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Physicochemical characterisation of ethanolic and aqueous Extracts of cinnamon bark and Aonla fruit

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Abstract
The present study investigated the influence of extraction solvent on the physicochemical characteristics of cinnamon bark (*Cinnamomum verum*), aonla fruit (*Emblica officinalis* Gaertn.), and their combined extracts for potential nutraceutical applications. Dried powders of cinnamon bark and aonla fruit were extracted separately and in combination using 80% ethanol and distilled water through maceration, followed by physicochemical characterization. The evaluated parameters included pH, moisture content, water activity and total ash content. The results demonstrated significant solvent-dependent variations in extract quality. Ethanolic extracts exhibited comparatively higher pH, lower moisture content, lower water activity, and reduced ash content than aqueous extracts. Cinnamon bark extract showed the highest pH (5.80), lowest moisture content (5.03%), lowest water activity (0.24), and lowest ash content (4.50%) in ethanol. In contrast, aonla fruit extract exhibited the greatest acidity (pH 3.60), highest moisture content (7.11%), highest water activity (0.45), and highest ash content (6.80%). Aqueous extracts consistently displayed higher moisture retention, water activity, and mineral content, with aonla recording the maximum ash content (8.23%) and water activity (0.52). The combined cinnamon–aonla extracts showed intermediate values for all physicochemical parameters, indicating a balanced contribution of both plant materials. These findings demonstrate that solvent polarity plays a decisive role in determining the physicochemical quality and stability of plant extracts. Ethanol extraction produced extracts with lower moisture availability and water activity, suggesting enhanced storage stability, whereas aqueous extraction improved mineral recovery. The study provides valuable insights into selecting suitable extraction systems for developing standardised polyherbal formulations, functional foods, and nutraceutical products based on cinnamon bark and aonla fruit.**:** Aonla (*Emblica officinalis*); Cinnamon bark (*Cinnamomum verum*).

Keywords: Ethanolic extraction, aqueous extraction, physicochemical properties, water solvent polarity

Introduction
Plant-derived bioactive compounds are increasingly recognised for their nutritional and therapeutic potential, particularly when standardised through extraction processes. Among these, cinnamon bark (*Cinnamomum verum*) and aonla fruit (*Emblica officinalis* Gaertn.) are notable for their diverse phytochemical compositions and broad biological activities. Cinnamon bark is enriched with cinnamaldehyde, eugenol, tannins, and polyphenols, which contribute to its antioxidant, antimicrobial, and metabolic-modulating properties (Khattak *et al*., 2025) [3]. Aonla fruit, widely consumed in South Asia, is one of the richest natural sources of ascorbic acid, alongside polyphenols, flavonoids, and tannins, making it highly effective in enhancing antioxidant potential and supporting physiological resilience (Kumari *et al*., 2019) [5].
Extraction of these bioactive compounds is essential to isolate, concentrate, and evaluate their therapeutic potential. Solvent polarity plays a decisive role in the recovery of phytochemicals, with ethanol favouring moderately polar compounds such as flavonoids and tannins. In contrast, water efficiently extracts highly polar constituents such as ascorbic acid and mineral salts (Sun *et al*., 2025) [14]. Comparative studies have demonstrated that optimised extraction methods significantly influence yield, stability, and bioactivity, thereby ensuring reproducibility and clinical relevance in nutraceutical and pharmaceutical applications (Abd Alelah & Mohammed, 2026) [1].

Moreover, physicochemical parameters such as pH, moisture content, water activity, and ash content provide critical insights into extract quality, microbial susceptibility, and shelf-life, guiding formulation strategies. Thus, cinnamon bark and aonla fruit represent promising plant matrices whose extraction and characterisation are vital for developing standardised, effective, and sustainable plant-based formulations. Their complementary phytochemical profiles, coupled with optimised extraction techniques, underscore their importance in advancing functional foods and nutraceuticals.

Material and Methods

Aonla fruits (var. Chakiya) were collected from the local market in Thrissur, Kerala, and cinnamon bark (*Cinnamomum verum* sp.) was collected from the Department of Plantation, Spice, Aromatic and Medicinal Plants, College of Agriculture, Thrissur, Kerala. The solvent used was distilled water and 80% ethanol (Food grade).

Extraction procedure

Aonla fruits were thoroughly washed, sliced, and deseeded, then dried in a cabinet tray dryer at 50 °C for 12 hours. Moisture content was monitored at 2-hour intervals and reduced to 6.30% by the end of the drying period. Cinnamon bark was shade-dried for 24 hours, with moisture levels recorded every 2 hours, ultimately reaching 9.60%. Aonla fruit and cinnamon bark were ground into fine powder (particle size 0.25 mm to 1.00 mm), followed by the ASTM standard, and sieved using a domestic grinder. Dried powder (100 g) and 80% hydro-ethanol solution (80% ethanol and 20% distilled water) are dissolved in a 1:4 ratio (Figure 1). Maceration was performed at room temperature (25 ± 2 °C) for seven days with intermittent shaking. The extract was filtered through vacuum filtration (Whatman™, Cytiva, USA). The extracts were concentrated using a vacuum rotary evaporator (BUCHI R100) at 40 °C for aonla fruit (Kumari and Khatkar, 2016) [4] and 60 °C for cinnamon bark (Sundoro and Sulistyowati, 2022) [15].

pH, moisture content, and water activity estimation

pH

A pH meter was used to measure the pH value of 1% suspension of the extract; an electrode was dipped in the sample, and the reading was recorded once it stabilised.

Moisture content (%)

The moisture content of the extract was estimated using a Radwag moisture analyser (Model: MAC 50, Poland). Two grams of the sample were placed in the sample dish. The moisture analyser indicated the measurement endpoint by a beep sound, giving a constant value for moisture. The average of three readings was recorded and expressed as a percentage.

Water activity (a_w)

The water activity of the extract was determined by a water activity meter (Labswift-Novasina, Switzerland). A small amount of powder was filled into the sample holder up to the indicated mark and then placed inside the water activity meter so that the sample would not touch the sensor in the lid. The endpoint was indicated by three beep sounds displaying the water activity readings digitally, and was recorded.

Total ash (%)

An empty silica crucible was weighed (W_1). About one gram (W_2) of the extract was added to the previously weighed crucible. The sample was ignited gradually in an electrical muffle furnace, increasing the heat to 500 °C until it was white, indicating the absence of carbon. Then it was cooled in a desiccator and reweighed (W_3). Total ash (%) was calculated using the following equation (Aziz *et al*., 2019) [2].

$$\text{Total ash (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

Where, W_1 – weight of empty crucible, W_2 – weight of previously weighed crucible with sample, W_3 – weight of crucible with the residue obtained.

Result and Discussion

pH

The pH values of the ethanolic and aqueous extracts derived from cinnamon bark, aonla fruit, and their combined formulations exhibited a consistent pattern, reflecting the intrinsic acidity of the botanical matrices and the influence of solvent polarity (Table 1). Cinnamon bark extracts recorded the highest pH values (5.80 in ethanol; 5.50 in aqueous), indicating a relatively lower acidic profile. In contrast, aonla fruit extracts displayed the most pronounced acidity, with pH values of 3.60 and 3.40 for ethanol and aqueous media, respectively, a result primarily attributable to the high concentration of organic acids inherent to the fruit pulp. The combined formulation demonstrated intermediate pH values of 4.70 in ethanol and 4.50 in aqueous extraction, suggesting a balanced, additive contribution from both plant materials rather than the dominance of a single component.

Across all samples, ethanolic extracts consistently exhibited slightly higher pH values compared to their aqueous counterparts. This phenomenon is likely explained by the intermediate polarity of ethanol, which facilitates a lower extraction efficiency of dissociated organic acids relative to water, thereby reducing the hydrogen ion concentration (H^+) in the resulting medium (Nguyen and Karboune, 2023) [6]. The comparatively higher pH of cinnamon extracts aligns with its phytochemical composition, which is characterised by a high density of polyphenols and tannins but lower levels of organic acids (Patel *et al*., 2024) [8]. Conversely, the stark acidity of the aonla fruit extracts is driven by an abundance of ascorbic acid and other organic acids, consistent with the acidity levels (2.25%) documented by Vishen *et al*. These findings underscore that the final pH characteristics of polyherbal extracts are critically modulated by the interplay between the inherent phytochemical profile of the raw materials and the dielectric properties of the extraction solvent.

Moisture content (%)

Moisture content of the ethanolic and aqueous extracts derived from cinnamon bark, aonla fruit, and their combined formulations demonstrated significant variations influenced by both the botanical matrix and the solvent polarity (Table 1). In the ethanolic extracts, aonla fruit exhibited the highest moisture content (7.11%), followed by the combined formulation (6.07%) and cinnamon bark (5.03%). A consistent trend was observed in the aqueous extracts, where aonla fruit recorded the maximal moisture level (8.50%), followed by the combined and cinnamon extracts at 7.30% and 6.20%, respectively. Collectively, aqueous extraction systems yielded higher moisture retention than their ethanolic counterparts, a phenomenon attributed to the high affinity of water for the hydrophilic constituents within the plant tissues. The consistently elevated moisture levels in aonla fruit extracts are likely a consequence of its rich profile of water-soluble compounds, including sugars, ascorbic acid, and organic acids, which facilitate effective water binding. This is supported by Nimse and More (2018) [7], who noted a high intrinsic moisture content (85.6%) in fresh aonla, and Prajapati (2009) [10], who documented comparable moisture levels (6.69%) in aqueous aonla extracts. Conversely, the lower moisture content in cinnamon bark extracts is primarily due to its dense, lignocellulosic architecture and lower density of hydrophilic components, consistent with the characterization of cinnamon by Tang *et al*. (2020) [16] as having relatively low moisture retention properties. The intermediate moisture values of the combined extract (6.07% in ethanol; 7.30% in water) reflect a synergistic balancing of the contrasting physicochemical properties of the two primary ingredients, highlighting the critical role of solvent-matrix interactions in determining the final moisture profile of the extracts.

Water activity (a_w)

Water activity, a fundamental indicator of the thermodynamic availability of free water for microbial proliferation and biochemical degradation, exhibited significant solvent-dependent variations across the extracts of cinnamon bark, aonla fruit, and their polyherbal formulations. In the ethanolic extracts, cinnamon bark demonstrated the lowest water activity (0.24), followed by the combined formulation (0.34) and aonla fruit (0.45). Conversely, the aqueous extracts consistently yielded elevated water activity values, measuring 0.35, 0.43, and 0.52 for cinnamon, the combined extract, and aonla, respectively, indicating that aqueous processing facilitates a greater retention of unbound water within the extract matrix. The diminished water activity observed in ethanolic media is primarily attributable to the lower polarity of ethanol, which restricts the solubilization of hydrophilic constituents and free water molecules; these findings corroborate the observations of Kumari *et al*. (2019) [5] and Sharma *et al*. (2019) [13], who noted similar trends in solvent-mediated moisture dynamics. The inherently low water activity in cinnamon bark likely stems from its lignified, fibrous architecture and paucity of hydrophilic compounds, whereas the higher values recorded for aonla fruit reflect its abundance of hygroscopic sugars, organic acids, and phenolics. As noted by Rani *et al*. (2022) [11], such hydrophilic profiles enhance water retention, potentially increasing susceptibility to microbial proliferation. Notably, the intermediate water activity values of the combined extract (0.34 in ethanol; 0.43 in water) suggest a compensatory balancing effect between the low-moisture characteristics of cinnamon and the hygroscopic nature of aonla fruit, highlighting the critical interplay between solvent polarity and intrinsic material properties in modulating the storage stability and shelf-life of botanical extracts.

Total Ash Content (%)

Quantification of total ash content, which serves as a critical indicator of the cumulative mineral composition within plant-derived extracts, revealed significant solvent-dependent variations in cinnamon bark, aonla fruit, and their composite formulations. In the present study, aqueous extracts consistently demonstrated superior mineral recovery compared to their ethanolic counterparts: cinnamon bark yielded 5.14% ash in water versus 4.50% in ethanol, while aonla fruit exhibited a more substantial disparity with 8.23% and 6.80%, respectively. Similarly, the combined formulation followed this trend, with aqueous extraction producing 6.79% ash content, surpassing the 5.69% obtained via ethanol extraction. The comparatively higher ash yield in aonla fruit relative to cinnamon bark is primarily attributed to its naturally dense mineral profile, characterised by high concentrations of calcium, phosphorus, and iron, which aligns with the findings of Salık *et al*. (2025) [12] and Parvez *et al*. who reported ash levels of 6.45% and 9.82% for these respective species. The enhanced recovery observed in aqueous media is consistent with the postulates of Mihaylova and Plaskova *et al*. (2023) [9], who emphasised that the high polarity and diffusivity of water facilitate stronger ionic interactions and a more effective liberation of mineral salts from the plant matrix than organic solvents like ethanol.

Table 1: Evaluation of biochemical parameters of ethanol and aqueous extracts of cinnamon bark and aonla fruit

Extraction	Raw material	pH	Moisture content (%)	Water activity (aw)	Total ash (%)
Ethanol extract	Cinnamon bark	5.80	5.03	0.24[d]	4.50[e]
	Aonla fruit	3.60	7.11	0.45[b]	6.80[b]
	Cinnamon bark and aonla fruit	4.70	5.99	0.34[c]	5.69[c]
Aqueous extract	Cinnamon bark	5.50	6.20	0.35[c]	5.14[d]
	Aonla fruit	3.40	8.50	0.52[a]	8.23[a]
	Cinnamon bark and aonla fruit	4.50	7.30	0.43[b]	6.79[b]
	SE±m	-	-	0.016	0.107
	CD@5%	NS	NS	0.036	0.333

Conclusion

The present study provides a systematic evaluation of the physicochemical profiles of ethanolic and aqueous extracts derived from cinnamon) bark, aonla fruit, and their respective polyherbal formulations. Our findings demonstrate consistent, solvent-dependent variations across critical parameters, including pH, moisture content, water activity, and total ash yield. Aqueous extraction systems generally exhibited lower pH values, higher moisture retention, elevated water activity, and superior mineral recovery compared to ethanolic counterparts, underscoring the decisive role of solvent polarity in modulating the extraction efficiency of hydrophilic and inorganic constituents. Specifically, cinnamon bark was characterised by lower acidity and moisture availability, a consequence of its dense lignocellulosic architecture, whereas aonla fruit displayed a robust profile of organic acids, hygroscopic sugars, and essential minerals. Notably, the combined extracts consistently reflected intermediate physicochemical values, indicating a synergistic balancing of the contrasting botanical properties. Collectively, these results highlight that the judicious selection of extraction solvents and a comprehensive understanding of raw material composition are essential for determining the stability, functionality, and standardisation of plant-based extracts. This investigation establishes a rigorous framework for developing optimised formulations that leverage the bioactive potential of cinnamon and aonla for applications in the nutraceutical and functional food sectors.

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