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The psyllid fauna (Hemiptera: Psylloidea) of vegetable fields in Brazil

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ABSTRACT

Some psyllids transmit '*Candidatus* Liberibacter solanacearum' (Lso), the causal agent of devastating plant diseases of cultivated Solanaceae and Apiaceae. The recent detection of *Bactericera cockerelli* and Lso in Ecuador seriously threatens these crops in South America. There, neither the role of native psyllids in the Lso epidemiology nor the psyllid fauna of vegetables are known. With the aim to identify potential vectors and risk scenarios for the spread of Lso in South America, a survey of the psyllid fauna of Solanaceae and Apiaceae crops and associated weeds was conducted in Brazil. Samples were taken at 29 localities in four states. A total of 2857 specimens were sampled, representing at least 37 species of 23 genera and seven families. The most frequent species on carrot, chilli pepper and potato were *Russelliana solanicola*, *R. capsici* and *Isogonoceraia divergipennis*, respectively. Immatures of *R. capsici* were found on chilli pepper and of *R. solanicola* on carrot and potato, confirming these plants as hosts. The two psyllid species have been suspected previously to transmit plant pathogens of unknown identity. *Russelliana solanicola* is one of the few polyphagous species. Here the species is reported for the first time from carrot. Recent collections in Rio Grande do Sul suggest that *Solanum laxum* represents the original host of *R. capsici,* which subsequently shifted to chilli pepper. Both, adaptation to agricultural crops and the possibility of ability to transmit pathogens, make the two *Russelliana* species dangerous potential vectors of Lso and other plant pathogens in South America.

Introduction

Jumping plant-lice or psyllids (Hemiptera: Psylloidea) are small phloem-sucking insects. Most of the approximately 4000 described species are highly host specific with only a few exceptions (Burckhardt et al., 2014; Ouvrard et al., 2015). While immatures can complete their development usually only on one or a few closely related plant species (=host plants), adults, which are always winged and therefore more mobile, can be encountered often also on non-hosts, called overwintering, shelter, food, or casual plants depending on the situation (Burckhardt et al., 2014). Some psyllids are economically important pests in agriculture, forestry and horticulture. The damage to plants can be direct or indirect. The most devastating damage is inflicted by those species that transmit plant pathogens (Burckhardt, 1994; Hodkinson, 2009; Queiroz et al., 2012)

Over the last decades, some psyllid species have emerged as major pests of vegetables, mainly as vectors of '*Candidatus* Liberibacter solanacearum' (Lso), the putative etiological agent of potato zebra chip and other disorders in Solanaceae and Apiaceae. The tomato-potato psyllid, *Bactericera cockerelli* (Šulc), one of the few polyphagous psyllid species (Burckhardt and Lauterer, 1997; Serbina et al., 2015), is notorious as a vector of Lso infecting potatoes and other Solanaceae in North and Central America as well as in New Zealand (Liefting et al., 2009; Munyaneza, 2012). Recently, *B. cockerelli* and later Lso also were detected in South America (Castillo Carrillo et al., 2019; Caicedo et al., 2020). *Bactericera trigonica* Hodkinson and *Dyspersa apicalis* (Foerster) (=*Trioza apicalis*) transmit other haplotypes of Lso to carrots and other members of Apiaceae in Europe and the Mediterranean including the Canary Islands (Munyaneza et al., 2010; Alfaro-Fernández et al., 2012; Tahzima et al., 2014; Teresani et al., 2014; Mawassi et al., 2018). Furthermore, *Bactericera nigricornis* currently found in Europe and Asia has shown to be capable of transmiting Lso to potato and carrots (Moreno et al., 2021).

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Bactericera cockerelli and Lso, which were recently discovered in Ecuador, represent a serious threat to the potato industry in South America (Castillo Carrillo et al., 2019; Caicedo et al., 2020). Recently the vector was also reported from Colombia and Peru but not Lso (ICA, 2021; SENASA, 2021). In the west Palaearctic, Lso infects other crops such as carrot and celery transmitted by native psyllids. This may happen also in South America. From South America, two *Russelliana* species, viz. *R. capsici* Burckhardt and *R. solanicola* Tuthill, are suspected to vector plant pathogens. *Russelliana capsici* (Figs 1A, B) was reported from Argentina (Buenos Aires, Entre Ríos) and Brazil (Minas Gerais, Panané, Santa Catarina, São Paulo) associated with witches' brooms on chilli pepper. It is suspected that the witches' brooms are caused by a *Candidatus* Liberibacter or Phytoplasma species (Burckhardt et al., 2012). *Russelliana solanicola* (Figs 1C, D) was reported as pest on potato and as vector of an unidentified pathogen causing 'Potato Yellows' (Tuthill, 1959; Chávez et al., 2003; Salazar, 2006). It is known from Argentina, Bolivia, Brazil, Chile, Peru and Uruguay (Serbina and Burckhardt, 2017) and represents another one of the few polyphagous psyllid species, associated with several families of eudicots (clade Caryophyllales + asterids) (Serbina et al., 2015).

As these plant pathogens are often controlled via their vectors, a better knowledge of the psyllid fauna of vegetable crops in South America is imperative and a matter of urgency. From Brazil, only 165 species of Psylloidea have been reported, of an estimated 1000 species that potentially occur there (Burckhardt and Queiroz, 2012, 2020, 2023). Similarly, there is a general lack of information on the psyllid fauna of vegetable crops in Brazil, making predictions about potential psyllid vectors of Lso difficult or even impossible. For closing this gap, a survey was conducted, sampling psyllids in vegetable fields in 16 important production areas in the Center-South region of Brazil with the aim to identify potential vector species of Lso and other phloem restricted plant pathogens.

Material and methods

From 2014 to 2016, vegetable fields at 87 localities were studied, and psyllids were found at 29 localities in 16 municipalities and four states of the Center-South region of Brazil (Table 1, Supplementary Material). The samples were taken using direct (visual inspection of plant, sweep net or beating tray) and indirect methods (yellow tray water trap).

For the visual inspection, 5–10 plants per species were examined for approximately one minute in each sampled area, counting the number of adult psyllids and checking for the presence or absence of immatures. With the sweep net and beating tray, 10 samples were taken consisting of 10 sweeps and four beats, respectively. In most localities, sampling using direct methods was performed on a single date, except for Piracicaba where samples were taken at nine dates (Supplementary Material). The psyllids were collected with an entomological aspirator and placed in vials with 70% ethanol for preservation. Eleven crop species and five weed species were examined (Table 2). The plant species varied according to their availability at different localities and sampling dates. Weeds, when present in pure clusters in or adjacent to the field, were sampled with a sweep net.

Each two yellow tray water traps were installed at approximately 60 cm above ground at three municipalities and four at one municipality (Table 1, asterisk). They were filled with 500 ml water and 3 ml of liquid detergent. The insects were collected every seven days during the sampling period, which varied between the locality (Supplementary Material): Campinas, SP (15 weeks), Maria da Fé, MG (9 weeks), Perdizes, MG (13 weeks) and Piracicaba, SP (8 weeks). The insects were sifted, manually sorted and preserved in 70% ethanol.

The psyllids were identified to genus and, if possible, to species. Voucher specimens are deposited in the Naturhistorisches Museum Basel, Switzerland (NHMB). The following additional material of *Russelliana capsici* collected by DB and DLQ was examined (NHMB):

Brazil: GO: 3 ♂, 1 ♀, 1 immature, 9 km NE Mossâmedes, Fazenda Ribeirão Bonito, -16.1150 -50.1972, 640 m, 20.ii.2018, chilli pepper, #274(6). – **MS**: 18 ♂, 29 ♀, 2 immatures, 1 skin, Rio Verde do Mato Grosso, BR163, -18.9281/9519 -54.8357/9339, 350–440 m, 13.xi.2012, chilli pepper, #68(6). – **PR**: 2 ♂, 7 immatures, 1 skin, Curitiba, Boa Vista, -25.3941 -49.2474, 930 m, 7.x.2018, chilli pepper, #312(1); 23 ♂, 17 ♀, 24 immatures, 2 skins, same but Jardim Botânico, -25.4437 -49.2391,

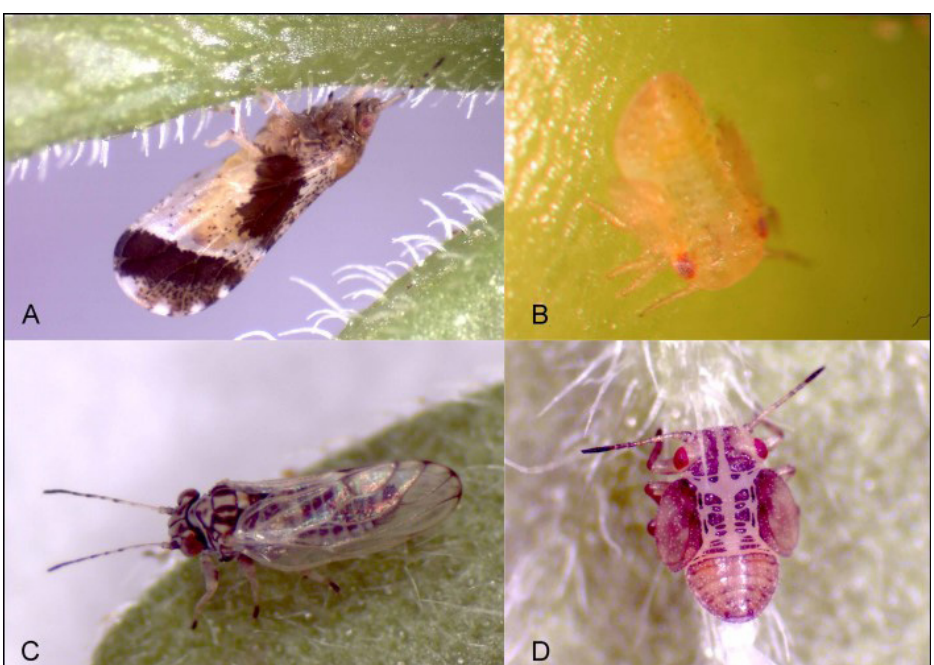

Figure 1 Habitus of *Russelliana* species; A) *R. capsici* Burckhardt, adult; B) *R. capsici immature*; C) *R. solanicola* Tuthill, adult; D) *R. solanicola*, immature. (Photos A, C, D: T.M.A. Kuhn; B: D.L. Queiroz).

Table 1
Collecting sites and dates of psyllid fauna collection (Hemiptera: Psylloidea) from vegetable fields in Brazil. GO = Goiás; PR = Paraná; MG = Minas Gerais; SP = São Paulo. Asterisks indicate localities with yellow tray water traps. Crop species: – Apiaceae: carrot (*Daucus carota* L.), celery (*Apium graveolens* L.), parsley [*Petroselinum crispum* (Mill.) Fuss]; – Solanaceae: African eggplant (*Solanum aethiopicum* Jacq.), chilli pepper (*Capsicum chinense* Jacq.), eggplant (*Solanum melongena* L.), potato (*Solanum tuberosum* L.), tobacco (*Nicotiana tabacum* L.).

State	Municipality	Locality	Geographical coordinates	Altitude	Collecting dates	Crop species
GO	Campo Alegre de Goiás	Projeto Paineiras, Yokio	-17.300443 -47.883381	946 m	29.ix.2015	potato
GO	Cristalina	Fazenda Santa Bárbara, Pivô 28	-16.219014 -47.467233	981 m	30.ix.2015	carrot
GO	Cristalina	Fazenda Santa Bárbara, Pivô 29	-16.222222 -47.469167	970 m	30.ix.2015	carrot
MG	Cristina	Produtor José Paulo Rocha	-22.300000 -45.270000	1280 m	03.vi.2015	potato
MG	Maria da Fé	Produtor Roberto Teodoro da Silva	-22.303889 -45.380000	1200 m	03.vi.2015	carrot
MG	Maria da Fé	*Sítio Alvorada	-22.290808 -45.333884	1351 m	29.ix–03.xii.2015, 20.xi.2015	carrot, potato
MG	Maria da Fé	Sítio Nossa Senhora Aparecida	-22.294219 -45.357400	1326 m	31.viii.2015	carrot
MG	Perdizes	Fazenda Rosário	-19.396869 -47.339022	1088 m	26.xi.2015	carrot
MG	Perdizes	Grupo Bergamasco	-19.394444 -47.332222	1070 m	26.xi.2015	carrot
MG	Perdizes	Grupo Rocheto	-19.317625 -47.395625	1065 m	20.xi.2014	potato
MG	Perdizes	*Grupo Rocheto, Pivô 19	-19.368556 -47.383306	1041 m	13.viii–30.x.2015	potato
MG	Perdizes	*Grupo Rocheto, Pivô 30	-19.347750 -47.401139	1013 m	13.viii–30.x.2015	potato
MG	Rio Paranaíba	Produtor Elcio Tamekuni	-19.301988 -46.261992	1139 m	05.viii.2015	carrot
MG	Rio Paranaíba	Produtor Leandro Fukuda	-19.292392 -46.154611	1164 m	13.v.2015	carrot
MG	Santa Juliana	Horta urbana	-19.309378 -47.529381	938 m	04.iii.2016	chilli pepper
MG	Tapiraí	Grupo Nascente	-19.871111 -46.269722	1255 m	19.xi.2014	potato
PR	Castro	Área Madureira	-24.824722 -49.895833	1000 m	20.iii.2015	potato
PR	Irati	Sítio Novo	-25.480250 -50.647611	928 m	03.xii.2015	tobacco
SP	Campinas	*Fazenda Santa Elisa, IAC	-22.858333 -47.080556	694 m	19.i–08.v.2015	potato
SP	Casa Branca	Campo Alegre, Pivô dos Macacos	-21.762292 -47.154736	696 m	23.ix.2015	carrot
SP	Casa Branca	Grupo Rocheto, Área Bolinha	-21.756389 -47.161944	695 m	23.ix.2015	potato
SP	Ibiúna	Marcio Hideriha, Talhão do Barracão	-23.662778 -47.348333	880 m	12.v.2016	carrot
SP	Ibiúna	Sítio Dona Edna	-23.721428 -47.192861	873 m	12.v.2016	parsley
SP	Ibiúna	Sítio Katahira	-23.646667 -47.171667	860 m	12.v.2016	celery
SP	Piracicaba	*ESALQ, Entomologia	-22.713389 -47.625822	538 m	12.ix–29.x.2014, 23.viii–21.ix.2016	chilli pepper, African eggplant, eggplant, potato
SP	Piracicaba	ESALQ, PACES	-22.704997 -47.634306	540 m	21.ix.2016	potato
SP	São José do Rio Pardo	Sítio dos Médicos	-21.680000 -46.960833	760 m	24.ix.2015	carrot
SP	São José do Rio Pardo	Sítio São Teodoro	-21.683839 -46.950458	709 m	24.ix.2015	carrot
SP	Sorocaba	Produtor Claudenir	-23.525964 -47.546103	579 m	16.iv.2015	eggplant

930 m, 19.vii.2012, chilli pepper, #44(2); 6 ♂, 5 ♀, 4 immatures, same but 15.ii.2013, chilli pepper, #94(9); 3 ♂, 4 ♀, same but Parque Bacacheri, -25.3900 -49.2303, 920 m, 6.iv.2013, chilli pepper, #98(3); 1 ♀, same but Parque Barigui, -25.4268 -49.3099, 900 m, 19.vii.2012, #43(-); 1 ♂, 4 ♀, same but Parque Passaúna, -25.4756 -49.3777, 930 m, 27–30.xi.2012, chilli pepper, #78(2); 5 ♂, 8 ♀, 11 immatures, 1 skin, same but Parque Passaúna, -25.5736 -48.9893, 940 m, 5.ii.2013, chilli pepper, #89(8); 9 ♂, 19 ♀, 1 immature, same but Parque Tanguá, -25.3810 -49.2848, 930 m, 6.ii.2013, chilli pepper, #90(16); 2 ♂, 1 ♀, same but Parque Tingui, -25.3887/3953 -49.3061/3062, 910–920 m, 31.i.2016, chilli pepper, #189(9). – **RJ**: 1 immature, Rio de Janeiro, Jardim Botânico, -22.9695 -43.2242, 10 m, 12.iv.2019, chilli pepper, #326(2); **RS**: 3 ♀, Barra do Quaraí, Parque Estadual do Espinilho, -30.1914 -57.5285, 50 m, 15.ix.2018, *Solanum laxum* Spreng., #294(7); 3 ♀, same but -30.1958 -57.5284, 60 m, 15.ix.2018, *Solanum laxum*, #295(2); 66 ♂, 43 ♀, 16 immatures, same but Saladeira/along Rio Quaraí, -30.2078 -57.5586, 50 m, 15.ix.2018, *Solanum laxum*, #297(1); 1 ♂, 2 ♀, Passo Fundo, Embrapa, campus, -28.2288 -52.4065, 640 m, 20.ix.2018, *Solanum laxum*, #306(7); RS, 5 ♂, 3 ♀, Santana do Livramento, Cerro Verde, -30.7784 -55.5808, 280 m, 11.ix.2018, *Solanum laxum*, #288(9); 1 ♀, same but near BR293, -30.7807 -55.6384, 310 m, 12.ix.2018, *Solanum laxum*, #290(7); RS, 1 ♂, 1 ♀, São Francisco de Assis, RS377 km 303, -29.4827 -55.0613, 290 m, 18.ix.2018, *Solanum laxum*, #304(7). – **SP**: 1 ♂, 4 ♀, Nova Odessa, Jardim Botânico Plantarum, -22.7788 -47.3142, 560 m, 3.iv.2019, chilli pepper, #314(1).

The nomenclature of psyllids follows Ouvrard (2022) and that of the plants the World Flora Online (WFO, 2022). The classification of psyllids is that of Burckhardt and Queiroz (2023).

Table 2
Crops and weed species sampled during the collection of psyllid fauna (Hemiptera: Psylloidea) from vegetable fields in Brazil.

Family	Latin name	Common name
Crops		
Apiaceae	*Apium graveolens* L.	celery
Apiaceae	*Daucus carota* L.	carrot
Apiaceae	*Petroselinum crispum* (Mill.) Fuss	parsley
Brassicaceae	*Brassica oleracea* var. capitata L.	cabbage
Solanaceae	*Capsicum annum* L.	bell pepper
Solanaceae	*Capsicum chinense* Jacq.	chilli or bonnet pepper, Chinese capsicum and many others
Solanaceae	*Nicotiana tabacum* L.	tobacco
Solanaceae	*Solanum aethiopicum* Jacq.	African or Ethiopian eggplant
Solanaceae	*Solanum lycopersicum* L.	tomato
Solanaceae	*Solanum melongena* L.	eggplant
Solanaceae	*Solanum tuberosum* L.	potato
Weeds		
Amaranthaceae	*Amaranthus* sp.	pigweed
Asteraceae	*Bidens pilosa* L.	hairy beggarticks and many others
Asteraceae	*Melampodium perfoliatum* (Cav.) Kunth	perfoliate blackfoot
Asteraceae	*Parthenium hysterophorus* L.	ragweed parthenium and many others
Solanaceae	*Solanum americanum* Mill.	American black nightshade

Results

During the survey, 2857 specimens (2818 adults and 39 immatures) were collected, representing at least 37 species of 23 genera and six families (Table 3). Of these, specimens representing 23 species could be identified to species, and the remainder only to genus or species group. These latter 14+ species represent undescribed species (e.g. *Mitrapsylla*) or species complexes (e.g. *Euceropsylla*), and describing and revising these is beyond the scope of the present study. The Brazilian psyllid fauna is poorly known and perhaps only 10% of the existing species are described (Burckhardt and Queiroz, 2012, 2020, 2023). Overall, the most frequent species were *R. solanicola*, *Isogonoceraia divergipennis* White and Hodkinson and *R. capsici* with 73%, 10% and 3%, respectively, of the total number of adult specimens collected (Tables 4 and 5). None of the currently known vectors of Lso, e.g. *Bactericera* species, were present in our collections, but two species were found that are suspected to vector plant pathogens, i.e. *R. capsici* and *R. solanicola* (Burckhardt et al., 2012; Serbina et al., 2015).

With direct methods, 2344 total adult specimens were found: 2269 on crop plants and 75 on weeds (Table 4). On carrot, of the 2065 total specimens, 1965 were *R. solanicola*, 68 were *Mitrapsylla* spp., 25 were *I. divergipennis* and the seven remaining specimens belonged to five other species. On chilli pepper, of the 107 total specimens, 98 were *R. capsici*, four were *R. solanicola*, two were *I. divergipennis*, and the remaining three specimens belonged to three other species. Of the 92 specimens collected from potato 77 were *I. divergipennis*, eight were *R. solanicola* and the remaining seven belonged to six other species. Among the weeds, only *Parthenium hysterophorus* L. yielded a high number of psyllids: 70 specimens of *R. solanicola*. No psyllids were collected on bell pepper (*Capsicum annuum* L.), cabbage (*Brassica oleracea* var. *capitata* L.), celery (*Apium graveolens* L.) and tomato (*Solanum lycopersicum* L.). A few single psyllids were found on tobacco (*Nicotiana tabacum* L.), parsley [*Petroselinum crispum* (Mill). Fuss], African or Ethiopian eggplant (*Solanum aethiopicum* Jacq.), and eggplant (*Solanum melongena* L.) among the crop plants, and *Amaranthus* spp. L., *Bidens pilosa* L., *Melampodium perfoliatum* (Cav.) Kunth and *Solanum americanum* Mill. among the weeds (Table 4).

The presence of immature psyllids is important to determine whether a particular plant constitutes a host (Burckhardt et al., 2014) or if the presence of the psyllid is just accidental. In our survey, all samples of *Russelliana capsici*, which always included some immatures (not shown in tables), were collected exclusively on chilli pepper, varieties 'biquinho', 'bode' and 'malagueta'. Similarly, the majority of specimens of *R. solanicola* were collected on carrot, on which we found also immatures (Supplementary Material). A single immature of *R. solanicola* was found on potato (Supplementary Material).

Yellow tray water traps were set up in fields of carrot, African eggplant, eggplant and potato (Table 5). The two psyllid species, which were represented by immatures in the direct collection methods, were not (*Russelliana capsici*) or only poorly (*R. solanicola*) represented in the traps. The most frequent species was *Isogonoceraia divergipennis* present in all traps but most numerous in fields of African eggplant. Two other psyllids, *Heteropsylla caldwelli* Burckhardt and *Paracarsidara* sp. had large numbers mostly in potato. The other species were represented in smaller numbers.

With both direct and indirect collecting methods, the largest numbers of individuals were found in late spring and early summer (September and October), particularly *Russelliana solanicola* on carrot in São José do Rio Pardo in 2015 (1872 individuals: 1861 adults and 11 immatures) and *Isogonoceraia divergipennis* on carrot and potato in Casa Branca in 2015 (99 adults, no immatures).

Discussion

At least 37 species were collected, of which only two develop on the studied vegetables: *Russelliana capsici* on chilli pepper and *R. solanicola* on carrot and potato. Chilli pepper, carrot and potato are, hence, confirmed host plants of the two species. Hosts of the other psyllids belong, as far as known, to the Fabaceae (over 15 species), Anacardiaceae, Asteraceae, Myrtaceae (each three species) and six other families with one or two species each (Table 1). Apart from the two *Russelliana* species, all psyllids were collected on non-host plants. An example to illustrate this is *I. divergipennis,* the second most abundant species in our study. The species is monophagous on *Caesalpinia pluviosa* (Burckhardt and Queiroz, 2012), a widely planted ornamental and shade tree (Lorenzi, 1992). It was found on carrot, chilli pepper, potato and tobacco, in addition to traps in all four crops. Since no immatures were found, its occurrence on potato (27% of the collections of this species) and other crops is accidental. Similar observations were made in European vegetable fields. In a study on Swiss carrot psyllids, 41 species (corresponding to over a quarter of the known Swiss psyllid fauna) were trapped, and only four of them develop on carrots (Burckhardt and Freuler, 2000). In Spain, representatives of seven psyllid genera (*Arytainilla*, *Bactericera*, *Blastopsylla*, *Cacopsylla*, *Ctenarytaina*, *Spanioza* and *Trioza*) have been found associated with carrot and potato (Antolínez et al., 2019), but only two *Bactericera* species actually develop on the crops: *B. nigricornis* (Foerster) on carrot and potato (Antolínez et al., 2019; Moreno et al., 2021); and *B. trigonica* Hodkinson on carrot and celery (Antolínez et al., 2017).

The species composition varied considerably from one locality to another, but no geographic patterns could be detected. The localities that were sampled with traps that were deployed for a longer period of time usually, but not always, had more diverse samples: Perdizes (11 weeks): 20 spp., Maria da Fé (6 weeks): 14 spp., Piracicaba (7 weeks): 12 spp.

Table 3
Psyllids collected during the project with their known host plants and general distribution. Asterisks indicate the assumed host family for psyllid taxa that were not identified to species.

Psyllid family	Psyllid subfamily	Psyllid species	Host family	Host species	Distribution
Aphalaridae	Phacopteroninae	*Pseudophacopteron longicaudatum* Malenovský, Burckhardt, Queiroz, Isaias & Oliveira, 2015	Apocynaceae	*Aspidosperma* spp.	Brazil
Aphalaridae	Rhinocolinae	*Leurolophus oriformae* Burckhardt & Basset, 2000	Anacardiaceae	*Lithraea* spp.	Argentina, Brazil
Aphalaridae	Spondyliaspidinae	*Blastopsylla occidentalis* Taylor, 1985	Myrtaceae	*Eucalyptus* spp.	Australia; adventive in Africa, America, Asia, Europe and Oceania
Aphalaridae	Spondyliaspidinae	*Ctenarytaina spatulata* Taylor, 1997	Myrtaceae	*Eucalyptus* spp.	Australia; adventive in America, Europe and Oceania
Aphalaridae	Spondyliaspidinae	*Glycaspis brimblecombei* Moore, 1964	Myrtaceae	*Eucalyptus* spp.	Australia; adventive in Africa, America, Asia, Europe and Oceania
Carsidaridae	Carsidarinae	*Paracarsidara* sp.	*Malvaceae	–	–
Liviidae	Liviinae	*Diclidophlebia crassiflagellata* (Burckhardt, 1996)	Malvaceae	*Luehea paniculata* Mart.	Brazil, Paraguay
Liviidae	Liviinae	*Diclidophlebia* sp.	–	–	–
Mastigimatidae		*Mastigimas anjosi* Burckhardt, Queiroz, Queiroz, Andrade, Zanol, Rezende & Kotrba, 2011	Meliaceae	*Cedrela fissilis* Vell., *Toona ciliata* M.Roem.	Brazil, Trinidad, Venezuela
Mastigimatidae		*Mastigimas* sp.	*Meliaceae	–	–
Psyllidae	Aphalaroidinae	*Baccharopelma dracunculifoliae* Burckhardt, Espírito-Santo, Fernandes & Malenovský, 2004	Asteraceae	*Baccharis dracunculifolia* DC.	Argentina, Brazil, Paraguay
Psyllidae	Aphalaroidinae	*Russelliana capsici* Burckhardt, 1987	Solanaceae	*Capsicum annuum* L., *Solanum laxum* Spreng.	Argentina, Brazil
Psyllidae	Aphalaroidinae	*Russelliana solanicola* Tuthill, 1959	polyphagous	polyphagous	Argentina, Bolivia, Chile, Peru; presumable adventive in Brazil and Uruguay
Psyllidae	Ciriacreminae	*Caradocia longiantennata* White & Hodkinson, 1980	Anacardiaceae	*Tapirira guianensis* Aubl.	Brazil
Psyllidae	Ciriacreminae	*Caradocia* sp.	*Anacardiaceae	–	–
Psyllidae	Ciriacreminae	*Euceropsylla martorelli* (Caldwell, 1944) group	*Fabaceae	–	–
Psyllidae	Ciriacreminae	*Euceropsylla russoi* Boselli, 1929 group	*Fabaceae	–	–
Psyllidae	Ciriacreminae	*Heteropsylla caldwelli* Burckhardt, 1987	Fabaceae	*Albizia adinocephala* (Donn.Sm.) Record, *A. edwallii* (Hoehne) Barneby & J.W. Grimes, *Enterolobium contortisiliquum* (Vell.) Morong, *E. cyclocarpum* (Jacq.) Griseb., *Senegalia polyphylla* (DC.) Britton	Argentina, Brazil, Colombia, Costa Rica, Nicaragua, Panama, Paraguay
Psyllidae	Ciriacreminae	*Heteropsylla cubana* Crawford, 1914	Fabaceae	*Leucaena* spp.	America; adventive in Africa, Asia, Australia and Oceania
Psyllidae	Ciriacreminae	*Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis, 1992	Fabaceae	*Mimosa diplotricha* Sauvalle	Brazil; adventive in Australia and Oceania
Psyllidae	Ciriacreminae	*Heteropsylla tenuata* Muddiman, Hodkinson & Hollis, 1992	Fabaceae	*Enterolobium contortisiliquum* (Vell.) Morong	Brazil
Psyllidae	Ciriacreminae	*Heteropsylla* sp.	*Fabaceae	–	–
Psyllidae	Ciriacreminae	*Isogonoceraia divergipennis* White & Hodkinson, 1980	Fabaceae	*Caesalpinia pluviosa* DC.	Brazil
Psyllidae	Ciriacreminae	*Isogonoceraia* sp.	*Fabaceae	–	–
Psyllidae	Ciriacreminae	*Jataiba uncigera* Burckhardt & Queiroz, 2020	Fabaceae	*Copaifera langsdorffii* Desf.	Brazil
Psyllidae	Ciriacreminae	*Mitrapsylla copaiferae* Burckhardt & Queiroz, 2020	Fabaceae	*Copaifera* spp.	Brazil
Psyllidae	Ciriacreminae	*Mitrapsylla gloriae* Burckhardt & Queiroz, 2020	Fabaceae	*Copaifera* spp.	Brazil
Psyllidae	Ciriacreminae	*Mitrapsylla* spp.	*Fabaceae	–	–
Psyllidae	Diaphorininae	*Diaphorina citri* Kuwayama, 1908	Rutaceae	*Citrus* spp., other Rutaceae	Asia; adventive in Africa, America and Oceania
Psyllidae	Macrocorsinae	*Apsyllopsis mexicana* (Crawford, 1914)	Fabaceae	*Hymenaea* spp.	Brazil, Mexico, Panama
Psyllidae	Platycoryphinae	*Platycorypha* sp.	*Fabaceae	–	–
Psyllidae	–	unidentified genus sp.	–	–	–
Triozidae		*Calinda plaumanni* Olivares & Burckhardt, 1997	Asteraceae	*Baccharis dracunculifolia* DC.	Brazil
Triozidae		*Calinda* sp.	*Asteraceae	–	–
Triozidae		*Leuronota* sp.	–	–	–
Triozidae		*Trioza tabebuiae* Santana & Burckhardt, 2001	Bignoniaceae	*Handroanthus* spp.	Brazil
Triozidae		*Trioza* sp.	–	–	–

Table 4
Psyllid species and number of individuals collected on vegetable crops (Carrot - *Daucus carota* L.; Parsley - *Petroselinum crispum* (Mill.) Fuss; Chilli pepper - *Capsicum chinense* Jacq.; Tobacco - *Nicotiana tabacum* L.; African eggplant - *Solanum aethiopicum* Jacq.; Eggplant - *Solanum melongena* L.; Potato - *Solanum tuberosum* L.) and weeds by direct sampling methods. See Supplementary Material for details.

Psyllid species	Crops							Weeds				
	Carrot	Parsley	Chilli pepper	Tobacco	African eggplant	Eggplant	Potato	*Amaranthus* sp.	*Bidens pilosa*	*Melampodium perfoliatum*	*Parthenium hysterophorus*	*Solanum americanum*
Baccharopelma dracunculifoliae						1						
Blastopsylla occidentalis			1									
Calinda plaumanni	1						1					
Calinda sp.							1					
Euceropsylla sp. *russoi* group	1						1					
Heterospylla cubana			1		1							
Heteropsylla tenuata			1									
Isogonoceraia divergipennis	25		2	1			77					
Jataiba uncigera										1		
Leuronota sp.							1					
Mitrapsylla copaiferae	2											
Mitrapsylla spp.	66	1				1	2	1				
Paracarsidara sp.	1											
Platycorypha sp.	3						1					
Russelliana capsici			98									
Russelliana solanicola	1965		4				8		2		70	1
genus sp.	1											

and Campinas (16 weeks): 4 spp. All of the 23 species that were identified to species have been reported previously from Brazil (Burckhardt and Queiroz, 2012, 2020). Sixteen of them represent native species that are widely distributed on hosts that often grow on the edges of fields. The other seven species are associated with crops; three species are native (the two *Russelliana* spp. and *Mastigimas anjosi* Burckhardt et al. on *Cedrela* and *Toona*), and four are adventive (*Blastopsylla occidentalis* Taylor, *Ctenarytaina spatulata* Taylor and *Glycaspis brimblecombei* Moore on eucalypts, as well as *Diaphorina citri* Kuwayama on *Citrus* and other rutaceous hosts).

We found the highest number of psyllids in late spring and early summer (September and October), which is consistent with other studies in Brazil. In citrus orchards in the State of São Paulo, the highest density of *D. citri* was observed in the same months (Yamamoto et al., 2001). A study on population fluctuations of the guava psyllid *Triozoida limbata* (Enderlein) showed that the species is present during the whole year, but with a peak in October (Dalberto et al., 2004). The large number of psyllids collected during spring indicates, in addition to population peaks, the increase in the movement of adult psyllids at this time of year, probably in search of suitable mates and hosts. In our study, this could explain the large numbers of adults of some species on the crops despite the fact that they do not develop on these plants (e.g. species of the genera *Heteropsylla*, *Mitrapsylla*, *Paracarsidara* or *Platycorypha*).

There were significant differences between direct and indirect sampling methods. The yellow trays yielded a larger species diversity, however, the most abundant species in the yellow trays were not the most common species observed directly on the plants. The most abundant species on carrot (*R. solanicola*) and potato (*I. divergipennis*) by direct collection methods were not the most collected in the yellow trays in these two crops. Since, yellow trays are not neutral traps and may attract insects different from the ones than land on a given crop (Hall et al., 2007), it is highly likely that several species collected in yellow trays in our work are migrant insects, which do not develop on the crop.

Russelliana capsici has been recorded from Argentina (Buenos Aires, Entre Ríos) and Brazil (MG, SC, SP) (Burckhardt et al., 2012). In the present study we collected the species in MG and SP and we examined additional material from Goiás, Mato Grosso do Sul, Rio de Janeiro and

Table 5
Psyllid species and number of individuals collected with yellow tray water traps in vegetable crop fields (Carrot – *Daucus carota* L.; African eggplant - *Solanum aethiopicum* Jacq.; Eggplant - *Solanum melongena* L.; Potato - *Solanum tuberosum* L.). See Supplementary Material for details.

Psyllid species	Carrot	African eggplant	Eggplant	Potato
Apsyllopsis mexicana				3
Blastopsylla occidentalis			2	5
Caradocia longiantennata				2
Caradocia sp.				1
Ctenarytaina spatulata				2
Diaphorina citri				1
Diclidophlebia crassiflagellata				1
Diclidophlebia sp.	1			
Euceropsylla sp. *martorelli* group		8	2	1
Euceropsylla sp. *russoi* group		5		1
Glycaspis brimblecombei			1	1
Heteropsylla caldwelli	3			60
Heterospylla cubana		14	3	3
Heteropsylla spinulosa				5
Heteropsylla sp.	2			
Isogonoceraia divergipennis	1	157	32	2
Isogonoceraia sp.			1	
Leurolophus oriformae				1
Mastigimas anjosi			4	3
Mastigimas sp.				1
Mitrapsylla copaiferae				1
Mitrapsylla gloriae				1
Mitrapsylla spp.	1	3	3	33
Paracarsidara sp.				56
Platycorypha sp.			1	30
Pseudophacopteron longicaudatum				2
Russelliana solanicola		1	1	4
Trioza tabebuiae		1		6
Trioza sp.				1

Rio Grande do Sul, thus expanding the known range of distribution. In RS we collected seven samples, including one with many immatures, on *Solanum laxum* (Solanaceae, tribe Solaneae), a new host record, which is within the subfamily Solanoideae only distantly related to *Capsicum* (tribe Capsiceae). *Solanum laxum* occurs naturally in southeastern Brazil from MG to RG, to the Río de la Plata in Argentina and Uruguay, and into Paraguay. The plant also is cultivated in temperate and subtropical regions around the world and is often naturalized (Knapp, 2013). On the other hand, chilli pepper is suspected to originate from tropical northern Amazonia (Pickersgill, 1971). Judging from the presumed native distribution of the two plants it seems more likely that *S. laxum* is the original host plant of *R. capsici* and chilli pepper constitutes a more recently acquired host. Shifts from native to introduced plants (but not necessarily the closest relatives) seem to turn the psyllids into invasive pests, as in *Diaphorina citri* (shift from *Murraya koenigii* (L.) Spreng. (=*Bergera koenigii* L.) to *Citrus*) or *M. anjosi* (shift from *Cedrela* to *Toona*) (Hollis, 1987; Burckhardt et al., 2011)

Russelliana solanicola is one of the few polyphagous psyllid species. It has been reported from plants in the Amaranthaceae, Asteraceae, Escalloniaceae and Solanaceae (Serbina et al., 2015; Serbina and Burckhardt, 2017). Here we report it for the first time from Apiaceae (carrot) which belongs to the same clade (asterid II) as Asteraceae and Escalloniaceae. Of all specimens of this species collected in our study, 96% were captured directly on carrot, at different locations in GO, MG and SP. *Russelliana solanicola* is widely distributed in subtropical and temperate South America and was reported as a pest of potato in Chile and Peru (Serbina et al., 2015). Interestingly, in our study *R. solanicola* was rare on this crop with only eight adults and one immature. The reason for this discrepancy is unknown, but it may be influenced by different environmental conditions or different host races. A similar case is known from another potato psyllid, *Bactericera nigricornis*. It is considered a severe pest of potato in Iran (Fathi, 2011) but was found only in very low numbers in Spain without any eggs or immatures (Antolínez et al., 2019). In our study, we collected a large number of *R. solanicola* on the weed *Parthenium hysterophorus* L. This weed is a confirmed host of *R. solanicola* (Serbina et al., 2015).

While the majority of the collected psyllid species does not seem to have any negative impact on the crops, the situation with the two *Russelliana* species is more serious, as both might be potential vectors of Lso or other plant pathogens. *Russelliana capsici* apparently shifted within Solanaceae from a native plant to a crop species and may do this again in future. *Russelliana solanicola* is known to colonize a broad range of crops and weeds. The wide host range shown by *R. solanicola* represents a serious threat to Solanaceae and Apiaceae crops if there is a Lso introduction in areas where the species is established. Accordingly, special attention should be given to countries such as Peru where *R. solanicola* and *B. cockerelli* may co-occur. The possibility exists that *R. solanicola* could acquire Lso, or that *B. cockerelli* could acquire the apparent pathogen transmitted by *R. solanicola* reported by Salazar (2006) and others. Psyllid testing is beyond the scope of this paper; however, we encourage routine monitoring of Lso and other relevant plant pathogens in this psyllid species to confirm its vectorial capacity and also as part of a surveillance strategy to avoid spill over of Lso and other vectored plant pathogens to other countries in the region.

Conclusions

This is the first comprehensive study of the psyllid fauna of vegetable fields in South America. *Russeliana capsici* was found to be associated with chilli pepper, and *R. solanicola* was found on carrot and potato. It is important to emphasize that this is the first report of *R. solanicola* from carrot. The two species develop on these crops, documented by the presence of immatures. The polyphagous *R. solanicola* also was found in large numbers on *Parthenium hysterophorus*, a weed that was known previously as a host (Serbina et al., 2015). During the survey, at least 37 additional psyllid species were found. Specimens of 23 of these species could be identified to species, with the remaining 14+ species being undescribed or belonging to genera that are taxonomically poorly known. Most of the species collected are native taxa often associated with Fabaceae, along with several adventive species associated with citrus and eucalypts. Even though some of the species were found in considerable numbers (*I. divergipennis, Heteropsylla caldwelli* or *Paracarsidara* sp.) none of these psyllids develop on any of the examined crop species.

Another very important conclusion from our study is that for monitoring psyllid populations in vegetable fields, direct methods, such as visual inspection or the use of a sweep net or beating tray, are much more efficient than yellow tray water traps. The traps collected only six specimens of *R. solanicola* compared to 98 adults of *R capsici* and 2050 adults of *R. solanicola* taken with direct methods.

To date, Lso has not been reported from South America outside of Ecuador (Castillo Carrillo et al., 2019; Caicedo et al., 2020), and it is unknown whether the two native *R. capsici* and *R. solanicola* would be capable of transmitting Lso. Salazar (2006) and others reported what they thought to be a virus transmitted by *R. solanicola* in potatoes in Peru. Moreover, Hansen et al (2022) and Kwak et al. (2021) reported a new *Candidatus* Liberibacter species associated with *R. capsici* that may be potentially pathogenic on *Capsicum*. The role played by weeds as reservoirs for the psyllids and associated plant pathogens is unknown. Future studies should address these aspects along with surveys to observe the spread of *B. cockerelli* and Lso, as well as plant pathogens associated with native *Russelliana* species, in South America.

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Conflicts of interest

The authors declare no conflict of interest

Author contribution statement

TMAK, JRSL, DB, DLQ conceived and designed the experiments. TMAK, DB, DLQ, GRT performed the experiments. TMAK, DB, DLQ identified the psyllids and analysed the data. JRSL, DLQ contributed reagents/materials/analysis tools. TMAK, JRSL, DB, DLQ, CAA wrote the paper. All authors read and approved the final version of the manuscript.

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Supplementary Material

The following online material is available for this article:

Psyllids collected in vegetable fields in the Center-South region of Brazil with information on state, locality, geographical coordinates, altitude, sampling date, crop species and sampled plant (if different both are given), methods, psyllid species with sampled number of specimens (N).