Review

PHYTOCHEMISTRY BIOACTIVITIES AND PRODUCT DEVELOPMENT POTENTIAL OF *MORINDA CITRIFOLIA* L.

Hoạt tính sinh học và tiềm năng phát triển sản phẩm từ cây nhàu (*Morinda citrifolia* L.)

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ABSTRACT

Morinda citrifolia L. is a tropical medicinal plant with long-standing traditional use and increasing relevance for phytochemical, pharmacological, and noni-based healthcare product development. This narrative review synthesizes available evidence on medicinal characteristics, plant parts used, phytochemical constituents, biological activities, and requirements for product standardization. The fruit is the principal raw material for juice, fermented preparations, dried-fruit tea, powders, and capsules, whereas leaves, roots, seeds, and stem bark provide comparative information on the distribution of bioactive constituents. Major compound groups include iridoid glycosides, polyphenols, flavonoids, coumarins, organic acids, polysaccharides, anthraquinones, and lignans. Deacetylasperulosidic acid, asperulosidic acid, scopoletin, rutin, and damnacanthal are important quality-related constituents, depending on the plant part and intended product. Preclinical studies support antioxidant, anti-inflammatory, antibacterial/antifungal, glucose-metabolism-modulating, neuroprotective, and anticancer-related activities; however, most findings remain derived from chemical assays, cell models, animal experiments, or non-standardized extracts. Therefore, development of noni as a science-based medicinal material or healthcare product should prioritize plant-part authentication, batch-to-batch chemical standardization, safety assessment, bioavailability evaluation, drug-interaction studies, and controlled clinical validation.

Keywords: Noni; *Morinda citrifolia* L.; biological activities; iridoid glycosides; phytochemistry; herbal standardization; healthcare products.

TÓM TẮT

Cây Nhàu (*Morinda citrifolia* L.) là một cây thuốc nhiệt đới có lịch sử sử dụng lâu đời trong y học cổ truyền và ngày càng có vai trò đáng kể trong nghiên cứu hóa thực vật, dược lý và phát triển các sản phẩm chăm sóc sức khỏe từ nhàu. Bài tổng quan tường thuật này tổng hợp các bằng chứng hiện có về đặc điểm dược liệu, các bộ phận của cây được sử dụng, thành phần hóa thực vật, hoạt tính sinh học và các yêu cầu đối với tiêu chuẩn hóa sản phẩm. Quả là nguyên liệu chính để sản xuất nước ép, các chế phẩm lên men, trà quả khô, bột và viên nang; trong khi lá, rễ, hạt và vỏ thân cung cấp thông tin so sánh về sự phân bố của các thành phần có hoạt tính sinh học. Các nhóm hợp chất chính bao gồm glycosid iridoid, polyphenol, flavonoid, coumarin, acid hữu cơ, polysaccharid, anthraquinon và lignan. Acid deacetylasperulosidic, acid asperulosidic, scopoletin, rutin và damnacanthal là những thành phần quan trọng liên quan đến chất lượng, tùy thuộc vào bộ phận của cây và loại sản phẩm dự kiến phát triển. Các nghiên cứu tiền lâm sàng cho thấy nhàu có hoạt tính chống oxy hóa, chống viêm, kháng khuẩn/kháng nấm, điều hòa chuyển

hóa glucose, bảo vệ thần kinh và các tác dụng liên quan đến chống ung thư; tuy nhiên, phần lớn các kết quả hiện nay vẫn chủ yếu xuất phát từ các thử nghiệm hóa học, mô hình tế bào, thí nghiệm trên động vật hoặc các dịch chiết chưa được tiêu chuẩn hóa. Vì vậy, việc phát triển nhàu thành nguyên liệu dược liệu hoặc sản phẩm chăm sóc sức khỏe có cơ sở khoa học cần ưu tiên xác thực bộ phận thực vật sử dụng, tiêu chuẩn hóa thành phần hóa học giữa các lô, đánh giá an toàn, đánh giá sinh khả dụng, nghiên cứu tương tác thuốc và xác nhận bằng các thử nghiệm lâm sàng có đối chứng.

Từ khóa: Nhàu; *Morinda citrifolia* L.; hoạt tính sinh học; glycosid iridoid; hóa thực vật; tiêu chuẩn hóa dược liệu; sản phẩm chăm sóc sức khỏe.

Received: 05/06/2026 |	Accepted: 23/07/2026 |	Online First: 14/09/2026 |

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I. INTRODUCTION

Viet Nam has abundant medicinal plant resources, including many species that have long been used in folk medicine and are increasingly studied in modern pharmaceutical sciences. Noni (*Morinda citrifolia* L.), scientifically known as *Morinda citrifolia* L. and belonging to the Rubiaceae family, is a familiar medicinal plant in central and southern Viet Nam. It is also known internationally as noni or Indian mulberry. In traditional medicine, the fruit, roots, and leaves of noni have been used for multiple purposes, including digestive support, pain relief, diuresis, blood circulation support, and the management of some external inflammatory conditions.[1-4]

Interest in noni is not based solely on traditional experience. Modern studies have reported numerous secondary metabolites in the fruit and other plant parts, particularly iridoid glycosides, anthraquinones, flavonoids, polyphenols, coumarins, organic acids, polysaccharides, and lignans.[5-7] These compounds have been associated with several biological activities, including antioxidant, anti-inflammatory, antibacterial, antifungal, glucose-metabolism-modulating, neuroprotective, and anticancer-related effects in preclinical models.[5,8]

A central problem in current noni research is the disconnection among botanical source, plant part, extract type, chemical markers, biological model, and product form. Studies on fruit juice, fermented fruit, leaves, roots, seeds, or isolated compounds are often discussed under the same name “noni”, although their chemical profiles and safety considerations can differ substantially. This creates uncertainty when preclinical findings are translated into quality specifications, product positioning, or clinical recommendations.

On this basis, the present narrative review aims to systematize available evidence on the noni plant, clarify the relationship among plant parts, major compound groups, reported biological activities, and product-development requirements, and identify priorities for product standardization, safety assessment, and appropriate clinical study design. Because fruit-

based preparations are the most common commercial forms, the fruit is discussed in detail, while data from leaves, roots, seeds, and stem bark are included to avoid inappropriate generalization across plant parts

II. REVIEW METHODOLOGY

This paper was conducted as a narrative review to systematize data related to the noni plant (*Morinda citrifolia* L.), with particular attention to fruit-based materials and products. Literature was selectively searched in academic databases and sources, including PubMed, Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar. Records available up to the period of manuscript preparation were considered. English and Vietnamese keywords were used either alone or in combination, including *Morinda citrifolia*, noni, noni fruit, phytochemistry, iridoids, deacetylasperulosidic acid, asperulosidic acid, scopoletin, damnacanthal, antioxidant, anti-inflammatory, antimicrobial, antifungal, anticancer, antidiabetic, neuroprotective, toxicity, safety, fermentation, and medicinal product development.

Documents were considered when they directly addressed botanical characteristics, plant parts used, chemical composition, biological activity, safety, toxicity, processing technology, or application-oriented development of noni. Priority was given to original research articles, review articles, phytochemical studies, *in vitro* and *in vivo* pharmacological studies, toxicity studies, product-related studies, and pharmacognostic references of scientific value. Records were excluded when the study object was unclear, the content was not directly related to *Morinda citrifolia* L., the material was mainly promotional, the methodology was insufficiently described, the content was duplicated, or the scientific data were not verifiable.

The reviewed evidence was organized into four thematic groups: medicinal characteristics and traditional use; distribution of major compound groups by plant part; relationships between chemical composition and biological activities investigated in chemical assays, in vitro models, *in vivo* models, or product-based studies; and requirements for product development, including chemical-marker standardization, quality control, safety, bioavailability, and clinical validation.

Because this is neither a systematic review nor a meta-analysis, no formal risk-of-bias scoring system was applied, and no pooled treatment effect was estimated. Instead, the paper emphasizes evidence trends, research gaps, distinctions between preclinical and clinical evidence, and practical implications for standardizing noni raw materials and developing noni-based healthcare products..

III. MEDICINAL CHARACTERISTICS AND PHYTOCHEMICAL BASIS OF *MORINDA CITRIFOLIA* L.

1. Botanical Characteristics, Ecological Distribution, and Plant Parts Used

Morinda citrifolia L. is a small perennial tree or shrub, commonly reaching approximately 3-8 m in height. The leaves are simple, opposite, large, glossy, and entire. The flowers are small, white, and arranged in globular axillary inflorescences. The fruit is a syncarp, ovoid to

oval in shape; when ripe, it turns ivory-white to pale yellow, becomes soft, and develops a characteristic pungent odor. The plant is light-demanding, adapts well to hot and humid climates, and can grow along rivers, field margins, alluvial soils, coastal sandy soils, or mildly saline areas.[1-3] Its broad ecological adaptability is an important advantage for developing noni as a medicinal raw material in Viet Nam. Representative morphology is shown in **Figure 1**.



Figure 1. Representative morphology of noni (*Morinda* citrifolia L.). (Image Source: medlatec.vn)

From a pharmacognostic perspective, several parts of the noni plant can be utilized, but they should not be treated as chemically equivalent materials. The fruit is the most studied part because it is used both as a food ingredient and as a raw material for noni-based healthcare products, including juice, fermented preparations, dried-fruit tea, powders, and capsules. The roots are rich in anthraquinones and are often used in folk remedies related to pain, blood circulation, or digestive support. The leaves contain flavonoids and phenolics and have been used externally, as decoctions, or as experimental materials for anti-inflammatory, antioxidant, and wound-healing research. Seeds and stem bark are less common in folk use but have research value because they contain oils, phenolics, lignans, anthraquinones, and other secondary metabolites.[4-6]

2. Nutritional Components and Major Secondary Metabolites in Noni Fruit

Noni fruit contains both basic nutrients and a diverse set of secondary metabolites. In the fresh fruit, water is the dominant component; in juice form, water content may exceed 90%, whereas protein, lipid, and carbohydrate levels vary with maturity, cultivation region, and processing method.[3,7] In addition to macronutrients, the fruit contains vitamin C, carotenoids, niacin, trace minerals, and various organic acids that contribute to the characteristic flavor of noni.[3,7] The coexistence of nutrients, organic acids, and secondary

metabolites places noni fruit at the interface of food ingredient, medicinal material, and healthcare-product raw material.

Iridoid glycosides are among the most important quality-related constituents of noni fruit. Phytochemical studies have isolated or quantified asperulosidic acid, deacetylasperulosidic acid, asperuloside, and other iridoids from the fruit.[9,10] Among them, deacetylasperulosidic acid (DAA) and asperulosidic acid (AA) are commonly used as important markers for assessing the quality of fruit-based raw materials because they can reflect differences in plant part, cultivation source, maturity, and processing method.[7,10] In product development, separate quantification of DAA and AA is more meaningful than measuring only total extract content, because total extract does not adequately reflect quality variation among raw-material batches.

Besides iridoids, noni fruit also contains polyphenols, flavonoids, coumarins, lignans, polysaccharides, and some anthraquinones at lower levels than in the roots.[5,9,11] Scopoletin, a coumarin often reported in the genus *Morinda*, is notable because it has been linked to biological activities such as antioxidant, anti-inflammatory, and cellular-response-modulating effects. Flavonoids and phenolic acids, including rutin, kaempferol glycosides, gallic acid, salicylic acid, and other phenolic derivatives, contribute to free-radical scavenging capacity and oxidative-stress modulation.[5,11] Polysaccharides from the fruit and fermented products are also of interest because they may participate in immunomodulation, redox balance, and gut-microbiota regulation.

3. Distribution of Compound Groups across Plant Parts

Each part of the noni plant accumulates secondary metabolites in a distinct pattern. Noni leaves are rich in polyphenols and flavonoids, among which rutin, quercetin, and kaempferol are frequently reported. Leaves also contain iridoids, triterpenoids, saponins, and tannins. This profile provides a plausible basis for experimental findings related to anti-inflammatory, antioxidant, and wound-healing activities.[5,12]

The roots are notable for anthraquinones, particularly damnacanthal, nordamnacanthal, rubiadin, alizarin, and related derivatives. Damnacanthal is often regarded as an important chemical marker of the roots. In addition to anthraquinones, the roots contain iridoids, flavonoids, sterols, triterpenoids, lignans, and coumarins, indicating a metabolite-accumulation pattern that differs clearly from the fruit and leaves.[5,13] Noni seeds contain oil, minerals, phenolic acids, and lignans, although data on seeds are much more limited than data on fruit, leaves, and roots.[5,6] Stem bark has been less extensively studied, but available data suggest the presence of anthraquinones, polyphenols, flavonoids, alkaloids, and terpenoids.[5,6]

This difference has practical implications: data from roots, leaves, or seeds should not be generalized to noni fruit when developing quality standards for fruit-based products. If a product is labeled as “noni fruit”, its chemical specifications should prioritize iridoids,

scopoletin, total polyphenols, total flavonoids, polysaccharides, and selected safety indices. If the product uses roots or a whole-plant combination, anthraquinone-related criteria and appropriate toxicity assessment should be added. Representative quality-related constituents are presented in **Figure 2**, while the distribution of major compound groups by plant part is summarized in **Table 1**.

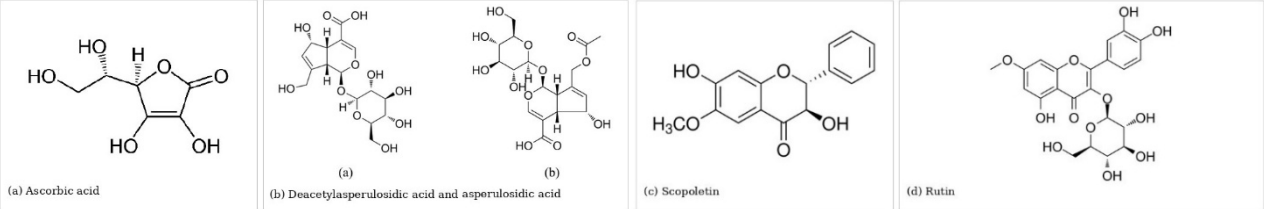


Figure 2. Representative quality-related constituents of noni. Chemical structures were redrawn by the authors based on structures reported in the cited phytochemical literature.

4. Implications of Phytochemical Data for Product Standardization

From a product-development perspective, noni should be standardized according to the declared plant part and product form. For fruit-based products, DAA and AA can serve as primary iridoid markers, while scopoletin, total polyphenols, total flavonoids, and polysaccharides may be used as complementary quality indicators. For root-containing materials, damnacanthal and other anthraquinone-related constituents should be considered because the root profile differs from the fruit. Whole-plant products require a broader specification and should not be assessed using only fruit markers.

Processing is a major source of chemical variability. Fresh juice, fermented juice, dried fruit, fruit powder, and organic-solvent extracts may have markedly different contents of iridoids, polyphenols, flavonoids, organic acids, and polysaccharides. Fruit maturity, harvest season, drying temperature, fermentation conditions, storage time, and extraction solvent can all influence the final chemical profile.[7,10,15] Therefore, product dossiers should clearly specify plant part, maturity stage, processing method, extraction solvent, marker-compound content, microbial quality, heavy-metal limits, solvent residues, and stability data rather than simply referring to the raw material as “noni”.

IV. BIOLOGICAL ACTIVITIES AND PRECLINICAL PHARMACOLOGICAL BASIS

The biological activities reported for noni should be interpreted in relation to plant part, extract type, experimental model, and level of evidence. **Table 2** consolidates representative activity groups, potentially related compound groups, and application-oriented implications. This structure is intended to link phytochemistry with biological outcomes and to reduce overgeneralization from isolated preclinical findings.

Table 1. Relative distribution of major compound groups according to the plant part used in *Morinda citrifolia* L.

Plant part	Prominent compound groups	Representative examples/markers	Pharmacological relevance
Fruit	Iridoid glycosides, polyphenols, flavonoids, coumarins, organic acids, polysaccharides, vitamins, and trace minerals	DAA, AA, scopoletin, rutin, gallic acid, vitamin C	Main raw material for juice, fermented products, teas, powders, and capsules; closely related to fruit-based phytochemical, nutritional, and antioxidant data.[7,9-11]
Leaves	Flavonoids, polyphenols, iridoids, triterpenoids, saponins, tannins	Rutin, quercetin, kaempferol, aucubin, asperulosidic acid	Source of bioactive constituents for research on inflammation, oxidative stress, wound healing, and immunomodulation.[5,12]
Roots	Anthraquinones, iridoids, flavonoids, sterols, triterpenoids, lignans, coumarins	Damnacanthal, nordamnacanthal, rubiadin, alizarin, scopoletin	Chemically distinct from the fruit; relevant to cellular-activity and hypoglycemic studies; anthraquinone-related safety should be considered.[13,14]
Seeds	Seed oil, phenolic acids, lignans, flavonoids, minerals	Caffeic acid, vanillic acid, morindolin, americanol, seed oil	Potential auxiliary material for nutritional or cosmetic products, although data remain limited compared with the fruit.[5,6]
Stem bark	Anthraquinones, phenolics, flavonoids, alkaloids, terpenoids	Morindone, rubiadin, and phenolic compounds	Limited data; further studies on quantification, safety, and application value are needed.[5,6]

1. Antioxidant Activity

Antioxidant activity is one of the most extensively studied directions for noni fruit and leaves. Several *in vitro* models, including DPPH, ABTS, and FRAP assays, show that noni extracts can scavenge free radicals or increase reducing capacity, particularly in fractions rich in polyphenols, flavonoids, and iridoids.[5,9] Fruit maturity, fruit part, and drying method clearly influence total phenolic content, ascorbic acid level, and antioxidant activity; incompletely ripe fruit may show higher antioxidant indices under some testing conditions.[15]

Mechanistically, polyphenols and vitamin C may participate in free-radical neutralization, whereas iridoids, polysaccharides, and coumarins may contribute to the regulation of oxidative stress and inflammatory responses. However, *in vitro* results cannot replace

evidence of biological efficacy in humans because bioavailability, metabolism, and dose may substantially alter actual effects.

2. Anti-inflammatory Activity

RAW 264.7 macrophage models, lipopolysaccharide (LPS)-activated systems, arthritis models, and colitis models have provided preclinical evidence for anti-inflammatory effects of noni. Leaf extracts containing scopoletin, epicatechin, and flavonoids may reduce inflammatory mediators such as nitric oxide (NO) and TNF-alpha, while also affecting the expression of genes related to inflammatory responses.[12] In fruit juice, compounds such as asperulosidic acid, rutin, nonioside A, and tricetin have been identified as inhibitors of LPS-induced inflammatory responses in macrophages.[16] Fruit-derived polysaccharides also reduced inflammatory markers in an experimental colitis model.[17]

These findings suggest that noni may be a source of natural anti-inflammatory agents. Nevertheless, most evidence remains at the cell or animal-model level. Translation to clinical application requires data on equivalent dosing, toxicity, and interactions with nonsteroidal anti-inflammatory drugs, corticosteroids, or immunomodulatory agents.

3. Antibacterial and Antifungal Activities

Noni fruit juice has shown inhibitory activity against several bacterial strains in agar diffusion assays, including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Proteus* spp.[18] Noni leaves also provide antibacterial compounds such as 5,15-dimethylmorindol, ferulic acid, p-hydroxycinnamic acid, methyl ferulate, and hydroxybenzoate/hydroxycinnamate derivatives.[19]

The significance of these data lies in the potential development of preservative, hygiene, cosmetic, or skin-care-support products. However, for the treatment of infections, MIC, MBC, spectrum of activity, host-cell toxicity, and possible effects on the normal microbiota must be determined.

4. Preclinical Anticancer Potential

Several extract fractions from noni fruit and leaves have been evaluated in cancer cell lines and animal models. Ethyl acetate extracts from the fruit inhibited the proliferation of MCF-7 and MDA-MB-231 breast cancer cell lines and reduced ROS generation in the investigated model.[21] Epicatechin- and scopoletin-rich noni leaves were reported to modulate pathways related to inflammation, angiogenesis, and apoptosis in leukemia models.[22] In a lung cancer model, leaf extract showed inhibitory effects on A549 cells and modulated endogenous antioxidant responses, apoptotic genes, and inflammatory responses.[23] Recent reviews also describe noni as a medicinal-plant source with anticancer potential while emphasizing the need for caution when extrapolating preclinical findings to human cancer treatment.[8]

From a pharmaceutical perspective, these data are valuable for guiding active-compound isolation, target investigation, and supportive-product development. Current evidence is not sufficient to regard noni as a cancer treatment or to recommend its use as a substitute for standard therapeutic regimens.

Table 2. Consolidated evidence on biological activities of *Morinda citrifolia* L. and implications for product development.

Activity	Plant part/form and model	Main findings	Potentially related compound groups	Evidence level and development implications
Antioxidant	Fruit and leaf extracts; fermented products; DPPH, ABTS, FRAP and related assays	Phenolics, iridoids, and secondary metabolites were associated with radical-scavenging or reducing capacity; fruit maturity and processing affected antioxidant indices.[5,9,15]	Polyphenols, flavonoids, vitamin C, iridoids, polysaccharides	Relatively consistent preclinical evidence. Standardization of extraction procedure, maturity, and quantitative markers is required before product claims are made.
Anti-inflammatory	Fruit juice compounds, leaf extracts, fruit-derived polysaccharides; LPS-stimulated RAW 264.7 macrophages, colitis and joint-related models	Asperulosidic acid, rutin, nonioside A, scopoletin, epicatechin, and polysaccharides were associated with reduced inflammatory mediators such as NO and TNF-alpha in experimental models.[12,16,17]	Scopoletin, epicatechin, rutin, asperulosidic acid, polysaccharides	Mechanistically plausible but mainly preclinical. Clinical studies and interaction assessment with anti-inflammatory or immunomodulatory drugs are needed.
Antibacterial / antifungal	Fruit juice agar diffusion assays; leaf fractions tested against selected bacterial strains	Fruit juice and leaf constituents showed inhibitory activity against selected microorganisms, including Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Proteus spp. in screening models.[18,19]	Phenolic acids, coumarins, indole/anthraquinone derivatives	Promising for hygiene-support, cosmetic, or preservative-oriented products. MIC, MBC, host-cell toxicity, and microbiota effects are needed for stronger application.
Glucose metabolism / hypoglycemic potential	Fermented fruit in high-fat-diet-induced obese mice; roots in streptozotocin-induced diabetic mice	Fermented fruit was associated with modulation of FoxO1-related signaling, while root constituents showed hypoglycemic effects in diabetic mouse models.[14,20]	Iridoids, anthraquinones, fermentation-derived metabolites	Promising for metabolic-disorder support, but not sufficient for therapeutic recommendation. Risk of hypoglycemia with antidiabetic medication requires careful evaluation.

Table 2. (Continued)

Activity	Plant part/form and model	Main findings	Potentially related compound groups	Evidence level and development implications
Preclinical anticancer potential	Fruit extracts in MCF-7 and MDA-MB-231 cells; leaf extracts in leukemia and A549 lung-cancer models; review-level synthesis	Extract fractions showed effects on cancer-cell proliferation, oxidative responses, inflammation, angiogenesis, apoptosis-related pathways, or related endpoints in preclinical models.[8,21-23]	Scopoletin, epicatechin, polyphenols, semi-polar fractions, anthraquinone-related constituents	Direction-setting preclinical evidence only. Selective toxicity, pharmacokinetics, long-term safety, and controlled clinical trials are required; noni should not be presented as a cancer
Neuroprotective / behavior-modulating potential	Scattered preclinical data and review-level interpretation, mainly inferred from antioxidant and anti-inflammatory mechanisms	Potential effects relate to oxidative-stress and inflammatory pathways, but disease-specific neurological models and active targets remain insufficiently defined.[5]	Polyphenols, flavonoids, iridoids, bioactive-rich fractions	Exploratory evidence. Active constituents, equivalent dosing, blood-brain-barrier relevance, and neurological safety need clarification.

5. Effects on Glucose Metabolism and Blood Glucose

Fermented noni fruit has been studied in the context of metabolic disorders. Some data indicate that fermented fruit juice may affect glucose metabolism through the regulation of the transcription factor FoxO1 in a high-fat-diet-induced obese mouse model.[20] Noni roots also contain iridoids and anthraquinones with hypoglycemic effects in streptozotocin-induced diabetic mice.[14] These findings are consistent with research directions on medicinal plants for supporting type 2 diabetes management.

However, blood-glucose control is a high-safety-demand area. Before broad recommendation, effective dose, risk of hypoglycemia when combined with antidiabetic drugs, effects on hepatic and renal function, and stability of fermented products must be clarified.

6. Neuroprotective and behavior-modulating potential

Available reviews and preclinical data suggest that noni may influence responses related to oxidative stress, inflammation, and neurological function, but studies specifically addressing neuroprotection remain limited.[5] Current data are scattered, lack specific neurological-disease models, and have not clearly identified the main active constituents or targets. Therefore, this activity group should be regarded only as an exploratory research direction requiring clarification of equivalent dosing and neurological safety before being interpreted in an application-oriented manner..

7. Evidence Stratification and Clinical Extrapolation

The biological activities of noni should not be

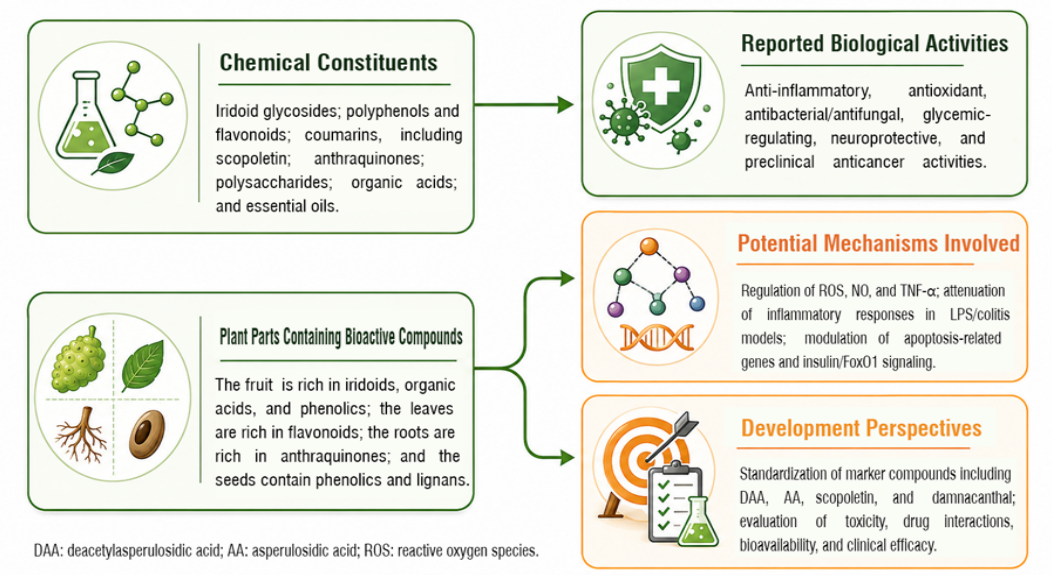


Figure 3. Integrated phytochemistry-bioactivity map of noni. Source: authors' synthesis

interpreted as having the same level of certainty. Based on the number of studies, reproducibility across models, and proximity to human application, current evidence can be stratified into three groups. The group with relatively consistent preclinical evidence includes antioxidant, anti-inflammatory, and antibacterial/antifungal activities because these effects have been repeatedly observed in chemical assays, cell systems, microorganisms, or animal models.[5,12,15,16,18,19] Even within this group, differences in plant part, extraction solvent, fruit maturity, fermentation procedure, and quantitative markers limit direct comparability among studies.

The group with promising but mainly mechanism-oriented evidence includes hypoglycemic, neuroprotective, and preclinical anticancer effects. Related studies often show notable biological signals, such as FoxO1 modulation in metabolic-disorder models, effects on behavioral or neurological mechanisms, or inhibition of cancer-cell proliferation.[5,8,14,20-23] Nevertheless, these results are insufficient to conclude therapeutic efficacy in humans because data on equivalent dose, pharmacokinetics, selectivity, long-term toxicity, and controlled clinical trials remain lacking.

The weakest evidence concerns specific clinical recommendations, including therapeutic indications, optimal dose, duration of use, appropriate patient groups, and drug-interaction risks. Thus, this paper regards noni as a potential source for product development, not as a source of evidence strong enough to replace drugs or standard treatment regimens. Such cautious interpretation should be maintained in future studies and in communication about noni-derived products. An integrated overview linking the major phytochemical constituents of noni with reported biological activities, potential mechanisms, and product-development perspectives is presented in **Figure 3.**

V. PRODUCT APPLICATIONS, SAFETY, AND STANDARDIZATION REQUIREMENTS

In practice, noni fruit is developed in many forms, including fresh juice, fermented fruit preparations, dried-fruit tea, fruit powder, capsules, extracts, and combinations in healthcare products. Leaves and roots are more common in folk remedies or experimental preparations, whereas seeds may provide oil for cosmetic or skin-care products. From a product-development perspective, fruit-based materials have the strongest commercial relevance because the fruit is easily recognized, has a longer history of food-related use, and has more chemical and processing data than other plant parts.[3,7]

Quality requirements should be defined separately for each product form. For fresh or pasteurized juice, relevant criteria include botanical authentication, fruit maturity, microbial limits, pH, soluble solids, organic acids, DAA, AA, scopoletin, and storage stability. For fermented preparations, the fermentation strain or spontaneous fermentation process, fermentation time, alcohol content where relevant, microbial safety, organic-acid profile, and stability of iridoids and phenolics should be controlled.[7] For dried-fruit tea and powders, moisture content, drying temperature, particle size, microbial contamination, heavy metals, pesticide residues, and marker-compound retention are important. For organic-solvent extracts or capsules, additional requirements include extraction solvent, drug-extract ratio, residual solvent, marker content, and batch-to-batch reproducibility.

A plant-part-specific marker strategy is essential. Fruit-based products should prioritize DAA and AA as iridoid markers, with scopoletin, total polyphenols, total flavonoids, and polysaccharides as complementary indicators.[10,11] Root-containing products should include anthraquinone-related controls, particularly damnacanthal or related constituents, because the root phytochemical profile differs from the fruit.[13,14] Whole-plant combinations should declare the proportion of each plant part and should not rely on fruit markers alone.

Safety assessment should also be product-specific. A history of traditional use and available safety data on noni fruit juice provide useful background information, but concentrated extracts, enriched fractions, fermented products, and multi-herbal combinations may have risk profiles different from traditionally consumed fruit.[24] Important safety endpoints include acute toxicity, subchronic toxicity, reproductive toxicity where relevant, hepatic and renal safety, allergenicity, microbial safety, and heavy-metal or solvent-residue contamination. Because noni preparations have been investigated in glucose metabolism, inflammation, and blood-circulation-related contexts, potential interactions with antidiabetic drugs, anticoagulants, antihypertensive agents, anti-inflammatory drugs, corticosteroids, and immunomodulatory agents should be evaluated before broad recommendations are made.

For clinical translation, the most realistic near-term direction is not to position noni as an independent therapeutic agent, but to develop

well-standardized healthcare products with cautious and evidence-appropriate claims. Exploratory clinical trials should use chemically characterized materials and clearly defined endpoints, such as oxidative-stress biomarkers, inflammatory markers, postprandial glucose or insulin-related indices, gastrointestinal tolerance, and quality-of-life indicators. Trial reports should specify dose, duration, product form, marker content, participant characteristics, concomitant medication, and adverse-event monitoring. Without these elements, preclinical activity cannot be reliably converted into product claims or therapeutic recommendations.

VI. DISCUSSION

The scientific value of noni lies in the combination of a diverse phytochemical profile and relatively consistent preclinical pharmacological signals. Compound groups such as iridoid glycosides, coumarins, polyphenols, flavonoids, polysaccharides, and anthraquinones provide a plausible basis for reported antioxidant, anti-inflammatory, antimicrobial, glucose-metabolism-related, and anticancer-related activities. However, this value currently remains mainly at the stage of medicinal-material development and is not sufficient to support therapeutic recommendations.

The major issue in current studies is heterogeneity. Fresh fruit, dried fruit, juice, fermented preparations, solvent extracts, leaf extracts, root extracts, and commercial products may differ markedly in chemical composition. Cultivation region, maturity, harvest time, drying, fermentation, and extraction solvent also influence the contents of DAA, AA, scopoletin, total polyphenols, and total flavonoids. When these markers are not adequately quantified, comparison among studies and extrapolation to practical applications become uncertain.

Data on hypoglycemic, neuroprotective, and anticancer-related effects require particular caution. Most evidence remains based on cell models, animal experiments, or whole extracts. These findings are useful for guiding mechanistic research and future study design, but they are not sufficient to consider noni as a therapeutic agent or as a substitute for standard treatment. This point should be emphasized to avoid overinterpretation in both research and product communication.

Regarding safety, a history of traditional use does not mean that all product forms are safe. Safety assessments of noni fruit juice provide useful background evidence, but concentrated extracts, fractions enriched in bioactive constituents, and combination products may have risk profiles different from those of traditionally consumed fruit.[24] Issues that require assessment include hepatic and renal toxicity, long-term toxicity, bioavailability, risk of active-constituent accumulation, and interactions with antidiabetic drugs, anticoagulants, antihypertensive agents, or anti-inflammatory drugs.

The most appropriate development direction at present is to establish noni products with clear quality specifications, adequate safety profiles, and cautious application targets. Future studies should prioritize raw-material standardization for each product form,

simultaneous quantification of key markers, control of microbial contamination, heavy metals, and solvent residues, and exploratory clinical trials with specific endpoints. This approach is more realistic than expanding efficacy claims beyond the current level of evidence.

VII. CONCLUSION

The noni plant (*Morinda citrifolia* L.) is a promising medicinal resource because different plant parts contain pharmacologically relevant constituents, including iridoid glycosides, polyphenols, flavonoids, coumarins, polysaccharides, anthraquinones, and lignans. Fruit-based materials have the strongest product-development relevance, whereas leaves, roots, seeds, and stem bark provide additional phytochemical and pharmacological evidence that should be interpreted in a plant-part-specific manner. Current data most consistently support preclinical antioxidant, anti-inflammatory, and antimicrobial activities, while glucose-metabolism-modulating, neuroprotective, and anticancer-related effects remain promising but insufficient for therapeutic extrapolation. The main challenges are heterogeneity of raw materials and extracts, limited bioavailability and pharmacokinetic evidence, insufficient long-term safety data, and a lack of controlled clinical trials using standardized products. Future development should prioritize botanical authentication, quantitative marker standardization, product-specific safety assessment, drug-interaction evaluation, and carefully designed clinical validation. With these requirements addressed, noni may be developed more rationally as a science-based medicinal material and noni-based healthcare product, rather than being promoted beyond the current level of evidence.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest related to this article.

FUNDING STATEMENT

This article received no commercial funding

ETHICS STATEMENT

This article is a literature review and involved no intervention in humans or animals.

DECLARATION ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence tools were used to support language editing, improve wording, and check spelling. These tools were not used to create data, modify data, analyze results, or replace the authors' expert judgment. The authors take full responsibility for the scientific content and conclusions of the article.

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