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Phytochemical Screening of Tamarind (*Tamarindus indica* L.) Seed and Peel Extracts under a Simplex-Centroid Solvent Design: Implications for the Valorization of Agro-Industrial By-Products

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Abstract

This study aimed to evaluate the phytochemical profile of tamarind seed and peel extracts using a simplex-centroid solvent design. Qualitative screening revealed a broader diversity of metabolites in seed extracts compared to peels. The solvent system showed limited influence on qualitative detection, indicating that matrix composition plays a dominant role. These findings highlight the potential of tamarind seeds as a source of bioactive compounds and support their valorization in functional food and bioproduct applications. However, further quantitative and biological studies are required. Tamarind (Tamarindus indica L.) processing generates significant amounts of seeds and peels, which are often underutilized despite their potential as sources of bioactive compounds. This study aimed to evaluate the phytochemical profile of tamarind seed and peel extracts using a simplex-centroid solvent design. Qualitative phytochemical screening revealed a broader diversity of metabolites in seed extracts, including flavonoids, tannins, terpenoids, saponins, amino acids, and cardiac glycosides, whereas peel extracts exhibited a limited profile, mainly characterized by reducing sugars. The solvent system showed minimal influence on qualitative detection, indicating that matrix composition plays a dominant role over extraction conditions in this context. The results highlight the relevance of tamarind seeds as a promising matrix for the recovery of bioactive compounds and support their potential valorization within sustainable and circular economy approaches. However, due to the qualitative nature of the analyses, further quantitative and biological studies are required to confirm these findings.

Keywords: agro-industrial by-products; functional compounds; phytochemical qualitative analysis; sustainability; Tamarindus indica; ultrasound-assisted extraction.

INTRODUCTION

The tamarind tree (*Tamarindus indica* L.) is a leguminous species of the *Fabaceae* family (subfamily *Caesalpinioideae*). Native to the tropical regions of Equatorial Africa, including Sudan, Ethiopia, Mozambique, Kenya, Tanzania, and Senegal, as well as the dry deciduous forests of Madagascar, the species is recognized as the sole representative of its genus. From its center of origin, *T. indica* has spread extensively throughout tropical and subtropical regions, particularly across India and Southeast Asia (Ebifa-Othieno et al., 2017, 2020). In Brazil, tamarind was introduced from India and has become well adapted and sub spontaneous in several regions, especially in semi-arid environments, where it is considered a typical fruit tree of the Northeast and is also found in transitional areas between the Cerrado and the Pantanal (Dantas et al., 2012; Góes et al., 2016; Pereira et al., 2016).

The species exhibits remarkable adaptability to diverse pedoclimatic conditions, including poor, acidic, saline, and nutrient-deficient soils, as well as degraded environments. Its deep root system confers tolerance to prolonged drought, making it particularly suitable for cultivation in semi-arid regions. These characteristics not only favor its agricultural expansion but also highlight its potential role in environmental restoration and sustainable land use (Ebifa-Othieno et al., 2020; García et al., 2012; Singh et al., 2025; Tapia-Pastrana et al., 2012).

Tamarind is widely cultivated in tropical regions and recognized for its nutritional and functional properties. While its pulp is extensively used in food applications, seeds and peels are commonly discarded as agro-industrial residues. In the context of sustainable food

systems and circular economy strategies, the valorization of these by-products has gained increasing attention due to their potential as sources of bioactive compounds, including phenolics, flavonoids, tannins, and terpenoids, which are associated with antioxidant and health-promoting properties (Amaral et al., 2022; Figueiredo et al., 2019; Maia et al., 2021; Martins et al., 2020; Sookying et al., 2022). As global demand for sustainable production models increases and circular economy, the valorization of plant residues has become a strategic avenue for reducing environmental impacts and generating high-value bioproducts (Garcia e Silva et al., 2020; Mansingh et al., 2021).

The by-products of tamarind fruit (peel and seeds) represent a substantial fraction of the total mass and, although often discarded, constitute promising sources of bioactive compounds with potential applications in the food and industrial sectors (Ferreira Junior et al., 2021; Garcia e Silva et al., 2020; Martins et al., 2020). However, their effective utilization depends on prior characterization, particularly of their phytochemical composition and functional properties, which is essential for identifying relevant compounds, guiding extraction strategies, and enabling safe and efficient industrial application. Once properly characterized, these materials can be explored as sources of additives or nutraceutical ingredients, contributing to the development of products with enhanced nutritional value, potential health benefits, improved sensory attributes, and extended shelf life (Faustino et al., 2019).

In this context, the phytochemical screening represents a preliminary yet essential approach for identifying classes of secondary metabolites and selecting promising matrices for further investigation. Although inherently qualitative, this approach provides critical guidance for subsequent quantitative, structural, and functional analyses (Assouguem et al., 2025; Negi et al., 2024). However, existing studies on tamarind have predominantly focused on individual matrices, mainly pulp or seeds, and have largely employed single-solvent extraction systems. As a result, the combined effects of matrix composition and solvent polarity on extraction efficiency remain insufficiently explored.

Moreover, the application of structured experimental designs to phytochemical extraction, particularly multicomponent solvent systems such as simplex-centroid mixtures, remains limited. These approaches enable systematic evaluation of solvent interactions across polarity gradients and may provide more comprehensive insights into extraction behavior than conventional methodologies.

Therefore, this study aimed to evaluate the qualitative phytochemical profile of tamarind seeds and peels using a simplex-centroid solvent design, with the objective of elucidating matrix-dependent extraction patterns and contributing to the valorization of agro-industrial by-products.

MATERIALS AND METHODS

Raw material and sample preparation

Tamarind (*Tamarindus indica* L.) by-products (peels and seeds) were obtained from two independent batches. Batch 1 (B1) consisted of fruits harvested in Gouveia, Minas Gerais, Brazil (-18.635627 S, -44.040043 W), while Batch 2 (B2) was supplied by a local agro-industrial cooperative located in Montes Claros, Minas Gerais, Brazil (−16.679523 S, −43.858362 W).

The materials were washed with potable water and sanitized using a sodium hypochlorite solution (200 ppm for 15 min). Peels were dried in a forced-air oven at 60 °C for 6 h, while seeds were subjected to thermal treatment at 150 °C for 15 min (Natukunda et al., 2016; Silva et al., 2022). Dried samples were milled using a knife mill (0.3 mm sieve), resulting in peel flour (FPB1, FPB2) and seed flour (FSB1, FSB2), as shown in Figure 1. The flours were stored in sealed polyethylene containers at -4 °C until analysis.

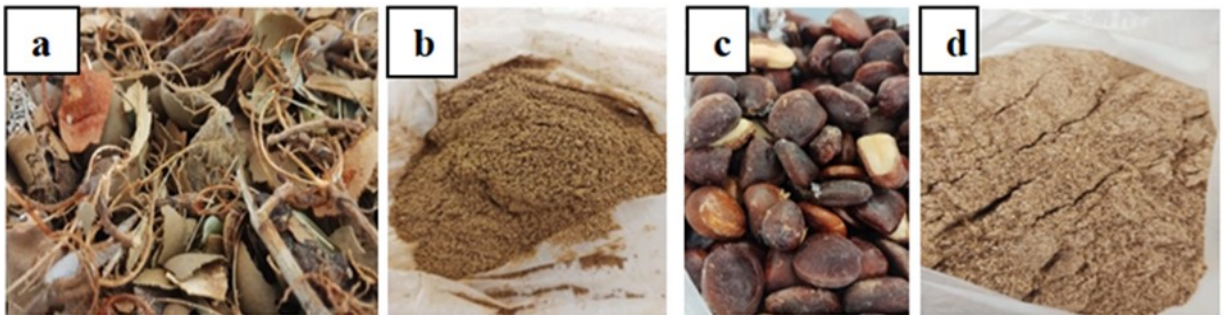

Figure 1. *Marsdenia tenacissima* found by author on Gunung Ijo Flowering twigs.

Experimental design

A simplex-centroid mixture design (Sousa et al., 2022) was employed to evaluate the influence of solvent composition on the extraction of phytochemical compounds. Three solvents with different polarities were used: water (X_1), acetone (X_2), and ethanol (X_3). The

design consisted of: three pure solvents (vertices), three binary mixtures (1:1), one ternary mixture (1:1:1), and three axial points, totaling ten experimental conditions (Table 1).

Extraction procedure

The extraction of bioactive compounds from the residues was based on a modified protocol described by Safdar et al. (2017). For each treatment, 0.5 g of sample was mixed with 25 mL of solvent system and subjected to magnetic stirring (25 °C, 60 min), followed by ultrasound-assisted extraction (50 kHz, 20 W, 20 min). The extracts were centrifuged (1200 × g, 15 min) and filtered under vacuum. The extraction procedure was performed in duplicate, and supernatants were combined to obtain a final volume of 50 mL (solid-to-solvent ratio of 1:100, w/v). Extracts were stored in amber vials at -4 °C until analysis.

Table 1. Solvent volumes used for the production of tamarind peel and seed extracts.

	Extract	Water (mL)	Acetone (mL)	Ethanol (mL)
Pure solvents	**1**	50.0	--	--
	2	--	-	50.0
	3	--	50.0	--
Binary mixture	**4**	25.0	--	25.0
	5	25.0	25.0	--
	6	--	25.0	25.0
Ternary mixture	**7**	16.5	16.5	16.5
Axial points	**8**	8.5	8.5	33.5
	9	8.5	33.5	8.5
	10	33.5	8.5	8.5

Phytochemical screening

Qualitative phytochemical screening was conducted using standard colorimetric and precipitation assays to detect major classes of metabolites (Lucena et al., 2020; Yadav & Agarwala, 2011), including amino acids, cardiac glycosides, flavonoids, phenolic compounds, reducing sugars, saponins, starch, tannins, terpenoids, and steroids. All assays were performed in triplicate, and results were expressed as presence (+) or absence (–) of each metabolite class based on visual observation of characteristic reactions.

Amino acid (ninhydrin test)

For the amino acid test, 2.0 mL of each extract was mixed with 2.0 mL of a 0.2% (w/v) alcoholic ninhydrin solution. The appearance of a violet color indicated the presence of amino acids and/or proteins cardiac glycosides

Cardiac glycosides (Keller-Killani's test)

A 2.5 mL aliquot of each extract was mixed with 1.0 mL of glacial acetic acid and 2 drops of a 2% (w/v) ferric chloride solution. The mixture was then transferred to a test tube containing 1.0 mL of concentrated sulfuric acid. The darkening of the solution and the appearance of a violet ring indicated the presence of cardiac glycosides.

Flavonoids (Shinoda's test)

A 2.0 mL aliquot of each extract was mixed with 2.0 mL of a 2% (w/v) sodium hydroxide solution. Subsequently, drops of concentrated hydrochloric acid were added; the color shift from dark yellow to light yellow was observed, indicating the presence of flavonoids.

Phenolic compounds (ferric chloride test)

To test for the presence of phenols, 2.0 mL of each extract was mixed with three drops of a 2.0% (w/v) alcoholic ferric chloride solution. The mixture was then shaken, and the appearance of a dark green or black coloration indicated the presence of phenols.

Reducing sugars (Fehling's test)

For this analysis, 1.0 mL of each extract was mixed with equal volumes of Fehling's reagents A (aqueous copper sulfate solution) and B (aqueous solution of sodium potassium tartrate and sodium hydroxide). Subsequently, the mixture was heated in a water bath at 65 °C for two minutes. The presence of a red coloration in the tube indicated the presence of reducing sugars.

Saponins (persistent foam layer)

In the saponin test, a mixture of 30 mL of distilled water and 2.0 mL of each extract was heated in a water bath at 100 °C until boiling. The formation of a persistent foam layer indicated a positive result for the presence of saponins.

Starch (iodine-potassium iodide test)

In this step, 1.0 mL of each extract was mixed with 1.0 mL of Lugol's solution. The appearance of a blue coloration indicated the presence of starch.

Tannins (ferric chloride test)

The addition of three drops of a 2.0% (w/v) alcoholic ferric chloride solution to 2.0 mL of each extract, under agitation, resulted in the formation of a dark blue or green precipitate, indicating the presence of tannins

Terpenoids (Salkowski's test)

For the terpene test, 0.5 mL of each extract was mixed with 2.0 mL of chloroform, followed by the careful addition of 3.0 mL of concentrated sulfuric acid along the sides of the test tube to form a layer. The appearance of a reddish-brown coloration at the interface indicated the presence of terpenoids.

Steroids (Liebermann-Burchard's test)

A 0.5 mL aliquot of each extract was mixed with 2.0 mL of concentrated acetic anhydride and 2.0 mL of concentrated sulfuric acid. The color change from violet to blue indicated the presence of steroids.

Data analysis

Due to the qualitative nature of the data, results were analyzed based on detection frequency across experimental conditions. A heatmap was constructed to visualize the distribution of phytochemical classes as a function of matrix type and solvent system. Additionally, a pseudo-regression approach based on mixture design principles was applied to evaluate the influence of solvent composition on metabolite detection. The response variable was defined as the frequency of positive detection for each metabolite class across the simplex-centroid design.

RESULTS AND DISCUSSION

Phytochemical profile and matrix effect

The qualitative phytochemical screening (Table 2) of tamarind peel (FPB1 and FPB2) and seed (FSB1 and FSB2) extracts revealed marked differences between matrices, as well as variability associated with the solvent systems defined by the simplex-centroid design. Seed extracts exhibited consistent detection of all evaluated metabolite classes, including flavonoids, phenolic compounds, tannins, saponins, terpenoids, and steroids, across all solvent systems. In contrast, peel extracts showed a highly restricted phytochemical profile, with reducing sugars being the only consistently detected compounds. The absence of secondary metabolites in peel extracts suggests that their occurrence is either negligible or below the detection limits of the applied methods.

Table 2. Qualitative phytochemical profile of tamarind peel and seed extracts as a function of solvent composition (simplex-centroid design).

Extract	Solvent system (W:A:E)	Matrix	Amino Acids	Flavonoids	Phenolics	Tannins	Saponins	Terpenoids	Steroids	Reducing Sugars	Starch
1	1:0:0	Peel	–	–	–	–	–	–	–	+	–
1	1:0:0	Seed	+	+	+	+	+	+	+	+	+
2	0:0:1	Peel	–	–	–	–	–	–	–	+	–
2	0:0:1	Seed	+	+	+	+	+	+	+	+	+
3	0:1:0	Peel	–	–	–	–	–	–	–	+	–
3	0:1:0	Seed	+	+	+	+	+	+	+	+	+
4	0.5:0:0.5	Peel	–	–	–	–	–	–	–	+	–
4	0.5:0:0.5	Seed	+	+	+	+	+	+	+	+	+
5	0.5:0.5:0	Peel	–	–	–	–	–	–	–	+	–
5	0.5:0.5:0	Seed	+	+	+	+	+	+	+	+	+
6	0:0.5:0.5	Peel	–	–	–	–	–	–	–	+	–
6	0:0.5:0.5	Seed	+	+	+	+	+	+	+	+	+
7	0.33:0.33:0.33	Peel	–	–	–	–	–	–	–	+	–
7	0.33:0.33:0.33	Seed	+	+	+	+	+	+	+	+	+
8	0.17:0.17:0.66	Peel	–	–	–	–	–	–	–	+	–
8	0.17:0.17:0.66	Seed	+	+	+	+	+	+	+	+	+
9	0.17:0.66:0.17	Peel	–	–	–	–	–	–	–	+	–
9	0.17:0.66:0.17	Seed	+	+	+	+	+	+	+	+	+
10	0.66:0.17:0.17	Peel	–	–	–	–	–	–	–	+	–
10	0.66:0.17:0.17	Seed	+	+	+	+	+	+	+	+	+

Note: W: water; A: acetone; E: ethanol.

This marked contrast highlights the dominant effect of matrix composition on phytochemical detection. Seeds, as storage tissues, are known to accumulate a wide range of primary and secondary metabolites associated with plant defense and germination, whereas peel tissues may contain lower concentrations of these compounds. Unlike a purely descriptive approach, the results were analyzed considering the influence of solvent composition (water, acetone, and ethanol) on the extraction efficiency of different classes of metabolites. This strategy allowed a more coherent interpretation of the relationship between extraction conditions and phytochemical detection.

Influence of solvent composition

The simplex-centroid design allowed the evaluation of solvent effects on phytochemical extraction. However, no significant variation in qualitative detection was observed across different solvent systems. For seed extracts, all solvent combinations resulted in positive detection of the evaluated metabolites, indicating that the extraction system operates under conditions of high efficiency regardless of solvent polarity. This behavior suggests that the extraction process reached a saturation regime, in which solvent variation does not influence qualitative outcomes. Similarly, for peel extracts, the absence of most metabolites was consistent across all treatments, indicating that solvent composition was not a limiting factor for their detection.

To enhance the interpretation of the qualitative phytochemical data, a heatmap (Figure 2) was constructed based on the frequency of detection of each metabolite class across the simplex-centroid design. The heatmap clearly illustrates the strong contrast between

matrices. Tamarind seed extracts exhibited consistent detection (frequency = 1.0) for nearly all classes of metabolites, indicating high robustness of extraction regardless of solvent composition. In contrast, peel extracts showed detection restricted almost exclusively to reducing sugars, with negligible presence of secondary metabolites.

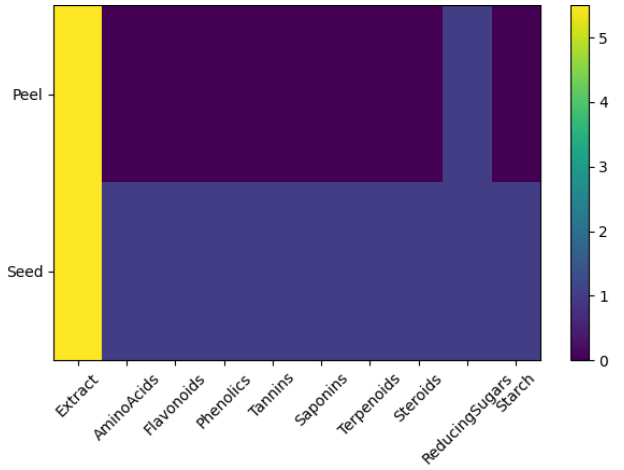

Figure 2. Phytochemical presence heatmap (mean across extratcs).

This visual approach reinforces that the matrix effect (seed vs peel) is the dominant factor influencing phytochemical detection, while the solvent system has a secondary or negligible effect under the tested conditions. Furthermore, the uniformity of responses in seed extracts suggests that the extraction system may already be operating in a plateau region, where solvent variation does not significantly change qualitative outcomes.

Pseudo-regression modeling of mixture effects

A pseudo-regression model based on mixture design was applied to assess the relationship between solvent composition and metabolite detection. For seed extracts, the response variable remained constant ($Y \approx 1$) across all experimental conditions, indicating no dependence on solvent composition. For peel extracts, the response was consistently null ($Y \approx 0$) for most metabolites, except for reducing sugars ($Y \approx 1$). Overall, the mixture model revealed that matrix composition exerts a significantly stronger influence than solvent system, limiting the applicability of optimization strategies based solely on solvent variation under the studied conditions.

Discussion

The phytochemical screening revealed a marked disparity between tamarind seed and peel extracts, with seeds consistently exhibiting a broader and more complex metabolite profile. Seed samples tested positive for multiple classes of secondary metabolites, including flavonoids, tannins, phenolics, saponins, terpenoids, and steroids, across all solvent systems, whereas peel extracts displayed a highly restricted profile, with reducing sugars as the predominant detectable compounds. This contrast reflects the distinct biological roles of these tissues: seeds function as metabolically active storage and defense structures, while peels are primarily structural matrices rich in polysaccharides (Corso et al., 2021; Sławińska & Olas, 2022).

This pattern is consistent with previous studies reporting the presence of phenolic compounds, flavonoids, and tannins in tamarind seeds (Farooq et al., 2022; Kumar & Sharma, 2014; Nyaga et al., 2023; Rana & Sharma, 2018; Senthilkumar et al., 2021), although quantitative comparisons suggest that extraction efficiency may vary depending on solvent systems and analytical methods. In contrast, the limited detection of metabolites in peels diverges from some reports describing bioactive compounds in pulp or peel fractions, suggesting that matrix composition, extraction conditions, or ecotype variability may play a decisive role. Moreover, high-temperature drying of seeds (150 °C) may have led to degradation of thermolabile compounds, potentially underestimating the true phytochemical content (Silva et al., 2022).

Kumar and Sharma (2014) investigated the phytochemical profile of *Tamarindus indica* seeds using ethanol, petroleum ether, and aqueous extracts, demonstrating a consistent presence of carbohydrates, proteins, amino acids, flavonoids, tannins, phenols, triterpenoids, and fixed oils across all solvent systems. Steroids and sterols were detected exclusively in the ethanolic extract, while alkaloids, glycosides, and anthraquinones were absent in all extracts. Among the solvents, ethanol yielded the most diverse phytochemical profile, whereas the aqueous extract showed the highest extraction yield. These findings highlight the influence of solvent polarity on metabolite recovery and reinforce the relevance of tamarind seeds as a source of bioactive compounds with potential pharmacological applications.

Rana and Sharma (2018) evaluated the phytochemical and nutritional composition of *Tamarindus indica* seeds and pulp using aqueous and ethanolic extracts, revealing a matrix-dependent distribution of bioactive compounds. Seed extracts showed the presence of saponins, tannins, and flavonoids, while alkaloids and glycosides were not detected. In contrast, pulp extracts contained saponins, alkaloids, and glycosides, but lacked tannins and flavonoids. These findings highlight the distinct chemical profiles of different plant parts and support their biological relevance, as compounds such as tannins, flavonoids, and saponins are associated with antioxidant and pharmacological activities. Additionally, the study reported high nutritional value, particularly in seeds, which exhibited higher carbohydrate content and significant levels of protein and fiber, reinforcing the potential of tamarind as a functional and nutritionally valuable resource.

Santos et al. (2021) evaluated the phytochemical profile of aqueous extracts from *Tamarindus indica* fruit peels, identifying the presence of alkaloids and tannins,

while flavonoids, steroids, triterpenoids, and saponins were not detected. The absence of certain metabolites, particularly flavonoids, was attributed to the limited extraction capacity of water as a solvent. Despite this restricted profile, the detected compounds, especially alkaloids and tannins, were associated with relevant biological properties, supporting the extract's photoprotective potential.

Senthilkumar et al. (2021) evaluated the phytochemical profile and antioxidant potential of unripe red tamarind (*Tamarindus indica* var. *rhodocarpa*) pulp using methanolic and ethanolic extracts. Qualitative analysis confirmed the presence of carbohydrates, phenols, tannins, flavonoids, alkaloids, terpenoids, and anthocyanins, while saponins, steroids, and glycosides were not detected. Quantitative results showed considerable variability among accessions, with notable levels of phenolics, flavonoids, tannins, and carbohydrates. Anthocyanin profiling identified cyanidin-3-glucoside as the dominant pigment, responsible for most of the red coloration, and associated with high antioxidant activity (62–94%). These findings highlight the potential of red tamarind pulp as a natural source of bioactive compounds and colorants for food and industrial applications.

Farooq et al. (2022) evaluated the phytochemical composition of tamarind pulp, seeds, and peels, demonstrating a matrix-dependent distribution of bioactive compounds. The shell aqueous extract showed the presence of several secondary metabolites, including phenols, flavonoids, tannins, saponins, and terpenoids, while primary metabolites were not detected. In contrast, seeds and pulp exhibited higher levels of phenolic and flavonoid compounds, with seed fractions generally showing greater concentrations than pulp in specific solvent systems. Quantitative analysis indicated phenolic and flavonoid contents ranging from 1.31 to 1.83 mg/g in seeds and up to 2.83 mg/g in pulp. These results highlight the influence of both plant matrix and extraction solvent on phytochemical recovery.

Nyaga et al. (2023) investigated the extraction and characterization of tannins from *Tamarindus indica* seeds, highlighting their potential for industrial applications in the leather sector. Phytochemical screening confirmed the presence of tannins, identified as condensed tannins, and flavonoids, while hydrolysable tannins were absent. Quantitative analysis revealed high levels of total phenolics (18.79 ± 0.14%) and tannins (15.14 ± 0.93%), with a tanning strength (1.73) exceeding the minimum requirement for effective leather processing. FTIR analysis further confirmed functional groups associated with polyphenolic structures. These findings demonstrate that tamarind seeds, often considered waste, represent a viable and sustainable source of bioactive compounds with industrial relevance.

Swathi et al. (2024) evaluated the phytochemical profile of red tamarind pulp using solvents of varying polarity, demonstrating a strong solvent-dependent extraction pattern. Polar extracts (methanol and water) showed the highest diversity and concentrations of phenolics, flavonoids, and anthocyanins, while less polar solvents extracted more specific compounds such as terpenoids and fixed oils. The high anthocyanin content was associated with the characteristic red pigmentation and significant antioxidant potential, highlighting the importance of solvent selection and the potential of this matrix for industrial applications.

Despite the qualitative nature of the data of this study, the simplex-centroid design provided valuable insights into extraction behavior across polarity gradients and represents a novel approach for tamarind by-products. Organic solvent mixtures, particularly acetone–ethanol, enhanced the detection of diverse metabolites in seeds due to their intermediate polarity. However, the lack of variation in responses across treatments indicates that solvent composition had limited influence, with matrix composition emerging as the main factor governing phytochemical profiles.

The consistency of phytochemical profiles across independent batches (Gouveia and Montes Claros) further supports the robustness of the findings. Despite geographic and edaphoclimatic variation, seed extracts exhibited stable qualitative profiles, suggesting potential genotype-related stability and reinforcing their suitability for industrial applications.

From a sustainability and valorization perspective, the results highlight tamarind seeds as a high-value agro-industrial byproduct. Representing approximately 60–70% of fruit mass (Jain et al., 2011), seeds combine high metabolite diversity with consistent extractability, supporting their potential use in functional foods, nutraceuticals, and biorefinery processes. Integration into circular production systems has been proposed as a strategy to reduce agro-industrial waste and generate added value (Martins et al., 2020). In contrast, the limited phytochemical diversity observed in peels suggests lower immediate applicability for bioactive compound extraction, although alternative extraction techniques (e.g., assisted extraction, enzymatic treatments) may enhance recovery. **[Insert here studies on peel valorization or alternative extraction technologies.]**

Notwithstanding these contributions, important methodological limitations must be considered. The qualitative nature of phytochemical screening restricts analytical resolution, precluding the determination of compound concentrations, extraction yields, or statistical differences between treatments. In addition, the application of a simplex-centroid design to a binary response system limits its inferential power. The absence of instrumental validation (e.g., HPLC, GC–MS) further constrains the robustness and reproducibility of the findings.

Future research should prioritize quantitative analyses to validate these findings, including spectrophotometric

assays (e.g., total phenolics and flavonoids), chromatographic profiling, and optimization of extraction conditions using response surface methodologies. Additionally, expanding the investigation to different Brazilian ecotypes and exploring functional properties (e.g., antioxidant, antimicrobial activity) will be essential to fully establish the industrial potential of tamarind byproducts.

Overall, the findings demonstrate that tamarind seeds constitute a robust and versatile source of bioactive compounds, with clear advantages over peel fractions under the evaluated conditions. This study advances current knowledge by integrating matrix comparison and solvent system evaluation, while also addressing a gap in the literature regarding Brazilian semi-arid germplasm.

CONCLUSIONS

The results demonstrate that tamarind seeds exhibit a broader qualitative phytochemical profile compared to peels, indicating their potential as a source of bioactive compounds. However, these findings are based on qualitative screening and should be interpreted as preliminary evidence. The study highlights the importance of matrix composition over solvent system in qualitative detection and reinforces the need for further quantitative and instrumental analyses to validate the functional potential of these by-products

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