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PHENOLIC COMPOUNDS IN HONEY BEE (APIS MELLIFERA) IN BRAZIL: A REVIEW

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ABSTRACT
Among the products produced by bees (Apis mellifera), honey is widely used for its nutritional potential and therapeutic benefits, which are associated with the content of phenolic compounds. These compounds are related to botanical, geographical and climatic origin. For this reason, Brazilian biodiversity makes it possible to produce very rich honeys in these compounds. Therefore, this review aims to synthesize available evidence on phenolic compounds in honeys of honeys (Apis mellifera), and their antioxidant activity with emphasis on honeys produced in Brazil. The Brazilian floral honeys showed a great variability in the phenolic content, as well as in the phenolic profile of these honeys. Some compounds were present in most honeys from different regions of the country as phenolic acids: gallic acid and p-coumaric acid and flavonoids (quercetin). Due to this, they showed variation in antioxidant activity. In conclusion, we hope that this review will be useful as a reference on the compounds present in monofloral honeys from botanical origins native to Brazil. In addition, we emphasize the antioxidant activity of these compounds, which have the potential to bring benefits to human health.

Keywords: Honey. Polyphenols. Antioxidants.

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INTRODUCTION

Brazil stands out for its rich diversity of biomes, which have great economic and socio-environmental relevance, especially due to the variety of climates and vegetation that favor the breeding of bees and the production of honeys with distinct characteristics. The Northeast region, in particular, presents ideal conditions for honey production, thanks to its diverse flora that makes resources such as nectar and pollen available throughout the year (Sant´ana *et al*., 2020).

Honey, produced by dehydrating and transforming nectar or secretions from live plants or excretions of plant-sucking insects in combination with substances secreted by bees, is a natural food recognized for its nutritious and healthy properties. Its composition, highly influenced by its botanical and geographical origin, is predominantly made up of carbohydrates, with sugar contents ranging from 80–85%, water (15–17%), and small amounts of protein (0.1–0.4%) (Palma-Morales; Huertas; Rodríguez-Pérez, 2023).

In addition, honey contains organic acids, amino acids, vitamins, lipids, aromatic compounds, flavonoids, enzymes, minerals, pollen grains, and phenolic compounds, which play an essential role in its biological and sensory properties (Almeida-Muradian *et al*., 2013; Israili, 2014; Rao *et al*., 2016).

The color of honey, which varies from light to dark tones, is largely determined by the phenolic and mineral compounds present, and its chemical characteristics are directly related to the floral species of origin (Rao *et al*., 2016). The classification of honey, based on its botanical origin, can be monofloral, when it is produced from the nectar of a single botanical species or if its presence is predominant and multifloral when it comes from more than one botanical species or classified as honey from melate made from secretions from the living parts of plants or excretions of plant-sucking insects (Brasil, 2000).

In addition, antimicrobial properties have been associated with its ingestion, due to its ability to inhibit the growth of various pathogenic microorganisms. This property is attributed to its high concentration of sugars, acidic pH, and the production of hydrogen peroxide. In addition, its antimicrobial efficacy is influenced by floral and geographical origin, harvest time, as well as processing and storage conditions (Viteri *et al*., 2021).

In this way, the recognition of honey has grown not only for its nutritional potential, but also for its therapeutic benefits. These attributes are directly related to the content of phenolic compounds and antioxidant capacity, aspects that reinforce the importance of promoting their consumption. In addition, honey production plays a relevant role in the regional economy, functioning as an important source of complementary income for many families (Almeida *et al*., 2016).

Several methods have been used to quantify the antioxidant capacity of bee honeys, given the complexity of their bioactive compounds and their different mechanisms of action. Among them, the ABTS method stands out, which expresses the results in Trolox equivalents (TE), offering standardized comparisons. The DPPH assay, widely used for its simplicity, has limitations related to water solubility and sensitivity to external conditions. FRAP, on the other hand, evaluates the reducing power at acid pH, being more suitable for hydrophilic compounds, while CUPRAC, performed at pH close to physiological, is versatile, covering both hydrophilic and lipophilic compounds (Sadowska-Bartosz; Bartosz, 2022).

In this context, the combined application of these antioxidant activity assays, such as ABTS, DPPH, FRAP and CUPRAC, allows a more comprehensive evaluation of honey, enabling a more accurate understanding of its functional properties. Thus, the present work aims to synthesize available evidence on phenolic compounds in honey bee (*Apis mellifera*), and their antioxidant activity with emphasis on honeys produced in Brazil, whose botanical diversity contributes to their unique characteristics.

METHODOLOGY

For this review article, we searched the PubMed, Science Direct, and Scopus electronic databases, considering studies published between 2012 and 2024. Search terms included "honey", "*Apis mellifera*", "phenolic", "antioxidant", and "Brazil" with their respective English terms alone or in combination.

The inclusion criteria used in this research were: (1) full articles published in English or Portuguese, (2) articles that addressed the content of phenolic compounds in floral honeys in Brazil by the species *Apis mellifera*, (3) article that addressed the content of antioxidant activity in honeys produced by the species *Apis mellifera*. Review articles, book chapters that did not address the content in Brazil, honeydew honeys, honeys produced by another type of bee and that were not available in full were excluded.

The selected articles were analyzed qualitatively, focusing on phenolic compounds and antioxidant activity in floral honeys from Brazil. The information was organized by region, floral origin, phenolic content, identified compounds, and antioxidant activity, and arranged in tables to facilitate comparison and discussion, highlighting research contributions and gaps.

PHENOLIC COMPOUNDS IN MONOFLORAL HONEYS

Phenolic compounds are considered secondary metabolites of plants, participating in plant growth, pigmentation, as antimicrobial agents, in the removal of free radicals, in the absorption of light and the attraction of pollinators, among other functions (Cheynier; Tomas-Barberan; Yoshida, 2015). As plants have high levels of these compounds, they will likely be transferred to honey during nectar collection by bees (De-Melo *et al*., 2018).

The total phenolic content in honey varies depending on the type of flower, geographic location, and climatic conditions. Thus, the analysis of this parameter can be useful to determine the floral and geographical origin of different types of honey (Sousa *et al*., 2018). Thus, a wide variety of monofloral honeys was observed in Brazil, honeys with a unique botanical origin from certain regions (Figure 1), as well as honeys of the same botanical origin from different regions of the country.

Honeys of floral origin *Serjania* and *Schinus*, in the Northeast and South regions, in the Northeast, Southeast and South, of *Eucalyptus*, such as honeys of the botanical genus *Acacia spp*, *Citrus sinensis*, *Coffea arabica in the* Midwest, Southeast and South of the country, *Croton* sp., *Hyptis sp.*, *Hovenia dulcis*, *Mimosa scabrella*, present in the Southeast and South regions of Brazil. In *Apis mellifera honeys* produced in Brazil, the total content of phenolic compounds so far has been determined to be between 0.130 and 191.17 mg EAG/100 g (Table 1).

In the northern region of Brazil, *Apis mellifera honeys* produced in the state of Pará, in areas of the Amazon, showed variations in total phenolic compounds between 4.27 and 154.28 mg GAE/100 g (Oliveira *et al*., 2012; Coast; Toro, 2021). In other investigations, in the Northeast region of the country, honey samples of *Apis mellifera L.*, included floral honeys of botanical origin in *Mimosa caesalpiniifolia*, *Pityrocarpa moniliformis*, *Eucalyptus*, *Cydonia oblonga* and multiflorals (Almeida *et al*., 2016; Archilia *et al*., 2021; Silva *et al*., 2020; Silva, D. *et al*., 2024; Sousa *et al*., 2018).

Mimosa caesalpiniifolia *honey* showed variation in total phenolic content (TFT) between 27.65 and 97.01 GAE/100 g, from different regions of Piauí (Silva *et al*., 2020; Silva, D. *et al*., 2024). On the other hand*, Pityrocarpa moniliformis* honey showed a wider variation, between 25.33 and 90.34 mg GAE/100 g (Almeida *et al*., 2016; Silva, D. *et al*.,

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2024). The other botanical origins showed phenolic values between 0.138 and 31 mg GAE/100 g (Almeida *et al*., 2016; Archilia *et al*., 2021) and monofloral honeys between 40.0 to 92.7 mg GAE/100 g (Almeida *et al*., 2016).

Figure 1. Map of Brazil with the botanical origin of honeys produced by bees (*Apis mellifera*) in the different regions of Brazil.

Source: Prepared by the author, 2025.

A great variability in the concentrations of phenolic compounds is also observed in the Midwest region of the country, in honeys of botanical origins in the states of Mato Grosso and Mato Grosso do Sul (Archilia *et al*., 2021; Silva, B. *et al*., 2024). Research carried out in the Southeast Region of Brazil, with honeys of different botanical origins, observed a wide variation in the contents of total phenolic compounds, from 0.298 to 105.05 mg GAE/100 g (Kadri *et al*., 2016; Liandra *et al*., 2012; Lira *et al*., 2014; Nunes *et al*., 2022; Pena-Júnior *et al*., 2022; Salgueiro *et al*., 2014; Silva, B. *et al*, 2024; Sant'ana *et al*., 2012).

In the research by Nunes *et al*. (2022), determined 112.60 ± 21.11 mg GAE/100 g when analyzing monofloral and heterofloral honeys, confirming that the contents of these compounds may vary according to the botanical origin of the nectar collected by the bee. In the analyzed samples of honeys from western Paraná, they showed a variation in total phenolic compounds between 11.39 and 61.27 mg GAE/100 g (Galhardo *et al*., 2021), from the southern region of the country, which have a great diversity of monofloral honeys studied and levels of phenolic compounds (Bueno-Costa *et al*., 2016; Brugnerotto *et al*., 2023; Galhardo *et al*., 2021; Gregório *et al*., 2021; Nascimento *et al*., 2018; Nunes *et al*., 2022; Ribeiro *et al*., 2020; Risélio *et al*., 2020; Royo *et al*., 2022; Silva, B. *et al*., 2024).

Flavonoids are the main polyphenols found in honey and can influence characteristics such as the aroma, color, and biological properties of this food (Lakhmili *et al*., 2024); These compounds ranged from 2.75 to 18.76 mg/100 g in research with honeys from the northern region of Brazil (Costa; Toro, 2021). Samples from Simplício Mendes, Picos and Valença in Piauí showed a variation from 5.43 to 13.02 mg QE/g, with an average of 8.33 ± 1.86 mg QE/g., and multifloral honey had the highest flavonoid content (Silva *et al*., 2020).

More recent studies carried out in Piauí observed that the honey identified from *Mimosa caelsapinifolia* obtained one of the highest levels of flavonoids, with 30.03 ± 1.01 mg QE/100 g. The floral honey of *Pityrocarpa moniliformis,* showed variation from 21.04 to 31.43 mg QE/100 g and of *Mimosa caesalpiniifolia* 22.64 to 30.03 mg QE/100 g, when comparing the floral honeys, revealed that the average content of flavonoids was similar between the two origins, with 24.70 QE/100 g and 25.70 mg QE/100 g, respectively (Silva, D. *et al*., 2024).

Table 1. Phenolic compounds in floral honeys of *Apis mellifera* bees produced in Brazil.

State	**Floral origin**	**Phenolic/Phenol Content***		**Identified compounds**	**References**
		FTa	FITf		
NORTHERN REGION					

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Stop		36.7 to 154.3	-	AG; AF; Apc; AV; Amc; AoC; Atc; Q	Oliveira *et al.*, 2012.
		15.2 to 16.5b 17.7 and 18.9b	-	AG; Acl; ACa; Apc; AIR; Q; K; The; C	Bandeira *et al.*, 2018
		4.3 to 145.4	2.7 to 18.8		Costa and Toro, 2021.
Roraima	Multifloral	250 to 548c	9 to 48.6f		Pontis *et al.*, 2014.
NORTHEAST REGION					
Alagoas	-	92.3 ± 13.5	28..7 ± 9.40		Duarte *et al.*, 2012.
Bahia	*Pityrocarpa moniliformes*	27 ± 2.3	-		Almeida *et al.*, 2016.
	Eucalyptus	31 ± 1.3	-		
	Multifloral	40 to 92.7	-		
	Psidium	330 to 341.5c	141.8 to 160.7g		Silva. I. *et al.*, 2021.
	Serjania	339 ± 3.0c	114.4 ± 7.9g		
	Schinus	325 ± 5.3c	216.3 ± 6.4g		
	Multifloral	260 to 273.4c	1718 to 183g		
Pernambuco	Multifloral	66 to 190e	31 to 167		Pinto-Neto *et al.*, 2024.
Piaui	-	22.1 to 23.4	-		Sousa *et al.*, 2018.
	Mimosa caesalpiniifolia	27.6 to 97.0	5.43 to 13		Silva, S. *et al.*, 2020.
	Cydonia oblonga	0.14 to 0.64	0.1 to 0.2		Archilia *et al.*, 2021.
	Mimosa caesalpiniifolia	43.1 to 67.4	21.7 to 30		Silva, D. *et al.*, 2024.
	Pityrocarpa moniliformis	25.3 to 90.3	21.0 to 31.4		
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
MIDWEST REGION					
Mato Grosso	*Acacia spp.*	33.,6 ± 1.4			Silva, B. et al., 2024.
Mato Grosso do Sul	*Citrus sinensis*	0.18 ± 0.01	0.1 ± 0.0		Archilia et al., 2021.
	Coffea arabica	0.27 to 0.34	0,2		
	Cofea arabica	39.3 ±1.1		AA	Silva, B. et al., 2024.
	Vernonia polyanthes	38.8 ± 2.1		AA; R	
	Multi-charter	74.6 ± 4.0		AA	

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SOUTHEAST REGION					
Rio de Janeiro and	*Citrus sp* *Honey* *Honey extract*	34 to 53.2 12.7 to 76.6	0.2 to 0.3 0.2 to 5.3	AG; APC; HBAP; AV; Apc; Asi; ApMB; ApMC; Q; THE; R; AC	Lianda et al., 2012.
São Paulo	*Multifloral* *Honey* *Honey extract*	42.8 to 78.2 24.2 to 71.8	0.2 to 4.3 0.3 to 0.9	AG; APC; HBAP; AV; Apc; Asi; ApMB; ApMC; Q; IQ; M	
	Gochnatia spp.	4.9 to 7.4	0.4 to 1.6	AA; AG; THE; Amc; AB; AC and AmMC; N	Salgueiro et al., 2014.
	Croton sp.	10.7 to 11	1,2	AA; AG; A4HB; THE; Apc; Amc; AB	
	Vernonia spp.	7.1 and 12.1	1,3	AA; AG; APC; AF, ApC, ApM; AC	
Rio de Janeiro, Minas Gerais and São Paulo	*Orange tree*	43.3 to 75.5	2.6 to 6.7		Lira et al., 2014.
Minas Gerais and	*Ambrosia*	88,8	7,6		Sant'ana et al., 2014.
Rio de Janeiro	*Anadenanthera*	112.6 ± 21.1	5.2 ± 2.2		
	Asteraceae	97.1 ± 9.9	5.5 ± 1.5		
	Citrus	71,2	2,3		
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
SOUTHEAST REGION					
Minas Gerais and	*Copaifera*	112,5	7,5		Sant'ana et al., 2014.
Rio de Janeiro	*Eucalyptus*	105.9 ± 33.8	9.2 ± 2.9		
	Gochnatia	121,8	4,1		
	Verbenaceae	144,1	5,1		
	Multifloral	98.8 ± 19.1	5.6 ± 2.3		
	Montanoa	100.70 ± 1.96	5.6 ± 0.7		
	Myrcia	105 ± 19.8	5.2 ± 2.7		
	Vernonia	132,6	9,9		
Holy Spirit	*Coffea arabica*	-	3.3 to 3.6F		Kadri et al., 2016.
		0.3 to 0.5	0.3 to 0.4		Archilia et al., 2021.
São Paulo	-	3,4 – 4,2	-		Nunes et al., 2022.
	Citrus sinensis	0.1 to 0.4	0.03 to 0.2		Archilia et al., 2021.

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	Citrus sinensis Blend	0.3 ± 0.0	0.1 ± 0.02		
	Coffea arabica	0.4 and 0.4	0.2 and 0.2		
	Eucalyptus spp	0.6 ± 0.0	0.4 ± 0.0		
	Eucalyptus spp Blend	0.723 ± 0.020	0.6 ± 0.0		
Minas Gerais	*Croton ssp.*	61,1	3,5		Sant'ana et al., 2011.
	Eucalyptus	82,8	5,8		
	Coffea arabica	0.4 ± 0.0	0.150 ± 0.010		Archilia et al., 2021.
	Coffea arabica Blend	0.5 ± 0.0	0.3 ± 0.0		
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
SOUTHEAST REGION					
Minas Gerais	*Baccharis spp.*	103.1 ± 1.0d	-		Schiassi et al., 2021.
	Citrus sinensis	95.6 ± 0.8d	-		
	Coffea spp.	110.4 ± 1.8d	-		
	Eucalyptus spp.	78.6 ± 1.2d	-		
	Mimosa scabrella	129.2 ± 1.2d	-		
	Saccharum officinarum L.	118.2 ± 1.4d	-		
	Vernonia polysphaera	102.5 ± 1.5d	-		
	Astronium urundeuva	142.5 ±2 2.6	-		Gardoni et al., 2022.
	Astronium urundeuva	54.9 to 101.8	4.9 to 18.9		Pena Júnior et al., 2022.
	Caryocar from Brasilia	48.8 ± 1.3	5.6 ± 0.2		
	Croton urucurana	45.5 ± 0.5	2.2 ± 0.1		
	Eremanthus incanus	51.4 ± 2.3	3.17 ± 0.2		
	Eucalyptus robusta	64 and 73.5	6.9 and 7.4		
	Hyptis sp.	62.9 ± 2.1	3.1 ± 0.1		
	Omphalea diandra	42.9 ± 2.2	3.4 ± 0.1		
	Serjania lethalis	42.5 ± 3.3	2.2 ± 0.1		
	Veronia scorpioides	107.9 ± 1.1	3.9 ± 0.3		
	Cissus rhombifolia	38.4 ± 1.9	-	NU	Silva, B. et al., 2024.
	Eucalyptus	10.3 ± 0.6	2.0 ± 0.2	AG; Acl; ACa; Apc; AIR; Q; K; The	Wisniewski et al., 2024

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	Multifloral	9.9 ± 0.9	2.2 ± 0.9	AG; Acl; Apc; AIR; The	
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
SOUTHEAST REGION					
Rio de Janeiro	*Croton ssp.*	63.1 to 175.4	2.4 to 3.1		Sant'ana et al., 2011.
	Eucalyptus	99 to 141.1	6.1 to 10.9		
	Gochnatia	104.7 to 129.3	6.4 to 7.6		
Minas Gerais and São Paulo	*Cissus rhombifolia Blend*	0.3 ± 0.0	0.3 ± 0.0		Archilia et al., 2021.
SOUTH REGION					
Rio Grande do Sul	*Eucalyptus and Multifloral*	61.2 to 111.4	3 to 10.5		Buenos-Costas et al., 2016
	-	57.7 ± 2.2	-	AG; Acl; AC; Apc; AF; AIR; Q; K; The; C	Cruz et al., 2016.
	Eucalyptus	37.0 to 100	0.01 to 1.5	AG; APC; Apc; AC; Mi; Q	Nascimento et al., 2018.
	Schinus terebinthifolius	51.5 to 97.5	0.01 to 2.6	AG; AC; Q	
	Hovenia dulcis	26.0 to 58.2	0.01 to 1.6	AG; Apc; Q	
Santa Catarina	*Pluchea Sagittalis*	40.3 to 80.8	0.01 to 1.1	AG; Q	
	Gaya Macrantha	56,5	0,40	AG	
	Multifloral	39.8 to 70.4	0.2 to 1.9	AG; AC; Mi; Q	
	Wild	38.47 to 93.30	5.1 to 12.9		Oliveira et al., 2020.
	Eucalyptus	80.5 6 ± 3.2	7.9 ± 0.1		
	White clover	63.9 ± 2.7	5.1 ± 0.02		
	Multifloral	58.3 to 83.5	5.6 to 7.5		
	Citrus sinensis	0.5 ± 0.02	0.2 ± 0.02		Archilia et al., 2021.
	Mimosa scabrella	109.6 to 142	-	Aca; Acl; Apc; APC; AF; AG; Wing; THE; H; IH; K; L; N; Pk; Pb; Q; R	Seraglio et al., 2017.
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
SOUTH REGION					
Santa Catarina	*Baccharis leucocephala*	30, 0 to 50.0	-	Wing; Apc; Apa; ApAB; MFA; T	Silva, P. et al., 2020.
	Hovenia dulcis	20.0 to 30.0	-	Wing; Apc; Mi	

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	Multifloral	30.0 to 90.0	-	Wing; Apc; AM; Ad	
	Eucalyptus spp	0.7 ± 0.02	0.628 ± 0.070		Archilia et al., 2021.
	-	5.1 to 4.2b	-		Nunes et al., 2022.
	Esccallonia sp.	56.9 to 59.5	-		Brugnerotto et al., 2023.
	-	2.5 to 7.2b	-		Nunes et al., 2023.
	Baccharis spp.	48.1 ± 1.8	-	AA; R	Silva, B. et al., 2024.
	Citrus aurantium	57.7 ± 1.6	-	AA; Wing	
	Escallonia spp.	55.7 ± 2.3	-	NU	
	Eucalyptus globulus	85.6 ± 3.1	-	AA; R	
	Hovenia dulcis	40.4 ± 2.3	-	AA	
Paraná	*Acacia polyphylla*	0.5 ± 0.00	0.1 ± 0.02		Archilia et al., 2021.
	-	11.4 to 61.3	8.0 to 45		Galhardo et al. 2021.
	-	143.7 to 191.2	399.8 to 852.3		Gregório et al., 2021.
	Multifloral	22.5 to 9.5	3.3 to 1.8	AG; Acl; ACa; Apc; AIR; Q; K; The	Wisniewski et al., 2024
		1.6 to 30.5	9.3 to 52.8		Ribeiro et al., 2022.
Santa Catarina and Rio Grande do Sul	-	18.2 to 148.6	0.04 to 8.1		Rizelio et al., 2020.
	Astronium urundeuva	74.7 ± 0.1	-		Royo et al., 2022.
	Caryocar from Brasilia	54.4 ± 0.03	-		
State	*Floral origin*	Phenolic/Phenol Content*		Identified compounds	References
		FTa	FITf		
SOUTH REGION					
Santa Catarina and Rio Grande do Sul	*Croton urucurana*	70.1 ± 0.03	-		Royo et al., 2022.
	Coffea arabica L.	84.8 ± 0.05	-		
	Serjania lethalis A.ST.-Hil	40.7 ± 0.03	-		
	Hyptis sp.	57.6 ± 0.0	-		
	Multifloral	52.4 ± 0.03	-		

Legend: AF: ferulic acid; GA: gallic acid; APC: protocatechuic acid; AS: syringic acid; ASa: salicylic acid; ApHB: p-hydroxybenzoic acid; A4HB: 4-hydroxybenzoic acids; AV: vanillic acid; ApC: p-coumaric acid; AoC: o-coumaric acid; AmC: m-coumarium acid; AmC: meta-coumaric; ASi: synapic acid; ApMB: p-methoxybenzoic acid, AC-cinnamic acid; ApM: p-methoxycinamic acid; AtC: transcinamic acid; AmMC: meta-methoxycinamic AB: benzoic acid; AA: abscisic acid; ACa: caffeic acid; ApAB: p-aminobenzoic acid; ACl: chlorogenic acid; RA: rosmarinic acid; AM: mandelic acid; ApA: p-anisic acid; Ad: aromadendrin; MPA: methoxyphenylacetic acid; A: apigenin; C: chrysin; G: galangin; L: luteolin; R: rutin; H: Hesperidin; IQ: isoquercetin; IH: Isorhamnetina; M:

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morina; Q: Quercetin; N: naringin; Mi: myricetin; S: syringaldehyde; K: kaempferol; Pb: pinocembrina; Pk: Pinobanksin T: taxifolin; NI- unidentified.
*Average of the samples analyzed. The values are expressed: FT- total phenolics - milligram equivalent to gallic acid ([amg] EAG.100g-1; [bmg] EAG.g-1; [CMG] EAG.Kg); [gmg] gallic acid equivalents per 100 g of fresh weight (mg GAEs/100 g f.w.); [tannic] acid equivalents (mgAT.100g); FIT- total flavonoids - milligram equivalent to quercetin ([fmg] EQ.100g-1; [gmg] EQ.kg1; [hmg] EQ.g-1);
Source: Survey data, 2025

Honey samples from the Southeast region of the country showed a variation in flavonoids from 0.36± 0.0 mg QE/100 g to 9.92± 3.14 mg QE/100 g, in the studies by Salgueiro *et al*. (2014) and Sant'ana *et al*. (2014), respectively. The variation in the content of this compound in honeys from the southern region of Brazil was very similar, ranging from 0.2 ± 0.7 mg QE/100 g, in the study by Nascimento *et al*. (2018), from 8.11 ± 0.06 mg QE/100 g, in the research by Rizélio *et al*., 2020 with *Apis mellifera honeys* from Rio Grande do Sul and Santa Catarina.

The color of food is the essential factor that mainly determines the acceptability of food (Sarker; Oba, 2020, 2021), is the first attractive attribute for a commercial honey, it is related to its intensity to botanical origin, to climatic factors during the flow of nectar and to the temperature at which the honey matures inside the hives, and storage conditions such as temperature and humidity, in addition to these factors, other factors such as mineral content also influence the color of honey (Aroucha *et al*., 2008; Silva *et al*., 2016). An increase in the concentration of phenolics was observed in darker honeys (Almeida *et al*. 2016; Bandeira *et al*., 2018).

Almeida *et al*. (2016) identified a significant correlation between color and phenolic content. The lightest samples had the lowest values, while the dark amber samples had the highest, suggesting that polyphenols contribute to the coloration of honey. This relationship was also demonstrated in honeys from the Amazon, where a positive correlation was observed between color, phenolic compound content, and antioxidant activity (Bandeira *et al*., 2018). These results reinforce the influence of phenolics not only on the color, but also on the bioactive properties of honey.

Phenolic compounds are transferred from plants to honeys, so each honey has a phenolic profile according to its floral origin used by bees in the preparation of honey, attesting to differences between regions (Kaškonienė *et al*., 2010). Due to this, the contents and profile of phenolic compounds are being investigated to be used as floral origin markers for monofloral honeys from different regions (Almeida *et al*., 2016).

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The phenolic compounds in Brazilian honeys show significant regional variability, reflecting the diversity of flora and environmental conditions in each location. Compounds such as gallic acid (GA), quercetin (Q), and p-coumaric acid (ApC) have been widely identified in several regions of the country, indicating their prevalence in Brazilian honeys. For example, in the North (Pará), these compounds were highlighted in the studies by Oliveira *et al*. (2012) and Bandeira *et al*. (2018), who also identified other phenolics such as ferulic acid (FA), vanillic acid (AV), apigenin (A), chrysin (A), and kaempferol.

Oliveira *et al*. (2012), highlight that the concentrations of phenolic compounds, gallic acid (FA), o-coumaric acid (AoC), quercetin (Q), vanillic acid (AV) and caffeic acid (ACa), present in the honeys of the different regions of Pará are capable of differentiating the honeys of the region. Similarly, in the Southeast, studies by Lianda *et al*. (2012) and Salgueiro *et al*. (2014) confirmed the presence of gallic acid, quercetin, and p-coumaric acid, along with additional phenolics such as protocatechuic acid (APC) and rutin (R).

On the other hand, some regions showed characteristic compounds, evidencing a specific signature. In the Midwest, for example, Silva *et al*. (2024) identified abscisic acid (AA) as the main phenolics, highlighting its possible link with the regional flora. In the South, the marked presence of compounds such as salicylic acid (ASa) and myricetin (Mi), identified by Nascimento *et al*. (2018) and Silva *et al*. (2024)., differentiates this region from the others. This regional specificity can be attributed to the floral sources used by the bees and the unique environmental conditions. However, in the Northeast region of Brazil, there are no studies that identify the phenolic profile of honeys in this region.

These findings reinforce that, while there are phenolic compounds common in honeys from different Brazilian regions, such as gallic acid, quercetin and protocatechuic acid, others, such as abscisic acid in the Midwest and salicylic acid in the South, are potential markers of the geographical and botanical origin of honey.

ANTIOXIDANT ACTIVITY OF MONOFLORAL HONEYS

Evaluating the antioxidant activity of a sample using a single method is practically unfeasible, which is why it is recommended to combine different methodologies, as is currently done. This is because antioxidants can act through various mechanisms. In addition, the same food can contain a complex mixture of antioxidants that operate through different pathways, resulting in synergistic reactions. Therefore, it is essential to diversify

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the analyses to contemplate all the possible mechanisms of action of the antioxidants present (Bhattacharyya *et al*., 2014).

Thus, studies carried out in four municipalities in the mesoregion of the northeast of Pará, known for its diversity of soils and botanical species, revealed that the darkest and with the highest polyphenol content showed the best antioxidant activities (Oliveira *et al*., 2012). The predominance of amber color was observed in the samples, with the darker colored honeys demonstrating greater antioxidant capacity than the light colored ones. These darker honeys were also classified as polyfloral, indicating a positive relationship between total phenolic content, antioxidant capacity, and color intensity (Almeida *et al*., 2016).

The antioxidant capacity of the honeys was evaluated by different methods. By means of the ABTS radical, it indicated a variation of 0.74 to 4.38 µM Trolox/g, while the FRAP assay for Apis *mellifera honeys* presented results between 0.98 and 4.72 µM/g (Table 2).

The color of honey is associated with its antioxidant capacity, and darker honeys have greater antioxidant action. This characteristic may be related to the presence of phenolic compounds, such as phenolic acids, flavonoids, anthocyanins, and flavones (Silva *et al*., 2016; Viteri *et al*., 2020).

Correlation tests carried out by Almeida *et al*., (2016) demonstrated that samples with higher polyphenol content (TPC) showed greater antioxidant activity, confirming the influence of phenolic compounds on the color and functionality of honey. The results of analysis of variance and significance tests revealed statistically significant differences between samples for the TPC, DPPH, FRAP and CUPRAC methods. The authors observed that the sample with the highest polyphenol content obtained better results in the DPPH, FRAP and CUPRAC assays, respectively. Significant correlations ($p < 0.05$) were observed between PCT and CUPRAC (0.55), DPPH and FRAP (0.73), and FRAP and CUPRAC (0.83). In addition, a strong correlation was established between color and antioxidant assays, indicating that darker honeys have greater antioxidant capacity.

Flavonoids, the main functional components of honey, contribute significantly to its antioxidant activity and bring beneficial effects to health (Alvarez-Suarez *et al*., 2010). In floral honeys of *Mimosa caesalpiniifolia*, the correlation between flavonoids and antioxidant activity was significant for both DPPH ($R^2 = 0.644$) and ABTS ($R^2 = 0.825$). However, for honeys of *Pityrocarpa moniliformis*, the correlation between phenolic compounds and

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ABTS was moderate (Silva, D. *et al.*, 2024). The highest antioxidant activity was found in the honey of *Mimosa caesalpiniifolia*, significantly surpassing that of *Pityrocarpa moniliformis* ($p < 0.05$), suggesting a relevant influence of botanical origin (Silva, D. *et al.*, 2024).

Table 2. Antioxidant activity of floral honeys of *Apis mellifera* bees produced in Brazil.

State	Floral origin	Antioxidant activity*				References
NORTHERN REGION						
Stop	-	-	**EC50f:** 8.9 to 41.8	-	-	Oliveira *et al.*, 2012.
						Bandeira *et al.*, 2018
	-	**ABTSa:** 0.7 to 4.4	-	**FRAPf:** 1.0 to 6.0	-	Costa, Toro 2021.
Roraima	Multifloral		**EC50e:** 3.2 to 8.8			Pontis *et al.*, 2014.
NORTHEAST REGION						
Alagoas	-	-	**DPPHp:** 5.5 to 13.2	**FRAPp:** 19.0 to 73.3		Duarte *et al.*, 2012.
Bahia	*Pityrocarpa moniliformes*	-	**DPPHd:** 13.1 ± 0.7 **EC50e:** ND	**FRAPa:** 99.4 ± 3.8	**CUPRACa:** 338.7 ± 8.45	Almeida *et al.*, 2016.
	Eucalyptus	-	**DPPHd:** 17.1 ± 0.9 **EC50e:** ND	**FRAPa:** 181.4 ± 21.6	**CUPRACa:** 592.8 ± 17.2	
	Multifloral	-	**DPPHd:** 7.3 to 25.9 **EC50e:** 8.2 to 14.4	**FRAPa:** 165.1 to 720.4	**CUPRACa:** 453.0 to 960.1	
	Psidium	-	**DPPHs:** 137.2 to 154.4	**FRAPt:** 232.9 to 310.8		Silva, I. *et al.*, 2021.
	Serjania	-	**DPPHs:** 151.85 ± 0.75	**FRAPt:** 341 ± 5.3		
	Schinus	-	**DPPHs:** 180.28 ± 2.55	**FRAPt:** 365.3 ± 5.2		
	Multifloral	**-**	**DPPHs:** 153.5 to 142.7	**FRAPt:** 2.4 to 5.5		
Pernambuco			**DPPHv:** 51.5 to 92	**FRAPu:** 204.5 to 717.9		Pinto-Neto *et al.*, 2024.
Piaui			**DPPHa:** 40.4 to 49.0			Sousa *et al.*, 2018.
	Mimosa caesalpiniifolia	-	**DPPHg:** 9.2 to 66.1 **EC50:** 0.15 to 1.24	-	-	Silva *et al.*, 2020.

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		ABTSa: 46.7 to 152.4	**DPPHa:** 67.7 to 126.4	-	-	Silva, D. *et al.*, 2024.
	Pityrocarpa moniliformis	**ABTSa:** 49.8 to 167.8	**DPPHa:** 18.04 to 118.7	-	-	Silva, D. *et al.*, 2024.
State	**Floral origin**	**Antioxidant activity***				**References**
MIDWEST REGION						
Mato Grosso	*Acacia spp.*		**DPPHl:** 5.5 ± 0.3	**FRAPm:** 151.1 ± 2.2		Silva, B,. *et al.*, 2024.
Mato Grosso do Sul	*Cofea arabica*		**DPPHl:** 6.4 ± 0.2	**FRAPm:** 181.4 ± 3.4		Silva, B,. *et al.*, 2024.
	Vernonia polyanthes		**DPPHl:** 5.7 ± 0.2	**FRAPm:** 166.9 ± 3.7		
	Multi-charter		**DPPHl:** 9.2 ± 0.4	**FRAPm:** 318.3 ± 6.3		
SOUTHEAST REGION						
Rio de Janeiro and	Citrus sp	**ABTSc:** 46.6 to 383.5	**EC50i:** 5.5 to 52.4	**FRAPj:** 35.0 to 438.7	-	Lianda *et al.*, 2012.
São Paulo	Multifloral	**ABTSc:** 58.7 to 316.5	**EC50i:** 8.2 to 51.4	**FRAPj:** 78.5 to 408.1	-	
	Gochnatia spp.	**ABTSc:** 30.9 to 137.8	**EC50i:** 302.8 to 1601.8	**FRAPj:** 23.9 to 67.4	-	Salgueiro *et al.*, 2014.
	Croton sp.	**ABTSc:** 67.7 to 131.4	**EC50i:** 278.6 to 638	**FRAPj:** 73.4 to 113.7	-	
	Vernonia spp.	**ABTSc:** 33.5 and 92.0	**EC50i:** 449 and 521.8	**FRAPj:** 34.1 and 116.5	-	
Rio de Janeiro, Minas Gerais and São Paulo	Orange tree	**ABTSk:** 90.5	**EC50e:** 15.7 to 57.0			Lira *et al.*, 2014.
Minas Gerais and	*Ambrosia*	-	**EC50e:** 42.1	-	-	Sant'ana *et al.*, 2014.
Rio de Janeiro	*Anadenanthera*	-	**EC50e:** 18.9 ± 8.2	-	-	
	Asteraceae	-	**EC50e:** 23.5 ± 5.3	-	-	
	Citrus	-	**EC50e:** 41.4	-	-	
	Copaifera	-	**EC50e:** 23.85=	-	-	
	Eucalyptus	-	**EC50e:** 23.5 ± 9.3	-	-	
	Gochnatia	-	**EC50e:** 13.6	-	-	

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	Verbenaceae	-	**EC50e:** 7.6	-	-	
	Multifloral	-	**EC50e:** 23.5 ± 9.3	-	-	
	Montanoa	-	**EC50e:** 26.9 ± 3.9	-	-	
State	**Floral origin**	**Antioxidant activity***				**References**
SOUTHEAST REGION						
Minas Gerais and	*Myrcia*	-	**EC50e:** 23.6 ± 11.5	-	-	Sant'ana *et al*., 2014.
Rio de Janeiro	*Vernonia*	-	**EC50e:** 13.1	-	-	
Minas Gerais	*Croton* ssp.	**ABTSb:** 101.7	**EC50e:** 30.0	**FRAPm:** 73.7		Sant'ana *et al*., 2011.
	Eucalyptus	**ABTSb:** 306.2	**EC50e:** 21.54	**FRAPm:** 208.87		
	Baccharis spp.	**ABTSq:** 26.5 ± 0.1	**DPPHr:** 1694 ± 1.9			Schiassi *et al*., 2021.
	Citrus sinensis	**ABTSq:** 25.1 ± 0.1	**DPPHr:** 1746.4 ± 0.6			
	Coffea spp.	**ABTSq:** 26.4 ± 0.4	**DPPHr:** 1699 ± 1			
	Eucalyptus spp.	**ABTSq:** 25.0 ± 0.1	**DPPHr:** 1794.2 ± 1,			
	Mimosa scabrella	**ABTSq:** 26.2 ± 0.01	**DPPHr:** 1701.2 ± 1.1			
	Saccharum officinarum L.	**ABTSq:** 27.0 ± 0.5	**DPPHr:** 1001.6 ± 1.9			
	Vernonia polysphaera	**ABTSq:** 24.1 ± 0.1	**DPPHr:** 1834.2 ± 0.6			
	Astronium urundeuva		**EC50e:** 15 to 20.3			Pena Júnior *et al*., 2022.
	Caryocar from Brasilia		**EC50e:** 62.1 ± 0.1			
	Croton urucurana		**EC50e:** 23.3 ± 0.2			
	Eremanthus incanus		**EC50e:** 24.2 ± 0.1			
	Eucalyptus robusta		**EC50e:** 19.2 and 16.1			
	Hyptis sp,		**EC50e:** 31.5 ± 0.2			
	Omphalea diandra		**EC50e:** 18.3 ± 0.2			
	Serjania lethalis		**EC50e:** 44.1 ± 0.1			
	Veronia scorpioides		**EC50e:** 18.42 ± 0.05			

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	Cissus rhombifolia		**DPPHl:** 3.58±0.17	**FRAPm:** 122.3 ±3.6		Silva, B., *et al*., 2024.
	Eucalyptus	**ABTS:** 29.8 ± 2.9	**EC50i:** 319.0 ±11.7			Wisniewski *et al*., 2024.
State	**Floral origin**	**Antioxidant activity***				**References**
SOUTHEAST REGION						
Minas Gerais	*Multifloral*	**ABTS:** 47.5 ± 7.5	**EC50i:** 359.8 ± 41.7			Wisniewski *et al*., 2024.
Rio de Janeiro	*Croton* ssp,	**ABTSb:** 70.1 to 247.5	**EC50e:** 36.8 to 83.0	**FRAPm:** 67.0 to 88.5		Sant'ana *et al*., 2011.
	Eucalyptus	**ABTSb:** 396.8 to 700.6	**EC50e:** 10.2 to 207.5	**FRAPm:** 229 to 388		
	Gochnatia	**ABTSb:** 474 to 689	**EC50e:** 17.1 to 33.4	**FRAPm:** 190 to 297		
SOUTH REGION						
Rio Grande do Sul	Multifloral	**ABTSh:** 60.2	**DPPHn:** 7.6			Buenos-Costas *et al*., 2016.
	-	**ABTSl:** 94.8 ± 17.0	**DPPHl:** 78.4 ± 30.1	**FRAPm:** 342 ± 3.6		Cruz *et al*., 2016.
	Eucalyptus	**ABTSh:** 52.4	**DPPHn:** 10.0			
	-	-	**DPPHe:** 25.4 to 105.3	**FRAPb:** 0.4 to 2.1	**ORACb:** 3.4 to 18.5	Nascimento *et al*., 2018.
	Schinus terebinthifolius	-	**DPPHe:** 54.7 to 127.6	**FRAPb:** 0.7 to 2.1	**ORACb:** 5.1 to 18.0	
	Hovenia dulcis	-	**DPPHe:** 34.5 to 277.1	**FRAPb:** 0.3 to 1.6	**ORACb:** 1.5 to 7.9	
	Pluchea Sagittalis	-	**DPPHe:** 96.1 to 294.3	**FRAPb:** 0.2 to 0.9	**ORACb:** 3.4 to 6.5	
	Gaya Macrantha	-	**DPPHe:** 86.0	**FRAPb:** 1.0	**ORACb:** 6.0	
	Multifloral	-	**DPPHe:** 48.3 to 139.1	**FRAPb:** 0.6 to 1.8	**ORACb:** 4.1 to 10.7	
	Wild	**ABTSh:** 45.2 to 222				Oliveira *et al*., 2020.
	Eucalyptus	**ABTSh:** 136 ± 3.6				
	White clover	**ABTSh:** 126 ± 4.4				

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	Multifloral	**ABTSh:** 66.7 to 124.6				
Santa Catarina	*Mimosa scabrella*		**DPPHI:** 31 to 38.3	**FRAPm:** 547 to 620		Seraglio *et al*., 2017.
	Esccallonia sp,		**DPPHI:** 10.6 to 15.4	**FRAPm:** 251 to 369		Brugnerotto *et al*., 2023.
State	**Floral origin**	**Antioxidant activity***				**References**
SOUTH REGION						
Santa Catarina	*Baccharis leucocephala*		**DPPHI:** 10.0 to 15.0	**FRAPm:** 200 to 300		Silva, P. *et al*., 2020.
	Hovenia dulcis		**DPPHI:** 5.0 to 10.0	**FRAPm:** 50 to 100		
	Multifloral		**DPPHI:** 5.0 to 10.0	**FRAPm:** 100 to 350		
	Baccharis spp,		**DPPHI:** 8.0 ± 0.2	**FRAPm:** 230 ± 4.0		Silva, B. *et al*, 2024,
	Citrus aurantium		**DPPHI:** 5.4 ± 0.2	**FRAPm:** 176 ± 3.8		
	Escallonia spp,		**DPPHI:** 10.3 ± 0.1	**FRAPm:** 316 ± 11.2		
	Eucalyptus globulus		**DPPHI:** 30.4 ± 1.5	**FRAPm:** 721 ± 17.7		
	Hovenia dulcis		**DPPHI:** 4.4 ± 0.2	**FRAPm:** 148.1 ± 4.0		
Paraná	-	**ABTSb:** 0.4 to 1.5	**DPPHb:** 0.04 to 0.2	**FRAPo:** 0.03 to 11.1		Galhardo *et al*., 2021.
	-		**EC50i:** 1.9 to 3.02			Gregório *et al*., 2021.
	-	**ABTS:** 11.9 to 35.6	**EC50i:** 122.6 to 261.3			Wisniewski *et al*., 2024.
	-		**DPPHIb:** 0.01 to 0.2			Ribeiro *et al*., 2022.
Santa Catarina and Rio Grande do Sul	-	**ABTSI:** 6.9 to 57.1	**DPPHI:** 10.3 to 84.3	**FRAPm:** 49.2 to 776.4		Rizelio *et al*., 2020.
	Astronium urundeuva		**EC50e:** 68.8 ± 2.4			Royo *et al*., 2022.
	Caryocar from Brasilia		**EC50e:** 105.6 ± 2.9			
	Croton urucurana		**EC50e:** 51.5 ± 1.5			
	Coffea arabica L,		**EC50e:** 77.7 ± 3.5			
	Serjania lethalis		**EC50e:** 150.7 ± 2.6			

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	Hyptis sp,		**EC50e:** 76.2 ± 3.3			
	Multifloral		**EC50e:** 72.8 ± 0.3			

TEAC: Trolox Equivalent Antioxidant Capacity (μmol TEAC 100 $^{g-1}$);
[b] micromole equivalent to TROLOX per gram (μmol ET. g^{-1});
[c] (mmol ET.100 mg^{-1});
[d] percentage of DPPH radical elimination capacity in 30 min;
[and] milligram per milliliter of honey (mg mL-1);
[f] milligram per gram of honey (mg 100 $^{g-1}$);
[g] percentage of sequestrant activity;
[h] milligram equivalent to TROLOX (mg ET.100 $^{g-1}$);
[i] microgram per milliliter of honey (μg mL-1);
[j] millimol ferrous sulfate per milligram of honey (mmol Fe^{+2} 100 mg^{-1});
[k] microgram equivalent to TROLOX (μg ET.100 $^{g-1}$);
[l] milligram equivalent to ascorbic acid (mg EAA.100g^{-1});
[m] micromole ferrous equivalent per hundred gram of honey (μM FE^{+}2,100 $^{g-1}$);
[n] milligram quercetin equivalent (mg EQ.100g^{-1});
[the] equivalent micromol of ferrous sulfate per gram of honey (μM FeSO 4,100 $^{g-1}$);
[p] milligram equivalent to gallic acid (mg EAG.100g^{-1});
[q] micromole equivalent to Trolox per gram of fresh weight (μM TEs/g f.w.);
[r] expressed in EC50 (g f.w./g DPPH);
[s] TEAC:Trolox Equivalent Antioxidant Capacity per liter (μmol TEAC. L-1);
[t] micromol ferrous sulfate equivalent per liter (μM $FeSO_4$. L-1);
[u] micromol ferrous sulfate equivalent per mL(μM FeSO 4.mL-1);
[v] percentage of DPPH radical elimination capacity at 15 min;
ND-not detected.

Honeys that had higher levels of total polyphenols and darker color demonstrated the best results of antioxidant activity (Oliveira *et al*., 2012). Honey color showed a positive correlation with antioxidant activity measured by the DPPH method (Bandeira *et al*., 2018), as well as phenolic compounds showed strong and moderate correlations with antioxidant activity evaluated by the FRAP and ABTS methods. The high correlation coefficient suggests that phenolic substances are one of the main components responsible for the anti-radical activity of honey (Costa; Toro, 2021).

Nascimento *et al*. (2021), confirmed, through samples collected in Bahia, the hypothesis that darker honeys have greater antimicrobial potential, since the honeys analyzed showed significant antibacterial activity, especially against *Staphylococcus aureus*. These findings reinforce the potential of honeys not only as sources of antioxidants, but also as functional foods and therapeutic agents, with promising applications in promoting human health and fighting free radicals and pathogens (Costa and Toro, 2021; Almeida *et al*., 2016).

Future studies, both *in vitro* and *in vivo*, are recommended to consolidate the evidence on the antioxidant and antibacterial potential of different regions of Brazil, expanding the understanding of the benefits of these bee products (Silva et al., 2024).

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CONCLUSIONS

The floral honey of *Apis mellifera* bees originating in Brazil is composed of several phenolic compounds that have antioxidant and antimicrobial activity, with variation in their chemical composition, which differed according to botanical and geographical origin. The geographical indication mark is little explored, as well as the lack of identification of these compounds in honeys from some regions makes it difficult to recognize honey by the presence of these bioactive compounds. In conclusion, we hope that this review will be useful as a reference on the compounds present in monofloral honeys from botanical origins native to Brazil. In addition, we emphasize the antioxidant activity of these compounds, which have the potential to bring benefits to human health.

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