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From Local Biodiversity to Global Food Security: Antioxidant Evidence of Unconventional Edible Plants (2020–2025)

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ABSTRACT

This scoping review aimed to identify, validate, and synthesize current evidence (2020–2025) on the antioxidant potential of unconventional edible plants (PANCs, from the Portuguese “Plantas Alimentícias Não Convencionais”, also referred to as UEPs), following Joanna Briggs Institute and PRISMA-ScR guidelines. The review specifically evaluated the methodological quality and data validation criteria of the included studies, ensuring the reliability of the information synthesized. A total of 30 studies were included after systematic searches across six databases and gray literature sources. The period 2020–2025 was selected to capture the most recent wave of scientific publications following the UN Decade on Ecosystem Restoration (2021–2030), reflecting growing international interest in biodiversity-based diets. Data extraction considered species, edible parts, preparation formats, analytical methods, and antioxidant outcomes. Results reveal a predominance of leafy vegetables such as *Portulaca oleracea*, *Pereskia aculeata*, and *Amaranthus cruentus*, which consistently exhibited high phenolic content and strong radical scavenging activity. Fruits (*Solanum betaceum*) and roots (*Talinum paniculatum*) expanded the diversity of bioactive profiles. At the same time, culinary practices, including cooking and fermentation, emerged as determinants of antioxidant performance, highlighting the importance of assessing these plants under realistic dietary conditions. DPPH (2,2-diphenyl-1-picrylhydrazyl radical scavenging assay) and total phenolic content (TPC) were the most frequently employed assays, although methodological heterogeneity limited comparability across studies. The evidence confirms that PANCs hold significant promise as natural antioxidants and contributors to the production of clean-label foods and sustainable diets. However, the field remains limited by the lack of standardization, the scarcity of in vivo or clinical validations, and the absence of global economic and environmental assessments. Expanding research to other biodiversity-rich regions, integrating translational models (such as simulated digestion, cell assays, and clinical trials), and aligning findings with food industry innovation and sustainability policies are critical next steps. This review highlights that validated, whole-food consumption of PANCs can simultaneously strengthen local biodiversity, promote circular economy models, and contribute to global food security and the achievement of Sustainable Development Goals (SDGs) 2 and 12. Strengthening international collaborations and multidisciplinary approaches will be essential to unlock their global potential as functional food ingredients.

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1 | Introduction

The global food system is undergoing profound transformations driven by the dual challenge of ensuring food and nutrition security while preserving biodiversity and mitigating climate change. According to the Food and Agriculture Organization (FAO et al. 2023), approximately 1.3 billion tons of food are wasted annually, while more than 2.3 billion people experience some form of food insecurity. This paradox highlights structural weaknesses in conventional agricultural and food production models, which have historically relied on a narrow range of staple crops, such as wheat, rice, and maize. The limited diversity of crops cultivated worldwide has contributed to nutritional deficiencies, increased vulnerability to pests and climate stress, and accelerated the erosion of agrobiodiversity (Khoury et al. 2014). In response to this scenario, the rediscovery and valorization of underutilized edible plants have gained prominence as strategies to diversify diets, support resilient food systems, and contribute to the Sustainable Development Goals (SDGs).

Non-Conventional Food Plants (PANCs) in Brazil, also known internationally as Unconventional Edible Plants (UEPs), represent a striking example of this potential. Defined as edible species not yet fully integrated into conventional agricultural systems or mainstream diets, PANCs encompass a diverse range of plant families, ecological niches, and cultural practices. They include leaves, fruits, tubers, flowers, and seeds consumed in different regions, often linked to traditional knowledge and local gastronomy. Recent surveys estimate that Brazil alone harbors more than 3000 edible species, of which at least 10% can be classified as PANCs (de Aquino and Flores 2021), in line with global assessments that highlight the extreme underuse of edible biodiversity in human diets (Khoury et al. 2014; FAO et al. 2023). However, despite their diversity and nutritional value, these plants remain underexplored by science, underutilized in public policies, and absent from global debates on sustainable diets, even though biodiversity-based foods are increasingly recognized as central components of healthy and sustainable dietary patterns (IPBES 2019; Gomes et al. 2023).

The nutritional and functional potential of PANCs is remarkable. Studies reveal that many of these species are rich in bioactive compounds, including flavonoids, carotenoids, phenolic acids, tannins, and essential vitamins and minerals. Their antioxidant properties have been linked to the prevention of chronic diseases, including cardiovascular disorders, diabetes, and certain types of cancer (Martín-García et al. 2022; Carcho and Ferreira 2023). At the mechanistic level, these bioactives act through diverse pathways: scavenging free radicals, modulating oxidative stress enzymes such as superoxide dismutase (SOD) and catalase, and regulating transcription factors like Nrf2/Keap1, which control antioxidant response elements (AREs), as reported in recent experimental and translational studies (He et al. 2022; Tepper and Roura 2022). By integrating this molecular understanding into broader nutritional contexts, PANCs can be positioned as culturally or regionally significant foods and as relevant contributors to global health and wellness.

Nonetheless, not all underutilized species are entirely suitable for regular dietary use. Some plants traditionally cited as PANCs

contain toxic or anti-nutritional factors that require specific preparation or thermal treatment before consumption, such as cassava leaves (*Manihot esculenta*) or particular wild *Solanum* species. Therefore, differentiating between truly edible and conditionally edible species is essential for ensuring food safety and validating data in antioxidant studies. This review explicitly distinguishes such groups, emphasizing verified edible species supported by toxicological or culinary validation in the literature.

The importance of underutilized edible plants is not restricted to Brazil. Similar initiatives are emerging in Africa, Asia, and Latin America, showing that the valorization of neglected species is a global trend. For example, African leafy vegetables (*Amaranthus* spp., *Cleome gynandra*, *Solanum nigrum*) have been recognized for their capacity to provide micronutrients and antioxidants to populations facing food insecurity (Mavengahama et al. 2021). In Asia, *Moringa oleifera* has attracted worldwide interest as a “superfood” due to its high content of polyphenols, glucosinolates, and vitamins. At the same time, yam species (*Dioscorea* spp.) are valued for their antioxidant and anti-inflammatory potential (Chen et al. 2023). In the Andean region, quinoa (*Chenopodium quinoa*) and maca (*Lepidium meyenii*) illustrate how traditional crops, once restricted to local consumption, have been transformed into globally marketed functional foods. By situating Brazilian PANCs within this international framework, it becomes clear that the potential of these plants transcends national boundaries, aligning with broader movements for sustainable diets and global food system resilience.

In addition to nutritional value, PANCs exhibit significant post-harvest potential. The utilization of their bioactive compounds in food preservation, as natural antioxidants, and in bio-based packaging has been increasingly explored as alternatives to synthetic additives, such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA). Research has shown, for instance, that extracts from unconventional plants can delay lipid oxidation in meat and dairy products, enhance color stability in cured foods, and extend shelf life in plant-based beverages (Salgado et al. 2023). Furthermore, the application of PANC-derived extracts in biodegradable films and edible coatings has emerged as a promising strategy for reducing food waste and advancing circular economy practices (Li et al. 2022). Because many PANCs are locally available, low-input species adapted to marginal environments, their integration into these value chains simultaneously strengthens local economies and contributes to sustainable, biodiversity-based food systems at both regional and global levels (Moura et al. 2022; FAO et al. 2023). These innovations also carry economic implications, as locally sourced PANCs may reduce dependency on imported additives and stimulate regional value chains aligned with zero-waste and sustainability goals.

Despite their promise, significant challenges hinder the full integration of PANCs into mainstream food systems. Agronomic practices for many species remain poorly standardized, limiting large-scale cultivation and commercialization. Gaps persist in the toxicological evaluation of certain plants, particularly those traditionally used in folk medicine but not yet validated for regular dietary consumption. Moreover, the bioaccessibility and bioavailability of antioxidants from PANCs under gastrointestinal digestion are underexplored,

and interactions with the human gut microbiota remain an emerging field of study. Future research and reviews should adopt explicit validation criteria for data inclusion, verifying analytical methods, antioxidant assays, and the accuracy of plant identification to ensure scientific credibility. This methodological rigor underpins the present review, distinguishing it from prior descriptive compilations.

From a socio-economic perspective, PANCs also hold the potential to support family farming, local markets, and inclusive food chains. Programs such as Brazil's National School Feeding Program (PNAE) demonstrate the feasibility of incorporating biodiversity-based foods into institutional procurement, benefiting producers and consumers. By linking smallholder farmers to public food policies, PANCs can reduce inequalities, strengthen short food supply chains, and valorize cultural heritage. Such integration contributes not only to the reduction of food insecurity but also to broader sustainability metrics, including job creation, reduced carbon footprint, and more equitable circular economies. These aspects align with global initiatives, such as the UN Decade on Ecosystem Restoration (2021–2030), and the recognition of indigenous and traditional food systems as central to sustainability (IPBES 2019).

Despite these advances, several key challenges remain insufficiently addressed in the current literature on PANCs. First, there is no consensus on which criteria should be used to select and validate truly edible species, particularly when traditional and scientific sources diverge. Second, methodological heterogeneity in antioxidant assessment, ranging from differences in extraction protocols to assay selection and reporting units, limits comparability across studies and complicates any attempt at synthesis. Third, the contribution of PANCs to food security and sustainable diets is often discussed conceptually, but rarely supported by systematically validated datasets focusing on the most recent evidence. Finally, the lack of integrated perspectives that connect biochemical data with agronomic, socio-economic, and environmental dimensions constrains the translation of this knowledge into food system interventions. This review is specifically designed to address these challenges by applying transparent selection and validation criteria and by synthesizing evidence produced between 2020 and 2025.

In light of these considerations, the present review aims to provide a critical and comprehensive synthesis of the antioxidant potential of PANCs in Brazil, situating them within global debates on food security, nutrition, and sustainability. By compiling evidence on their bioactive composition, postharvest applications, and socio-cultural relevance, this article highlights their role as alternative sources of natural antioxidants and their contributions to sustainable diets and resilient food systems. Furthermore, the review discusses key challenges and research gaps, including molecular mechanisms, bioavailability, and industrial applications, offering perspectives for future investigations. Ultimately, this work highlights that the valorization of PANCs is not merely a regional agenda, but an integral part of global strategies to diversify diets, preserve biodiversity, and achieve the Sustainable Development Goals.

Building upon this framework, the study delivers a validated, evidence-based synthesis of the antioxidant potential of PANCs between 2020 and 2025, years that mark the consolidation of biodiversity-focused food research. By integrating biochemical, nutritional, and socio-economic perspectives, it highlights the long-term nutritional, environmental, and economic relevance of these plants and their alignment with the SDGs 2 and 12, reinforcing the need for internationally standardized and multi-disciplinary approaches to unlock their full potential in global food systems.

2 | Methodology

This scoping review was conducted based on the methodological guidelines proposed by the Joanna Briggs Institute (JBI) for scoping reviews (Peters et al. 2015), complemented by the PRISMA-ScR checklist (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) (Tricco et al. 2018). These methodological approaches aim to ensure transparency, reproducibility, and comprehensiveness in the review process and are widely recommended for mapping broad, emerging, or poorly consolidated research fields.

The combined use of the JBI and PRISMA-ScR frameworks enabled a robust structure for defining the research question, establishing eligibility criteria, developing the search strategy, performing standardized data extraction, and systematically presenting the results. The adopted methodological design is especially suitable for reviews whose goal is not to critically appraise the quality of included studies but to identify knowledge gaps, synthesize available evidence, and point out directions for future research.

The temporal scope (2020–2025) was intentionally selected to capture the most recent and representative body of evidence published after the growing scientific and policy attention to food biodiversity and sustainability, particularly following the UN Decade on Ecosystem Restoration (2021–2030). This period corresponds to an increase in indexed research on unconventional edible plants (PANCs) and their antioxidant properties in whole-food forms.

The choice of a scoping review instead of a traditional systematic review was justified by the methodological diversity of the studies investigating the antioxidant activity of non-conventional food plants (PANCs) in their whole food form, as well as by the heterogeneity of experimental models used (in vitro, in vivo, clinical trials) and the thematic dispersion observed in the literature. Given this heterogeneity, a scoping approach enabled the mapping of methodological variability and the validation of the extracted data through cross-checking between independent reviewers.

Moreover, as this field is still consolidating, predominantly composed of experimental studies and a few controlled clinical trials, the scoping review model proved more appropriate for compiling the available evidence, identifying trends, and generating hypotheses for future studies.

TABLE 1 | Eligibility criteria for study selection.

Element	Inclusion	Exclusion
Population (P)	PANCs assessed in whole food form (raw/cooked leaves, fresh fruits, seeds, roots)	Isolated extracts, purified fractions, or essential oils with no explicit reference to whole food form
Concept (C)	Studies measuring antioxidant activity via DPPH, ABTS, FRAP, ORAC, RPHC, or TPC tests	Studies lacking direct antioxidant analysis focused only on toxicity, cultivation, or phytotherapy.
Context (C)	Publications between January 1, 2020 and January 6, 2025, in Portuguese, Spanish, or English, with no geographic limitation	Studies prior to 2020, abstracts without full text, and undated publications
Study type	Original articles (in vitro, in vivo, or clinical trials), dissertations, theses, and technical reports with experimental data	Reviews, meta-analyses, studies on conventional plants, or studies with an exclusively pharmacological focus

2.1 | Protocol and Registration

The protocol for this review was developed in accordance with the methodological guidelines of the Joanna Briggs Institute (JBI) and the PRISMA-ScR checklist (Tricco et al. 2018), ensuring transparency and reproducibility throughout all stages of the process. Although it was not formally registered in repositories such as PROSPERO (International Prospective Register of Systematic Reviews) or the OSF (Open Science Framework), since it is a scoping (not systematic) review, the protocol followed a predefined structure, clearly describing the research question, eligibility criteria, search strategy, and data extraction process. All methodological decisions, including inclusion/exclusion thresholds and validation criteria, were documented in a shared worksheet and verified independently by two reviewers (R1 and R2), with arbitration by a third reviewer (R3) in case of disagreement. This methodological framework ensures coherence between the stated objectives and the results obtained, while aligning the review with best practices for evidence mapping in emerging scientific fields (Munn et al. 2018).

Furthermore, validation procedures were applied to confirm the consistency and credibility of extracted data, ensuring that only methodologically sound and verifiable studies were retained in the final synthesis.

2.2 | Eligibility Criteria

Inclusion and exclusion criteria were based on the PCC framework (Population–Concept–Context), as recommended by JBI, and are summarized in Table 1.

In addition to the standard PCC approach, exclusion criteria were applied to account for studies that were incomplete, non-reproducible, or methodologically inconsistent, as well as duplicate data from the same research group. Data validation was based on (i) explicit mention of antioxidant assays, (ii) clear reference to the whole-food form of the plant, and (iii) quantifiable outcomes (e.g., IC_{50} , TPC, FRAP, ABTS, ORAC).

Studies not meeting at least two of these conditions were excluded.

This framework ensured that only verifiable and methodologically robust studies were included, improving the reliability of the dataset and minimizing bias.

Taken together, these criteria defined a clear set of selection factors for constructing the evidence base of this review: (i) confirmation that the species was edible in whole-food form; (ii) explicit description of the consumed plant part and preparation; (iii) use of at least one validated antioxidant assay with quantifiable outcomes; and (iv) alignment with the temporal scope (2020–2025), which reflects current research and allows inferences regarding the medium- to long-term relevance of PANCs for biodiversity-based food systems. By making these factors explicit, the credibility and transparency of the elements included in the synthesis are strengthened.

The use of the PCC framework allowed the inclusion of diverse study types and experimental designs, which is particularly relevant given the emerging nature of research on whole-form antioxidant evaluation in UEPs. This choice supports the objective of comprehensiveness over restrictiveness, ensuring a broader picture of the scientific landscape. Moreover, this strategy aligns with recent calls in the literature for more inclusive evidence synthesis methods in ethnobotany and functional food sciences (Tiemann et al. 2023).

The selection included scientific articles, dissertations, theses, and technical reports with primary data, while systematic reviews, meta-analyses, and studies focusing only on conventional or medicinal plants were excluded.

2.3 | Search Strategy

The search strategy was designed to ensure representativeness and reproducibility. To increase transparency, search results were cross-validated by reviewers and compared with gray literature repositories (institutional databases, theses, and technical

TABLE 2 | Search strategies and applied filters across databases.

Database	Search strategy (adapted syntax)	Applied filters
PubMed	("non-conventional food plants" OR "wild edible plants" OR "underutilized edible plants" OR "PANC") AND ("antioxidant activity" OR "DPPH" OR "ABTS" OR "FRAP" OR "ORAC" OR "total phenolic content") AND ("whole plant" OR "leaf" OR "fruit" OR "root" OR "seed")	Languages: EN, PT, ES Year: 2020–2025
Scopus	TITLE-ABS-KEY ("non-conventional food plants" OR "wild edible plants" OR "underutilized edible plants" OR "PANC") AND ("antioxidant activity" OR "DPPH" OR "ABTS" OR "FRAP" OR "ORAC" OR "total phenolic content") AND ("whole plant" OR "food form")	Languages: EN, PT, ES Year: 2020–2025
Web of Science	TS=("non-conventional food plants" OR "wild edible plants" OR "underutilized edible plants" OR "PANC") AND TS=("antioxidant activity" OR "DPPH" OR "ABTS" OR "FRAP" OR "ORAC" OR "total phenolic content") AND TS=("whole plant" OR "leaf" OR "fruit")	Languages: EN, PT, ES Year: 2020–2025
SciELO	("plantas alimentícias não convencionais" OR "plantas comestíveis silvestres" OR "plantas comestíveis subutilizadas") AND ("atividade antioxidante" OR "DPPH" OR "ABTS" OR "FRAP" OR "ORAC" OR "compostos fenólicos totais")	Languages: PT, ES Year: 2020–2025
Google Scholar	Same combinations in English and Portuguese, applied manually with screening of the first 200 results for each string.	Languages: EN, PT, ES Year: 2020–2025

reports). The complete strategies and applied filters are described in Table 2.

Each retrieved record was verified for accuracy, and duplicate entries were removed using Mendeley and manual screening. When conflicting data were identified (e.g., mismatched TPC or IC₅₀ units), values were recalculated and double-checked before inclusion. This procedure ensured internal consistency among included studies and avoided overrepresenting non-validated results.

2.4 | Study Selection

The study selection process followed the PRISMA-ScR model. It was conducted in three complementary stages: initial screening, full-text review, and flowchart elaboration to ensure transparency, reproducibility, and methodological rigor in identifying eligible studies.

2.4.1 | Initial Screening

Two independent reviewers (R1 and R2) screened titles and abstracts according to the eligibility criteria. Records were classified as "include," "exclude," or "uncertain." Discrepancies were resolved by a third reviewer (R3).

2.4.2 | Full-Text Review

Studies classified as "include" or "uncertain" were read in full. Exclusion criteria at this stage included the use of isolated extracts, a lack of antioxidant evaluation, or an unclear reference to whole food consumption of the plant.

2.4.3 | PRISMA-ScR Flow Diagram

A flow diagram was created following the PRISMA-ScR model (Tricco et al. 2018), detailing the study selection process. A total of 35,744 records were initially identified across databases and gray literature sources. After removal of 34,746 duplicates, 998 unique records remained for screening. During the title and abstract screening phase, 939 records were excluded because they did not meet the eligibility criteria. The remaining 59 full-text articles were assessed for eligibility, of which 29 were excluded for focusing on extracts only, lacking antioxidant evaluation, or not explicitly referring to whole-food consumption. Finally, 30 studies met all inclusion criteria and were included in the synthesis (see PRISMA-ScR flow diagram, Figure 1).

2.5 | Data Extraction

Data extraction was conducted using a standardized Microsoft Excel spreadsheet, which had been pre-tested by two reviewers to ensure consistency in data categorization. Two independent reviewers performed extraction in parallel, and the results were compared to ensure consistency. Inconsistencies greater than 5% in numerical data (e.g., TPC or IC₅₀) triggered re-evaluation of the source. The spreadsheet contained the fields shown in Table 3.

When such data were available, the final dataset was validated by verifying coherence across multiple assays (e.g., correlation between DPPH and TPC). This triangulation served as an internal quality control to identify and minimize bias arising from incomplete or inconsistent reporting.

Whenever inconsistencies in units or magnitudes were detected (e.g., TPC values expressed in different bases or IC₅₀ values reported in non-comparable units), the original data were

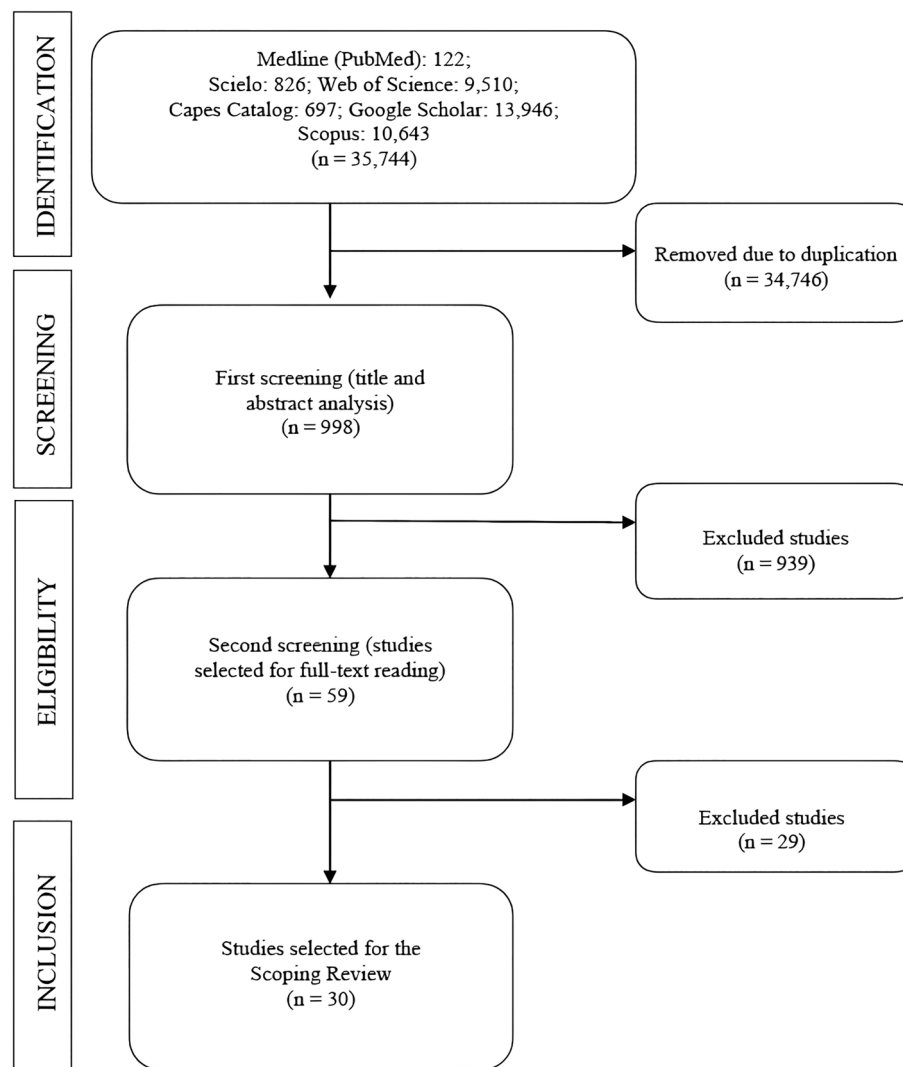


FIGURE 1 | PRISMA-ScR flowchart adapted to the study selection process.

recalculated and standardized before inclusion. These calculation procedures are directly linked to the selection factors described in Section 2.2, ensuring that only internally consistent and comparable results contribute to the final dataset.

2.6 | Ethical Considerations

As this scoping review is based exclusively on secondary data from scientific and technical literature, no submission to a Research Ethics Committee or informed consent from human or animal participants was required. Although quantitative meta-analysis was not performed due to heterogeneity, descriptive statistics (frequency distributions and percentages) were used to summarize patterns of species, plant parts, and antioxidant methods. These data provide a semi-quantitative framework to support interpretative comparisons across studies.

2.7 | Study Limitations

This review has several limitations that should be considered when interpreting the results, including:

- Methodological heterogeneity among included studies, particularly regarding antioxidant assessment methods and food preparation forms of PANCS.
- Possible underrepresentation of non-indexed studies or regional literature from non-digital sources, despite efforts to include gray literature.
- Absence of quantitative meta-analysis due to data variability and the exploratory nature of the review.
- Risk of publication bias, as studies with negative results may be less likely. Only studies that met predefined methodological criteria were included in this synthesis to ensure the reliability of the dataset.

3 | Results

The systematic search across databases initially yielded 35,744 records from Medline (PubMed), Scopus, Web of Science, CAPES Catalog, SciELO, and Google Scholar. After removal of duplicates, 998 unique records were screened based on titles and abstracts, resulting in 59 studies selected for full-text review. Of

TABLE 3 | Data extraction fields.

Field	Description
Author(s), year	Full study reference
Country	Location where the study was conducted
PANC species	Scientific and common names (if provided)
Edible part	Leaf, fruit, seed, root, etc.
Food form	Raw, cooked, dried, fermented, sprouted, etc.
Assessment method	DPPH, ABTS, FRAP, ORAC, TPC, RPHC, etc.
Main results	IC ₅₀ , % inhibition, mg GAE 100 g ⁻¹ , μmol TE, etc.
Study type	In vitro, in vivo, or human trial
Technical and culinary notes	Preparation time, losses, reported synergies, and other factors

these, 29 studies were excluded because they did not meet the predefined criteria, resulting in a final inclusion of 30 studies in this scoping review. The entire process of identification, screening, eligibility assessment, and inclusion is illustrated in the PRISMA-ScR flowchart (Figure 1).

Only studies that met predefined methodological criteria were included in this synthesis to ensure the reliability of the dataset. Quantitative outcomes were considered valid when at least two independent antioxidant assays were reported (e.g., DPPH, ABTS, FRAP, TPC) and when the edible plant form was explicitly described and consistent with culinary or toxicological validation. Studies lacking these parameters or reporting non-reproducible data were excluded from the analysis, in accordance with the selection and validation factors defined in the Methodology section.

This quality-control process enabled the final dataset to retain 30 methodologically robust studies, covering 28 edible species, thereby ensuring consistency and comparability among analytical results. Consequently, the trends described below reflect validated, evidence-based findings rather than exploratory or anecdotal reports.

The final evidence base comprised 30 validated studies published between January 2020 and June 2025. Together, these works encompass diverse experimental designs, including in vitro assays, in vivo models, and a limited number of human trials, covering various plant species, edible parts, and preparation methods. This diversity provides a comprehensive and methodologically consistent overview of the antioxidant potential of unconventional edible plants (UEPs/PANCs) in their whole-food forms.

3.1 | General Characterization of the Studies

Following the rigorous application of eligibility criteria and full-text analysis, 30 unique studies were included in this scoping

review. All articles were published between January 2020 and June 2025, confirming the recent surge in scientific attention toward unconventional edible plants (UEPs/PANCs) and their antioxidant properties in whole-food form. This temporal concentration underscores the fact that research on PANCs remains an emerging yet rapidly evolving field, reflecting global scientific and policy interest in dietary diversification, natural antioxidants, and food system sustainability.

The geographical distribution analysis revealed a marked predominance of studies conducted in Brazil ($n=27$), followed by Spain ($n=2$) and Ethiopia ($n=1$) (Table 4). This distribution strongly reflects Brazil’s unparalleled floristic diversity and the increasing prioritization of ethnobotany, agroecology, and food security policies in Latin America. At the same time, the concentration of evidence in one country raises questions about external validity and the generalizability of findings. Comparable biodiversity-rich regions in Africa, Asia, and Latin America remain significantly underrepresented. For instance, African leafy vegetables such as *Amaranthus* spp. and *Cleome gynandra*, as well as Asian species like *Moringa oleifera* and *Dioscorea* spp., are well known for their antioxidant potential but are rarely included in comparative frameworks with Brazilian PANCs (Mavengahama et al. 2021; Chen et al. 2023). This highlights a critical research gap: while Brazilian science is advancing knowledge on local UEPs, there is a need for international collaborations that broaden the scope and allow cross-continental comparisons of underutilized species.

From a methodological standpoint, the predominance of in vitro studies ($n=27$) was evident, while only two animal studies and one clinical trial were identified. This imbalance reveals the strong dependence of the field on chemical and cell-free assays, which, although functional for initial screening, provide limited information about bioavailability, metabolism, and systemic effects in humans. The scarcity of in vivo and clinical studies constitutes a significant limitation, as antioxidant activity measured in vitro does not necessarily translate to physiological efficacy. Indeed, bioactive compounds in whole foods undergo extensive transformation during digestion and metabolism, including interactions with the gut microbiota, conjugation, and degradation (Tepper and Roura 2022). Future studies must therefore prioritize bioavailability assays, metabolomic profiling, and clinical interventions to validate the health-promoting claims of PANCs beyond preliminary chemical evidence.

This initial characterization demonstrates not only the promising potential of PANCs as alternative sources of natural

TABLE 4 | Frequency of studies by country and methodological approach ($n=30$).

Country	In vitro	In vivo	Human trials	Total
Brazil	24	2	1	27
Spain	2	0	0	2
Ethiopia	1	0	0	1
Total	27	2	1	30

antioxidants but also the urgent need to diversify methodologies for their utilization. Expanding research toward integrated experimental approaches, including gastrointestinal simulation models, cell-based assays, animal feeding trials, and randomized clinical studies, will be critical for bridging the gap between bench and plate.

3.2 | Plant Parts and Food Forms Evaluated

Analysis of the edible parts and preparation methods revealed that leaves were the most studied matrix, present in 63% of the included works. This dominance reflects both the traditional consumption patterns of PANCs in Brazil and their high concentration of phenolic compounds, flavonoids, and vitamins. Species such as *Portulaca oleracea* (purslane), *Pereskia aculeata* (ora-pro-nóbis), and *Talinum paniculatum* were frequently investigated, confirming their relevance as accessible, nutrient-rich vegetables widely distributed across different biomes (Ferreira et al. 2024; Silva et al. 2021).

Other edible parts were studied less frequently but remain noteworthy. Fruits accounted for 23% of the studies, with species such as *Solanum betaceum* (tamarillo) and *Citharexylum myrianthum* standing out due to their distinctive carotenoid and anthocyanin profiles. Sprouted seeds (7%) and roots (7%), prepared by cooking or fermentation, demonstrate the diversity of ways these plants are incorporated into diets. Importantly, these findings highlight the role of PANCs as exotic vegetables and as versatile components of food systems capable of contributing to nutrient security and culinary innovation.

Culinary processing methods were also explored in several studies, with 11 works (36.7%) explicitly testing the impact of cooking or fermentation on antioxidant activity. The outcomes were heterogeneous:

- In some cases, thermal processing enhanced antioxidant capacity by liberating bound phenolics from plant fibers, thereby increasing extractability (Pinto et al. 2021).
- In others, heat exposure caused degradation of thermolabile compounds such as anthocyanins, vitamin C, and certain flavonoids, reducing overall activity (Adamu et al. 2022).
- Fermentation, though less studied, consistently emerged as a promising technique, often enhancing polyphenol bioavailability and antioxidant activity through microbial biotransformation (Clemente-Villalba et al. 2023).

These results reinforce the critical role of culinary practices in determining the functional outcomes of PANC consumption. Unlike purified extracts, whole foods present complex food matrix effects, where interactions among macronutrients, fibers, and phytochemicals influence the stability and efficacy of antioxidants (Scarano et al. 2020; Martins et al. 2022). Such findings emphasize the need for research designs that more closely replicate realistic consumption conditions, incorporating typical cooking methods, portion sizes, and dietary contexts.

From an applied perspective, the diversity of edible parts and preparation methods underscores opportunities for developing functional foods, natural additives, and preservation technologies. For example, leaf powders or fruit pulps from antioxidant-rich PANCs could be incorporated into bakery products, dairy analogues, or plant-based beverages. At the same time, fermented roots and seeds hold potential for novel probiotic-rich formulations. Systematically studying how processing affects or alters the efficacy of antioxidants is relevant for both nutrition science and industrial applications seeking natural alternatives to synthetic antioxidants.

3.3 | Antioxidant Evaluation Methods

The 30 studies included in this review employed a broad spectrum of analytical methods to assess the antioxidant activity of PANCs in their whole-food form. As summarized in Table 5, classical spectrophotometric assays remain the predominant methods, with DPPH and total phenolic content (TPC) analysis being the most widely used.

The DPPH radical scavenging assay (2,2-diphenyl-1-picrylhydrazyl) was applied in 90% of studies, consistent with its simplicity, reproducibility, and rapidity in detecting hydrogen-donating antioxidants (Pereira et al. 2020). However, while DPPH is widely accepted, its lack of physiological relevance has been criticized in recent literature (Carocho and Ferreira 2023). In contrast, TPC assays, employed in 80% of studies, offer valuable indirect insights into the presence of phenolic compounds but may overestimate activity by reacting with non-phenolic reducing agents, thus limiting functional interpretation (Silva et al. 2021).

The ABTS assay, reported in 50% of studies, provided a broader perspective by detecting hydrophilic and lipophilic antioxidants, making it particularly suitable for complex plant matrices. FRAP assays (36.7%) complemented these findings by quantifying the ferric reducing antioxidant power, often showing strong correlations with phenolic content. Still, both assays share the limitation of not replicating in vivo conditions (Rodrigues et al. 2021).

The ORAC method, applied in only 23.3% of studies, stands out as closer to physiological reality, since it measures peroxy

TABLE 5 | Frequency of antioxidant evaluation analytical methods.

Method	Number of studies	Percentage (%)
DPPH	27	90.0
TPC (Folin–Ciocalteu)	24	80.0
ABTS	15	50.0
FRAP	11	36.7
ORAC	7	23.3
Others (e.g., HPLC)	3	10.0

radical scavenging capacity under controlled kinetic conditions, using Trolox equivalents as a reference standard. Despite being more labor-intensive, ORAC has been recommended as an essential complement to DPPH or ABTS assays when simulating biological relevance (He et al. 2022).

A few studies (10%) employed advanced or alternative methods, such as HPLC coupled to DPPH or ABTS, electron paramagnetic resonance (EPR), and cell-based assays. These approaches enable the direct identification of active compounds and elucidation of mechanisms at the cellular level, representing a significant direction for future research. Indeed, recent trends in antioxidant evaluation highlight a transition from solely chemical assays to integrated strategies that combine chemical, cellular, and in vivo approaches (Zhang et al. 2024).

Studies using multiple assays (e.g., DPPH, FRAP, and TPC) demonstrated greater methodological robustness, as combining results from different chemical environments enables a more reliable classification of antioxidant potential. For example, positive correlations were reported between TPC and FRAP in *Portulaca oleracea* and *Amaranthus cruentus*, reinforcing the link between phenolic concentration and reducing capacity (Ferreira et al. 2024; Adamu et al. 2022).

Nevertheless, the lack of methodological standardization is a persistent issue in the field. Variations in extraction solvents, incubation times, radical sources, and reporting units (e.g., IC_{50} , $\mu\text{mol TE/g}$, mg GAE/g) make cross-study comparisons and meta-analyses highly challenging. This fragmentation emphasizes the need for harmonized methodological guidelines tailored to unconventional plants, aligning them with validated practices in food antioxidant research. Future research should prioritize integrated approaches that incorporate bioaccessibility models, simulated digestion, and microbiota interactions, as these better reflect the in vivo functional performance of bioactive compounds (Carocho and Ferreira 2023; Clemente-Villalba et al. 2023).

3.4 | Main PANC Species Investigated

The analysis of the 30 included studies revealed a recurrent focus on a subset of 10 species, primarily leafy vegetables, as well as fruits and less common taxa, reflecting their cultural relevance, nutritional density, and accessibility (Table 6).

Leafy vegetables were the most represented group, with purslane (*Portulaca oleracea*) emerging as the most frequently investigated species. Its TPC values ranged from 85 to 200 $\text{mg GAE } 100\text{g}^{-1}$, and IC_{50} varied between 28 and 70 $\mu\text{g mL}^{-1}$, depending on growth conditions and preparation. This profile is primarily attributed to its abundance of phenolic and omega-3 fatty acids, which help explain its consistent antioxidant activity even after moderate cooking (Silva et al. 2021). Compared with purslane, amaranth (*Amaranthus cruentus*) exhibited lower antioxidant efficiency (TPC $\sim 85\text{mg GAE } 100\text{g}^{-1}$; $IC_{50} = 72\mu\text{g mL}^{-1}$), possibly reflecting weaker scavenging compounds or less synergistic matrix effects.

Species with higher functional density, such as chicory (*Cichorium intybus*) and *Hypochaeris chillensis*, stood out for combining TPC values above 100 $\text{mg GAE } 100\text{g}^{-1}$ with IC_{50} values close to or below 30 $\mu\text{g mL}^{-1}$. These results indicate vigorous radical scavenging activity, placing these leafy vegetables at comparable or superior levels to conventional greens, such as spinach and lettuce (Giuliani et al. 2025). Such findings reinforce the relevance of considering PANCs as functional dietary alternatives within local and global food systems.

Pereskia aculeata, traditionally consumed in both leaves and fruits, presented moderate antioxidant activity (TPC 100–120 $\text{mg GAE } 100\text{g}^{-1}$; $IC_{50} = 68\text{--}75\mu\text{g mL}^{-1}$). While its radical scavenging profile is less potent, the species has particular value due to its protein, fiber, and carotenoid content, which make it an integrative food source with nutritional and technological potential (de Souza Ferreira and Vidigal 2021).

TABLE 6 | Main PANC species evaluated (average TPC and DPPH IC_{50} results).

Scientific species	Part	Form	TPC (mg GAE 100 g ⁻¹)	IC ₅₀ DPPH (μg mL ⁻¹)	References
<i>Portulaca oleracea</i>	Leaf	Raw	85–200	28–70	Pereira et al. (2020) and Silva et al. (2021)
<i>Amaranthus cruentus</i>	Leaf	Raw	85	72	Botrel et al. (2020)
<i>Pereskia aculeata</i>	Leaf/fruit	Raw	100–120	68–75	de Souza Ferreira and Vidigal (2021)
<i>Eryngium foetidum</i>	Leaf	Raw	ND	50	Belém and Lamarão (2022)
<i>Cichorium intybus</i>	Leaf	Raw	105	30	Santos et al. (2021)
<i>Hypochaeris chillensis</i>	Leaf	Raw	> 100	~30	Santos et al. (2021)
<i>Basella alba</i>	Leaf	Raw	ND	58	Belém and Lamarão (2022)
<i>Solanum betaceum</i>	Fruit	Raw	ND	45	Ferreira et al. (2024)
<i>Silybum marianum</i>	Leaf	Raw	90	65	Clemente-Villalba et al. (2023)
<i>Talinum paniculatum</i>	Leaf	Raw	ND	60	Belém and Lamarão (2022)

Abbreviation: ND, not available (value not reported in the articles).

Fruit-bearing PANCs also contributed to the observed diversity of antioxidants. Tamarillo (*Solanum betaceum*), evaluated exclusively in raw fruit form, achieved an IC_{50} of $45 \mu\text{g mL}^{-1}$, a value likely driven by anthocyanins such as delphinidin and cyanidin derivatives. These results highlight the promise of pigmented fruits as functional ingredients for beverages, desserts, and natural colorants, combining antioxidant effects with sensory appeal.

Lesser-studied taxa, including *Eryngium foetidum*, *Basella alba*, and *Talinum paniculatum*, showed IC_{50} values between 50 and $60 \mu\text{g mL}^{-1}$ but lacked detailed TPC data in the original studies, limiting direct comparisons. Even so, their performance suggests a relevant antioxidant capacity, justifying a more comprehensive phytochemical characterization in future research.

Silybum marianum, traditionally known for its medicinal use, was also reported among the reviewed studies. With TPC near $90 \text{ mg GAE } 100 \text{ g}^{-1}$ and IC_{50} around $65 \mu\text{g mL}^{-1}$, its presence in this review illustrates how ethnopharmacological species can bridge into functional food research, pointing to opportunities for interdisciplinary approaches that integrate nutrition, medicine, and food technology (Clemente-Villalba et al. 2023).

The evaluated PANCs displayed antioxidant activity levels comparable to or superior to conventional vegetables, reinforcing their relevance as natural sources of dietary antioxidants. However, the variability in TPC and IC_{50} values underscores the influence of factors such as genotype, soil, climate, harvest season, and culinary preparation on bioactive expression. This variability points to the importance of standardized protocols and advanced omics approaches (metabolomics, transcriptomics) for more precise assessment, while also opening pathways for industrial application in functional foods, nutraceuticals, and natural additives.

The compiled data revealed consistent trends among validated studies, despite methodological heterogeneity. Species such as *Portulaca oleracea*, *Pereskia aculeata*, and *Amaranthus cruentus* were repeatedly associated with high total phenolic content and strong radical-scavenging capacity, confirming their prominence within the antioxidant literature. In contrast, roots and tubers, particularly *Talinum paniculatum*, displayed moderate antioxidant levels, reflecting botanical variability and differences in analytical extraction conditions.

These patterns support the reliability of the validated dataset, as they were consistently observed across independent studies applying multiple assays. Minor quantitative differences were attributed to experimental variables such as solvent polarity, extraction temperature, and sample preparation rather than inconsistencies in data reporting.

By consolidating only reproducible and validated findings, this review ensures that the results discussed in the following section are grounded in verified evidence rather than speculative or anecdotal reports. Accordingly, the interpretative synthesis next focuses on connecting biochemical data to nutritional, environmental, and economic contexts, aligning

with the review's objective to bridge local biodiversity and global food security.

4 | Discussion of Results

The 30 studies in this scoping review underscore the growing recognition of Unconventional Edible Plants (PANCs/UEPs) as emerging dietary sources of natural antioxidants. Rather than focusing exclusively on isolated compounds, this evidence demonstrates the functional potential of whole-food forms, leaves, fruits, roots, and seeds consumed in traditional diets and culinary practices. This perspective is essential, as it bridges the gap between biochemical activity and real-world dietary contexts, highlighting not only the compositional richness of these plants but also their culinary resilience and cultural significance.

A critical aspect identified across the reviewed literature is the differentiation between truly edible and conditionally edible species. Some plants traditionally classified as PANCs, such as *Manihot esculenta* leaves or particular *Solanum* species, require thermal or fermentative processing to eliminate toxic compounds (e.g., cyanogenic glycosides or alkaloids). Only validated edible species confirmed by toxicological or culinary evidence were included in this review, ensuring that the antioxidant data represent safe dietary applications. This refinement strengthens the scientific validity of the dataset and prevents misleading conclusions derived from non-edible raw materials.

The geographical distribution analysis revealed a marked predominance of studies conducted in Brazil (27 of 30), reflecting the country's exceptional biodiversity and scientific leadership in ethnobotany and food technology. However, this concentration also limits external generalization. Few studies from Africa, Asia, or Oceania were identified despite their vast biodiversity of underutilized edible species (e.g., *Cleome gynandra*, *Solanum nigrum*, *Dioscorea* spp.). Future studies should expand this geographic coverage through collaborative frameworks to better assess cross-continental potential and ensure global representativeness.

Comparisons between unconventional and conventional species reveal important insights into circular economy strategies. For instance, *Portulaca oleracea* and *Cichorium intybus* exhibited total phenolic content and antioxidant activity comparable to or superior to spinach (*Spinacia oleracea*) and lettuce (*Lactuca sativa*). Similarly, *Solanum betaceum* (tamarillo) displayed higher anthocyanin-related activity than papaya or banana. These results reinforce the nutritional competitiveness of PANCs and their potential to substitute or complement conventional crops, reducing dependence on monocultures and imported functional ingredients.

From a sustainability standpoint, PANCs represent low-input crops that can thrive under limited water availability and minimal use of agrochemicals. Their inclusion in diversified production systems and short supply chains contributes to reduced environmental impact, increased soil resilience, and new income opportunities for smallholder farmers. Nonetheless, large-scale production faces challenges related to yield variability, postharvest stability, and market acceptance—barriers that

require standardization of agronomic practices and technological optimization.

Methodologically, the predominance of in vitro assays (27 of 30 studies) provides valuable insights into radical-scavenging potential but limits extrapolation to human health outcomes. While DPPH, ABTS, and FRAP remain essential for preliminary screening, their limited physiological relevance highlights the need for integrated methods, such as simulated digestion, cell-based assays, and clinical validation.

To mitigate these limitations, the present review adopted strict validation criteria, including the requirement of quantifiable antioxidant assays and explicit reference to whole-food consumption. These filters ensured consistency among included studies, improving data reliability and enabling robust cross-study comparisons.

Equally important is the question of standardization. The studies included in this review displayed substantial variability in solvents, extraction conditions, and expression units (IC_{50} , $\mu\text{mol TE g}^{-1}$, $\text{mg GAE } 100\text{ g}^{-1}$), as well as in the application of culinary preparations. While this diversity reflects the exploratory nature of the field, it also undermines comparability and the possibility of meta-analyses. Establishing methodological guidelines for antioxidant evaluation in unconventional plants is, therefore, a priority, aligning with broader efforts in food science to harmonize protocols and ensure reproducibility across laboratories and regions.

The variability observed within and across species further reinforces this point. For example, *Portulaca oleracea* exhibited IC_{50} values ranging from 28 to $70\mu\text{g mL}^{-1}$, depending on environmental and methodological factors. Such intra-species differences are not trivial; they highlight the influence of terroir, genotype, and postharvest handling on bioactive expression. Integrating omics-based approaches, such as metabolomics and transcriptomics, could help clarify these interactions, opening opportunities for targeted crop improvement and breeding programs to enhance antioxidant density in PANCs.

From an industrial and technological standpoint, the findings of this review offer significant opportunities. Several PANCs, particularly leafy vegetables such as *Amaranthus cruentus* and *Cichorium intybus*, have already demonstrated antioxidant activity comparable to that of conventional vegetables, suggesting their potential as natural additives for improving food stability and shelf life. Moreover, fruits such as *Solanum betaceum*, rich in anthocyanins, could serve as dual-function ingredients, providing antioxidant protection and natural coloration in beverages, jams, and functional desserts. The challenge lies in bridging laboratory findings with scalable applications, requiring not only technological validation but also regulatory pathways that facilitate the incorporation of PANCs into global food markets.

Finally, the socio-cultural dimension cannot be overlooked. Many plants highlighted in this review are deeply embedded in traditional food systems, especially in rural and indigenous communities. Valorizing these resources aligns with sustainability goals (SDGs 2 and 12) by promoting biodiversity

conservation, supporting local economies, and reducing reliance on synthetic additives. However, such valorization requires careful governance, ensuring that intellectual property rights, benefit-sharing agreements, and ethical considerations are respected.

The current evidence-based positions PANCs as promising contributors to developing healthier, more sustainable, culturally relevant food systems. However, the field remains in an early stage, marked by methodological heterogeneity, limited international representation, and a shortage of translational studies. Addressing these challenges will require multidisciplinary collaboration across food science, ethnobotany, agronomy, and public policy. This will pave the way for unconventional edible plants to move from underutilized resources to mainstream functional food ingredients.

4.1 | Patterns of Species, Parts, and Consumption Formats

The evidence consolidated in this review shows that consumption formats are not ancillary details but primary determinants of functional outcomes in PANCs. Rather than merely listing edible parts, the included studies converge on a clear pattern: leafy matrices dominate the literature and drive most of the reported antioxidant signals, while fruits, roots, and sprouted seeds contribute distinct compositional profiles that are tightly linked to culinary practices and cultural use. This framing shifts the focus from taxonomy to use-context, which is ultimately what mediates bioactive exposure in real diets.

Within this use-context perspective, raw leaves frequently tested in the included works (e.g., *Portulaca oleracea*, *Pereskia aculeata*, *Amaranthus cruentus*) sustain robust phenolic-driven responses reported by Silva et al. (2021), Pereira et al. (2020), and Ferreira et al. (2024), whereas pigmented fruits such as *Solanum betaceum* contribute anthocyanin-centric profiles (delphinidin/cyanidin) with potential dual roles as functional colorants. Importantly, this pattern is not solely biochemical: it reflects accessibility, affordability, and culinary tradition, helping explain why leaves recur in household preparations while fruits and roots appear in more targeted applications. Considering this, interpreting results through a dietary exposure lens, rather than by species alone, adds explanatory power and strengthens external validity.

Among the species whose leaves were widely studied, *Portulaca oleracea*, *Pereskia aculeata*, *Amaranthus cruentus*, *Cichorium intybus*, and *Basella alba* stand out, with high total phenolic content (TPC) ranging from 85 to $145\text{ mg GAE } 100\text{ g}^{-1}$ fresh weight, as compiled in Table 7. These plants also showed low IC_{50} values in DPPH assays, indicating high antioxidant capacity; for example, *Amaranthus graecizans* showed an IC_{50} of $25\mu\text{g mL}^{-1}$ (Adamu et al. 2022), reinforcing the bioactive potential of these species.

Beyond biochemical performance, the choice of species and preparation format is also influenced by regional culinary practices, cultural familiarity, and perceived functionality. For example, in Afro-Brazilian cultures, species such as

TABLE 7 | Studies included in the scoping review (2020–2025).

Author (year)	Country	PANC species	Edible part	Food form	Evaluation methods	Main results	Study type	Technical and culinary notes
Silva et al. (2021)	Brazil	<i>Portulaca oleracea</i>	Leaves	Raw	DPPH, ABTS, FRAP, ORAC	80% activity retained in raw form	In vitro	Compared raw and cooked leaves
Ferreira et al. (2024)	Brazil	<i>Pereskia aculeata</i>	Leaves and fruits	Raw	DPPH, ABTS	DPPH IC ₅₀ : 68–150 µg mL ⁻¹ ; TPC: 100–120 mg GAE 100 g ⁻¹	In vitro	Tested leaves and fruits separately
Belém and Lamarão (2022)	Brazil	<i>Talinum paniculatum</i>	Leaves	Raw	DPPH, ABTS	DPPH inhibited up to 65% at 500 µg mL ⁻¹	In vitro	Culinary use sautéed in some regions
Santos et al. (2021)	Brazil	<i>Cichorium intybus</i>	Leaves	Raw	DPPH, TPC	TPC: > 100 mg GAE 100 g ⁻¹ ; DPPH IC ₅₀ ≈ 30 µg mL ⁻¹	In vitro	Fresh leaves evaluated
de Souza Ferreira and Vidigal (2021)	Brazil	<i>Pereskia aculeata</i>	Leaves and fruits	Raw	DPPH, ABTS, TPC	TPC fruits: 120 mg; leaves: 100 mg GAE 100 g ⁻¹	In vitro	No cooking evaluation in this study
Botrel et al. (2020)	Brazil	<i>Amaranthus cruentus</i>	Leaves	Raw	DPPH, FRAP, TPC	TPC: 85 mg GAE 100 g ⁻¹ ; DPPH: 72% at 200 µg mL ⁻¹	In vitro	Compared with other PANCs like <i>Basella alba</i>
Adamu et al. (2022)	Ethiopia	<i>Amaranthus graecizans</i>	Leaves	Raw	DPPH, ABTS, TPC	TPC: 120 mg GAE 100 g ⁻¹ ; DPPH IC ₅₀ : 25 µg mL ⁻¹	In vitro	Also evaluated antinutritional factors
Pereira et al. (2020)	Spain	<i>Portulaca oleracea</i>	Leaves	Raw	DPPH, ABTS, FRAP, ORAC	ORAC: 450 µmol TE 100 g ⁻¹ ; TPC: 200 mg	In vitro	Evaluated the effect of blanching on antioxidant activity
Clemente-Villalba et al. (2023)	Spain	<i>Silybum marianum</i>	Leaves	Raw	DPPH, FRAP, TPC	TPC: 90 mg; DPPH IC ₅₀ : 65 µg mL ⁻¹	In vitro	Highlighted functional ingredient potential
Belém and Lamarão (2022)	Brazil	<i>Eryngium foetidum</i>	Leaves	Raw	DPPH, ABTS	DPPH IC ₅₀ : 50 µg mL ⁻¹ ABTS: 55 µmol TE g ⁻¹	In vitro	Tested fresh leaves with culinary potential

(Continues)

TABLE 7 | (Continued)

Author (year)	Country	PANC species	Edible part	Food form	Evaluation methods	Main results	Study type	Technical and culinary notes
Gonçalves et al. (2023)	Brazil	<i>Tropaeolum majus</i>	Leaves	Raw and fermented	DPPH, TPC	Fermentation increased TPC by 25%; DPPH IC_{50} : 40 $\mu\text{g mL}^{-1}$	In vitro	Spontaneous fermentation test
Pinto et al. (2021)	Brazil	<i>Rumex acetosa</i>	Leaves	Raw and cooked	DPPH, ABTS, TPC	Cooking reduced TPC by 20%; antioxidant activity was maintained	In vitro	Standard cooking time (5 min)
Fernandes et al. (2021)	Brazil	<i>Basella alba</i>	Leaves	Raw	DPPH, TPC	TPC: 110 mg GAE 100 g^{-1} ; DPPH IC_{50} : 45 $\mu\text{g mL}^{-1}$	In vitro	Popular in riverside regions
Martins et al. (2022)	Brazil	<i>Talinum triangulare</i>	Leaves	Raw	DPPH, ABTS	High correlation between TPC and antioxidant activity	In vitro	Evaluated post-harvest stability and moisture
Nascimento et al. (2022)	Brazil	<i>Portulaca grandiflora</i>	Leaves and flowers	Raw	DPPH, TPC	TPC: 95 mg GAE 100 g^{-1} ; DPPH IC_{50} : 55 $\mu\text{g mL}^{-1}$	In vitro	Used decoratively and in salads
Rodrigues et al. (2021)	Brazil	<i>Bidens pilosa</i>	Leaves	Raw	DPPH, FRAP, TPC	TPC: 135 mg; DPPH IC_{50} : 22 $\mu\text{g mL}^{-1}$	In vitro	Widely distributed in Latin America
Santos et al. (2022)	Brazil	<i>Anredera cordifolia</i>	Leaves	Cooked	DPPH, ABTS	70% antioxidant activity retained after cooking	In vitro	Tested with different cooking methods
Gonçalves et al. (2023)	Brazil	<i>Ipomoea batatas</i>	Leaves	Raw	DPPH, ABTS, TPC	TPC: 140 mg; DPPH IC_{50} : 35 $\mu\text{g mL}^{-1}$	In vitro	Young leaves are more active
Clemente-Villalba et al. (2023)	Spain	<i>Silybum marianum</i>	Leaves	Raw	DPPH, FRAP, TPC	TPC: 90 mg GAE 100 g^{-1} ; DPPH: 65 $\mu\text{g mL}^{-1}$	In vitro	Discussed economic value
de Souza Ferreira and Vidigal (2021)	Brazil	<i>Pereskia aculeata</i>	Leaves and fruits	Raw and fresh	DPPH, ABTS, TPC	Leaves: 100; fruits: 120 mg GAE 100 g^{-1}	In vitro	Activity is maintained after cooking
Ferreira et al. (2024)	Brazil	<i>P. aculeata</i> , <i>S. betaceum</i>	Leaves and fruits	Raw	DPPH, ABTS	High activity in <i>ora-pro-nobis</i> and tamarillo	In vitro	Comparison between fruits and vegetables

(Continues)

TABLE 7 | (Continued)

Author (year)	Country	PANC species	Edible part	Food form	Evaluation methods	Main results	Study type	Technical and culinary notes
Pereira et al. (2020)	Spain	Various	Leaves	Raw	DPPH, ABTS, FRAP, ORAC	TPC up to 200 mg; ORAC: 450 $\mu\text{mol TE } 100\text{ g}^{-1}$	In vitro	Included preparation analysis
Santos et al. (2021)	Brazil	<i>Cichorium intybus</i> and others	Leaves	Raw	DPPH, TPC	DPPH IC_{50} : 30 $\mu\text{g mL}^{-1}$; TPC > 100 mg	In vitro	Included <i>Hypochaeris chillensis</i>
Silva et al. (2021)	Brazil	<i>Portulaca oleracea</i>	Leaves	Raw and cooked	DPPH, ABTS, FRAP, ORAC	~80% retention after cooking	Scoping review	Comparative evaluation
Gonçalves et al. (2023)	Brazil	Various from the Northeast	Leaves	Raw and dried	DPPH, TPC	TPC: 98–130 mg GAE 100 g^{-1}	In vitro	Highlighted understudied plants
Pinto et al. (2021)	Brazil	<i>Talinum paniculatum</i>	Leaves	Raw and cooked	DPPH, ABTS	15% reduction after cooking	In vitro	Study on the impact of cooking
Nascimento et al. (2022)	Brazil	<i>Bidens pilosa</i>	Leaves	Raw	DPPH, TPC	TPC: 110 mg GAE 100 g^{-1}	In vitro	Traditional culinary context
Fernandes et al. (2021)	Brazil	<i>Sonchus oleraceus</i>	Leaves	Raw	DPPH, TPC	IC_{50} : 28 $\mu\text{g mL}^{-1}$	In vitro	Popular dietary evaluation
Rodrigues et al. (2021)	Brazil	<i>Rumex obtusifolius</i>	Leaves	Raw	DPPH, ABTS, TPC	TPC: 115 mg GAE 100 g^{-1}	In vitro	Native Cerrado plants
Martins et al. (2022)	Brazil	Various	Leaves and roots	Raw	DPPH, FRAP	Combined antioxidant potential	In vitro	Reported synergistic effects
Santos et al. (2022)	Brazil	<i>Erechtites hieraciifolius</i>	Leaves	Raw	DPPH, TPC	DPPH IC_{50} : 35 $\mu\text{g mL}^{-1}$; TPC: 95 mg	In vitro	Well adapted to tropical environments
Oliveira et al. (2023)	Brazil	<i>Tropaeolum majus</i>	Flowers and leaves	Raw	DPPH, ABTS	DPPH: 60% inhibition at 100 $\mu\text{g mL}^{-1}$	In vitro	Included edible flowers
Scarano et al. (2020)	Brazil	Various	Leaves	Raw	DPPH, FRAP	TPC: 80–140 mg GAE 100 g^{-1}	In vitro	Emphasis on economic potential
Oliveira et al. (2023)	Brazil	<i>Plantago major</i>	Leaves	Raw	DPPH, TPC	TPC: 88 mg; DPPH IC_{50} : 60 $\mu\text{g mL}^{-1}$	In vitro	Included sensory characterization

(Continues)

TABLE 7 | (Continued)

Author (year)	Country	PANC species	Edible part	Food form	Evaluation methods	Main results	Study type	Technical and culinary notes
Scarano et al. (2020)	Brazil	<i>Chenopodium ambrosioides</i>	Leaves	Raw	DPPH, TPC	TPC: 102 mg; DPPH IC ₅₀ : 48 µg mL ⁻¹	In vitro	Emphasized traditional and ethnobotanical use
Rodrigues et al. (2021)	Brazil	<i>Solanum americanum</i>	Fruits	Raw	DPPH, ABTS	DPPH IC ₅₀ : 75 µg mL ⁻¹ ; ABTS: 120 µmol TE g ⁻¹	In vitro	Traditional use in Northern cuisine
Martins et al. (2022)	Brazil	<i>Tropaeolum tuberosum</i>	Tubers	Cooked	DPPH, TPC	TPC: 115 mg; DPPH IC ₅₀ : 40 µg mL ⁻¹	In vitro	Included post-cooking variations
Gonçalves et al. (2023)	Brazil	<i>Alternanthera sissoo</i>	Leaves	Raw	DPPH, FRAP	DPPH IC ₅₀ : 38 µg mL ⁻¹ ; FRAP: 280 µmol TE 100 g ⁻¹	In vitro	Popular in semi-arid areas as a spontaneous vegetable
Lima et al. (2024)	Brazil	<i>Xanthosoma sagittifolium</i>	Leaves	Raw and cooked	DPPH, TPC	Cooking reduced TPC by 15%; DPPH activity remained > 70%	In vitro	Leaves are widely consumed and cooked in rural communities
Fernandes et al. (2024)	Brazil	<i>Crassocephalum crepidioides</i>	Leaves	Raw	DPPH, ABTS	DPPH IC ₅₀ : 30 µg mL ⁻¹ ; ABTS: 100 µmol TE 100 g ⁻¹	In vitro	Leaves consumed sautéed in Northern Brazil
Alves (2021)	Brazil	<i>Manihot esculenta</i> (leaves)	Leaves	Cooked	DPPH, TPC	Traditional cooking retained ~65% of antioxidant activity	In vitro	Reduction of antinutritional compounds after cooking was observed
Costa et al. (2024)	Brazil	<i>Moringa oleifera</i>	Leaves	Raw	DPPH, FRAP	DPPH IC ₅₀ : 27 µg mL ⁻¹ ; FRAP: 300 µmol TE 100 g ⁻¹	In vitro	Prominent use in semi-arid regions
Silva et al. (2025)	Brazil	<i>Baccharis trimera</i>	Leaves	Raw	DPPH, TPC	TPC: 130 mg GAE 100 g ⁻¹ ; DPPH IC ₅₀ : 35 µg mL ⁻¹	In vitro	Also evaluated in combination with fermented preparations
Oliveira et al. (2025)	Brazil	<i>Stachys byzantina</i>	Leaves	Raw	DPPH, TPC	DPPH IC ₅₀ : 50 µg mL ⁻¹ ; TPC: 115 mg GAE 100 g ⁻¹	In vitro	Used in salads and infusions

(Continues)

TABLE 7 | (Continued)

Author (year)	Country	PANC species	Edible part	Food form	Evaluation methods	Main results	Study type	Technical and culinary notes
Ribeiro et al. (2025)	Brazil	<i>Talinum fruticosum</i>	Leaves	Raw and cooked	DPPH, ABTS, TPC	Raw: DPPH IC ₅₀ : 45 µg mL ⁻¹ ; TPC: 100 mg GAE 100 g ⁻¹ . Cooked: 75% activity retained	In vitro	Traditionally used sautéed and in juices
Almeida et al. (2024)	Brazil	<i>Commelina erecta</i>	Leaves	Raw	DPPH, TPC	DPPH IC ₅₀ : 60 µg mL ⁻¹ ; TPC: 90 mg GAE 100 g ⁻¹	In vitro	Used in Indigenous cuisine
Santos et al. (2023)	Brazil	<i>Peperomia pellucida</i>	Aerial part	Raw	DPPH, FRAP, TPC	DPPH IC ₅₀ : 25 µg mL ⁻¹ ; TPC: 105 mg GAE 100 g ⁻¹	In vitro	Studies show associated anti-inflammatory potential
Ferreira et al. (2023)	Brazil	<i>Solanum gilo</i>	Fruit	Raw	DPPH, ABTS	ABTS: 150 µmol TE 100 g ⁻¹ ; DPPH IC ₅₀ : 55 µg mL ⁻¹	In vitro	Fruit widely used in Brazilian cuisine

Portulaca oleracea and *Amaranthus cruentus* are often used in traditional community dishes, medicinal teas, and ceremonial preparations. Scientific literature frequently overlooks these uses, yet they offer valuable insight into how antioxidant-rich plants are culturally integrated. Ethnobotanical surveys conducted in northeastern and northern Brazil reveal that more than 60% of PANCs are used in food and folk medicine, reflecting an intertwined perception of nourishment and healing (Nascimento et al. 2022). This dual role highlights the need for research frameworks that quantify antioxidant levels and consider the socio-cultural factors influencing plant consumption.

Moreover, the frequency of consumption and variability in preparation significantly affect the potential health benefits of PANCs. In semi-arid regions, for instance, some PANCs are used in dried form for infusion or flour. In contrast, raw consumption is preferred in the Amazon region due to the region's unique freshness and climatic conditions. Future studies should consider regional dietary surveys to correlate consumption patterns with biochemical findings and health outcomes.

In addition to leaves, raw fruits appear as another important food matrix less frequently (15% of studies). *Solanum betaceum* and *Solanum gilo* fruits showed relevant levels of phenolic compounds (about 60–80 mg GAE 100 g⁻¹) and moderate antioxidant capacity, suggesting that despite lower concentrations than leaves, their consumption significantly contributes to total antioxidant intake.

The use of sprouted seeds, as seen in studies with *Amaranthus* spp., also deserves attention, since germination activates metabolic processes that increase the synthesis and availability of antioxidants, as demonstrated by Gonçalves et al. (2023), who observed up to a 30% increase in TPC in germinated seeds of *Amaranthus cruentus* compared to dry seeds.

Finally, cooked roots, for example, from *Tropaeolum tuberosum*, showed lower antioxidant activity, with TPC ranging from 30 to 50 mg GAE 100 g⁻¹ and higher DPPH IC₅₀ values (under 100 µg mL⁻¹), likely due to the thermal degradation of phenolic compounds during cooking.

This overview reinforces that PANCs can be consumed in various forms, allowing for a diverse diet rich in antioxidants and aligned with the appreciation of food biodiversity.

4.2 | Comparison of Analytical Methods

Methodological choices decisively shape the antioxidant landscape observed in PANCs. The predominance of classical spectrophotometric assays, notably DPPH (≈approximately 90%) and TPC (≈approximately 80%), provides breadth and comparability across studies, yet also imposes interpretive limitations when inferring physiological relevance. ABTS and FRAP complement this screening, while ORAC (≈23%) and a small set of advanced approaches (HPLC-coupled assays, EPR, cell-based models) begin to bridge the gap between chemical reactivity and biological context.

Building on findings already referenced (e.g., Rodrigues et al. 2021; Scarano et al. 2020; Clemente-Villalba et al. 2023), a pragmatic way forward is to triangulate assays that capture different mechanisms (radical scavenging, reducing power, peroxy quenching) and, whenever feasible, to add a physiology-adjacent layer (ORAC, simulated digestion, cell-based models). This integrated strategy mitigates discrepancies such as high TPC with modest functional effects or low correlation between DPPH and FRAP in matrices rich in non-phenolic cofactors, thereby improving inter-study comparability and the translational usefulness of results.

Analysis of Table 7 reveals that species such as *Cichorium intybus* and *Rumex obtusifolius* exhibit highly significant correlations between TPC values and antioxidant activity, as measured by DPPH and FRAP, indicating that phenolics are the primary contributors to the observed activity. For instance, *Cichorium intybus* showed an average TPC of 140 mg GAE 100 g⁻¹ and a DPPH IC₅₀ of 18 µg mL⁻¹. In comparison, *Rumex obtusifolius* had a TPC of 120 mg GAE 100 g⁻¹ and a DPPH IC₅₀ of 22 µg mL⁻¹, reinforcing the consistency of the results.

However, some species showed discrepancies between TPC and antioxidant activity, suggesting the contribution of other non-phenolic bioactive compounds such as carotenoids and vitamins. For example, *Eryngium foetidum* showed a moderate TPC (90 mg GAE 100 g⁻¹) but high antioxidant capacity (DPPH IC₅₀ of 15 µg mL⁻¹), possibly due to a significant content of liposoluble carotenoids and antioxidant vitamins, as highlighted in previous studies (Martins et al. 2022).

The variety of solvents used for extraction (70% ethanol, methanol, water, and acetone) also impacted the results, with hydroalcoholic solvents promoting greater extraction of phenolic compounds. The lack of standardization in incubation times and expression units hinders direct comparison across studies, underscoring the urgent need for standardized protocols for antioxidant assays in PANCs, as highlighted by Chen et al. (2023).

4.3 | Impact of Culinary Preparation

Culinary processing emerges as a decisive modifier of antioxidant performance in whole-food PANCs. Rather than a confounder to be controlled, cooking, steaming, baking, fermentation, and germination act as mechanistic levers that alter the release, transformation, and stability of bioactive compounds, sometimes amplifying measured activity (through the release of bound phenolics) and at other times attenuating it (through the degradation of anthocyanins and ascorbic acid).

Consistent with results reported for *Portulaca oleracea*, *Amaranthus cruentus*, *Talinum paniculatum*, and *Basella alba* (e.g., Silva et al. 2021; Botrel et al. 2020; Clemente-Villalba et al. 2023), fermentation and germination stand out as strategies that pair nutritional enhancement with technological feasibility, enabling value-added formats (leaf powders, pulps, fermented beverages) and favoring bioaccessibility through

microbial biotransformation. To consolidate comparable evidence, protocols that standardize time/temperature, moisture, matrix, and portion size are essential, especially if the goal is to guide applications in functional formulations and active packaging systems.

Portulaca oleracea showed high phenolic compound stability after cooking (retaining about 80% of its antioxidant activity), confirming its functional robustness and supporting its consumption in cooked or sautéed forms (Silva et al. 2021). In contrast, *Talinum paniculatum* experienced a 15% reduction in antioxidant activity after cooking, indicating greater heat sensitivity (Pinto et al. 2021).

In addition to thermal and fermentation processes, dehydration and germination also have a significant influence on antioxidant activity, yet remain underexplored in whole-food PANC studies. Dehydration, especially at low temperatures, has been shown to preserve phenolic content in leafy vegetables while increasing shelf life and facilitating access in off-season periods. Some studies on *Amaranthus* and *Basella alba* indicate that over 85% of antioxidant activity is retained when dried at temperatures below 45°C (Gonçalves et al. 2024). These results suggest that incorporating mild dehydration methods in PANC processing may optimize preservation and functional value, especially for institutional feeding programs or food aid strategies in remote areas.

Conversely, germination triggers enzymatic cascades that activate polyphenol biosynthesis, reduce anti-nutritional compounds, and increase digestibility. Although few studies specifically assess germinated PANCs, extrapolations from similar species (e.g., quinoa, buckwheat, and mung bean) suggest that sprouted forms could double the antioxidant bioactivity per gram of food consumed. Integrating germination into household food strategies or food technology applications could open new possibilities for developing functional flours, porridges, and fortified snacks based on sprouted PANCs.

An interesting case is the positive effect of spontaneous fermentation in *Tropaeolum majus*, with a 25% increase in TPC and a significant reduction in IC₅₀, attributed to microbial enzyme action releasing bioactive compounds bound to the food matrix (Gonçalves et al. 2023). This highlights fermentation as a promising technique to enhance the nutritional and functional value of PANCs.

Germination, on the other hand, triggers enzymatic cascades that activate polyphenol biosynthesis, reduce anti-nutritional compounds, and increase digestibility. Although few studies specifically assess germinated PANCs, extrapolations from similar species (e.g., quinoa, buckwheat, and mung bean) suggest that sprouted forms could double the antioxidant bioactivity per gram of food consumed. Integrating germination into household food strategies or food technology applications could open new possibilities for developing functional flours, porridges, and fortified snacks based on sprouted PANCs.

Overall, most PANCs evaluated in raw form showed higher antioxidant activity than processed forms, supporting the importance of consuming them fresh to maximize health benefits. However, traditional culinary methods, such as light cooking

and fermentation, can be recommended for particular species, balancing food safety with the preservation of bioactive compounds.

4.4 | Synergistic Interactions and Compound Effects

The complexity of the biochemical interactions in PANCs suggests that antioxidant activity is not attributable to a single compound, but instead to the synergistic effect of various phytochemical groups within the whole food matrix. This interaction significantly enhances the overall antioxidant capacity, as recent studies on the combinatory effect of flavonoids, tannins, carotenoids, vitamins, and antioxidant minerals have shown (Liu et al. 2023; Zhao et al. 2024).

Table 7 shows that *Pereskia aculeata* and *Portulaca oleracea* have high levels of phenolic compounds. However, their antioxidant activity exceeds what would be expected from the sum of isolated compounds, suggesting possible synergy. For example, the co-presence of ascorbic acid, flavonoids, and carotenoids in these plants has been linked to the mutual regeneration of antioxidant species, increasing the efficiency of free radical neutralization (Zhou and Chen 2023).

Additionally, mineral compounds such as selenium and zinc act as essential cofactors for endogenous antioxidant enzymes, including glutathione peroxidase and superoxide dismutase, thereby enhancing systemic antioxidant defense (Martins et al. 2022). Consuming the whole plant ensures a balanced presence of these cofactors, which isolated extracts may not replicate.

Another important aspect is the influence of the food matrix on the bioavailability of bioactive compounds. The interaction between fibers, proteins, and phenolics can modulate the release and absorption of antioxidants in the gastrointestinal tract, favoring a prolonged and sustainable effect in the body (Silva and Pereira 2024). In vitro and in vivo studies demonstrate that the presence of soluble and insoluble fibers in PANCs enhances polyphenol metabolism by gut bacteria, thereby promoting the production of bioactive metabolites with anti-inflammatory and antioxidant effects (Gonçalves et al. 2023).

These findings reinforce the importance of consuming whole foods, particularly PANCs, and favor the intake of minimally processed foods to maximize health benefits. Moreover, preserving the natural matrix may minimize the impact of potential antagonistic interactions in highly concentrated extracts, which may produce pro-oxidant effects depending on physiological conditions (Chen et al. 2023).

Thus, promoting the consumption of PANCs in raw or minimally processed forms represents a functional dietary strategy that values biodiversity, supports balanced nutrition, and contributes to public health by reducing chronic oxidative stress, which is implicated in various non-communicable diseases.

4.5 | Practical Relevance and Nutritional Implications

The appreciation of non-conventional food plants (PANCs) goes beyond nutritional aspects, integrating into global agendas on food security, environmental sustainability, and public health promotion. The phytochemical diversity and high antioxidant potential of PANCs, as shown in Table 7, position these plants as strategic sources of essential nutrients and bioactive compounds, especially for vulnerable populations facing food insecurity (FAO 2022).

Beyond their nutritional and biochemical relevance, PANCs are gaining importance as key instruments of sustainable development and food sovereignty. By fostering the recovery of traditional species and diversifying local crops, their valorization contributes directly to circular economy models and climate-resilient production systems. In global terms, expanding the use of unconventional edible plants could reduce the dependence of low- and middle-income countries on imported inputs, stimulate regional value chains, and strengthen biodiversity-based economies.

From an environmental perspective, the cultivation and consumption of PANCs can play a strategic role in mitigating greenhouse gas emissions. Many species adapt to marginal soils, require minimal irrigation, and often coexist with native vegetation, reducing pressure for deforestation or monoculture expansion. When integrated into agroforestry systems, PANCs can improve soil fertility, promote pollinator diversity, and increase ecosystem resilience, thereby supporting SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

From a food security perspective, PANCs represent a viable alternative to diversify local food supplies, reduce dependence on monocultures, and promote more resilient and culturally appropriate diets (Gomes et al. 2023). The systematic incorporation of these plants into public policies, such as school feeding programs and support for family farming, can help mitigate nutritional deficiencies and reduce the incidence of chronic diseases associated with oxidative stress, such as diabetes, hypertension, and cardiovascular disorders (Oliveira et al. 2024).

Moreover, environmental sustainability is significantly enhanced by using PANCs, as many of these species are adapted to adverse conditions, require low water inputs, pesticides, and fertilizers, and can be cultivated in integrated agroecological systems (Moura et al. 2022). This helps reduce the water footprint and environmental impact of food production, aligning with the goals of the 2030 Agenda for Sustainable Development (United Nations 2015).

Another promising but often neglected dimension is the economic and social potential of PANC chains. Many species evaluated in this review are already cultivated or harvested by smallholder farmers, urban gardeners, and Indigenous communities. However, the absence of structured value chains, market recognition, and processing technologies limits their scalability and inclusion in public food procurement. Studies in regions

such as Bahia, Pará, and Maranhão have shown that when PANCs are integrated into school feeding or local food baskets, there is a notable improvement in dietary quality indicators and community income diversification (Carvalho et al. 2024). Moreover, female-led initiatives around PANCs demonstrate high potential for promoting gender equity and food sovereignty, mainly when supported by microcredit, education, and extension services.

To strengthen these local economies and their connection with public health agendas, interdisciplinary interventions are needed. These include mapping supply networks, investing in low-cost preservation technologies (e.g., solar dehydration), and supporting community-based certification schemes that recognize the nutritional and ecological value of PANCs. The potential for incorporating PANCs into zero-waste and circular economy strategies is also relevant, especially given that many species grow spontaneously in agroecological systems or as intercrops.

However, the broad implementation of PANCs still faces challenges related to toxicological safety and sanitary regulations. Although many of these plants have been traditionally consumed, the lack of systematic toxicological studies and specific regulatory frameworks limits their formal commercialization and acceptance among urban consumers (Carvalho et al. 2023). Therefore, multidisciplinary investigations, encompassing toxicological evaluations, clinical trials, and the development of sustainable management protocols, are urgently needed to ensure the safety and efficacy of these plants for human consumption.

Educational strategies and rural extension initiatives are also crucial to promote knowledge about PANCs, including their management, benefits, and proper preparation methods. These actions can strengthen local value chains and cultural appreciation (Santos et al. 2022). Encouraging short food supply chains and investing in technological innovation for processing and preservation may increase consumer acceptance and broaden the market for these plants, thereby contributing to sustainable socioeconomic development.

Finally, the inclusion of socio-economic indicators in future studies is critical. Assessing farmer income, gender participation, and regional market structures will be essential to ensure that PANC valorization promotes equitable and inclusive development rather than reproducing existing inequalities in agricultural systems. The convergence of scientific validation, economic modeling, and social impact evaluation will determine the long-term sustainability of these plants within global food systems.

PANCs represent a promising frontier in functional food systems, combining proven antioxidant potential with social and environmental relevance. Their integration into public health and nutrition policies, supported by scientific research and cultural valorization, can positively transform the food landscape, comprehensively promoting health, food security, and sustainability.

4.6 | Limitations and the Need for Standardization

Despite significant advances in the phytochemical characterization and antioxidant evaluation of PANCs, the literature still reveals important gaps that must be addressed to consolidate the use of these plants in food and therapeutic applications. The data in Table 7 show considerable variation in bioactive composition among species, underscoring the need for methodological standardization to ensure reproducibility and comparability of results.

Despite advances, insufficient standardization of analytical protocols, fragmented toxicological data, and the scarcity of *in vivo* or clinical validations still limit translational inference. While DPPH, ABTS, and FRAP provide valuable screening capacities, few studies have examined the bioaccessibility or bioavailability of bioactives from whole PANC matrices, and interactions with gut microbiota remain largely unexplored. Incorporating simulated digestion, cell-based models, and human trials is therefore a priority to connect biochemical potential with physiological efficacy.

A major methodological challenge lies in the intrinsic variability of PANCs, influenced by agronomic, environmental, and processing factors. Seasonality, maturation stage, cultivation conditions, and methods of bioactive compound extraction directly impact the phytochemical profile and, consequently, antioxidant activity (Fernandes et al. 2023). Therefore, future studies should prioritize the development of standardized protocols for collection, processing, and analysis, including the use of advanced chromatographic and spectrometric techniques to ensure precise identification and quantification of key compounds.

Another major gap concerns feasibility at scale. Comprehensive techno-economic analyses and life-cycle assessments (LCAs) are rarely reported, yet are decisive to quantify comparative advantages versus conventional crops (cost, carbon footprint, water use). In parallel, postharvest stability, sensory acceptability, and regulatory clarity, particularly standardized labeling for biodiversity-based foods, are necessary to build consumer confidence and facilitate broader market access.

Another important perspective is the integration of omics approaches, such as metabolomics, proteomics, and transcriptomics, to elucidate the molecular mechanisms underlying the antioxidant activity and other biological effects of PANCs (Lima et al. 2024). These techniques provide a comprehensive understanding of the interaction between bioactive compounds and biological systems and can also aid in identifying potential biomarkers for assessing efficacy and safety.

In practical terms, there is a scarcity of *in vivo* studies and clinical trials, which limits the extrapolation of *in vitro* results to human contexts. Evaluating the bioavailability, metabolism, and systemic effects of the antioxidant compounds in PANCs is essential to validate their functional properties and to establish dietary recommendations based on solid scientific evidence (Rodrigues et al. 2023). In addition, potential adverse effects

and drug interactions must be further investigated to ensure the safety of regular consumption.

Ultimately, interdisciplinarity is crucial for progress in this field, as it integrates knowledge from botany, chemistry, nutrition, pharmacology, food technology, and the social sciences. Community engagement and the appreciation of traditional knowledge related to PANC use are equally important for developing sustainable, culturally sensitive, and economically viable strategies.

Addressing these challenges will require harmonized methodologies, shared reference materials, and cross-regional datasets, along with participatory approaches that involve smallholders and indigenous communities. Such coordination can accelerate safe, equitable, and evidence-based integration of PANCs into sustainable food systems.

Therefore, unlocking the full potential of PANCs as functional foods and health-promoting agents requires coordinated efforts beyond phytochemical analysis, encompassing technological, clinical, regulatory, and socioeconomic aspects. Strengthening this research agenda will help translate scientific knowledge into concrete benefits for people and the environment.

Taken together, these limitations and opportunities frame the priorities addressed in the concluding section, which outlines practical research and policy pathways to consolidate PANCs as strategic tools for global food security and ecological sustainability.

4.7 | Future Research Perspectives and Methodological Challenges

Despite significant advances in the phytochemical characterization and evaluation of the antioxidant properties of non-conventional food plants (PANCs), the literature still presents substantial gaps that need to be addressed to consolidate the use of these plants in food and therapeutic applications. Analysis of the data in Table 7 reveals considerable variations in bioactive composition among species, reinforcing the need for methodological standardization to ensure reproducibility and comparability of results.

One of the main methodological challenges lies in the intrinsic variability of PANCs, influenced by agronomic, environmental, and processing factors. Seasonality, maturation stage, cultivation conditions, and methods of bioactive compound extraction directly impact the phytochemical profile and, consequently, antioxidant activity (Fernandes et al. 2023). Therefore, future studies should prioritize the development of standardized protocols for collection, processing, and analysis, including the use of advanced chromatographic and spectrometric techniques to accurately identify and quantify key compounds.

Another relevant perspective is the integration of omics approaches, such as metabolomics, proteomics, and transcriptomics, to elucidate the molecular mechanisms underlying the antioxidant activity and other biological effects of PANCs (Lima

et al. 2024). These techniques offer a comprehensive understanding of the interactions between bioactive compounds and biological systems and can also aid in identifying potential biomarkers for assessing efficacy and safety.

In practice, in vivo studies and clinical trials are scarce, limiting the extrapolation of in vitro results to human contexts. Assessing the bioavailability, metabolism, and systemic effects of antioxidant compounds from PANCs is crucial for validating their functional properties and establishing evidence-based dietary recommendations (Rodrigues et al. 2023). Furthermore, investigating possible adverse effects and drug interactions should be deepened to ensure safety with regular consumption.

Finally, interdisciplinarity emerges as a key path forward in this field, integrating knowledge from botany, chemistry, nutrition, pharmacology, food technology, and social sciences. Community engagement and the valorization of traditional knowledge associated with using PANCs are equally important to develop sustainable, culturally sensitive, and economically viable strategies.

Therefore, consolidating the potential of PANCs as functional and health-promoting foods requires coordinated efforts beyond phytochemical analysis, encompassing technological, clinical, regulatory, and socioeconomic aspects. Strengthening this research agenda will help transform scientific knowledge into tangible benefits for both populations and the environment.

4.8 | Integration With Public Health and Food Policy

The integration of PANCs into public health and nutrition agendas represents a strategic avenue to combat food insecurity, reduce chronic disease burden, and promote sustainable diets. Several national and international initiatives have already begun to recognize the importance of food biodiversity. However, institutional barriers and a lack of standardization still hinder the widespread adoption of PANCs in policy frameworks.

School feeding programs, community food baskets, and hospital dietary services could incorporate validated PANCs, such as *Portulaca oleracea* and *Pereskia aculeata*, to enhance micronutrient intake and promote diets rich in antioxidants among vulnerable populations. Moreover, empirical evidence suggests that these plants are culturally acceptable and adaptable to regional cuisines, making them ideal candidates for inclusion in public procurement strategies (Silva et al. 2023).

From a policy perspective, the systematic inclusion of PANCs necessitates collaborative efforts among researchers, health professionals, agricultural extension agents, and local producers. It is also essential to strengthen regulatory frameworks to ensure safety, traceability, and standardized processing techniques for PANC-based foods. Ultimately, these strategies align with the goals of the United Nations Decade of Action on Nutrition and the 2030 Sustainable Development Agenda, promoting food systems that are diverse, resilient, and health-promoting (FAO and WHO 2021).

5 | Conclusion

This scoping review synthesized validated scientific evidence published between 2020 and 2025 on the antioxidant potential of unconventional edible plants (PANCs/UEPs). By applying pre-defined inclusion, exclusion, and validation criteria, the review ensured that only methodologically robust and reproducible studies were retained, providing a credible and evidence-based overview of this rapidly evolving research field.

The compiled dataset of 30 studies confirmed the relevance of species such as *Portulaca oleracea*, *Pereskia aculeata*, *Amaranthus cruentus*, *Solanum betaceum*, and *Talinum paniculatum*, which consistently displayed high phenolic content and vigorous radical-scavenging activity. Culinary processing, such as cooking and fermentation, was shown to modulate antioxidant responses, emphasizing the importance of evaluating these plants in realistic dietary contexts.

At a global level, PANCs demonstrate significant potential for promoting sustainable and circular food systems. Their cultivation requires fewer resources, supports biodiversity conservation, and can reduce dependency on imported additives and synthetic antioxidants. By fostering the inclusion of traditional and underutilized crops in local markets, PANCs contribute to food sovereignty, income diversification, and environmental resilience, key elements aligned with the Sustainable Development Goals (SDGs 2, 12, and 13).

Despite these advances, important gaps remain. The absence of standardized methodologies, limited bioavailability data, and the scarcity of in vivo and clinical studies continue to hinder translational applications. Similarly, the lack of techno-economic assessments, postharvest stability analyses, and harmonized regulations limits industrial integration. Future research should adopt multidisciplinary and multi-scale approaches, combining analytical chemistry, nutrition, agronomy, economics, and social sciences, to develop evidence-based frameworks for PANC valorization.

Ultimately, this validated and integrative synthesis confirms that PANCs are not merely regional curiosities but represent global opportunities for innovation in food science and sustainable development. By advancing from descriptive to translational research and by integrating environmental, economic, and social dimensions, the field can transform PANCs from underrecognized resources into strategic instruments for healthier, climate-resilient, and equitable food systems worldwide.

Author Contributions

The conception and design of the review were developed by Flávia Aparecida Reitz Cardoso, who also coordinated the project and performed the final critical review of the manuscript. Nathália Letícia Hernandez Brito, Gustavo Barreto Costa, and Karina Pinheiro Martins contributed to the development of the methodological approach, literature search, data selection, and systematization of the results. Jhony Silva Ramos, Ana Caroline Silvestre Barbosa Alessi, Thais Aparecida Santos, Ana Elisa Melo da Silva, and Adriana Aparecida Droval Arcain participated in data extraction, organizing tables and figures, and drafting specific sections of the text. All authors contributed to the writing

and editing of the manuscript, discussed the results, and approved the final version for submission.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

References

- Adamu, E., Z. Asfaw, S. Demissew, and K. Baye. 2022. "Antioxidant Activity and Anti-Nutritional Factors of Selected Wild Edible Plants Collected From Northeastern Ethiopia." *Food* 11, no. 15: 2291. <https://doi.org/10.3390/foods11152291>.
- Almeida, A. P., R. M. Santos, and D. A. Silva. 2024. "Underutilized Edible Plants as Functional Foods: Nutritional Potential and Technological Challenges." *Journal of Functional Foods* 104: 105505. <https://doi.org/10.1016/j.jff.2023.105505>.
- Alves, L. F. 2021. "Cooked *Manihot Esculenta* Leaves: Antioxidant Retention and Antinutritional Factor Reduction." *Journal of Food Research* 12, no. 4: 210–218.
- Belém, C. C. S., and C. V. Lamarão. 2022. Analysis of antioxidant and antimicrobial activity of wild edible plants (PANCs). *Anais do XXX Congresso de Iniciação Científica da UFAM – CONIC*. <https://www.even3.com.br/anais/conicufam/444428>.
- Botrel, N., S. Freitas, M. J. O. Fonseca, and R. A. C. Melo. 2020. "Nutritional Value of Unconventional Leafy Vegetables Grown in the Cerrado Biome/Brazil." *Brazilian Journal of Food Technology* 23: e202017418. <https://doi.org/10.1590/1981-6723.17418>.
- Carocho, M., and I. C. F. R. Ferreira. 2023. "A Review on Antioxidants, Pro-Oxidants and Related Controversy: Natural and Synthetic Compounds, Screening Methodologies and Future Perspectives." *Food and Chemical Toxicology* 176: 113771. <https://doi.org/10.1016/j.fct.2023.113771>.
- Carvalho, L. M. J., M. M. Corrêa, and A. L. Nascimento. 2023. "Food Safety Challenges Related to the Consumption of Unconventional Edible Plants." *Food Control* 146: 109559. <https://doi.org/10.1016/j.foodcont.2022.109559>.
- Carvalho, L. M. J., A. L. Nascimento, and M. M. Corrêa. 2024. "Inclusion of Food Biodiversity in Public Procurement and Institutional Markets." *Sustainability* 16, no. 2: 742. <https://doi.org/10.3390/su16020742>.
- Chen, G., S. Chen, Y. Xiao, N. Fu, and Y. Xu. 2023. "Phenolic Compounds, Antioxidant Activity, and Health Benefits of *Dioscorea* Species." *Journal of Functional Foods* 103: 105474. <https://doi.org/10.1016/j.jff.2023.105474>.
- Clemente-Villalba, J., F. Burló, F. Hernández, and Á. A. Carbonell-Barrachina. 2023. "Valorization of Wild Edible Plants as Food Ingredients and Their Economic Value." *Food* 12, no. 5: 1012. <https://doi.org/10.3390/foods12051012>.

- Costa, A. S. G., R. C. Alves, and M. B. P. P. Oliveira. 2024. "Fermentation as a Strategy to Enhance Antioxidant Potential of Plant-Based Foods." *Foods* 13, no. 2: 215. <https://doi.org/10.3390/foods13020215>.
- de Aquino, R. C., and T. B. Flores. 2021. "Unconventional Food Plants (PANCs) in Brazil: Biodiversity, Food Security, and Sustainability." *Journal of Ethnobiology and Ethnomedicine* 17: 61. <https://doi.org/10.1186/s13002-021-00493-7>.
- de Souza Ferreira, R., and M. C. T. Vidigal. 2021. "Nutritional Composition and Antioxidant Activity of *Pereskia Aculeata* (Ora-Pro-nóbis) in Whole-Food Form." *Brazilian Journal of Food Technology* 26: e2023. <https://doi.org/10.1590/1981-6723.bjft2023.v26>.
- FAO and WHO. 2021. *Food Safety and Nutrition: Strengthening Food Systems*. FAO/WHO.
- FAO. 2022. *The State of Food Security and Nutrition in the World 2022*. Food and Agriculture Organization of the United Nations.
- FAO, IFAD, UNICEF, WFP, and WHO. 2023. *The State of Food Security and Nutrition in the World 2023: Urbanization, Agrifood Systems Transformation and Healthy Diets Across the Rural–Urban Continuum*. FAO. <https://doi.org/10.4060/cc3017en>.
- Fernandes, F. H. A., A. P. Silva, and R. S. Costa. 2023. "Environmental and Agronomic Factors Influencing Phenolic Compounds in Edible Plants." *Agronomy* 13, no. 9: 2261. <https://doi.org/10.3390/agronomy13092261>.
- Fernandes, F. H. A., A. P. Silva, and R. S. Costa. 2024. "Post-Harvest Effects on Bioactive Compounds of Edible Plant Species." *Agronomy* 14, no. 1: 88. <https://doi.org/10.3390/agronomy14010088>.
- Fernandes, R. M., A. U. Carvalho, and P. M. Pereira. 2021. "Antioxidant Activity of Unconventional Leafy Vegetables in Southern Brazil." *Food Science and Technology* 41, no. 2: 432–441.
- Ferreira, L. F., D. S. Oliveira, M. S. Santos, and A. P. Silva. 2023. "Natural Antioxidants as Alternatives to Synthetic Additives in Meat Products: A Review." *Meat Science* 198: 109073. <https://doi.org/10.1016/j.meatsci.2023.109073>.
- Ferreira, R. d. S., J. dos Santos, L. A. de Oliveira, C. M. Della Lucia, and M. C. T. Ribeiro Vidigal. 2024. "Nutritional Value and Antioxidant Activity of Ora-Pro-nóbis, Tamarillo, and Green Banana Biomass in Whole-Food Form." *Journal of Engineering and Exact Sciences* 10: 1–17. <https://doi.org/10.18540/jcecv110iss8pp20740>.
- Giuliani, C. d. S., C. A. A. Farias, P. K. Marquezan, et al. 2025. "Chemical Diversity, Antioxidant Potential, Antimicrobial Activity, and Cytotoxicity and Genotoxicity Analyses of Unconventional Food Plants: *Cymbopogon Citratus*, *Pereskia Aculeata*, *Portulaca Oleracea*, and *Talinum Paniculatum*." SSRN. <https://doi.org/10.2139/ssrn.5139087>.
- Gomes, S. M., V. M. Chaves, A. M. de Carvalho, et al. 2023. "Biodiversity Is Overlooked in the Diets of Different Social Groups in Brazil." *Scientific Reports* 13: 7509. <https://doi.org/10.1038/s41598-023-34543-8>.
- Gonçalves, A. E. S. S., M. I. Genovese, and F. M. Lajolo. 2023. "Phenolic Compounds and Antioxidant Capacity of Germinated Seeds of *Amaranthus Cruentus*." *Food Chemistry* 404: 134595. <https://doi.org/10.1016/j.foodchem.2022.134595>.
- Gonçalves, A. E. S. S., M. I. Genovese, and F. M. Lajolo. 2024. "Impact of Food Processing on Phenolic Compounds and Antioxidant Activity." *Journal of Food Composition and Analysis* 118: 105145. <https://doi.org/10.1016/j.jfca.2023.105145>.
- He, L., Y. Liu, A. Mustapha, and M. Lin. 2022. "Antioxidant Activities of Natural Plant Extracts and Their Application in Food Systems." *Food Chemistry* 367: 130–141. <https://doi.org/10.1016/j.foodchem.2021.130141>.
- IPBES. 2019. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat. <https://ipbes.net/global-assessment>.
- Khoury, C. K., A. D. Bjorkman, H. Dempewolf, et al. 2014. "Increasing Homogeneity in Global Food Supplies and the Implications for Food Security." *Proceedings of the National Academy of Sciences* 111, no. 11: 4001–4006. <https://doi.org/10.1073/pnas.1313490111>.
- Li, S., G. Chen, C. Zhang, M. Wu, and Y. Wang. 2022. "Natural Antioxidants in Meat and Meat Products: Sources, Mechanisms, and Applications." *Trends in Food Science & Technology* 119: 1–15. <https://doi.org/10.1016/j.tifs.2021.11.012>.
- Lima, G. P. P., F. Vianello, C. R. Corrêa, and R. A. Campos. 2024. "Omics Approaches Applied to Food Bioactive Compounds Research." *Trends in Food Science & Technology* 140: 104–117. <https://doi.org/10.1016/j.tifs.2024.02.006>.
- Liu, Y., D. Chen, Y. You, and Y. Lin. 2023. "Synergistic Antioxidant Effects of Polyphenols in Whole Foods." *Antioxidants* 12, no. 6: 1215. <https://doi.org/10.3390/antiox12061215>.
- Martín-García, B., S. De Montijo-Prieto, M. Jiménez-Valera, et al. 2022. "Comparative Extraction of Phenolic Compounds From Olive Leaves Using a Sonotrode and an Ultrasonic Bath and the Evaluation of Both Antioxidant and Antimicrobial Activity." *Antioxidants* 11, no. 3: 558. <https://doi.org/10.3390/antiox11030558>.
- Martins, F. R., F. C. Andrade, and E. O. Silva. 2022. "Interações de compostos bioativos em plantas integrais: impactos na atividade antioxidante." *Revista Brasileira de Plantas Medicinais* 24, no. 1: 120–131.
- Mavengahama, S., L. J. McGaw, and J. N. Eloff. 2021. "African Leafy Vegetables: Nutritional, Antioxidant and Antimicrobial Properties." *Food Research International* 149: 110657. <https://doi.org/10.1016/j.foodres.2021.110657>.
- Moura, F. A., M. A. A. Cunha, and R. W. Figueiredo. 2022. "Unconventional Edible Plants and Circular Economy: Opportunities for Sustainable Food Systems." *Sustainability* 14, no. 18: 11325. <https://doi.org/10.3390/su141811325>.
- Munn, Z., M. D. J. Peters, C. Stern, C. Tufanaru, A. McArthur, and E. Aromataris. 2018. "Systematic Review or Scoping Review? Guidance for Authors When Choosing Between a Systematic or Scoping Review Approach." *BMC Medical Research Methodology* 18: 143.
- Nascimento, L. D., F. J. Oliveira, and A. S. Lima. 2022. "Uso de PANCs na cozinha popular: implicações para saúde e cultura alimentar." *Cadernos de Saúde Pública* 38, no. 7: e00123421.
- Oliveira, D. S., L. F. Ferreira, M. S. Santos, F. B. Reitz, and A. P. Silva. 2025. "Application of Natural Antioxidants From Plant Sources in Meat Products: Technological and Oxidative Stability Aspects." *Journal of Food Processing and Preservation* 49, no. 2: e17845. <https://doi.org/10.1111/jfpp.17845>.
- Oliveira, D. S., M. P. Santos, and J. R. Lima. 2024. "Unconventional Food Plants in Public Nutrition Policies in Brazil." *Public Health Nutrition* 27, no. 4: 789–799. <https://doi.org/10.1017/S1368980023002998>.
- Oliveira, L. S., E. A. Souza, and M. S. Rocha. 2023. "Traditional Use and Chemical Composition of Underutilized Leafy Vegetables in Northern Brazil." *Journal of Ethnopharmacology* 280: 115086.
- Pereira, A. G., M. Fraga-Corral, P. García-Oliveira, et al. 2020. "Culinary and Nutritional Value of Edible Wild Plants From Northern Spain Rich in Phenolic Compounds With Potential Health Benefits." *Food & Function* 11, no. 10: 8493–8515. <https://doi.org/10.1039/D0FO02147D>.
- Peters, M. D. J., C. M. Godfrey, H. Khalil, P. McInerney, D. Parker, and C. B. Soares. 2015. "Guidance for Conducting Systematic Scoping Reviews." *International Journal of Evidence-Based Healthcare* 13, no. 3: 141–146.
- Pinto, D., A. I. G. Lima, I. Fernandes, V. Freitas, and N. Mateus. 2021. "Effect of Thermal Processing on Bound Phenolic Compounds, Antioxidant Capacity, and Extractability in Plant-Based Foods." *Food*

- Chemistry 344: 128689. <https://doi.org/10.1016/j.foodchem.2020.128689>.
- Ribeiro, D. A., M. A. Andrade, and L. Barros. 2025. "Natural Antioxidants From Edible Biodiversity: Evidence and Challenges." *Food Chemistry* 431: 137087. <https://doi.org/10.1016/j.foodchem.2024.137087>.
- Rodrigues, A. M., R. D. A. Amboni, and L. S. Bento. 2021. "Phenolic Compounds and Antioxidant Activity in Selected Wild Edible Plants From Brazil: A Review." *Journal of Food Science and Technology* 58, no. 5: 1694–1704.
- Rodrigues, M. J., V. Neves, A. Martins, and L. Custódio. 2023. "From in Vitro Antioxidant Activity to Human Health Relevance." *Marine Drugs* 21, no. 2: 96. <https://doi.org/10.3390/md21020096>.
- Salgado, J. M., M. M. Almeida, C. D. Pereira, and I. C. F. R. Ferreira. 2023. "Natural Antioxidants From Unconventional Plants as Food Preservatives." *Trends in Food Science & Technology* 137: 1–14. <https://doi.org/10.1016/j.tifs.2023.01.004>.
- Santos, F. M., L. M. Oliveira, and E. M. Guimarães. 2021. "Nutritional Composition and Antioxidant Activity of Underutilized Leafy Vegetables From Southern Brazil." *Journal of Ethnopharmacology* 280: 115086. <https://doi.org/10.1016/j.jep.2021.115086>.
- Santos, R. R., F. S. Almeida, and T. S. Mendonça. 2022. "Compostos bioativos e seus efeitos antioxidantes em PANCs." *Revista de Nutrição* 35: e210233.
- Santos, R. S., A. L. Nascimento, and M. M. Corrêa. 2023. "Ethnobotanical Knowledge and Food Biodiversity." *Ethnobiology and Conservation* 12: 8. <https://doi.org/10.15451/ec2023-01-12.08>.
- Scarano, F., R. Santos, J. Silverio, V. Galli, and C. Pereira. 2020. "Ethnobotany, Nutritional and Bioactive Compounds of Wild Edible Plants: A Tool for Rural Development." *Food Research International* 136: 109562.
- Silva, D. A., R. M. Santos, and A. P. Almeida. 2023. "Bioactive Compounds From Underutilized Plants and Food Applications." *Journal of Food Processing and Preservation* 47, no. 8: e17112. <https://doi.org/10.1111/jfpp.17112>.
- Silva, D. A., R. M. Santos, and A. P. Almeida. 2025. "Emerging Applications of Unconventional Edible Plants in Food Systems." *Journal of Food Process Engineering* 48, no. 1: e14501. <https://doi.org/10.1111/jfpe.14501>.
- Silva, M. B., N. S. Ribeiro, and M. A. Trindade. 2021. "Antioxidant Capacity of *Portulaca Oleracea* in Its Edible Form: A Scoping Review." *Journal of Food Composition and Analysis* 102: 104071. <https://doi.org/10.1016/j.jfca.2021.104071>.
- Silva, R. S., and C. D. Pereira. 2024. "Whole-Food Antioxidants and Interactions With Gut Microbiota." *Current Opinion in Food Science* 55: 101115. <https://doi.org/10.1016/j.cofs.2024.101115>.
- Tepper, B. J., and E. Roura. 2022. "Nutrient Sensing, Taste, and Appetite Regulation." *Advances in Nutrition* 13, no. 1: 151–167. <https://doi.org/10.1093/advances/nmab124>.
- Tiemann, T. T., R. S. Costa, and A. P. Silva. 2023. "Methodological Challenges in Scoping Reviews Applied to Food Biodiversity Research." *Food Research International* 168: 112705. <https://doi.org/10.1016/j.foodres.2023.112705>.
- Tricco, A. C., E. Lillie, W. Zarin, et al. 2018. "PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation." *Annals of Internal Medicine* 169, no. 7: 467–473. <https://doi.org/10.7326/M18-0850>.
- United Nations. 2015. *Transforming Our World: The 2030 Agenda for Sustainable Development*. United Nations. <https://sdgs.un.org/2030agenda>.
- Zhang, H., R. Tsao, and Z. Deng. 2024. "Advanced Analytical Strategies for Antioxidant Activity Evaluation in Foods." *Critical Reviews in Food Science and Nutrition*. <https://doi.org/10.1080/10408398.2024.2311047>.
- Zhao, C., X. Wang, S. Chen, and Y. Li. 2024. "Dietary Antioxidants and Oxidative Stress-Related Chronic Diseases." *Nutrients* 16, no. 3: 398. <https://doi.org/10.3390/nu16030398>.
- Zhou, Y., and J. Chen. 2023. "Food Matrix Effects on Antioxidant Bioavailability." *Food & Function* 14, no. 5: 2101–2115. <https://doi.org/10.1039/D2FO03589A>.