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Chemical properties of fleshy fruits in a rural-urban gradient: nutritional implications for urban frugivorous birds

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SUMMARY
This study aims to analyze the chemical properties of fleshy fruits in urban and rural areas, investigating nutritional variations and possible impacts on frugivorous consumers, especially urban birds. Five plant species, common in urban and rural areas, were selected to assess the chemical properties of the fruits, including pH, soluble solids, acidity, sugars, vitamin C, pigments, phenols, and antioxidant capacity. Birds' consumption of fruits was also monitored in both environments. The originality of this study lies in the approach to the influence of urbanization on the chemical properties of fruits and their nutritional implications for urban frugivorous birds, contributing to the understanding of plant-animal interactions in urban contexts. The results indicated variations in the chemical parameters of the fruits among plant species and environmental gradients but without a clear pattern. Some species exhibited significant differences in their chemical compositions between urban and rural areas, suggesting adaptations to urban environmental stress. This study's theoretical and methodological contributions highlight the complexity of plant responses to urban environments and the importance of considering the specificities of each species and the environmental conditions to which they are exposed. This study's social and environmental implications are relevant for managing urban biodiversity and conserving frugivorous birds in cities, suggesting that the selection of plant species for urban afforestation should consider the fruits' nutritional properties and their attractiveness to local fauna.

KEYWORDS: Urban ecology. Plant adaptation. Urban biodiversity.

1 INTRODUCTION

Urbanization, characterized by expanding built-up areas, represents a significant environmental disturbance in contemporary times and is identified as one of the primary drivers of global biodiversity loss (GRIMM et al., 2008; REN et al., 2023). This unprecedented phenomenon demonstrates that the urban population surpasses the rural population, reflecting a significant global shift: with the human population growth projected at 1% per year, it is expected that by 2050, approximately 66% of the world's population, or seven out of ten individuals, will reside in urban areas (UNITED NATIONS, 2019). This fact underscores the imminent need for urban expansion to accommodate the growing number of inhabitants (HUANG et al., 2019; SIMKIN et al., 2022).

Urban greening has been proposed as a fundamental strategy to mitigate the negative impacts of urbanization on biodiversity (ALVEY, 2006; OLDFIELD et al., 2013; LIU & SLIK, 2022). The planting of trees in urban settings enhances the complexity of the built environment and promotes the survival and persistence of diverse animal and plant populations, establishing a positive relationship between urban vegetation cover and biodiversity (ALVEY, 2006; ARONSON et al., 2017; ZHAO et al., 2023). Additionally, urban trees play a crucial role in providing nutrient-rich and energy-rich food resources for fauna through their plant parts, such as flowers and fruits (CORLETT, 2005; SILVA, 2018; LIU & SLIK, 2022; SILVA et al., 2023).

Simultaneously, trees in urban areas are essential for filtering atmospheric pollutants and fine particles, many of which are emitted by vehicles (HAN et al., 2020; DIENER & MUDU, 2021; MANDAL et al., 2023; VENTER et al., 2024). This filtering function raises essential questions about the potential effects of vehicular pollution on the nutritional qualities of edible plant parts (AMATO-LOURENCO et al., 2020; BUSCAROLI et al., 2021; BRANDNER & SCHUNKO, 2022), which are crucial for the ecology, behavior, and health of consumer animals (KLASING, 1998; GILARDI & TOFT, 2012; BRIGHTSMITH & CÁCERES, 2017; SILVA et al., 2023). The advancement of urbanization forces many animals to live and feed in urban environments (MCKINNEY, 2002; BENINDE et al., 2015; LEPCZYK et al., 2023), potentially facing risks of adverse nutritional impacts resulting from vehicular pollution. In this context, assessing the nutritional chemical properties of food resources offered by plants to urban fauna is imperative.

2 OBJECTIVES

This study compares the chemical properties of fleshy fruits from urban areas exposed to vehicular pollution with those from less contaminated rural regions. The goal is to discern variations in the nutritional qualities of fruits due to environmental differences and to assess possible adverse effects on frugivorous consumers, with a particular emphasis on urban avifauna.

3 METHODS

3.1 Study area

The study occurred in the Presidente Prudente municipality in the Pontal do Paranapanema region, western São Paulo State, Brazil. The region has a megathermic Aw climate, with two defined seasons: a rainy between October and March and a dry from April to September. The municipality's total area is 560.637 km², but only about 11% is covered by natural vegetation, indicating a predominantly anthropogenic landscape marked by agricultural and livestock activities. Presidente Prudente is the largest city in the region, with an estimated population of 225,271 inhabitants in 2017, with 96% residing in the urban area.

3.2 Investigated plant species

Five plant species common in urban and rural areas were selected: mango (*Mangifera indica*, Anacardiaceae), guava (*Psidium guajava*, Myrtaceae), jambolan (*Syzygium cumini*, Myrtaceae), mulberry (*Morus nigra*, Moraceae), and weeping fig (*Ficus benjamina*, Moraceae). The selection was based on the frequent consumption of their fruits by various birds and the distinct phenological patterns, including asynchronous, extended, and biannual fruiting, ensuring fruit availability throughout the year.

3.3 Sampling design

The study compared the chemical, therefore nutritional, properties of fruits from plants in environments with different pollution levels. Three urban public roads with high vehicular traffic (Av. 14 de Setembro, Av. 11 de Maio, and Av. Osvaldo da Silva) and two rural sites (Ponte Alta and Gramado Presidente Prudente) with low vehicular traffic were selected. A total of 50 plants (10 of each species) were monitored for one year, with five plants of each species allocated on public roads and five allocated in rural areas.

3.4 Evaluation of the chemical and biochemical fruit properties

Up to 500g of ripe fruits from each of the 50 plants selected for the study were collected, totaling ten plants of each of the five investigated species, 25 in each environment. The ripening stage of the fruits was standardized to ensure comparability between samples. The collected fruits were packed in polyethylene bags and transported to the laboratory, where they were stored at -80°C until analysis. In the laboratory, the fruits from each plant were separated into batches representing the repetitions, and the plants represented the treatments.

The chemical analyses were performed according to the methodology of the Adolfo Lutz Institute (2005) and included: 1) pH – determined directly with a digital pH meter; 2) Soluble solids – performed with a bench refractometer; 3) Titratable acidity – performed by titration with NaOH solution (0.1N), results were expressed in g of citric acid per 100ml of juice and 4) Total reducing sugars (TRS) – performed by hot and cold titration with Fehling's solution, the results expressed in g of glucose per 100 ml of solution.

The biochemical analyses were: 5) Vitamin C (method 364/IV; IAL, 2005) 6) Pigments (performed according to the methodology proposed by Sims; Gamon, 2002, the results were expressed in mg per 100 grams of fresh matter); 7) Total phenols (performed according to the method proposed by Singleton; Rossi (1965) and the results expressed in mg per gram of dry matter, equivalent in tannic acid); 8) Antioxidant capacity (determined as proposed by Brand-Williams et al. 1995).

These chemical parameters were chosen because they indicate the fruits' nutritional quality and potentially influence the attractiveness and consumption of frugivorous birds.

3.5 Observations of bird frugivory

Bird fruit consumption was monitored focally on fruiting plants in both urban and rural environments. Observations were made in the early morning and late afternoon, periods of most significant bird activity. Visiting birds were identified and classified at the species level, and their feeding behavior, i.e., whether they ingested the pulp or the seed, was recorded.

3.6 Data analysis

After collecting and analyzing the chemical properties of the fruits, the data were organized and grouped by environment (urban and rural areas) for each investigated plant species. The main objective was to verify whether the chemical properties of the fruits differ significantly between urban and rural areas. For this purpose, the Mann-Whitney U Test was employed, with a significance level of 5% ($p < 0.05$). This non-parametric test was chosen because it is appropriate for comparing two independent samples without assuming a normal data distribution.

The results of the chemical analyses of the fruits were compared with reference values established in the literature for each chemical component analyzed. This comparison allowed for the evaluation of the nutritional quality of the fruits in both environments. The reference values were obtained from previous studies that determined acceptable chemical parameters to measure the quality of the fruits of the evaluated plant species (Table 1).

Comparing the obtained results with the reference values made it possible to infer the quality of the fruits in terms of their nutritional value. Fruits that presented values within the acceptable ranges were classified as good quality. At the same time, those that deviated from these standards were analyzed for possible negative impacts on urban biodiversity, especially regarding consumption by frugivorous birds.

Table 1 – Values established as acceptable chemical parameters for measuring the quality of the fruits of the plant species evaluated in this study. The superscript numbers correspond to the bibliographic sources from which the values were obtained.

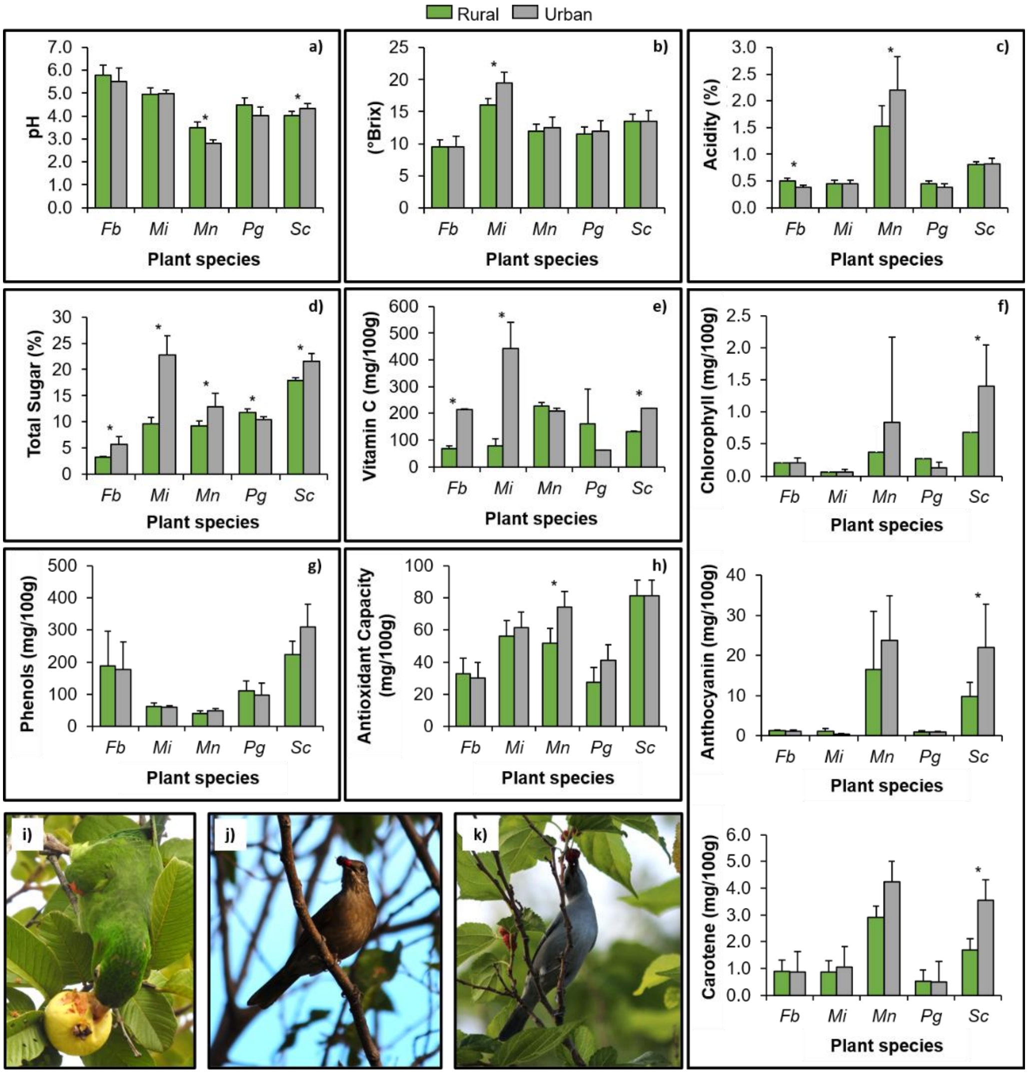
Chemical component	**Values for plant species**				
	F. benjamina	***M. indica***	***M. nigra***	***P. guajava***	***S. cumini***
pH	5.52 to 7.8[1]	2.6 to 5.6[9]	3.43 to 3.69[17]	3.0 to 4.27[25]	2.95 to 9.0[33]
Soluble Solids	0.55 to 15.2 (°Brix)[2]	8 to 60 (°Brix)[10]	9.30 to 32 (°Brix)[18]	9.2 to 13.12 (°Brix)[26]	9 to 19 (°Brix)[34]
Titratable Acidity	4.85%[3]	0.11% to 1.4%[11]	0.14% to 1.97%[19]	0.34% to 1.19%[27]	0.55% to 4.6%[35]
Total Sugars	0.25% to 31%[4]	3.5% to 38.85%[12]	3.68% to 13.6%[20]	5.63% to 8.85%[28]	39% to 288.96%[36]
Vitamin C	0.61 to 5.6109 mg/100g[5]	18 to 125.62 mg/100g[13]	11.11 to 366.67 mg/100g[21]	53.6 to 187.60 mg/100g[29]	0.179 to 99 mg/100g[37]
Pigments	0.02 to 17 mg/100g[6]	0.05 to 4.6 mg/100g[14]	0.08 to 193 mg/100g[22]	0.31 to 0.97 mg/100g[30]	0.157 to 16.9 mg/100g[38]
Total Phenols	50.80 to 735.11 mg/100g[7]	1.11 to 2.382 mg/100g[15]	134.73 to 1684 mg/100g[23]	0.47 to 179.26 mg/100g[31]	82.45 to 705.01 mg/100g[39]
Antioxidant Capacity	38.15 to 94.01 mg/100g[8]	23.1 to 2930 mg/100g[16]	16.87 to 10245.96 mg/100g[24]	0.41 to 94.90 mg/100g[32]	2.27 to 168 mg/100g[40]

Source: [1] Lang et al. (1990); Sandabe et al. (2005); Eddy et al. (2014). [2] HosomI (2017); Zúñiga et al. (2018). [3] Abdel-Aziz et al. (2019). [4] Schmitz et al. (2000); Abdou et al. (2004); Veneklaas et al. (2005). [5] Hakiman et al. (2009); Nawaz et al. (2020); Nurviana et al. (2020). [6] Lang et al. (1990); Cuba et al. (2020); Shah et al. (2017). [7] Imran et al. (2014); Singh et al. (2019); Abdel-Hameed et al. (2008). [8] Hakiman et al. (2009); Saptarini et al. (2015); Singh et al. (2019). [9] Brandão et al. (2003); Vasconcelos et al. (2018); Vilar et al. (2019). [10] Brandão et al. (2003); Vasconcelos et al. (2018); Vilar et al. (2019). [11] Vilar et al. (2019); Miguel et al. (2013); Brandão et al. (2003). [12] Medlicott et al. (1984); Brandão et al. (2003); Baloch et al. (2011). [13] Brandão et al. (2003); Ma et al. (2011); Costa et al. (2019). [14] Parikh et al. (1990); Maciel et al. (2009); Lucena et al. (2011). [15] Maciel et al. (2009); Arbos et al. (2013). [16] Ma et al. (2011); Arbos et al. (2013). [17] Ercisli et al. (2006); Ercisli et al. (2007); Nayab et al. (2020). [18] Ercisli et al. (2007); Okatan (2018); Farahani et al. (2019). [19] Okatan et al. (2016); Okatan (2018); Farahani et al. (2019). [20] Ozgen et al. (2008); Mikulic-Petkovesk et al. (2012). [21] Okatan (2018); FarahanI et al. (2019); Nayab et al. (2020). [22] Guha et al. (2012); Brandão et al. (2011); Farahani et al. (2019). [23] Ercisli et al. (2006); Farahani et al. (2019); Nayab et al. (2020). [24] Vizzoto et al. (2012); Okatan (2018); Farahani et al. (2019). [25] Souza et al. (2010); Coser et al. (2014); Etemadipoor et al. (2019). [26] Souza et al. (2010); Hong et al. (2012); Maji et al. (2015). [27] Etemadipoor et al. (2019); Hong et al. (2012). [28] Souza et al. (2010); Ramos et al. (2011); Maji et al. (2015). [29] Souza et al. (2010); Hong et al. (2012); Maji et al. (2015). [30] Fernandes et al. (2007); Watanabe et al. (2011); Etemadipoor et al. (2019). [31] Watanabe et al. (2011); Oliveira et al. (2011); Haida et al. (2011). [32] Oliveira et al. (2011); Haida et al. (2011); Maji et al. (2015). [33] Venkitakrishnan et al. (1997); Faria et al. (2011); Correia et al. (2014). [34] Lago et al. (2006); Barcia et al. (2012); Correia et al. (2014). [35] Lago et al. (2006); Correia et al. (2014); Mussi et al. (2015). [36] Venkitakrishnan et al. (1997); Lago et al. (2006); Barcia et al. (2012). [37] Banerjee et al. (2004); Brandão et al. (2011); Pereira et al. (2012). [38] Venkitakrishnan et al. (1997); Barcia et al. (2012); Faria et al. (2011). [39] Brandão et al. (2011); Jayachandra et al. (2012); Veber et al. (2015). [40] Banerjee et al. (2004); Kuskoski et al. (2006); Veber et al. (2015).

4 Results

The chemical and nutritional parameters of the fruits showed contrasting variations between plant species and rural and urban environmental gradients but without a clear pattern (Figure 1). Below are the details of the comparisons.

Figure 1 – Chemical and nutritional characteristics of fruits from rural and urban areas (a–h). Acronyms: *Fb* = *Ficus benjamina*; *Mi* = *Mangifera indica*; *Mn* = *Morus nigra*; *Pg* = *Psidium guajava*; *Sc* = *Syzygium cumini*. (*) Indicates a significant difference (Mann-Whitney U test; $p < 0.05$). Error bars represent the standard deviation. Birds: i) *Psittacara leucophthalmus* consuming fruits of Pg; j) *Turdus leucomelas* foraging fruit of Mn; k) *Thraupis sayaca* ingesting fruit of Mn.



Source: Authors (2024).

Note: Photo (i) Amanda G. Cherutte; j) Douglas A. Ferreira; K) Caio V. de Almeida.

4.1 pH

The pH values of the fruits of *F. benjamina* (5.0-6.5), *M. indica* (4.5-5.2), and *P. guajava* (3.7-5.0) were similar in rural and urban areas (Figure 1a). In contrast, the fruits of *M. nigra* showed a significantly higher pH in the rural area (3.3-3.8) than in the urban area (2.7-3.1). The fruits of *S. cumini* also showed significant differences, with a higher pH in the urban area (4.1-4.6) compared to the rural area (3.8-4.3). All values are within the acceptable limits of Table 1.

4.2 Soluble Solids

The soluble solids values in the fruits of *F. benjamina* (7.5-12.5 °Brix), *M. nigra* (10-15 °Brix), *P. guajava* (10-15 °Brix), and *S. cumini* (12.5-17.5 °Brix) were similar in rural and urban areas (Figure 1b). In contrast, the fruits of *M. indica* showed significantly higher values in the urban area (17.5-20 °Brix) compared to the rural area (15-17.5 °Brix) (Figure 1b). All values are under Table 1.

4.3 Titratable Acidity

Titratable acidity values in *M. indica* (0.35-0.51%), *P. guajava* (0.32-0.54%), and *S. cumini* (0.74-1.02%) fruits were comparable in both rural and urban areas (Figure 1c). Conversely, *F. benjamina* fruits exhibited higher acidity in rural areas (0.45-0.58%) compared to urban areas (0.32-0.42%) (Figure 1c). *Morus nigra* fruits displayed increased acidity values in urban areas (1.28-2.78%) relative to rural areas (1.06-1.92%) (Figure 1c). Most values align with those in Table 1, except for *F. benjamina*.

4.4 Total Sugars

The total sugar content in *F. benjamina* fruits was significantly higher in urban areas (4.1-7.6%) than in rural areas (3.2-3.5%) (Figure 1d). A similar trend was observed for *M. indica* (urban: 16.2-25%, rural: 8.5-11.1%), *M. nigra* (urban: 10.6-16.7%, rural: 8.1-10.4%), and S. cumini (urban: 19.2-23.3%, rural: 17.2-18.5%). In contrast, *P. guajava* exhibited higher total sugar content in rural areas (11.1-12.5%) compared to urban areas (10-11.1%). Most values are consistent with those in Table 1, except for *P. guajava* and *S. cumini*.

4.5 Vitamin C

Vitamin C levels in *M. nigra* (193.73-242.2 mg/100g) and *P. guajava* (61.6-308.2 mg/100g) fruits were similar in both rural and urban areas (Figure 1e). In contrast, F. benjamina fruits showed significantly higher vitamin C levels in urban areas (211.34-220.15 mg/100g) than in rural areas (57.2-83.7 mg/100g). *Mangifera indica* fruits also exhibited significant differences, with higher values in urban areas (361.05-612.02 mg/100g) than in rural areas (35.2-105.7 mg/100g). Similarly, *S. cumini* had higher vitamin C levels in urban areas (220.15 mg/100g) than in rural areas (132.1-136.5 mg/100g). Most values do not conform to those in Table 1, except for *M. nigra* and *F. benjamina*.

4.6 Pigments

Total chlorophyll content in *F. benjamina* (0.12-0.33 mg/100g), *M. indica* (0.008-0.11 mg/100g), *M. nigra* (0.0008-3.10 mg/100g), and *P. guajava* (0.03-0.49 mg/100g) fruits were comparable in both rural and urban areas (Figure 1f). However, *S. cumini* exhibited significantly higher values in urban areas (0.76-2.29 mg/100g) than in rural areas (0.32-1.03 mg/100g). For anthocyanins, values were similar in *F. benjamina* (0.69-1.55 mg/100g), *M. indica* (0.20-2.18 mg/100g), *M. nigra* (3.44-41.13 mg/100g), and *P. guajava* (0.56-1.57 mg/100g) fruits in both areas (Figure 1f). However, *S. cumini* had higher values in urban areas (12.26-35.07 mg/100g) than in rural areas (3.66-12.50 mg/100g). Carotenoid content was similar in *F. benjamina* (0.74-1.06 mg/100g), *M. indica* (0.42-2.03 mg/100g), *M. nigra* (0.91-7 mg/100g), and *P. guajava* (0.35-0.65 mg/100g) fruits in both rural and urban areas (Figure 1f). In contrast, *S. cumini* showed higher values in urban areas (2.01-5.30 mg/100g) than in rural areas (0.63-2.70 mg/100g).

4.7 Total Phenols

Total phenol values in *F. benjamina* (75.63-367.63 mg/100g), *M. indica* (54.37-81.71 mg/100g), *M. nigra* (32.01-59.56 mg/100g), *P. guajava* (46.58-138.04 mg/100g), and *S. cumini* (166.91-374.31 mg/100g) fruits were similar in both rural and urban areas (Figure 1g). Most values align with those in Table 1, except for *M. nigra*.

4.8 Antioxidant Capacity

Antioxidant capacity values in *F. benjamina* (26.13-43.40 mg/100g), *M. indica* (27.35-86.32 mg/100g), *P. guajava* (16.57-66.57 mg/100g), and *S. cumini* (78.18-85.67 mg/100g) fruits were comparable in both rural and urban areas (Figure 1h). In contrast, *M. nigra* fruits exhibited significantly higher antioxidant capacity values in urban areas (71.62-77.29 mg/100g) than in rural areas (35.38-68.12 mg/100g). Except for *F. benjamina*, all other values are consistent with those in Table 1.

4.9 Bird frugivory

The fruits attracted 32 bird species (see Figures 1i to 1k), with 23 taxa recorded in the rural area and 21 in the urban area (Table 2). A total of 1,135 fruit consumption observations were made, with 324 in the rural area and 811 in the urban area. *Tangara sayaca* (Figure 1k) was the most frequently observed species consuming fruits in the urban area and the second most frequent in the rural area. *Turdus leucomelas* (Figure 1j) was the most commonly observed species consuming fruits in the rural environment. No fruit consumption of *P. guajava* was recorded in the rural area, nor was *M. indica* in the urban area. Among all plant species, *M. nigra* was the plant whose fruits were most consumed in both environments (Table 2). *Ficus benjamina* and *M. indica* plants were more visited by frugivorous birds for their pulp in rural areas. Conversely, *M. nigra*, *P. guajava*, and *S. cumini* plants had their fruits sought after by birds primarily in the urban area (Table 2).

5 DISCUSSION

The investigation of variations in the chemical properties of fruits in rural and urban contexts revealed remarkable complexity. Contrary to initial predictions, the comparative analysis did not demonstrate uniform patterns of significant change attributable to the urban environment. This finding highlights the resilient biochemical nature of the examined plant species, which, for the most part, maintained their essential chemical properties, aligned with the patterns established in the scientific literature (see Table 1 and included references) despite the distinct environmental pressures present in urban areas (MCKINNEY, 2008; ARONSON et al., 2014).

Table 2 – Birds attracted to the fruiting monitored plant species.

Family	**Species**	**Rural areas**					**Urban areas**				
		Fb	***Mi***	***Mn***	***Pg***	***Sc***	***Fb***	***Mi***	***Mn***	***Pg***	***Sc***
Columbidae	*Columba livia*	0	0	0	0	0	0	0	1	0	0
	Zenaida auriculata	0	0	0	0	0	0	0	1	0	3
Cuculidae	*Crotophaga ani*	0	0	2	0	0	0	0	3	0	0
Furnariidae	*Furnarius rufus*	0	0	0	0	0	0	0	1	0	0
Icteridae	*Cacicus haemorrhous*	2	5	19	0	2	0	0	0	0	0
	Gnorimopsar chopi	0	0	0	0	1	0	0	0	0	0
	Icterus pyrrhopterus	0	0	2	0	1	0	0	0	0	0
Mimidae	*Mimus saturninus*	2	0	0	0	1	0	0	5	9	0
Psittacidae	*Brotogeris chiriri*	1	7	1	0	2	0	0	10	4	0
	Psittacara leucophthalmus	0	0	0	0	0	4	0	9	10	46
Rallidae	*Pardirallus nigricans*	0	0	0	0	1	0	0	0	0	0
Ramphastidae	*Pteroglossus castanotis*	2	0	0	0	0	0	0	0	0	0
	Ramphastos toco	4	0	0	0	0	0	0	0	0	0
Thraupidae	*Conirostrum speciosum*	0	0	0	0	0	0	0	9	0	0
	Dacnis cayana	0	1	0	0	0	0	0	0	0	0
	Euphonia chlorotica	0	0	0	0	0	0	0	7	2	2
	Nemosia pileata	0	0	3	0	0	0	0	20	0	0
	Tangara cayana	0	0	4	0	0	0	0	6	0	0
	Tangara palmarum	0	0	0	0	0	0	0	1	0	0
	Tangara sayaca	12	1	53	0	6	16	0	569	3	8
Tityridae	*Tityra cayana*	0	0	1	0	0	0	0	0	0	0
Troglodytidae	*Troglodytes musculus*	0	0	1	0	0	0	0	0	0	0
Turdidae	*Turdus leucomelas*	74	0	52	0	25	0	0	9	1	8
Tyrannidae	*Elaenia flavogaster*	0	0	0	0	0	0	0	3	0	0
	Elaenia spectabilis	0	0	0	0	1	0	0	2	0	0
	Legatus leucophaius	0	0	4	0	0	0	0	2	0	0
	Machetornis rixosa	0	0	0	0	0	0	0	0	1	1
	Megarynchus pitanguá	0	0	1	0	0	0	0	2	0	1
	Myiodynastes maculatus	0	0	4	0	0	0	0	0	0	0
	Pitangus sulphuratus	0	0	12	0	10	9	0	14	0	6
	Tyrannus melancholicus	0	0	3	0	0	0	0	0	0	0
	Tyrannus savana	0	0	1	0	0	3	0	0	0	0
Total of visits		**97**	**14**	**163**	**0**	**50**	**32**	**0**	**674**	**30**	**75**

Source: Authors (2024).
Note: *Fb* = *Ficus benjamina*; *Mi* = *Mangifera indica*; *Mn* = *Morus nigra*; *Pg* = *Psidium guajava*; *Sc* = *Syzygium cumini*.

Certain species exhibited specific discrepancies in their chemical compositions, suggesting a differentiated response to urban environmental factors. This phenomenon indicates the need for a more granular analysis, considering each species's uniqueness and the specific environmental conditions they are exposed to (BENINDE et al., 2015). The study corroborates that plant responses to urban environments are multifaceted and can vary significantly between species (JIM & CHEN, 2008; STROHBACH et al., 2012; CONWAY & VANDER VECT, 2015).

The role of urban environmental factors, such as pollution and elevated CO_2 concentrations, in modulating the chemical properties of fruits emerges as a central theme in this discussion. These factors can induce physiological changes in plants that, in turn, affect the chemical composition of the fruits (SHOCHAT et al., 2006; ALBERTI et al., 2017; LORENZO et al., 2018). This study adds to the growing evidence that plants in urban environments may develop adaptive mechanisms to mitigate environmental stress, reflected in their biochemical properties (PICKETT et al., 2011; STROHBACH et al., 2012; HÄFFNER et al., 2018).

Bird frugivory in urban areas and how it relates to the chemical properties of fruits are other notable aspects revealed by the research. Birds' preference for fruits in urban areas, possibly influenced by alterations in the chemical composition of the fruits, highlights the interconnection between urban flora and fauna (BURGHARDT et al., 2009; GILARDI & TOFT, 2012). This dynamic suggests that urban environmental modifications may have broader implications for urban ecosystems, affecting not only plants but also the trophic networks in which they are embedded (TRYJANOWSKI et al., 2015; LEVEAU et al., 2015; TEIXIDO et al., 2022).

6 CONCLUSION AND PERSPECTIVES

This study provides relevant insights into the impact of the urban environment on the chemical properties of fruits of some plant species, offering some notion of its implications for bird frugivory in urban areas. The results indicate that while most species maintain their fundamental chemical characteristics unchanged, there are specific variations that suggest adaptations to urban environmental stress. These findings highlight the complexity of plant-environment interactions in urban contexts and the resilience and adaptability of plant species.

The analysis also emphasizes the interconnection between urbanization and ecological dynamics, suggesting that biodiversity conservation in cities requires an integrated approach. Future studies should delve deeper into understanding how these adaptations affect the diet of frugivorous birds and other species in the urban ecosystem and investigate urban planning strategies that promote wildlife-friendly habitats. Finally, this study contributes to the understanding of urban ecology and the adaptive strategies of plants in the face of urbanization, with implications for urban biodiversity, environmental management, and conservation. The importance of interdisciplinarity in managing urban biodiversity is highlighted, paving the way for future investigations that combine ecology, urban planning, and social sciences.

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