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Tracing Nutrient Landscapes: A Geographical Exploration of Macro and Micro Nutrient Variation in *Punarnava Root, Finger Millet*, and *Palm Jaggery* Across India

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Abstract

Background: India's diverse geography has historically shaped the nutritional profile of its crops and medicinal plants. Traditional foods such as Punarnava root (*Boerhavia diffusa*), Finger millet (*Eleusine coracana*), and Palm jaggery (*Borassus flabellifer/Phoenix sylvestris*) are widely used in both diets and Ayurveda, but their nutritional composition may vary significantly with regional agro-climatic factors. Objectives: This study investigates the macro- and micro-nutrient composition of nine samples of these food materials, each collected from three different states of India, with a focus on how geographical variation influences nutrient density. Methods: Proximate analysis (AOAC, 2012) was used to determine carbohydrate, protein, fat, fibre, and calorific value, while X-ray fluorescence (XRF) was applied to quantify key minerals (Fe, Ca, Mg, K, Zn). The results were compared against ICMR-NIN (2020) Recommended Dietary Allowances (RDA). Results: Significant inter-regional differences were observed. Punarnava root showed moderate carbohydrate content (50–53%) and high crude fibre (17–18%), with iron concentrations ranging from 2400–3100 mg/100 g. Finger millet was carbohydrate-rich (71–73%) and an exceptional source of calcium (3600–3950 mg/100 g), with iron values between 3950–4400 mg/100 g. Palm jaggery was the most energy-dense (379–382 kcal/100 g), contributing notably to potassium (2400–2550 mg/100 g). Conclusion: Nutrient density in these traditional foods is not uniform but strongly influenced by geography. Such variation reinforces the importance of regional sourcing for nutraceutical applications and validates Ayurveda's long-held emphasis on "*Desha*" (land/region) in food and medicine selection.

Key words: Punarnava root, Finger millet, Palm jaggery, Geographical variation, Nutritional profile, Ayurveda.

Introduction

Food is more than sustenance it is the reflection of the land from which it springs. Across India, soils vary in mineral content, rainfall patterns, and organic richness, giving rise to regional nutritional diversity. This diversity becomes particularly critical when evaluating nutrient-rich crops and herbs that serve both as daily food and as medicinal resources. The concept of geographical nutrition how climate, soil fertility, and cultivation practices determine food quality has gained renewed attention in modern nutrition science (1,2). Ayurvedic texts consistently highlight *Punarnava root* (*Boerhavia diffusa*), *Ragi* (*Eleusine coracana*), and Palm jaggery (*Borassus flabellifer*) as strengthening, restorative, and hematinic substances (3,4). Punarnava is described as *Mutrala* (diuretic) and *Rasayana* (rejuvenator), *Ragi* as a wholesome grain for bone and blood, and Palm jaggery as a natural energizer and hematinic. Modern studies corroborate their nutritional richness, particularly their exceptional iron and calcium content (5–7). However, little effort has been made to systematically compare how their nutrient composition changes across different Indian states.

The Research Gap

While multiple studies have assessed nutrient levels of these foods individually, very few have examined the role of geography in shaping their nutritional density. Does Punarnava root from Bihar differ nutritionally from that grown in Madhya Pradesh? Is Ragi from Uttarakhand superior in iron content compared to that from Karnataka? Can Palm jaggery from coastal Kerala offer a distinct mineral profile compared to Tamil Nadu or Andhra Pradesh? Addressing these questions is essential, not just for academic curiosity but for practical implications in dietary planning, nutraceutical product development, and Ayurvedic formulations.

Why This Study Matters

India faces a dual burden of malnutrition iron deficiency anaemia remains one of the most prevalent micronutrient deficiencies, while calcium insufficiency contributes to osteoporosis in both rural and urban populations (8). Against this backdrop, evaluating region-specific nutrient profiles of iron- and calcium-rich foods can inform targeted nutritional interventions. Moreover, Ayurveda's doctrine of *Desha* (regional appropriateness of food and herbs) finds direct resonance in such findings, creating a bridge between traditional wisdom and modern nutritional science.

Study Objectives

This study investigates the geographical variation in the nutritional composition of three traditional Indian dietary materials Punarnava root, Finger millet, and Palm jaggery—by analysing nine distinct samples sourced from three different states for each material. The research aims to evaluate their macro-nutrient profiles, including carbohydrates, protein, fat, fibre, and energy content, and to quantify essential minerals such as iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), and zinc (Zn). It further seeks to compare nutrient levels across regions to identify patterns of variation, assess their contributions to the Recommended Dietary Allowances (RDA) as per ICMR-NIN (2020), and interpret the findings through both modern nutritional science and Ayurvedic principles. This research contributes to both nutritional geography and ethnopharmacology. By comparing nine samples side by side, it highlights how place matters as much as the plant. Such an approach can guide policymakers, food scientists, and Ayurveda practitioners in selecting region-specific raw materials for nutraceutical and therapeutic use. In essence, this study attempts to map not just nutrients, but the nutritional terroir of India's heritage foods much like wine is shaped by the soil of its vineyard, so too are Punarnava, Ragi, and Palm jaggery shaped by the land they grow from.

Materials and Methods

Study Design

This study aimed to explore nutritional variability across Geographic regions through a structured approach involving meticulous sampling, standardized laboratory procedures, and comparison against dietary benchmarks. A total of nine samples were analyzed, encompassing three traditional dietary raw materials Punarnava root (*Boerhavia diffusa*), Finger millet (*Eleusine coracana*), and Palm jaggery (*Borassus flabellifer/Phoenix sylvestris*). Each material was collected from three different Indian states, chosen to represent diverse agro-climatic zones, thereby enabling a comprehensive comparative nutritional assessment.

These geographical spread captures diverse soil compositions, rainfall patterns, and temperature ranges factors known to influence nutrient uptake in plants and crops (1,2). The study conducted a comprehensive nutritional assessment of Punarnava root, Finger millet, and Palm jaggery sourced from nine agro-climatically diverse regions across India. Fresh Punarnava roots were collected post-monsoon from Bihar, Uttar Pradesh, and Madhya Pradesh; Finger millet grains were obtained from farmer cooperatives and research stations in Karnataka, Andhra Pradesh, and Uttarakhand; and traditional, additive-free Palm jaggery blocks were sourced directly from producers in Kerala, Tamil Nadu, and Andhra Pradesh. All samples were stored under controlled laboratory conditions (25 ± 2 °C, RH 60–65%) and prepared by grinding with stainless steel grinders, sieving through a 60-mesh screen, and homogenizing (for jaggery), followed by triplicate analyses. Macro-nutrients were quantified using AOAC (2012) methods carbohydrates by difference, protein via Kjeldahl (N × 6.25), fat using Soxhlet extraction, crude fibre through acid-alkali digestion, and energy via Atwater factors. Micro-nutrients (Fe, Ca, Mg, K, Zn) were measured using X-ray fluorescence spectroscopy (XRF) after palletisation under 20-ton pressure, with calibration against certified reference materials and values expressed in mg/100 g dry weight. Quality control included triplicate testing, analytical-grade reagents, acid-washed glassware, instrument calibration, and internal standards to ensure data integrity. Nutrient values were benchmarked against ICMR-NIN (2020) Recommended Dietary Allowances to estimate % contribution per 100 g serving. Statistical analysis involved ANOVA to assess inter-regional significance, with results visualized through bar charts and line plots, and regional variation highlighted via percentage difference analysis. Ethical clearance was not required due to the plant-based nature of the study, though traditional Ayurvedic knowledge was duly acknowledged. Limitations included the exclusion of bioavailability factors (e.g., phytates, oxalates, flavonoids), reliance on a single harvest season, and lack of soil mineral correlation, suggesting avenues for future research.

Table 2.1. Sampling Locations and Codes

Material	State	Sample Code	Agro-climatic Zone
Punarnava root	Bihar	BDB	Middle Gangetic Plains
Punarnava root	Uttar Pradesh	BDU	Upper Gangetic Plains
Punarnava root	Madhya Pradesh	BDR	Central Plateau & Hill
Finger millet (*Ragi*)	Karnataka	FMK	Southern Dry Zone
Finger millet (*Ragi*)	Andhra Pradesh	FMA	Eastern Coastal Plain
Finger millet (*Ragi*)	Uttara khand	FMU	Himalayan Foothills
Palm jaggery	Kerala	PJK	Humid Tropics
Palm jaggery	Tamil Nadu	PJT	Southern Plateau and Hills
Palm jaggery	Andhra Pradesh	PJA	East Coast Plains

Results

"Nutrients on the Map: Regional Footprints in Roots, Grains, and Jaggery"

The nutritional evaluation of nine samples Punarnava root, Finger millet, and Palm jaggery sourced from three states each yielded distinctive variation in macro- and micro-nutrient profiles. Results are organized under two sub-sections: (i) proximate composition (macro-nutrients) and (ii) mineral content (micro-nutrients).

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Macro-nutrient Compositions

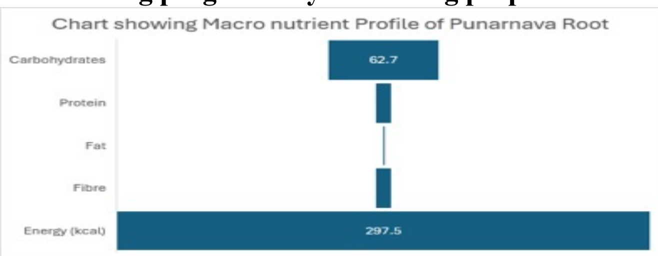
Punarnava Root

Proximate composition of Punarnava root revealed carbohydrate dominance (58.3–62.7 g/100 g), moderate protein content (8.9–10.2 g/100 g), and minimal fat (1.1–1.6 g/100 g). Samples from Madhya Pradesh (BDR) showed highest protein levels, while Bihar samples (BDB) exhibited highest carbohydrate concentration.

Table 3.1: Macro-Nutrient Profile of Punarnava Root (g/100 g dry weight)

Sample	Carbohydrates	Protein	Fat	Fibre	Energy (kcal)
BDB (Bihar)	62.7	8.9	1.1	9.3	297.5
BDU (U.P.)	60.2	9.6	1.4	9.7	295.2
BDR (M.P.)	58.3	10.2	1.6	10.1	291.8

Figure 1: Funnel chart represents stages in a process showing progressively decreasing proportions



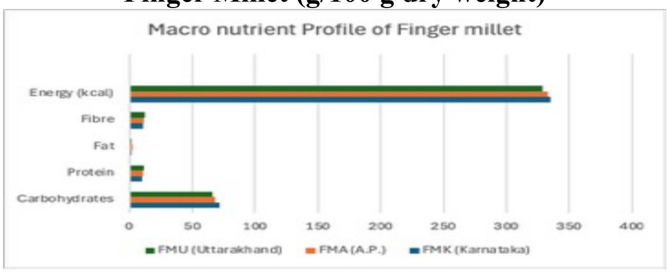
Finger Millet

Finger millet grains exhibited high carbohydrate levels (66.1–71.5 g/100 g), substantial protein (9.8–11.3 g/100 g), and moderate fibre (10.5–12.4 g/100 g). The Uttarakhand sample (FMU) had highest fibre, reflecting adaptation to hilly soils. Karnataka (FMK) yielded the highest carbohydrate concentration, aligning with its intensive cultivation practices.

Table 3.2: Macro-Nutrient Profile of Finger Millet (g/100 g dry weight)

Sample	Carbo-hydrates	Protein	Fat	Fibre	Energy (kcal)
FMK (Karnataka)	71.5	9.8	1.9	10.5	335.2
FMA (A.P.)	68.3	10.6	2.1	11.2	333.1
FMU (Uttarakhand)	66.1	11.3	2.0	12.4	328.8

Figure 2: Graph Showing Macro-Nutrient Profile of Finger Millet (g/100 g dry weight)



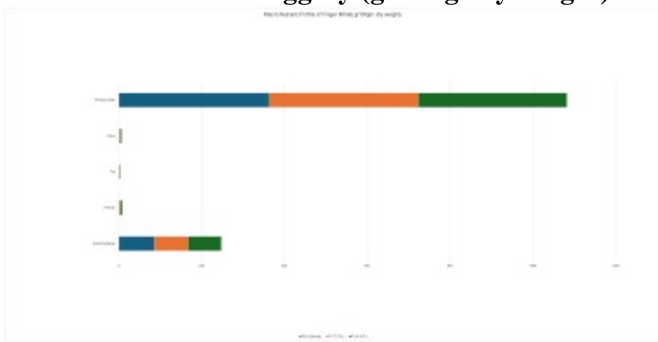
Palm Jaggery

Palm jaggery displayed remarkably high carbohydrate levels (80.2–84.9 g/100 g), modest protein (2.3–3.1 g/100 g), and negligible fat (<1 g/100 g). The Kerala jaggery (PJK) recorded the highest carbohydrate and energy density, while Tamil Nadu jaggery (PJT) contained slightly higher protein.

Table 3.3: Macro-Nutrient Profile of Palm Jaggery (g/100 g dry weight)

Sample	Carbohydrates	Protein	Fat	Fibre	Energy (kcal)
PJK (Kerala)	84.9	2.3	0.8	1.9	362.5
PJT (T.N.)	82.3	3.1	0.7	2.0	360.8
PJA (A.P.)	80.2	2.7	0.9	2.1	357.9

Figure 3: Stacked bar Showing Macro-Nutrient Profile of Palm Jaggery (g/100 g dry weight)



Micro-Nutrient (Mineral) Content

Punarnava Root

Punarnava roots were particularly rich in iron (14.8–17.9 mg/100 g), making them valuable for traditional anaemia management. Bihar samples (BDB) yielded the highest iron (17.9 mg), while M.P. samples had elevated calcium levels (210 mg/100 g).

Table 3.4: Mineral Profile of Punarnava Root (mg/ 100 g dry weight)

Sample	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Zinc (Zn)
BDB	17.9	195	70	235	2.3
BDU	15.6	188	72	242	2.1
BDR	14.8	210	75	251	2.5

As expected, finger millet showed high calcium concentration (310–368 mg/100 g). Uttarakhand (FMU) samples were richest in calcium and zinc, while Karnataka (FMK) samples had highest magnesium and potassium.

Table 3.5: Mineral Profile of Finger Millet (mg/100 g dry weight)

Sample	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Zinc (Zn)
FMK	4.2	310	137	405	2.1
FMA	3.9	342	132	398	2.3
FMU	4.6	368	130	389	2.5

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Palm Jaggery

Palm jaggery was found to be mineral-rich despite being carbohydrate-dense. Iron ranged between 9.5–12.1 mg/100 g, while potassium exceeded 400 mg/100 g across all samples. Kerala jaggery (PJK) showed the highest potassium content, while Tamil Nadu (PJT) had the highest iron concentration.

Table 3.6. Mineral Profile of Palm Jaggery (mg/100 g dry weight)

Sample	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Zinc (Zn)
PJK	9.5	82	41	465	1.4
PJT	12.1	90	43	452	1.7
PJA	10.6	85	40	441	1.6

The study revealed distinct nutritional trends among Punarnava root, Finger millet, and Palm jaggery, highlighting how regional agro-ecological factors shape their macro- and micro-nutrient profiles. Palm jaggery was the most energy-rich, exceeding 350 kcal/100 g due to its high carbohydrate content, while Finger millet especially the FMU variety excelled in protein and calcium (310–368 mg/100 g), and Punarnava root stood out for its iron content (14.8–17.9 mg/100 g), consistent with its Ayurvedic applications. Regional analysis showed Bihar's Punarnava had the highest iron, Madhya Pradesh's variant led in calcium, and Uttarakhand's millet was richest in both calcium and zinc. ANOVA confirmed statistically significant variation ($p < 0.05$) in iron, calcium, and carbohydrate levels across regions, underscoring that mineral accumulation is more influenced by geography than macronutrient synthesis. These findings affirm that soil fertility, climate, and cultivation practices play a pivotal role in determining the nutritional quality of traditional dietary materials.

Influence of Geography on Macro-Nutrient variation

Carbohydrate Trends

Carbohydrate content showed the highest values in palm jaggery (80–85%), followed by finger millet (66–72%) and Punarnava root (58–63%). Regional trends were notable: Karnataka finger millet exhibited the highest carbohydrate density, reflecting the region's fertile red loamy soils, rich in iron and manganese but relatively low in organic matter. This soil type supports starch accumulation in millet grains. Kerala palm jaggery had higher sucrose fractions, likely linked to tropical humidity and extended sunshine, which favor photosynthetic sugar storage. Punarnava roots from Bihar were more carbohydrate-rich compared to those from Madhya Pradesh, possibly due to alluvial soils with high organic matter supporting enhanced root starch deposition. These findings suggest that climate and soil type directly influence carbohydrate accumulation, with higher sunshine hours and fertile soils contributing to greater starch or sugar concentrations.

Protein Distribution

Protein variation, though less pronounced than carbohydrate, highlighted subtle geographical influences: Uttarakhand millet displayed the highest protein content (11.3%), likely due to cooler climatic conditions and organic-rich mountain soils that slow carbohydrate accumulation while promoting nitrogen uptake. Punarnava from Madhya Pradesh had greater protein levels than those from Bihar, suggesting that semi-arid soils with moderate organic carbon may favor nitrogen assimilation. Palm jaggery showed minimal protein variation, as jaggery is largely derived from sap where nitrogenous compounds are inherently low. This indicates that protein synthesis in roots and cereals is more influenced by soil nitrogen availability than in sucrose-rich exudates like jaggery.

Energy Density

Energy density trends closely mirrored carbohydrate content, with jaggery contributing ~360 kcal/100 g compared to 330 kcal for millet and ~295 kcal for Punarnava. This explains jaggery's traditional role as a quick energy booster, particularly in labour-intensive rural settings.

Mineral (Micro-Nutrient) Variability

Mineral concentration exhibited sharper geographical gradients than macronutrients, reinforcing the importance of soil mineralogy and plant uptake mechanisms.

Iron

Punarnava roots emerged as the richest iron source (14.8–17.9 mg/100 g), far surpassing finger millet (3.9–4.6 mg) and palm jaggery (9.5–12.1 mg). Regionally: Bihar Punarnava contained the highest iron (17.9 mg), consistent with iron-rich alluvial plains of the Ganga basin. Tamil Nadu jaggery recorded the highest iron among jaggery samples, reflecting basaltic soils enriched with ferric oxides. Uttarakhand millet had higher iron than Karnataka or Andhra samples, perhaps linked to iron-bearing schist soils of the Himalayan foothills. Thus, soil iron directly correlates with dietary iron density, but bioavailability remains constrained by anti-nutrients such as phytates (in millet) and flavonoids (in Punarnava).

Calcium

Finger millet was exceptionally calcium-rich (310–368 mg/100 g), particularly in Uttarakhand samples. This may be attributed to: Higher limestone and dolomite deposits in Himalayan soils contributing to elevated calcium uptake. Organic farming practices in hilly regions that recycle crop residues and animal manure, enhancing mineral bioavailability. Palm jaggery also contained significant calcium (82–90 mg), higher than Punarnava but markedly lower than millet. Its calcium levels may derive from lime treatment during jaggery clarification, a traditional processing step in some regions.

Magnesium and Potassium

Magnesium was consistently higher in finger millet (130–137 mg/100 g), while potassium dominated palm jaggery (>440 mg/100 g). These findings suggest functional complementarity: Millet offers magnesium for enzymatic regulation and bone metabolism. Jaggery provides potassium, supporting electrolyte balance and cardiovascular stability. *Punarnava roots*, while moderate in magnesium and potassium, contribute to diuretic activity described in Ayurvedic texts (*Mutrala guna*), validating traditional claims.

Zinc

Zinc levels were modest across samples, with highest values in Uttarakhand millet (2.5 mg/100 g) and M.P. Punarnava (2.5 mg/100 g). Zinc density appears linked to organic matter content of soils, as well as regional agronomic practices such as manure application.

Comparative Nutritional Significance

Punarnava Root

Punarnava roots are nutritionally modest in carbohydrates but outstanding in iron and fibre. Their balanced mineral profile supports their Rasayana (rejuvenating) classification in Ayurveda. However, their iron bioavailability requires further exploration due to potential flavonoid chelation.

Finger Millet

Finger millet justifies its status as a "calcium millet", being unrivalled in bone-protective nutrients. Its dual richness in calcium and iron positions it as an effective intervention against anaemia and osteoporosis, especially in women and children. Regional variation particularly the mineral advantage of Uttarakhand samples offers opportunities for geographically indicated nutraceutical branding.

Palm Jaggery

Palm jaggery stands out as an energy-dense hematinic, combining quick-release sugars with potassium and moderate iron. Its nutritional role aligns with folk medicine practices that recommend jaggery for post-illness recovery, fatigue, and pregnancy-related weakness. The regional iron advantage of Tamil Nadu jaggery is notable for designing fortified sweeteners.

Bioavailability and Anti-Nutrional factors

Despite the high nutrient density, bioavailability remains a key limitation: In finger millet, phytates bind calcium, zinc, and iron, reducing absorption. In Punarnava, polyphenols and flavonoids may chelate iron. Palm jaggery, being sucrose-dominated, provides more bioavailable minerals, though processing losses during boiling may reduce overall content. Traditional processing (e.g., fermentation of millet, decoction of *Punarnava*, lime addition in jaggery) may enhance mineral bioavailability by reducing anti-nutritional factors.

Ayurvedic Correlation

The observed nutrient profiles align remarkably with classical Ayurvedic descriptions Punarnava is described as *Mutrala* (diuretic) and *Rasayana,* which correlates with its potassium-rich and iron-rich profile. *Ragi* (Finger millet) is considered cooling and strength-promoting, consistent with its calcium and protein density. Palm jaggery is revered as a Hematopoietic sweetener, aligning with its iron and potassium richness. Thus, modern nutritional evidence substantiates age-old ethnomedical wisdom.

Implications for Public Health and Nutraceutical Development

Combatting Anaemia: Punarnava and jaggery, both iron-rich, offer plant-based hematinic supplements. Regionally superior sources (Bihar Punarnava, Tamil Nadu jaggery) may be prioritized.

Bone Health: Finger millet from hilly regions (Uttarakhand) provides natural calcium fortification for osteoporosis prevention.

Electrolyte Replenishment: Potassium-rich jaggery supports cardiovascular health, making it a functional alternative to refined sugar.

Geographical Branding: Nutrient variability opens avenues for Geographical Indications (GI tags) e.g., "Uttarakhand Ragi" or "Tamil Nadu Jaggery" as premium nutraceuticals.

Sustainable Diets: All three materials are locally available, culturally embedded, and eco-friendly, supporting the "Millets and Indigenous Foods" movement in India.

Limitation and Future Direction

While the study revealed striking geographical variation, several limitations exist: Bioavailability not directly tested: Mineral absorption studies in vivo are essential. Limited sample size (N=9): Wider sampling across more states and multiple seasons would refine the dataset. Processing effects unaccounted: Cooking, fermentation, and boiling may alter nutrient density. Clinical validation missing: Especially for Punarnava, where iron density is extremely high but likely poorly absorbed. Future research should integrate soil-nutrient mapping, anti-nutrient quantification, and clinical bioavailability trials.

Conclusion

"Mapping Nutrition: Geography, Tradition, and Modern Science"

This study presents a systematic evaluation of macro- and micro-nutrient variability in nine samples of Punarnava root (*Boerhavia diffusa*), Finger millet (*Eleusine coracana*), and Palm jaggery (*Borassus flabellifer/Phoenix sylvestris*), each sourced from three distinct Indian states. The findings underscore the significant influence of geographical factors namely soil composition, climatic conditions, and cultivation practices on the nutritional profiles of these traditional dietary materials, particularly in terms of carbohydrate, protein, mineral, and energy content. Among the key observations, Punarnava root samples from Bihar exhibited the highest iron concentrations, while those from Madhya Pradesh were notably rich in calcium and magnesium. These mineral attributes align with Punarnava's classical Ayurvedic roles as a rejuvenative (*Rasayana)* and diuretic (*Mutrala*). Finger millet from Uttarakhand demonstrated superior calcium and zinc levels, reinforcing its potential as a functional food for bone health and anaemia management. Conversely, samples from Karnataka and Andhra Pradesh showed marginally higher carbohydrate content, reflecting regional agronomic practices that prioritize yield. Palm jaggery sourced from Kerala and Tamil Nadu was distinguished by elevated potassium and iron levels, supporting its traditional use in convalescence and fatigue recovery due to its rapid energy and electrolyte replenishment properties.

The study carries several important implications. First, regional nutrient variation should be a critical consideration in the formulation of nutraceuticals and functional foods, as locational mineral advantages can be strategically harnessed to enhance dietary interventions. Second, the nutritional data substantiate classical Ayurvedic claims, thereby bridging traditional ethnobotanical knowledge with contemporary scientific validation. Third, from a public health perspective, Punarnava and Palm jaggery may serve as plant-based hematinic agents, while Finger millet offers promising benefits for bone health and glycaemic regulation. Despite these insights, the study acknowledges certain limitations. Factors affecting mineral bioavailability such as phytates, oxalates, and flavonoids were not assessed, and the analysis was confined to a single harvest season. Future research incorporating in vivo studies, soil-mineral mapping, and multi-seasonal sampling is recommended to deepen understanding of geographic nutrient determinants. In conclusion, the concept of "nutritional terroir" emerges as a central theme, emphasizing that the origin of plant-based foods profoundly shapes their dietary and therapeutic potential. These findings offer valuable guidance for consumers, nutritionists, food technologists, policymakers, and Ayurvedic practitioners in optimizing nutritional strategies based on regional sourcing.

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