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Navara Rice (*Oryza sativa* L.): A Comprehensive Review of Its Ethnobotany, Phytochemistry, and Pharmacological Properties

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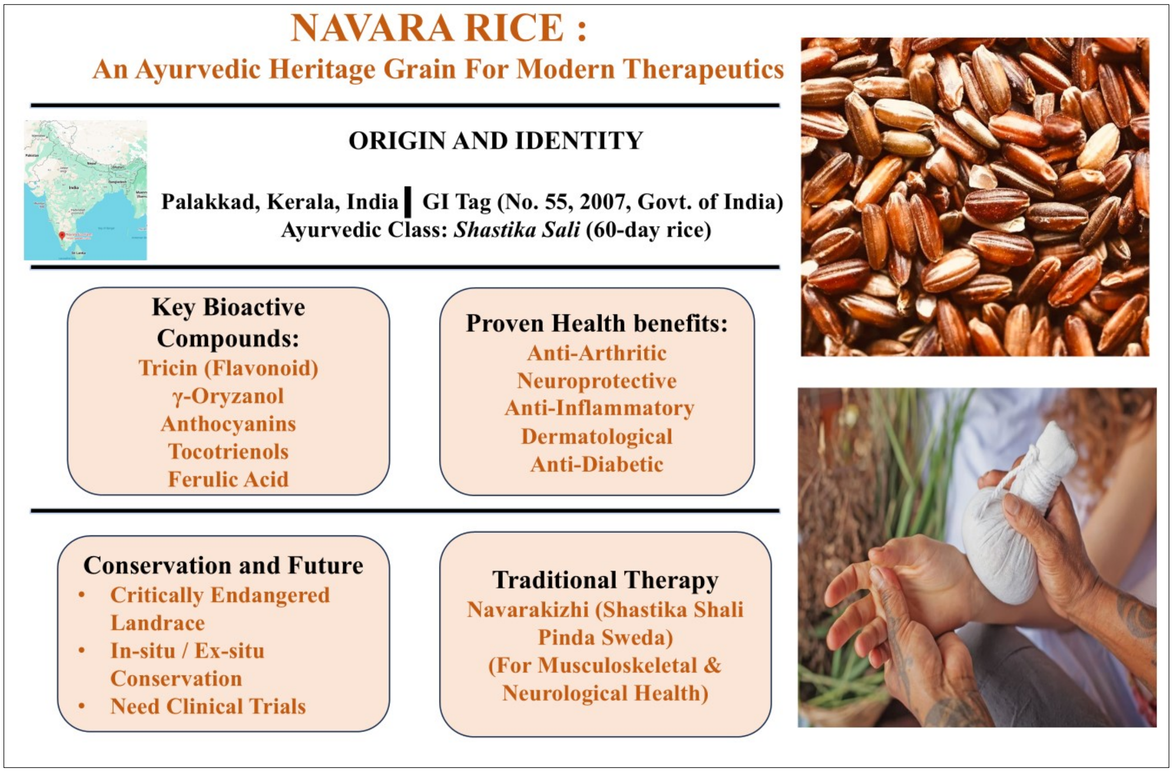
Abstract

Navara rice (*Oryza sativa* L.), a unique pigmented landrace traditionally cultivated in Kerala, India, holds a revered status in Ayurveda as a medicinal grain (*Oushadha*) rather than a mere dietary staple. Distinguished for its use in restorative therapies like *Navarakizhi*, its pharmacological potential is attributed to a distinctive phytochemical profile. This review systematically compiles and critically evaluates the existing scientific literature on Navara rice, encompassing its ethnobotany, agronomy, biochemical composition, and pharmacological properties. The analysis confirms that Navara is rich in bioactive compounds, including exceptionally high levels of tricin, γ-oryzanol, anthocyanins, and tocotrienols, which contribute to its potent *in vitro* and *in vivo* antioxidant, anti-inflammatory, anti-arthritic, and neuroprotective activities. Scientific evidence substantiates its traditional use in managing musculoskeletal and neurological disorders, with emerging data suggesting potential dermatological, wound-healing, and chemopreventive benefits. Despite its promise, Navara faces significant conservation challenges due to low yield and genetic erosion, though initiatives like the Geographical Indication (GI) tag offer pathways for sustainable utilization. This synthesis underscores the convergence of traditional knowledge and modern science, highlighting the need for standardized clinical trials and advanced biotechnological approaches to fully harness the therapeutic potential of this valuable agro-medicinal resource.

Keywords: Navara, *Oryza sativa*, phytochemicals, antioxidant activity, *Ayurveda*, Neuroprotection

Graphical Abstract



1. Introduction

1.1 The Global context of Rice Biodiversity

Rice (*Oryza sativa L*) is a staple food crop for more than half of the world's population. Its exceptional significance in global food security is underscored by its extensive cultivation across diverse environments, ranging from the waterlogged paddy fields of Asia to the upland fields of African and American continents. Beyond the calorific values, rice is a significant source of dietary energy, protein and essential micro nutrients, establishing it as an integral component of socio-economic stability and cultural identity of billions of populations. Centuries of cultivation and selection have resulted in a vast genetic diversity, with thousands of landraces adapted to specific agro-ecological niches. However, the Green Revolution's focus on high-yielding varieties has led to a dramatic reduction in this genetic pool, risking the loss of unique alleles that confer resistance to biotic and abiotic stresses, as well as enhanced nutritional and medicinal properties. The international trade of rice depends on high-yielding commercial varieties but scientists have discovered a vast unexplored genetic diversity within traditional landraces (Khush*et al*., 1997; Dwivedi *et al*., 2016).

1.2 Navara: A Paradigm of Ayurvedic Pharmacology.

Among these traditional landraces, Navara rice holds a prominent position. It is a short-duration, pigmented rice, traditionally cultivated in the Palakkad region of Kerala. The name "Navara" is derived from the Malayalam word *Navam*, meaning "nine", believed to represent either its nine-grained panicle structure or its cultivation cycle corresponding to nine lunar months.Often referred to as the "golden grain of Ayurveda," Navara has been highly valued in traditional Ayurvedic and folk medicine for its restorative and therapeutic properties**(Figure 1)**.Its history is deeply interwoven with the ancient system of

Ayurveda, where it is classified not as a common food grain (*Dhanya*), but as a potent medicinal substance (*Oushadha*). Its significance is deeply rooted in the ancient Indian system of medicine, Ayurveda, where it is classified as a *Shastika Sali*—a rice maturing in 60 days, believed to possess superior medicinal qualities (Warrier *et al*., 1996). Classical texts like the *Susruta Samhita* and *Ashtanga Hridaya* explains its virtues for rejuvenating the nervous system, strengthening the musculoskeletal framework, and treating skin diseases (Sharma, 2001).

Figure 1. Navara Rice grains

1.3 Rationale and Scope of the Review

While Navara's traditional uses are well-documented in Ayurvedic literature, a systematic compilation and critical analysis of modern scientific studies validating these claims are necessary to bridge the gap between traditional knowledge and evidence-based medicine. Several isolated studies have investigated its antioxidant capacity, anti-arthritic properties, and unique biochemical makeup, but a holistic review is lacking. This paper aims to provide a comprehensive synthesis of the agricultural, biochemical, pharmacological, and ethnomedicinal aspects of Navara rice. The objectives are to detail the botanical and agronomic characteristics and elucidate its unique biochemical and nutritional composition. And critically review the scientific evidence for its pharmacological properties. Additionally, to discuss the conservation challenges and future research directions.

2. Botanical and Agronomic Characterization

2.1 Botanical description and Classification

Navara belongs to the *Oryza sativa* L. species, part of the *indica* subspecies. It is an annual grass characterized by its relatively short stature and specific morphological traits. The precise taxonomic hierarchy of Navara from International Rice Research Institute (IRRI) is given in **Table 1**.

Kingdom	:	*Plantae*
Phylum	:	*Tracheophyta*
Class	:	*Liliopsida*
Order	:	*Poales*
Family	:	*Poaceae*
Genus	:	*Oryza*
Species	:	*Oryza sativa* L.
Subspecies	:	*Indica*
Cultivar	:	Navara (also orthographically represented as 'Njavara') (Nair et al. 2014).

Table 1. Taxonomical Hierarchy of Navara Paddy

The Navara plant exhibits an erect growth habit, typically reaching a height of 90–110 cm at maturity **(Figure 2)**. The leaves are linear-lanceolate, with a smooth and hairless surface, measuring 15–30 cm in length and possessing ligules and auricles—distinctive, diagnostic features of the *Oryza* genus.The inflorescence is a compact panicle of intermediate length, supporting a moderate grain count per panicle. A defining feature of Navara rice is the morphology and coloration of its grain. The grains possess a black husk (lemma and palea) and a red-brown pericarp, indicating high anthocyanin and polyphenol content, which contribute to medicinal and antioxidant properties. The grains are classified as short-bold and are distinctly aromatic upon cooking, a sensory attribute noted in traditional and contemporary quality assessments. Two major Navara types exist: the black-glumed variety and the golden yellow-glumed type, with the former most often preferred for Ayurvedic and medicinal purposes (Deepa *et al*., 2008).

Figure 3. Matured Navara Paddy Plant with grains

2.2. Agro-climatic Requirements and Cultivation Practices

Navara paddy is primarily cultivated during the post-monsoon cropping period, locally referred to as the rabi rice-growing season in southern India. This season typically begins in late October or early November, coinciding with the northeast monsoon rains, and extends until the harvest period between January and February (Manickam *et al*., 2018; Tamil Nadu Agricultural University, 2022). The prevailing agro-climatic conditions during this period—moderate rainfall, mild temperature, and relatively stable humidity—provide optimal conditions for the growth and development of Navara paddy. The variety displays broad adaptability to fluctuating weather patterns, moderate soil moisture, and cooler climatic phases, making it suitable for diverse agro-ecological zones in Kerala and Tamil Nadu.

The yield potential of Navara paddy often exceeds that of conventional rice varieties grown under similar conditions. This enhanced productivity is mainly due to its well-adapted growth cycle, which aligns with the environmental parameters of the post-monsoon period, thereby maximizing photosynthetic efficiency and grain filling during the reproductive stage (Kumar *et al*., 2020). The crop also exhibits natural resistance to several rice diseases and insect pests, reducing farmers' reliance on chemical pesticides and ensuring sustainable production systems (Ramesh *et al*., 2017).

Moreover, Navara paddy demonstrates efficient nutrient uptake dynamics, particularly in absorbing essential macronutrients and micronutrients from the soil, which supports robust tillering, vigorous growth, and higher grain weight even under moderate soil fertility conditions (Chithra and Padmaja, 2019). These properties make it possible to cultivate Navara over a wide range of soil types with reduced dependence on synthetic fertilizers.

An additional advantage of Navara cultivation is its water-use efficiency. The crop's moderate water requirements align with the rainfall distribution of the northeast monsoon and the residual soil moisture during the rabi period. This efficient utilization of available water resources lowers the risk of yield fluctuations caused by either moisture deficit or waterlogging, encouraging sustainable rice cultivation in water-limited environments (TNAU, 2022). Collectively, these agro-physiological traits position Navara paddy as a climate-resilient, resource-efficient variety suited to contemporary sustainable rice farming systems in southern India.

3. Biochemical, Nutritional and Phytochemical Composition

Navara rice is distinguished by a unique biochemical profile and substantial nutritional value, contributing to its diverse applications in traditional medicine and human nutrition. The grain is a rich source of complex carbohydrates, protein, and dietary fiber. In addition, it contains noteworthy levels of essential minerals, including iron, zinc, magnesium, phosphorus, and calcium (Earth2Pot, 2024; Gaunaturals, 2024; DharaniNaturals, 2025; Deepa *et al*., 2008).The biochemical composition of Navara rice includes elevated concentrations of polyphenols, flavonoids, anthocyanins, and other antioxidant phytochemicals (S. Rao *et* al., 2010; Nayeem *et al*., 2021; Goufo*et al*.,2014). These compounds are recognized for their strong free-radical scavenging activity, which supports anti-inflammatory and immunomodulatory functions. High levels of γ-oryzanol, tricin, and tocotrienols have been identified in the bran and pericarp, further enhancing its health-promoting properties (Chithra and Padmaja, 2019).The nutritional and phytochemical composition of Navara rice per 100 g is summarized in **Table 2.**

Component	Amount	Reference
Energy	1628 KJ	Earth2Pot, 2024; Deepa *etal*., 2008; Gaunaturals, 2024; DharaniNaturals, 2025
Carbohydrates	70-73 g	
Protein	9.0-9.7 g	
Fat	2.0-3.1 g	
Dietary Fiber (g)	5.0 g	
Iron (mg)	0.88-3.5 mg	
Zinc (mg)	14.85 mg	
Calcium (mg)	20 mg	
Magnesium (mg)	45 mg	
Phosphorous (mg)	130 mg	
Vitamin B6	1.97 mg	

Table 2. Nutritional composition of Navara rice (per 100 g grain)

3.1. Phytochemistry of Navara Rice

Navara rice (*Oryza sativa* L.), historically renowned for its medicinal and nutritional attributes, is distinguished by a complex phytochemical profile that contributes to its antioxidant, anti-inflammatory, and therapeutic potential. The rice bran and whole grains of Navara are notably rich in phenolic compounds, flavonoids, anthocyanins, and a range of secondary metabolites. Quantitative phytochemical analysis shows that Navara rice possesses significantly higher total phenolic and flavonoid contents than non-medicinal or non-pigmented rice varieties. The total phenolic content in Navara rice bran reaches up to 12.72 ± 0.6 mg gallic acid equivalents (GAE)/g, while total flavonoid content can be as high as 8.51 ± 0.05 mg quercetin equivalents (QE)/g. The predominant phenolic acids identified include ferulic acid, p-coumaric acid, and isoferulic acid, which are known to exert strong antioxidant activities (Rao *et al*., 2010; Gogoi *et al*., 2025).

Navara rice is an exceptional source of flavonoids such as tricin and its flavonolignan derivatives. Tricin concentration in Navara rice is up to 16–40 times higher than in standard rice cultivars and such compounds contribute to its potent anti-inflammatory properties. In addition, the red-brown pericarp and, in some strains, black husk (lemma and palea) are indicative of elevated anthocyanin levels, contributing further to its free-radical scavenging capacity. Methanolic extracts of Navara rice demonstrate IC_{50} values for DPPH and nitric oxide radical scavenging as low as 30.85μg/mL, which is correlated with high phenolic density (Zeenath Khan *et al*., 2024; Mohanlal *et al*., 2011; Nayeem *et al*., 2020).

Further phytochemical investigations have identified the presence of γ-oryzanol, tocotrienols, and phytosterols such as β-sitosterol and campesterol in Navara rice bran. Minor constituents including alkaloids, saponins, and tannins have also been detected, which may support additional pharmacological and nutraceutical functions. Antioxidant activity in Navara rice is consistently superior, as shown by high reducing power and ABTS+ radical cation scavenging assays (Rao *et al*., 2010).A compound-specific summary of major phytochemicals identified in Navara rice is provided in **Table 3.**

Compound/Class	Amount (mean ± SE or range)	Basis/Standard	Analytical Method	Reference
Total phenolics	12.72 ± 0.6 mg GAE/g bran	Gallic acid equivalents	Folin–Ciocalteu assay	Rao *et al*., 2010
Total phenolics	800–1160mg GAE/100g grain	Gallic acid equivalents	Folin–Ciocalteu assay	Gogoi *et al*., 2025
Total flavonoids	8.51 ± 0.05 mg QE/g bran	Quercetin equivalents	Aluminum chloride colorimetry	Rao *et al*., 2010
Total flavonoids	965–1854 mg CE/100g grain	Catechin equivalents	Aluminum chloride colorimetry	Zeenath Khan *et al*., 2024
Anthocyanins	4.5–39.7 mg C3G/100g grain	Cyanidin-3-glucoside equiv.	Differential pH/UV-Vis spectro.	Zeenath Khan *et al*., 2024
Tricin (flavone)	Up to 16–40× vs. white rice	Relative	HPLC/LC-MS	Mohanlal *et al*., 2021
γ-Oryzanol	~2340 mg/100g bran	-	HPLC	Gogoi *et al*., 2025

Tocotrienols	Detected	-	HPLC	Gogoi *et al*., 2025
Ferulic acid, p-Coumaric acid	Detected (major free/bound phenolic)	-	HPLC	Gogoi *et al*., 2025
β-Sitosterol, Campesterol	Detected	-	GC-MS	Hima Rasheed *et al*., 2018
Alkaloids, Saponins, Tannins	Present (qualitative)	-	Phytochemi-cal screening	Hima Rasheed *et al*., 2018
DPPH radical scavenging	IC_{50}: 30.85–87.72 μg/mL	-	DPPH assay	Gogoi *et al*., 2025
Reducing power	Absorbance: up to 2.98 at 700 nm	-	Oyaizu's method	Rao *et al*., 2010

Table 3. Major Phytochemicals and Antioxidant Activities in Navara Rice (Bran or Whole Grain).

3.2. Comparative Phytochemical Profiling with Other Medicinal Rice Cultivars

A critical assessment of Navara's distinctiveness requires a comparative analysis against other well-characterized pigmented and medicinal rice cultivars, such as Thai Black Jasmine rice, Indonesian Cempo Ireng, and Japanese Haigamochi. While Navara is notably distinguished by its exceptionally high concentrations of tricin and γ-oryzanol, a systematic comparison contextualizes its relative phytochemical standing. For instance, certain Indonesian black rice genotypes (e.g., Cempo Ireng) have been reported to possess total anthocyanin concentrations exceeding 100 mg cyanidin-3-glucoside equivalents (C3G)/100g, a level that can surpass that typically found in Navara (Goufo *et al*., 2014; Pereira-Caro *etal*., 2013). Conversely, Navara's significance is underscored not by a single dominant compound, but by a synergistic combination of potent flavonoids, oryzanols, and tocotrienols. This unique phytochemical ensemble defines its specific medicinal niche and differentiates it from other pigmented varieties that may be richer in a single class of antioxidants. Such a comparative profile is indispensable for identifying Navara's unique value proposition in nutraceutical development and for guiding modern breeding programs aimed at developing these high-value, health-promoting traits from various landraces into agronomically superior cultivars.

4. Pharmacological Properties and Health Benefits

4.1. Antioxidant activity

Navara rice exhibits remarkable antioxidant activity, primarily attributed to its high concentrations of polyphenols, flavonoids, and γ-oryzanol. Several in vitro studies have employed established assays such as 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and ferric reducing antioxidant power (FRAP) to demonstrate that Navara rice bran extracts possess significantly greater free radical scavenging capacity than extracts derived from conventional, non-pigmented rice varieties. The superior antioxidant potential of Navara is evidenced by low IC_{50} values in DPPH and nitric oxide scavenging assays, indicating strong hydrogen-donating ability and effective neutralization of reactive oxygen species. This antioxidant activity plays a critical role in mitigating oxidative stress, a key pathological factor in aging, neurodegenerative disorders, and inflammatory diseases. The strong correlation observed between total phenolic and flavonoid contents and antioxidant capacity underscores the importance of these bioactive compounds in the therapeutic potential of Navara rice (Ghasemzadeh *et al*., 2018; Priya *et al*., 2015).

4.2. Anti-inflammatory and Anti-arthritic Properties

Navara rice has been the subject of extensive investigation for its significant anti-inflammatory and anti-arthritic properties, providing a scientific foundation for its longstanding use in Ayurveda for treating rheumatic conditions. In vivo evidence from rodent models of adjuvant-induced arthritis has confirmed that oral administration of Navara rice extract produces a marked reduction in clinical signs, including pawedema and joint inflammation, while also mitigating radiographic joint damage (Nair *et al*., 1993). The underlying mechanism for this efficacy involves the modulation of key inflammatory pathways. Navara extracts have been shown to downregulate the expression of pivotal pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), and interleukin-6 (IL-6), and to suppress the activity of the cyclooxygenase-2 (COX-2) enzyme (Lee et al., 2016). A critical bioactive component implicated in this response is the flavonoid; tricin, which is found in high concentrations in Navara and is known to inhibit central inflammatory signalling cascades. These collective findings substantiate the traditional application of Navara rice and underscore its potential as a source of natural therapeutic agents for inflammatory and arthritic pathologies.

4.3. Neuroprotective Effects

The neuroprotective properties of Navara rice, historically documented in Ayurveda for the management of neurological disorders (*Vata vyadhi*), are supported by contemporary pharmacological evidence. This bioactivity is largely mediated by a synergistic combination of bioactive compounds, notably tocotrienols and flavonoids, which target multiple pathways implicated in neurodegeneration (Sen *et al*., 2006; Khanna *et al*., 2005).

The primary mechanism involves potent antioxidant activity within the central nervous system. Key bioactive components, particularly tocotrienols, demonstrate the ability to cross the blood-brain barrier, directly neutralizing reactive oxygen species (ROS) and mitigating lipid peroxidation of neuronal membranes, thereby preserving mitochondrial function (Jang *et al*., 2009). Furthermore, *in vitro* and animal model studies indicate that Navara constituents can modulate hallmark pathologies of neurodegenerative diseases, including inhibiting the aggregation of beta-amyloid (Aβ) peptides in Alzheimer's disease and suppressing neuroinflammation via glial cell modulation (Chen *et al*., 2020; Lee *et al*., 2016). This multi-target pharmacological profile provides a mechanistic basis for its traditional application in therapies like *Navarakizhi*, suggesting a potential role for Navara as a functional food in supporting cognitive health and countering neuro-degenerative processes.

4.4. Dermatological Applications

Navara rice demonstrates significant potential in dermatological health, applied through both dietary consumption and topical formulations. Its efficacy is primarily attributed to its high concentration of antioxidant compounds, such as ferulic acid and γ-oryzanol, which scavenge free radicals and mitigate oxidative stress, a key contributor to premature skin aging. Concurrently, its anti-inflammatory properties, mediated through the inhibition of pro-inflammatory cytokines, are relevant for managing chronic skin conditions such as psoriasis and atopic dermatitis (Draelos *et al*., 2010).

Topically, Navara rice bran is valued for its emollient and wound-healing properties. The bran's physical granularity provides a mild exfoliating effect, while its lipid and phytosterol content supports skin barrier repair and hydration. These observed biological activities provide a mechanistic basis for clinical reports from Panchakarma therapy centres, which document improvements in skin complexion, texture, and hydration following treatments incorporating Navara-based preparations (Kumar *et al*., 2012). Thus, the dermatological utility of Navara rice, long recognized in traditional practice, is supported by its multifaceted antioxidant, anti-inflammatory, and barrier-strengthening pharmacological profile.

4.5. Other Potential Health Benefits

Beyond its well-characterized effects, preliminary investigations suggest Navara rice possesses several other therapeutic benefits for further exploration. In the context of wound healing, Navara extract has been demonstrated to significantly accelerate wound contraction in diabetic rat models, a effect attributed to its capacity to promote fibroblast proliferation and enhance collagen synthesis at the wound site (Subramanian *et al*., 2014). Furthermore, *in vitro* studies indicate a potential chemo preventive role, with Navara bran extract shown to inhibit cell proliferation and induce apoptosis in various human cancer cell lines, suggesting promising cytotoxic properties that warrant extensive investigation (Henderson *et al*., 2012). Additionally, the high dietary fibre and polyphenol content characteristic of Navara imply a potential for modulating postprandial blood glucose levels, although direct anti-diabetic studies on this specific cultivar remain limited and necessitate further validation (Ito *et al*., 2020).

These diverse biological activities position Navara as a multi-functional grain with significant potential for application in nutraceutical and therapeutic development.

5. Navara in Ayurveda and Traditional Medicine

Within the Ayurvedic pharmacopoeia, Navara rice holds a distinguished position classified as *Shastika Sali*, with its unique 60-day growth cycle, which is believed to concentrate its medicinal potency. Ayurvedic texts describe its properties as sweet (*madhura*) and unctuous (*snigdha*), attributing to it the capacity to balance *Vata* and *Pitta doshas*. It is specifically indicated for its body-strengthening (*brimhana*), tissue-promoting (*dhatuvardhaka*), and diuretic properties, establishing it as a fundamental restorative substance (Sharma. 2001). The most prominent application of these properties is in the specialized sudation therapy known as *Navarakizhi* or *Shastika Shali Pinda Sweda* **(Figure 3)**.

Figure 3. ***Navara Kizhi*** **treatment in Ayurvedic clinical practice.**

This intricate procedure involves the preparation of boluses filled with Navara rice that has been cooked in a decoction of *Bala* (*Sida cordifolia*), milk, and water. These warm, medicated boluses are then systematically massaged over the patient's body by trained therapists for 60-90 minutes daily over a period of 7 to 14 days. The therapy is a cornerstone for treating musculoskeletal and neurological conditions, including arthritis, muscle wasting, spasticity, and for general rejuvenation in debilitated patients (Tripathi, 2003). The therapeutic mechanism is postulated to be multifactorial, involving the transdermal absorption of bioactive compounds from Navara and the co-administered herbs, significant improvement in peripheral circulation from the vigorous massage, and a profound nourishing effect on the deep tissues (*Majja Dhatu*), thereby validating its enduring role in Ayurvedic clinical practice (Shylaja *et al*., 2014).

6. Conservation Status and Economic aspects

Navara rice faces significant threats of genetic erosion due to a confluence of agronomic and economic constraints, including inherently low yield, high cultivation costs, and intense competition from high-yielding modern varieties. Historically, its cultivation was relegated to a few acres, classifying it as a critically endangered landrace and highlighting the urgent need for concerted conservation strategies (Ramesh *et al*., 2013). In response, multi-faceted initiatives have been implemented. Key institutions like the Kerala Agricultural University (KAU) maintain live germplasm and conduct research on crop improvement, while community-led efforts by NGOs and farmer cooperatives, such as the "Navara Samrakshana Samiti," promote on-farm conservation by establishing secure market linkages (Kerala Agricultural University. 2019). These *in-situ* efforts are complemented by *ex-situ* conservation through seed banking in national repositories like the National Bureau of Plant Genetic Resources (NBPGR), ensuring the long-term preservation of its genetic diversity (Sing *et al*., 2013).

A pivotal development in safeguarding Navara's identity and economic potential was the granting of the Geographical Indication (GI) tag in 2007 (GI No. 55), which legally protects its unique properties intrinsic to Kerala's geographical environment (GI No.55, Govt. of India 2007). This certification has been instrumental in branding, preventing misappropriation, and facilitating its market positioning as a niche, premium product. This was done by the Navara Eco Farm, located in Palakkad, Kerala, India **(Figure 4)**.

Figure 4. Navara Eco Farm, Palakkad, Kerala, India

The economic viability of Navara cultivation is further enhanced by the development of a value-added product chain, which includes Navara rice powder, bran oil, and ready-to-use packs for traditional therapies like *Navarakizhi* (Smith *et al*., 2018). This strategic approach, combining legal protection with product diversification, creates a sustainable economic model that incentivizes conservation through use, thereby ensuring the continued existence of this invaluable agro-biodiversity resource.

7. Challenges and Future Perspectives

Significant scientific and translational challenges currently impede the full realization of Navara's therapeutic potential. A primary obstacle is the critical absence of robust clinical validation, specifically large-scale, randomized, double-blind, placebo-controlled human trials, to conclusively establish its efficacy for specific disease states. Furthermore, the lack of standardized extracts with quantified biomarker compounds (e.g., γ-oryzanol, cyanidin-3-glucoside) hinders reproducible research and nutraceutical development. A deeper understanding of the precise molecular mechanisms and signaling pathways modulated by Navara's bioactive compounds is also required, alongside comprehensive pharmacokinetic studies to elucidate the absorption, distribution, metabolism, and excretion (ADME) profiles of its key constituents.

A significant translational limitation impedes the conversion of Navara's extensive pre-clinical pharmacodynamic data into validated clinical applications. Notwithstanding compelling evidence from *in vitro* assays and animal models elucidating its antioxidant, anti-inflammatory, and neuroprotective mechanisms, a definitive clinical corroboration remains absent. The extant human data are primarily constituted by non-controlled observational studies, anecdotal accounts, and investigations into complex Ayurvedic interventions (e.g., *Navarakizhi*), which, while suggestive of therapeutic potential, are fundamentally limited by a lack of methodological stringency. These studies typically fail to incorporate critical design elements such as randomization, blinding, placebo control, and quantifiable physiological biomarkers, thereby precluding causal inference and objective efficacy assessment.

The imperative remains for future research to conduct rigorous Phase II/III clinical trials utilizing standardized, chemically characterized Navara extracts. Such investigations are essential to quantitatively determine pharmacokinetic profiles, establish dose-response relationships, and validate clinical efficacy against specific pathophysiological endpoints, such as serum inflammatory cytokine levels in rheumatoid arthritis or cognitive function scores in neurodegenerative decline.

Future research must therefore adopt a multi-pronged strategy to address these gaps. Agronomic efforts should focus on employing marker-assisted selection and genetic engineering to develop high-yielding cultivars that retain their unique phytochemical profile, thereby enhancing cultivation viability. Concurrently, research must pivot towards translational applications, including the development of standardized nutraceutical and cosmeceutical formulations. The integration of systems biology approaches—utilizing genomics, transcriptomics, and metabolomics—will be crucial for comprehensively understanding the genetic basis of its medicinal properties. Finally, well-designed clinical studies are essential to systematically evaluate Navara's role as a complementary therapy in the management of chronic conditions such as rheumatoid arthritis and neurodegenerative disorders, effectively bridging traditional wisdom with evidence-based medicine.

8. Conclusion

Navara rice transcends its role as a staple food, representing a functionally significant grain with inherent pharmacologic properties. This systematic review has consolidated compelling scientific evidence that validates its traditional Ayurvedic applications, demonstrating that its potent antioxidant, anti-inflammatory, and neuroprotective activities are mediated by a distinct phytochemical ensemble. While significant challenges persist, predominantly related to agronomic constraints and genetic erosion, strategic initiatives such as its Geographical Indication status, increasing market recognition as a functional food, and dedicated conservation programs provide a viable pathway for its sustainable utilization. The future trajectory for Navara hinges on a synergistic paradigm that integrates traditional ethnobotanical knowledge with advanced biotechnological innovation. This multi-disciplinary framework is essential to fully elucidate and harness its therapeutic potential, thereby ensuring the preservation and application of this invaluable agro-medicinal resource for future generations.

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Conflict of interest

The authors declare that they have no competing interests.

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