	Campo Mourão/PR	Cm	23°59'29.21"	52°21'17.37"	547
	Capanema/PR	Cn	25°41'51.89"	53°46'32.86"	391
	Cornélio Procópio/PR	Cp	23° 9'58.95"	50°36'42.02"	574
	Cunha Porã/SC	Cu	26°52'43.77"	53°10'12.33"	529
	Frederico Westphalen/RS	Fw	27°22'44.07"	53°24'1.75"	566
	Guaraciaba/SC	Gr	26°34'54.16"	53°31'17.92"	653
	Guarujá do Sul/SC	Gs	26°23'28.64"	53°31'10.91"	704
	Ingaí/MG	Ig	21°24'13.35"	44°55'43.25"	943
	Irani/SC	In	26°59'51.44"	51°52'24.40"	1114
	Iraceminha/SC	Ir	26°49'36.30"	53°15'57.09"	446
	Itumbiara/GO	It	18° 7'8.18"	49°14'46.21"	608
	Jurandá/PR	Ju	24°24'47.47"	52°49'4.13"	599
	Lavras/MG	La	21°12'38.80"	45° 3'31.98"	910
	Lapa/PR	Lp	25°45'28.68"	49°44'35.98"	941
	Luz/MG	Lu	19°47'27.76"	45°38'17.53"	647
	Maringá/PR	Ma	23°21'0.74"	51°53'58.02"	494
	Mandaguari/PR	Md	23°30'46.98"	51°42'45.86"	710
	Nova Erechim/SC	Ne	26°53'39.18"	52°55'16.46"	509
	Nova Ponte/MG	Np	19°10'38.61"	47°41'20.43"	946
	Pouso Alegre/MG	Pa	22°15'15.74"	45°52'54.21"	872
	Passo Fundo/RS	Pf	28° 8'20.32"	52°17'24.10"	696
	Pimenta/MG	Pi	20°27'56.14"	45°48'8.95"	811
	Pulador/RS	Pu	28°29'26.82"	52°33'6.41"	515
	Santo Antônio do Sudoeste/PR	As	26° 4'38.11"	53°42'41.51"	564
	São José do Cedro/SC	Sc	26°28'3.72"	53°30'12.79"	735
	Santa Juliana/MG	Sj	19°51'52.12"	47°28'22.20"	894
	Santa Mariana/PR	Sm	23° 8'59.42"	50°32'9.34"	483
	São Miguel do Oeste/SC	So	26°41'41.32"	53°31'1.63"	667
	São Gonçalo do Sapucaí/MG	Ss	21°54'6.76"	45°37'43.45"	873
	Santa Tereza do Oeste/PR	Sz	25° 1'35.34"	53°34'33.47"	723
	São Mateus do Sul/PR	St	25°54'20.49"	50°26'41.07"	788
	São Sebastião da Bela Vista/MG	Sv	22° 8'7.17"	45°44'59.58"	851
	Três Corações/MG	Tc	21°39'16.73"	45°18'57.45"	919
	Toledo/PR	To	24°39'0.27"	53°44'55.22"	529
	Uberlândia/MG	Ub	19°11'17.12"	48° 9'27.76"	908
Northeast	Balsas/MA	Bl	7°34'22.50"	45°57'43.26"	299
	Baixa Grande do Ribeiro/PI	Br	7°49'2.55"	45° 2'26.11"	430
	São Raimundo das Mangabeiras/MA	Sr	6°59'21.82"	45°25'58.60"	297
	Tasso Fragoso/MA	Tf	8°29'46.09"	45°46'38.84"	285
	Vargem Limpa/MA	Vl	7°38'24.20"	46°20'54.32"	378

from maize in different stages of development, with a total of 67 samples in 2005, 72 samples in 2006 and, 59 samples in 2007.

Insects were transported inside plastic bags in an icebox, later they were kept for 1 h inside a freezer, and then transferred to vials with 70% ethanol. All samples were taken to the Entomology Laboratory of Embrapa Cerrados (Planaltina/ Distrito Federal, Brazil), where leafhoppers and planthoppers were separated from the other insect species by a stereomicroscope at 60X magnification.

Taxonomic identification

Leafhoppers and planthopper specimens were first separated at the morphospecies level and counted. Afterwards they were sent to the Division Entomology at the National University of La Plata (La Plata, Buenos Aires, Argentina), where the identification at species level was done subfamilies taxonomic keys (Dietrich 2005) and by specific taxonomic keys (Linnavuori 1959; Young 1977; Remes Lenicov 1982; Paradell 1995; Remes Lenicov & Virla 1999). Vouchers of the collected and identified material are deposited in the Entomological Museum of Embrapa Cerrados (CPAC).

Data Analysis

The abundance of each leafhopper and planthopper species was estimated as the average number of collected specimens for each sample in each locality. Estimations of species richness were used to verify sampling effort accuracy in relation to Cicadellidae and Delphacidae species diversity. Species richness was estimated by the non-parametric estimators: Jackknife 1, Jackknife 2, Chao1 and Chao 2. These mathematical equations were, respectively:

$$J1 = Sobs + L\left(\frac{n\text{-}1}{n}\right); J2 = Sobs + \left[\frac{L(2n\text{-}3)}{n}\right] - \left[\frac{M(n\text{-}2)^2}{n(n\text{ - }1)}\right];$$

$$C1 = Sobs + \left(\frac{a^2}{2b}\right) \text{ and } C2 = Sobs + \left(\frac{L^2}{2M}\right),$$

where: *J1* = Jackknife estimation of the first order ; *J2* = Jackknife estimation of the second order; *C1* = Chao estimation of the first order; *C2* = Chao estimation of the second order; *Sobs* = total number of species present in *n* samples; *L* = number of species that occurred in only 1 sample; *n* = total number of samples; *M* = number of species that occurred in only 2 samples; *a* = number of species represented by only 1 specimen, and *b* = number of species represented by only 2 specimens (Chao 1984, 1987; Palmer 1991). Estimations of species richness were performed with the data of all the samples obtained in this study and also, separately, for the samples collected in the center-south and in the northeast of Brazil.

The Jaccard similarity index was used to compare the center-south and northeast regions. This mathematical equation was:

$$Jsi = \frac{a}{a + b + c},$$

where: *Jsi* = Jaccard's similarity index; *a* = number of species shared by 2 regions and, *b* and *c* = number of species unique to the center-south and the northeast regions, respectively (Jaccard 1908). The similarity between regions was estimated for Delphacidae and Cicadellidae families separately, and also for the total leafhoppers and planthoppers collected.

The species richness and abundance of leafhoppers and planthoppers species were compared between the center-south region, where maize is intensively cultivated, in some places in 2 consecutive seasons per yr, and the northeast region, where maize production has increased in recent yr. These 2 regions differ widely with regard to climate, maize growing seasons and cultivation conditions, which may be reflected in differences in the Cicadellidae and Delphacidae fauna associated with maize.

Results and Discussion

A total of 12,849 insect specimens were collected in 198 samples, of which 4,746 specimens (36.9%) belonged to the Hemiptera. Furthermore, the hemipteran families Cicadellidae (89.2%), and Delphacidae (4.3%) accounted for 93.5% of the specimens collected. In addition, specimens from Achilidae, Aphididae, Cercopidae, Derbidae, Membracidae, Nogodinidae and Psyllidae families were also identified and represented only 6.5% from the total number of hemipteran specimens in the study (Table 2).

Considering only the families Cicadellidae and Delphacidae, in relation to the total number of specimens collected in the 3-yr study, it was observed that the Cicadellidae were more abundant than Delphacidae in the center-south states of Brazil, representing between 94.3 and 99.0% of the specimens collected in this region. On the other hand, the Delphacidae were relatively more abundant in the northeast region, ranging from 45.1 up to 76.0% of the specimens collected.

Regarding species richness of the leafhoppers and planthoppers, a total of 39 species (30 species of Cicadellidae and 9 species of Delphacidae) were identified (Tables 3 and 4). The species richness estimates by the Jackknife1 and 2, and Chao 1 and 2 estimators were, respectively, 49, 48, 43 and 44 species. This result means that between 83.0 and 90.7% of the leafhoppers and planthoppers species present in the maize crop were collected

TABLE 2. AVERAGE NUMBER OF SPECIMENS OF INSECTA AND HEMIPTERA (CICADELLIDAE, DELPHACIDAE AND OTHERS) PER SAMPLE COLLECTED IN MAIZE CROPS IN THE CENTER-SOUTH AND THE NORTHEAST REGIONS OF BRAZIL IN THE YEARS 2005, 2006 AND 2007.

Local/Yr	Insecta	Hemiptera	Cicadellidae	Delphacidae	Others[1]	Total
Center-south/2005	31.5	9.6	7.4 (76.6)[2]	0.3 (2.8)	2.0 (20.6)	41.1
Northeast/2005	17.7	5.2	2.8 (54.1)	2.3 (44.4)	0.1 (6.5)	22.9
Center-south/2006	87.0	72.6	70.7 (97.3)	0.7 (1.0)	1.2 (1.7)	159.6
Northeast/2006	20.4	9.0	1.1 (12.3)	2.5 (27.9)	5.4 (59.8)	29.4
Center-south/2007	28.8	4.7	3.5 (74.3)	0.2 (4.5)	1.0 (21.3)	33.5
Northeast/2007	11.6	3.8	0.8 (19.7)	2.4 (62.3)	0.7 (18.0)	15.4
Average (%)	40.9	24.0	21.4 (89.2)	1.0 (4.3)	1.6 (6.5)	64.9

[1]Other Hemiptera.
[2]Numbers in parentheses represent the relative percent of specimens in relation to the total number of hemipterans collected.

in the 198 samples obtained in this study. For the center-south the corresponding species richness estimates were 46, 49, 38 and 43 species, and for the northeast the corresponding estimates were 28, 33, 33 and 33 species. These results represent between 71.4 and 92.1%, and 63.6 and 75.0% of the species present in maize in the center-south region, and the northeast region, respectively. These richness indexes obtained indicated that sampling effort in relation to the study of the diversity of the Cicadellidae and Delphacidae species was satisfactory.

A total of 27 species of Cicadellidae were identified in the center-south states of Brazil (Goiás, Minas Gerais, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul), and 18 of these species were found exclusively in these states. A total of 13 leafhopper species were identified in the northeast region (Maranhão and Piauí), with 3 species exclusively found in this area (Table 3). Eight species of Delphacidae were identified in the samples from the center-south region of Brazil, along with 8 more in the northeast region, with only 1 species exclusively found in each region (Table 4). The Jaccard similarity indexes estimated for the center-south region and northeast region were 0.30 for Cicadellidae, 0.78 for Delphacidae, and 0.41 for the 2 families together. These results indicate that there is a great difference in the Cicadellidae fauna among the 2 studied regions and a similar fauna of the Delphacidae family.

The 10 most abundant species in this study accounted for 97.6% of all Cicadellidae and Delphacidae collected, and these were: *D. maidis* (n = 3,994), *Sogatella kolophon* (Kirkaldy) (n = 74), *Rotigonalia limbatula* (Osborn) (n = 53), *Planicephalus flavicosta* (Stål) (n = 41), *Tagosodes cubanus* (Crawford) (n = 41), *Pyrophagus tigrinus* Remes Lenicov & Varela (n = 36), *Balchutha incisa* (Matsumura) (n = 32), *Agallia albidula* Uhler (n = 22), Delphacidae sp.1 (n = 21) and *Atanus declivatus* Linnavuori (n = 15).

Eight Cicadellidae and Delphacidae species found in this study were recorded as vectors of virus and or mollicutes in maize, i.e., the leafhoppers *D. maidis*, *P. flavicosta*, *C. teapae* and *Extianus obscurinervis* (Stål) and the planthoppers *S. kolophon*, *P. tigrinus*, *Toya propinqua* (Fieber) and *P. maidis*. Five species were reported for the first time in Brazil, i.e., the species *A. declivatus* and *A. dubius* (Cicadellidae) and *S. kolophon*, *T. cubanus* and *P. tigrinus* (Delphacidae).

Until now, only *D. maidis* and *P. maidis* were reported and widely known as vectors of mollicutes and/or viruses in maize crops in Brazil. The corn leafhopper (*D. maidis*) is the vector of *S. kunkelli*, maize bushy stunt phytoplasma and *Maize rayado fino virus* (Nault 1980, 1990). *Dalbulus maidis* represented 90.1% among all collected leafhoppers and planthoppers and was present in 64.1% (n = 127) of the samples. Furthermore, it was collected in all states, except in Piauí (Table 3).

Differences in abundance of *D. maidis* were observed depending of the year. A total of 89.8% of all *D. maidis* specimens collected in this study were obtained in 2006, being the state of Goiás responsible for 56.8% of this total. In the northeast region, the incidence of this leafhopper species was higher in 2005, when 92.3% of the total *D. maidis* specimens were collected. These results confirm previous studies that point this species as the most abundant Cicadellidae in maize, and the main vector of maize pathogens in Brazil (Oliveira et al. 2002a, 2004; Lopes & Oliveira 2004).

The corn planthopper, *P. maidis*, which has a pantropical distribution (Singh & Seetharama 2008), is the vector of *Maize mosaic virus*, present in Brazil (Lopes & Oliveira 2004) and Argentina (Remes Lenicov & Mariani 2001), and of *Maize stripe virus*, reported in Colombia (Varon de Agudelo & Martinez-Lopez 1980). This species also was capable of transmitting *Mal de Río Cuarto virus* to maize under experimental conditions (Virla et al. 2004; Giménez Pecci et al. 2012). This planthopper was found in the states of Maranhão (81.8% of the collected specimens), Minas Gerais and Rio Grande do Sul.

TABLE 3. AVERAGE NUMBER OF LEAFHOPPERS (CICADELLIDAE) PER SAMPLE COLLECTED BY SWEEP NET IN MAIZE CROPS IN SEVERAL STATES OF BRAZIL IN THE YEARS 2005, 2006 AND 2007.

	2005								2006								2007							
	State								State								State							
Species	MA	PI[1]	GO	SP[1]	MG	PR	SC	RS	MA	PI[1]	GO	SP	MG	PR	SC	RS	MA	PI	GO	SP[1]	MG	PR	SC	RS
Agallia albidula	0.000	—	0.111	—	0.000	0.067	0.000	0.167	0.000	—	0.273	0.000	0.000	0.524	0.200	0.250	0.000	0.000	0.100	—	0.000	0.000	0.000	0.000
Agallia sp.1	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Agalliana ensigera	0.000	—	0.000	—	0.000	0.000	0.400	0.167	0.000	—	0.000	0.000	0.000	0.000	0.200	0.083	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Agalliana sticticolis	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.067	0.200	0.000
Amplicephalus dubius	0.000	—	0.111	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Atanus curvilínea	0.000	—	0.444	—	0.000	0.067	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	0.100	—	0.000	0.000	0.000	0.000
Atanus declivatus	0.038	—	1.111	—	0.000	0.067	0.000	0.000	0.000	—	0.182	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	—	0.000	0.000	0.000	0.000
Balcluhta sp.1	0.038	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Balclutha incisa	0.000	—	0.000	—	0.000	0.000	0.000	0.333	0.500	—	0.909	1.000	0.000	0.238	0.000	0.000	0.167	0.250	0.000	—	0.167	0.000	0.000	0.000
Chlorotettix fraterculus	0.038	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.273	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Cicadellidae sp.1	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.200	0.000
Copididonus hyalinipennis	0.038	—	0.000	—	0.000	0.067	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Curtara pagina	0.038	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Dalbulus maidis	2.308	—	8.556	—	2.500	5.667	7.800	3.000	0.250	—	206.091	2.000	4.000	12.524	32.400	73.333	0.000	0.000	4.900	—	1.333	1.333	6.800	0.167
Deltocephalinae sp.1	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Diedrocephala variegata	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	—	0.000	0.000	0.000	0.000
Empoasca curveola	0.077	—	0.000	—	0.000	0.067	0.400	0.000	0.000	—	0.000	0.000	0.000	0.143	0.000	0.000	0.083	0.250	0.100	—	0.000	0.000	0.000	0.167
Exitianus obscurinervis	0.000	—	0.000	—	0.000	0.067	0.000	0.000	0.000	—	0.000	0.000	0.500	0.000	0.000	0.083	0.000	0.000	0.000	—	0.000	0.000	0.400	0.000
Haldorus sexpunctatus	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.600	—	0.000	0.000	0.000	0.000
Hortensia similis	0.000	—	0.111	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Macugonalia leucomelas	0.000	—	0.000	—	0.000	0.000	0.200	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Molomea lineiceps	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	—	0.000	0.000	0.000	0.000
Neophlepsius sp.1	0.000	—	0.000	—	0.000	0.000	0.000	0.167	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Planicephalus flavicosta	0.077	—	1.000	—	0.000	0.000	0.000	0.667	0.350	—	1.000	0.000	0.000	0.000	0.000	0.250	0.250	0.000	0.200	—	0.000	0.000	0.000	0.000
Protalebrella sp.1	0.000	—	0.222	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Rotigonalia limbatula	0.115	—	1.000	—	0.333	0.000	0.200	0.000	0.000	—	1.636	1.000	0.000	0.095	0.200	0.000	0.000	0.000	1.900	—	0.000	0.000	0.000	0.000
Sibovia sagata	0.000	—	0.000	—	0.167	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Stirellus picinus	0.038	—	0.111	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Unerus sp.1	0.000	—	0.000	—	0.000	0.133	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.100	—	0.000	0.000	0.000	0.000
Typhlocibinae sp.1	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.000	0.000	—	0.000	0.000	0.000	0.000
Average/State	2.692	—	12.778	—	3.000	6.200	9.000	4.500	1.100	*	210.909	4.000	4.500	13.571	33.400	74.083	0.833	0.500	8.200	*	1.500	1.400	7.600	0.333
Average/Year					5.537								51.333								2.814			

[1]Sampling not performed in this state in this yr. Abbreviations of names of states are as follows: MA-Maranhão, PI-Piauí, GO-Goiás, SP-São Paulo, MG-Minas Gerais, PR-Paraná, SC-Santa Catarina and RS-Rio Grande do Sul.

TABLE 4. AVERAGE NUMBER OF PLANTHOPPERS (DELPHACIDAE) PER SAMPLE COLLECTED BY SWEEP NET IN MAIZE CROPS IN SEVERAL STATES OF BRAZIL, IN THE YEARS 2005, 2006 AND 2007.

	2005								2006								2007							
	State								State								State							
Species	MA	PI[1]	GO	SP[1]	MG	PR	SC	RS	MA	PI[1]	GO	SP	MG	PR	SC	RS	MA	PI	GO	SP[1]	MG	PR	SC	RS
Caenodelphax teapae	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.200	0.000
Delphacidae sp.1	0.269	—	0.000	—	0.000	0.000	0.000	0.000	0.250	—	0.000	0.000	0.000	0.000	0.000	0.000	0.583	0.000	0.000	—	0.333	0.000	0.000	0.000
Delphacidae sp.2	0.077	—	0.000	—	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	—	0.000	0.000	0.000	0.000
Delphacodes saxicola	0.000	—	0.000	—	0.000	0.000	0.000	0.000	0.050	—	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Peregrinus maidis	0.038	—	0.000	—	0.167	0.000	0.000	0.000	0.400	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.083
Pyrophagus tigrinus	0.346	—	0.222	—	0.333	0.133	0.000	0.000	0.050	—	0.545	0.000	0.000	0.095	0.000	0.000	0.083	1.750	0.200	—	0.167	0.067	0.000	0.000
Sogatella kolophon	1.231	—	0.444	—	0.000	0.000	0.000	0.000	0.400	—	0.909	0.000	0.000	0.048	0.000	0.000	1.000	1.500	0.000	—	0.167	0.000	0.000	0.000
Tagosodes cubanus	0.077	—	0.000	—	0.000	0.000	0.000	0.000	1.250	—	1.273	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
Toya propinqua	0.269	—	0.000	—	0.000	0.000	0.000	0.000	0.100	—	0.182	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	—	0.000	0.000	0.000	0.000
Average/State	2.308	—	0.667	—	0.500	0.133	0.000	0.000	2.500	—	3.000	0.000	0.000	0.190	0.000	0.000	1.917	3.750	0.200	—	0.667	0.067	0.200	0.083
Average/Year					1.060								1.208								0.797			

[1]Sampling not performed in this state in this yr. Abbreviations of names of states are as follows: MA-Maranhão, PI-Piauí, GO-Goiás, SP-São Paulo, MG-Minas Gerais, PR-Paraná, SC-Santa Catarina and RS-Rio Grande do Sul.

The planthopper, *P. tigrinus*, was observed in the states of Maranhão, Piauí, Goiás, Minas Gerais and Paraná (Table 4). Under experimental conditions, this species was capable of transmitting *Mal de Río Cuarto virus* to maize (Velazquez et al. 2006). Another Delphacidae capable of transmitting this virus under experimental conditions is *T. propinqua* (Velazquez et al. 2001; Mattio et al. 2005), which was collected in Goiás and Maranhão (Table 4). *Toya propinqua* also is the vector of *Cynodon chlorotic streak virus* and, under experimental conditions, transmitted *Maize rough dwarf virus* to maize plants (Harpaz 1972). Only 2 specimens of the planthopper *Caenodelphax teapae* (Fowler), the insect vector of the *Urochloa hoja blanca virus* in grass [*Urochloa plantaginea* (Link) RD Webster] (Miranda et al. 2001) and of the *Mal de Río Cuarto virus* in maize, under experimental conditions (Giménez Pecci et al. 2012), were detected in the states of Goiás and Santa Catarina (Table 4).

Mal de Río Cuarto virus is a quarantine virus in Brazil (Giménez Pecci et al. 2012). This virus caused severe losses in maize production in Argentina (Lenardón et al. 1998; Ornaghi et al. 1999; Truol et al. 2001). Because the planthopper species, *C. teapae*, *P. maidis*, *P. tigrinus* and *T. propinqua*, are potential vectors of *Mal de Río Cuarto virus* and are present in Brazil, there is a serious risk of introduction of this virus.

The leafhopper, *P. flavicosta*, already recorded in several Brazilian states (Cavichioli & Zanol 1991), is abundant in weeds associated with cereal crops as wheat, oats and corn and is widely distributed in America (Linnavuori 1959; Kramer 1971). This species is the vector of phytoplasmas (Dabek 1982; Eckstein 2010) and *Maize chlorotic dwarf waikavirus* in maize (Lopes et al. 1994). This species was reported as one of the most abundant leafhoppers in the Atlantic forest in the state of Minas Gerais (Coelho 1997). In our study, *P. flavicosta* was observed in the states of Maranhão, Goiás and Rio Grande do Sul (Table 3). Studies about the natural infectivity of this leafhopper and transmission of phytoplasma to maize could be important to verify the variability of this mollicute and the potential of this leafhopper species as a disease vector in maize. The leafhopper, *E. obscurinervis*, collected in the states of Minas Gerais, Paraná, Santa Catarina and Rio Grande do Sul, was recently reported as an experimental vector of *S. kunkelli* in maize, in Argentina (Carloni et al. 2011).

The planthopper, *S. kolophon*, which has worldwide distribution (Asche & Wilson 1990), is the vector of the rhabdovirus of Pangola grass [*Digitaria decumbens* Stent & *D. ciliaris* (Retz.) Koeler] (Greber 1979). Also, experimentally, this species transmitted *Maize sterile stunt* to maize (Greber 1982). *Sogatella kolophon* was recorded in the states of Maranhão, Piauí, Goiás, Minas Gerais and Paraná. However, 78.4% of the specimens were collected in Maranhão and Piauí (Table 4) suggesting that this species is most common in the northeast region.

Agallia albidula, a leafhopper that is the vector of *Tomato curly top virus* (Coelho et al. 2001), and has been reported in several states of Brazil, was collected in the states of Goiás, Paraná, Santa Catarina and Rio Grande do Sul (Table 3). The species *Empoasca curveola* Oman, apparently widely distributed in Brazil (Table 3), has been reported as a phytoplasma vector to beet, in Chile (Salgado 2001).

The species *Agalliana ensigera* Oman and *A. sticticolis* (Stål) are very common on potato, cotton, wheat, tobacco, and beet, and are vectors of *Curly top virus* (Costa 1957; Silva et al. 1968). These species were only found in the center-south states of Brazil as well the species *Macugonalia leucomelas* (Walker) (Table 3). *Macugonalia leucomelas* is common in citrus and it is the vector of the bacterium *Xylella fastidiosa* (Almeida et al. 2005).

The Delphacidae *T. cubanus* is the vector of *Hoja blanca virus* in rice in America (King & Saunders 1984) and was recorded in the states of Maranhão and Goiás, with 65.8% of the specimens collected in Maranhão (Table 4).

We observed that Cicadellidae and Delphacidae diversity in Brazil is comparable to other countries in South America. Between 25 and 35 Cicadellidae species were reported in Argentina (Remes Lenicov 1982; Tesón et al. 1986; Paradell 1995; Paradell et al. 2001; Luft Albarracin et al. 2008) including: *D. maidis*, *A. ensigera*, *Amplicephalus dubius* (Linnavuori), *Chlorotettix fraterculus* (Berg), *E. curveola*, *E. obscurinervis*, *Haldorus sexpunctatus* (Berg), *Hortensia similis* (Walker), *Copididonus hyalinipennis* (Stål), *P. flavicosta*, *B. incisa*, *Stirellus picinus* (Berg) and *Curtara pagina* De Long and Freytag, that were also found in our study. Regarding the Delphacidae family, 11 species were reported in Argentina (Remes Lenicov & Virla 1999; Velazquez et al. 2006) and 4 species in Uruguay (Remes Lenicov et al. 2000). The species *T. propinqua*, *S. kolophon*, *P. maidis and P. tigrinus* reported in Argentina and Uruguay are also present in Brazil.

In the only other study of Cicadellidae species in maize crops conducted in Brazil (Lopes & Oliveira 2004), 6 species were identified, and 3 of them were coincident with the present results, i.e., *D. maidis*, *E. obscurinervis* and *H. similis*.

We speculate that the observed differences in abundance and species richness of the Delphacidae and, mainly, Cicadellidae families in Brazil may have implications for the incidence and severity of diseases that occur in maize and that are caused by phytopathogens transmitted by insects in the center-south and northeast states of the country. In Brazil, the diseases whose

pathogens are transmitted by Cicadellidae are generally more frequent, more severe and are recorded mainly in the center-south states than those whose vectors are Delphacidae (Oliveira et al. 1998; Oliveira et al. 2002b). The almost complete lack of information about disease outbreaks in maize transmitted by insect vectors in northeastern Brazil may be the result not only of the lack of surveys in this region, but also the result of differences in abundance and species richness of Cicadellidae and Delphacidae fauna in relation to the center-south region states.

The results of our study also showed that several detected species are insect vectors of phytopathogens. It is possible that the majority of the leafhopper and planthopper species identified have weeds or others plant species as preferred hosts, but many could eventually feed on maize and infect it with phytopathogens. For this reason, it is important to know their epidemiological role in the dissemination of diseases in this crop. The presence of potential vectors of *Mal de Río Cuarto virus* points out the necessity to reinforce monitoring to avoid the introduction and spread of this quarantine virus in Brazilian commercial maize crops.

Although our study includes 4 regions, 8 states, and 48 locations in Brazil, the results presented here are preliminary, due to the large territory of Brazil, its numerous biogeographic regions, where corn is grown, and the fact that diversity and abundance of Cicadellidae and Delphacidae is influenced by the maize growth stage and the composition and abundance of weeds associated with crop. Future studies in other regions of the country are still needed for the deeper knowledge of the fauna of Cicadellidae and Delphacidae in maize in Brazil.

Conclusions

The species richness of Cicadellidae and Delphacidae species in maize crops in Brazil is similar to the species richness of these families in other countries of South America, specifically Argentina and Uruguay. Among the Cicadellidae and Delphacidae species that were collected in maize crops in Brazil, there are several species reported as insect vectors of phytopathogens, including viruses and mollicutes that can infect maize. In Brazil, 4 planthopper species, which are potential vectors of the quarantine *Mal de Río Cuarto virus,* were collected in maize crops.

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