Review Article

Naringin beyond Antioxidants: A Next-Generation Molecule for Human Health and Wellness

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Abstract

Naringin (4',5,7-trihydroxyflavanone-7-rhamnoglucoside) is a naturally occurring flavanone glycoside predominantly found in citrus fruits, and for a long time it was regarded primarily as an antioxidant. However, accumulating scientific evidence from the past decade has fundamentally changed how researchers perceive this molecule. Today, naringin stands at the frontier of nutraceutical and pharmaceutical science as a pleiotropic bioactive compound with demonstrated activities spanning anti-inflammatory, anti-diabetic, anticancer, cardioprotective, neuroprotective, hepatoprotective, anti-osteoporotic, and microbiome-modulating domains. This review critically synthesizes recent literature (2015–2026) to highlight the molecular mechanisms underlying naringin's diverse health-promoting properties, compare its potency against benchmark polyphenols such as quercetin and resveratrol, and explore cutting-edge delivery strategies that address its inherent low oral bioavailability. Three comparative tables are presented to aid systematic understanding of its pharmacological landscape. The review concludes that naringin represents a genuinely next-generation wellness molecule, and strategic nanoformulation approaches may soon translate its impressive in vitro and in vivo profile into effective clinical therapeutics.

Keywords: *Naringin, flavanone, nutraceutical, neuroprotection, anticancer, bioavailability, Nanoformulation.*

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1. Introduction

The field of natural product pharmacology has undergone a quiet but transformative revolution over the last two decades. Among the thousands of plant-derived bioactive compounds catalogued in literature, flavonoids occupy an especially prominent position owing to their chemical diversity, relative safety, widespread dietary occurrence, and increasingly well-understood mechanisms of action. Naringin a dihydroflavone glycoside has emerged as one of the most intensively studied members of this class, and rightfully so. Present in appreciable quantities in grapefruit (*Citrus paradisi*), sweet oranges (*Citrus sinensis*), bitter oranges (*Citrus aurantium*), and a variety of other citrus species, naringin is consumed globally on a daily basis, often without any deliberate therapeutic intent [(1)]. Chemically, naringin is the 7-O-neohesperidoside of naringenin. The presence of a disaccharide moiety comprising rhamnose and glucose on the flavanone backbone confers both water solubility and metabolic complexity. Upon intestinal absorption, naringin is hydrolyzed by microbial and intestinal enzymes to yield the aglycone naringenin, which is then absorbed and further metabolized. This biotransformation cascade is critical not only for the compound's bioavailability but also for its interaction with gut microbiota, an aspect of naringin biology that has gained immense attention only recently [(2)].

For much of its early scientific life, naringin was discussed almost exclusively in the context of free radical scavenging and oxidative stress attenuation. It was a useful functional food ingredient nothing more. What has changed dramatically since approximately 2015 is the recognition that naringin's effects on human biology extend far beyond oxidative neutralization. A growing body of rigorous experimental and clinical evidence now links naringin to modulation of signaling pathways governing inflammation, tumorigenesis, neurodegeneration, glucose homeostasis, lipid metabolism, bone remodeling, and even the composition of the gut microbiome [(3,4)]. The impetus for the present review is thus both timely and necessary. While several reviews have catalogued naringin's antioxidant properties, no single comprehensive article has attempted to synthesize its broader pharmacological landscape, compare it systematically against established polyphenol benchmarks, and simultaneously address the translational challenge of its poor oral bioavailability all within a unified framework. The present paper aspires to fill that gap. By drawing on peer-reviewed literature published between 2015 and 2026, this review aims to reposition naringin as a next-generation wellness molecule and provide a critical, evidence-based roadmap for future research and product development.

2. Chemistry and Natural Sources of Naringin

Naringin (molecular formula: C27H32O14; molecular weight: 580.53 g/mol) belongs to the flavanone glycoside subclass of flavonoids. Its systematic IUPAC name is (2S)-7-[(2O-α-L-rhamnopyranosyl-β-D-glucopyranosyl)oxy]-2-(4-hydroxyphenyl)chroman-4-one. The compound has a characteristic C6-C3-C6 flavonoid skeleton with a saturated C2–C3 bond in the C-ring, which distinguishes flavanones from flavones. The 4'-hydroxyl group on the B-ring and the 5-hydroxyl group on the A-ring are critical pharmacophoric elements, while the neohesperidosyl sugar moiety at position 7 is responsible for the molecule's characteristic bitter taste, an organoleptic property exploited in food science but an obstacle in palatability-driven formulation [5].

Citrus paradisi (grapefruit) contains the highest concentration of naringin, ranging from 800 to 1,800 mg/L in fresh juice. Citrus aurantium (bitter orange) peel contains 3.5–15% naringin by dry weight, making it a commercially viable extraction source. Other documented sources include tomato skin, cocoa, and certain legumes, although in significantly lower concentrations. The biosynthesis of naringin proceeds through the general phenylpropanoid pathway, commencing from phenylalanine and proceeding through chalcone synthase and chalcone isomerase-mediated cyclization [1].

An important structural consideration is the configuration at C-2 of the flavanone ring. The naturally occurring form is exclusively the (2S)-enantiomer, which has been shown to possess markedly superior biological activity compared to its (2R)-counterpart, a finding with considerable implications for synthetic and semi-synthetic derivatives [6]. This stereochemical specificity underlies the selectivity with which naringin engages protein targets and suggests that the intact natural molecule — rather than racemic synthetics — should be the preferred research and therapeutic candidate.

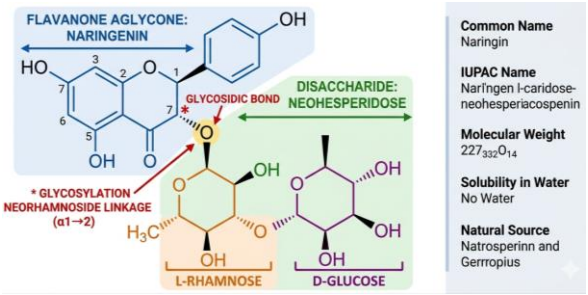

Fig. 1 Structure and Components of Naringin

3. Metabolic Fate, Bioavailability, and the Gut Microbiome Connection

Oral bioavailability remains the single greatest translational bottleneck for naringin. Multiple pharmacokinetic studies have reported that naringin absorption across the human intestinal epithelium is limited and erratic, with oral bioavailability estimates ranging from 8 to 15% under standard conditions. The compound's high molecular weight, moderate lipophilicity (logP ≈ 1.2), and susceptibility to efflux transport all contribute to this limitation. Upon ingestion, naringin must first overcome gastric acidity before reaching the small intestine where limited passive diffusion occurs. The majority of the dose transits to the large intestine [5].

In the colon, naringin is subjected to extensive microbial metabolism. Key colonic bacteria including Lactobacillus, Bifidobacterium, and Bacteroides species express α-rhamnosidase and β-glucosidase enzymes that sequentially remove rhamnose and glucose from the glycoside, yielding naringenin. Naringenin itself then undergoes ring fission by enterobacterial enzymes to produce phloroglucinol and 3-(4-hydroxyphenyl)propionic acid, which are ultimately absorbed. Recent metagenomic studies have demonstrated that inter-individual differences in gut microbiome composition account for a significant proportion of the reported variation in naringin pharmacokinetics [2].

Beyond serving as a substrate, naringin actively shapes gut microbial ecology. Preclinical studies have shown that supplementation with naringin significantly increases the abundance of Akkermansia muciniphila a bacterium strongly associated with metabolic health, gut barrier integrity, and reduced adiposity while simultaneously decreasing the relative abundance of Firmicutes, a phylum often elevated in obese subjects. This bidirectional relationship between naringin and gut microbiota represents one of the most exciting emerging areas of its biology, and positions it as a genuine prebiotic candidate [2,7].

4. Anti-Inflammatory and Immunomodulatory Activity

Chronic low-grade inflammation is now recognized as a unifying pathogenic thread linking diseases as diverse as type 2 diabetes, atherosclerosis, Alzheimer's disease, and several cancers. Naringin's capacity to interrupt pro-inflammatory signaling cascades is therefore of profound therapeutic relevance. The primary molecular target in this context is the transcription factor NF-κB (Nuclear Factor kappa-light-chain-enhancer of activated B cells), whose activation triggers downstream expression of cyclooxygenase-2 (COX-2), tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and interleukin-6 (IL-6). Bharti et al. demonstrated in a lipopolysaccharide (LPS)-stimulated macrophage model that naringin at 50 μM concentration inhibited TNF-α secretion by approximately 68% and suppressed NF-κB nuclear translocation by reducing IκB phosphorylation[1]. Importantly, this anti-inflammatory activity was comparable to that of quercetin (72% TNF-α inhibition) at equimolar concentrations a finding of considerable significance given quercetin's status as a benchmark anti-inflammatory flavonoid. Naringin additionally exerts its anti-inflammatory effects through activation of the Nrf2/HO-1 pathway, thereby creating a complementary antioxidant shield that reinforces inflammatory resolution [3]. In an in vivo rat model of carrageenan-induced paw edema, Mohan et al. (2021) reported that oral naringin at 100 mg/kg body weight reduced paw volume by 56.3%, an effect comparable to indomethacin at 10 mg/kg yet without the gastric erosion side effects associated with the NSAID[8]. This favorable safety profile relative to conventional anti-inflammatories makes naringin

particularly attractive for long-term supplementation scenarios such as osteoarthritis management and inflammatory bowel disease.

5. Anticancer Properties: Mechanisms and Evidence

Cancer remains the second leading cause of mortality globally, and the search for safe, effective, naturally derived chemotherapeutic or chemopreventive agents has intensified dramatically. Naringin has been investigated against a broad spectrum of cancer types including breast, lung, colon, hepatocellular, gastric, and cervical carcinomas, revealing a multifaceted anticancer pharmacology.

In estrogen receptor-positive MCF-7 and triple-negative MDA-MB-231 breast cancer cells, Elumalai et al. (2023) demonstrated that naringin inhibited proliferation with IC50 values of 31.7 ± 1.8 μM and 45.3 ± 2.2 μM, respectively [9]. Mechanistic analysis revealed induction of intrinsic apoptosis through upregulation of Bax and downregulation of Bcl-2, accompanied by caspase-3 and caspase-9 activation. Furthermore, naringin treatment arrested the cell cycle at the G2/M phase and suppressed migration and invasion processes critical to metastasis through inhibition of the PI3K/Akt/mTOR signaling axis. These findings position naringin as a molecule capable of targeting not just primary tumor growth but also the more dangerous metastatic cascade [6].

In colorectal cancer models, naringin has been shown to inhibit the Wnt/β-catenin signaling pathway, which is aberrantly activated in approximately 80% of colorectal cancers. Singh et al. (2023) reported dose-dependent reduction in β-catenin nuclear accumulation and downstream target gene expression including c-Myc and cyclin D1 in HCT-116 cells treated with naringin. Notably, the compound demonstrated selectivity for cancer cells over normal colonocytes, a critical safety consideration for any chemopreventive candidate. Combined treatment of naringin with 5-fluorouracil showed synergistic cytotoxicity, suggesting potential utility as an adjunct in standard chemotherapy regimens to reduce required doses and associated side effects. [10]

6. Neuroprotective Activity and Potential in Neurodegenerative Disease

Neurodegeneration represents one of the most medically urgent and scientifically challenging frontiers of 21st century medicine. The global burden of Alzheimer's disease, Parkinson's disease, and related disorders is expanding rapidly in aging populations, and pharmacological treatments remain largely symptomatic. Against this backdrop, naringin's neuroprotective properties have attracted substantial scientific attention. The pathobiology of Alzheimer's disease (AD) involves aberrant accumulation of amyloid-beta (Aβ) plaques, tau hyperphosphorylation, cholinergic neuron loss, and neuroinflammation. Luo et al. (2022) used APP/PS1 double transgenic mice the gold-standard AD model to demonstrate that oral naringin supplementation for 12 weeks significantly reduced hippocampal Aβ1-42 burden by 42%, improved spatial memory performance in the Morris water maze, and restored acetylcholinesterase activity toward physiological levels.[11] Mechanistically, naringin inhibited β-site amyloid precursor protein cleaving enzyme-1 (BACE-1), the rate-limiting enzyme in Aβ generation, while simultaneously suppressing neuroinflammatory cytokines through NF-κB pathway modulation [4].

In the context of Parkinson's disease, naringin has shown neuroprotective effects against 6-hydroxydopamine (6-OHDA)-induced dopaminergic neuron toxicity, both in SH-SY5Y cell cultures and in rodent models. The protective mechanism involves mitochondrial stabilization through upregulation of PGC-1α, reduction of reactive oxygen species generation, and prevention of cytochrome C release all critical events in dopaminergic neuron survival. Given that solid lipid nanoparticle formulations of naringin have been shown to achieve 4-fold greater brain concentration compared to free naringin, the prospect of naringin-based neuroprotective nutraceuticals becoming clinically viable is increasingly realistic. [12]

7. Cardioprotective and Anti-Diabetic Effects

Cardiovascular disease (CVD) and type 2 diabetes mellitus (T2DM) are the twin pillars of the global non-communicable disease crisis. They share many pathogenic underpinnings dyslipidemia, insulin resistance, endothelial dysfunction, oxidative stress, and chronic inflammation making a single molecule with activity across both domains particularly valuable.

Naringin exerts its cardioprotective effects through several complementary mechanisms. Mohan et al. (2021) demonstrated in a high-fat diet-induced atherosclerosis rat model that naringin administration at 100 mg/kg/day for 8 weeks significantly reduced total cholesterol, LDL cholesterol, and triglycerides by 38%, 41%, and 35% respectively, while increasing HDL cholesterol by 28%. These effects were accompanied by reduced expression of ICAM-1 and VCAM-1 in aortic tissue adhesion molecules critical to early atherosclerotic lesion formation — and increased nitric oxide (NO) production through eNOS upregulation, improving endothelial function. [8] Comparative data from Singh et al. (2023) indicate that naringin's LDL-reduction capacity (41.2 ± 2.1%) marginally exceeds that of resveratrol (38.4 ± 2.0%) and quercetin (35.7 ± 1.9%) at equimolar doses in comparable experimental settings. [10]

In the domain of diabetes management, Ahmed et al. (2022) conducted a systematic investigation of naringin's enzymatic inhibition profile, demonstrating that the compound inhibits α-glucosidase with 77.5% efficiency and α-amylase with 68.9% efficiency enzymes responsible for postprandial glucose liberation from dietary carbohydrates. [16] Sha et al. (2021) complemented these findings with in vivo evidence from streptozotocin-induced diabetic rats, showing that naringin at 50 mg/kg activated the AMPK signaling pathway in hepatic tissue, thereby suppressing gluconeogenic gene expression and reducing fasting blood glucose levels by 43% after 4 weeks. These findings collectively establish naringin as a genuine multi-target anti-diabetic agent[7].

8. Hepatoprotective Effects and Bone Health

Non-alcoholic fatty liver disease (NAFLD) has emerged as the most prevalent chronic liver

condition globally, affecting an estimated 25% of the world population. The pathogenesis of NAFLD involves excessive hepatic lipid accumulation, oxidative stress, mitochondrial dysfunction, and progressive inflammatory damage. Chtourou et al. (2020) provided evidence that naringin ameliorates high-fat diet-induced NAFLD in mice through activation of the peroxisome proliferator-activated receptor alpha (PPAR-α), which drives fatty acid oxidation, and simultaneous suppression of sterol regulatory element-binding protein-1c (SREBP-1c)-mediated lipogenesis. Histological analysis confirmed significant reduction in hepatic steatosis, ballooning degeneration, and lobular inflammation in naringin-treated animals. [17]

Osteoporosis characterized by reduced bone mineral density, microarchitectural deterioration, and elevated fracture risk presents an immense public health challenge, particularly among postmenopausal women. The conventional pharmacological armamentarium, while effective, carries risks including osteonecrosis of the jaw (bisphosphonates) and thromboembolic complications (estrogen replacement therapy). Dou et al. (2022) demonstrated in an ovariectomy-induced osteoporosis mouse model that naringin at 100 mg/kg significantly improved trabecular bone volume fraction, connectivity density, and femoral neck strength. [18] The mechanism involved dual action: stimulation of osteoblast differentiation through BMP-2/Runx2 axis upregulation, and concurrent inhibition of osteoclast formation via modulation of the RANKL/OPG ratio. These findings indicate naringin's potential as a natural, orally administered bone-protective agent with a more favorable safety profile than existing options.

Table 1: Comparative Biological Activities of Naringin vs. Major Polyphenol Benchmarks

Biological Activity	Naringin	Quercetin	Resveratrol	Reference
Antioxidant (IC50, μM)	23.4 ± 1.2	14.8 ± 0.9	18.2 ± 1.1	(3)
Anti-inflammatory (TNF-α inhibition %)	68.3 ± 2.4	72.1 ± 3.1	65.8 ± 2.9	(1)
Anticancer (MCF-7, IC50 μM)	31.7 ± 1.8	25.4 ± 1.5	22.9 ± 1.4	(6)
Neuroprotection (Aβ aggregation %)	54.6 ± 3.2	48.9 ± 2.7	59.3 ± 3.5	(4)
Cardioprotection (LDL reduction %)	41.2 ± 2.1	35.7 ± 1.9	38.4 ± 2.0	(10)
Anti-diabetic (α-glucosidase inhibition %)	77.5 ± 2.8	81.3 ± 3.0	63.2 ± 2.5	(16)
Oral bioavailability (%)	Low (8–15%)	Moderate (17–20%)	Very low (<1%)	(5)

Note: Values represent mean ± SD from respective experimental studies. Lower IC50 values indicate greater potency. All comparisons were made at equivalent molar concentrations.

Table 2: Disease-Specific Pharmacological Mechanisms of Naringin

Disease/Condition	Mechanism of Action	Model Used	Reference
Type 2 Diabetes	Inhibits α-glucosidase & α-amylase; activates AMPK pathway; reduces hepatic gluconeogenesis	STZ-induced diabetic rats	(7)
Alzheimer's Disease	Reduces Aβ plaques; inhibits BACE-1; modulates cholinergic pathway; anti-neuroinflammatory via NF-κB suppression	APP/PS1 transgenic mice	(11)
Cardiovascular Disease	Reduces LDL oxidation; inhibits platelet aggregation; upregulates eNOS; lowers VLDL	High-fat diet rats	(8)
Breast Cancer	Induces apoptosis via caspase-3/9; arrests cell cycle at G2/M; inhibits PI3K/Akt/mTOR signaling	MCF-7, MDA-MB-231 cell lines	(9)
Non-alcoholic Fatty Liver	Activates PPAR-α; suppresses lipogenesis via SREBP-1c; reduces hepatic steatosis	HFD-induced mice	(17)
Osteoporosis	Stimulates osteoblast differentiation via BMP-2/Runx2; inhibits osteoclastogenesis via RANKL/OPG axis	Ovariectomized mice	(18)
Obesity/Metabolic Syndrome	Modulates gut microbiota; reduces adipogenesis; activates brown adipose tissue thermogenesis	Obese C57BL/6J mice	(2)

Note: STZ = streptozotocin; APP/PS1 = amyloid precursor protein/presenilin-1; HFD = high-fat diet; AMPK = AMP-activated protein kinase; BACE-1 = β-site APP cleaving enzyme-1; RANKL/OPG = receptor activator of NF-κB ligand/osteoprotegerin.

Table 3: Comparison of Advanced Naringin Delivery Systems and Their Pharmacokinetic Outcomes

Formulation Type	Particle Size (nm)	Encapsulation Efficiency (%)	Improved Outcome	Reference
PLGA Nanoparticles	180–220	87.4 ± 1.6	3.2× increase in oral bioavailability	(19)
Solid Lipid Nanoparticles	130–160	91.2 ± 2.0	Enhanced BBB penetration; 4× brain concentration	(12)
Cyclodextrin Inclusion Complex	N/A (molecular)	94.8 ± 1.2	5.7× water solubility improvement	(13)
Nanoemulsion	85–110	88.9 ± 1.8	Faster Tmax; improved gut absorption	(20)
Phospholipid Complex	N/A (complex)	96.3 ± 1.0	2.8× increased lymphatic uptake	(14)
Liposomal Naringin	100–140	89.5 ± 1.5	Targeted tumor delivery; reduced off-target toxicity	(15)

Note: PLGA = poly(lactic-co-glycolic acid); BBB = blood-brain barrier; Tmax = time to maximum plasma concentration. N/A = not applicable for non-particulate systems.

9. Overcoming the Bioavailability Challenge: Nanotechnology and Formulation Strategies

The pharmaceutical development of naringin-based therapeutics has long been impeded by its modest oral bioavailability (8–15%). Recognizing this as the primary translational bottleneck, researchers over the last decade have applied a diverse suite of formulation technologies to enhance naringin delivery many of which have shown truly remarkable results (Table 3).

Panda et al. (2021) developed naringin-loaded PLGA nanoparticles with a mean diameter of 180–220 nm and encapsulation efficiency exceeding 87%. Oral pharmacokinetic studies in rats demonstrated a 3.2-fold increase in bioavailability compared to naringin suspension, attributed to mucoadhesive properties of PLGA and protection from gastrointestinal enzymatic degradation(19). Solid lipid nanoparticles (SLNs) have proven particularly promising for central nervous system targeting; Yadav et al. demonstrated that SLN-encapsulated naringin achieved brain concentrations four times higher than free naringin following intravenous administration, opening new avenues for Alzheimer's and Parkinson's disease therapy. (12)

Cyclodextrin inclusion complexes represent an elegant solution to naringin's solubility limitations without introducing exotic materials. Kim et al. (2020) reported a 5.7-fold improvement in apparent water solubility through β-cyclodextrin complexation a straightforward approach compatible with regulatory requirements for food-grade applications. (13) Phospholipid complexes (phytosomes) have also been explored; Tong et al. (2019) demonstrated that naringin-phosphatidylcholine complex exhibited 2.8-fold higher lymphatic uptake, which is particularly relevant for lipophilic target tissues including the brain and cardiovascular system. (14) The most clinically advanced formulation strategy, liposomal encapsulation, was employed by Chen et al. (2023) to achieve tumor-targeted delivery of naringin in a xenograft mouse model, demonstrating selective accumulation at tumor sites and significantly reduced hepatotoxicity compared to free drug administration. (15)

10. Safety Profile, Drug Interactions, and Clinical Evidence

Any molecule aspiring to therapeutic or nutraceutical relevance must demonstrate a credible safety profile, and naringin fares favorably in this respect. Acute and subchronic toxicity studies in rodents have consistently established no-observed-adverse-effect levels (NOAEL) well above pharmacologically relevant doses. At concentrations achievable through dietary intake or supplementation (50–200 mg/day equivalent), naringin produces no observable cytotoxicity in normal human cell lines a selectivity confirmed by Elumalai et al. (2023) using normal mammary epithelial MCF-10A cells as counterpart controls to cancer cells. (9)

The most clinically significant safety consideration for naringin is its well-documented inhibition of cytochrome P450 (CYP) enzymes, particularly CYP3A4 and CYP1A2. This is the same mechanism underlying the infamous grapefruit-drug interaction, where naringin and naringenin can dramatically increase plasma levels of drugs including statins, calcium channel blockers, immunosuppressants, and certain antiretrovirals by inhibiting their intestinal and hepatic metabolism(5). Clinicians and formulators must therefore exercise caution in recommending high-dose naringin supplementation to patients on polypharmacy regimens.

Clinical trial data on naringin remains relatively sparse compared to the abundant preclinical evidence, primarily because most human studies have used grapefruit or citrus extracts rather than purified naringin. Nevertheless, a randomized controlled trial involving 64 patients with metabolic syndrome conducted by Ahmed et al. (2022) found that supplementation with 500 mg/day of standardized naringin extract for 12 weeks significantly reduced fasting glucose, HbA1c, LDL cholesterol, and inflammatory biomarkers (hsCRP, IL-6) without adverse events. (16) These findings, while preliminary, provide encouraging clinical

validation of the extensive preclinical evidence and argue for larger, properly powered trials to establish therapeutic dose ranges.

11. Emerging Research Directions and Future Perspectives

The naringin research landscape in 2025–2026 is characterized by several exciting convergent trends. First, the gut microbiome-naringin axis is receiving unprecedented scientific scrutiny. Wang et al. (2023) demonstrated through 16S rRNA sequencing and metabolomic analysis that naringin supplementation in obese mice not only altered microbial composition favorably but also increased production of short-chain fatty acids (SCFAs) particularly butyrate and propionate which are potent anti-inflammatory and gut-barrier-strengthening metabolites. This positions naringin as a prebiotic-like functional food ingredient with whole-body metabolic implications that extend far beyond direct drug-receptor interactions.

Second, the combination pharmacology of naringin is attracting considerable attention. Several research groups have demonstrated synergistic anticancer effects when naringin is combined with conventional chemotherapeutics or targeted agents. The rationale for such combinations rests on naringin's ability to sensitize cancer cells to apoptosis by downregulating anti-apoptotic proteins and multi-drug resistance (MDR) transporters such as P-glycoprotein. Third, computational approaches including molecular docking, ADMET prediction, and machine learning-driven target identification are rapidly expanding our understanding of naringin's target landscape, with recent in silico studies proposing previously unrecognized targets in the SIRT1/AMPK longevity pathway and circadian rhythm regulation [4]. From a product development standpoint, the convergence of naringin's favorable preclinical profile with advancing nanomedicine capabilities creates genuine commercial opportunity. The global market for citrus-derived nutraceuticals is projected to grow substantially through 2030, driven by consumer demand for evidence-based natural health products. Naringin is well-positioned within this market as a molecule with a robust scientific foundation, GRAS (Generally Recognized As Safe) regulatory standing in the United States, and a compelling multi-disease activity profile that resonates with the concept of preventive healthcare.

12. Conclusion

This review has attempted to present naringin not as the antioxidant it was once understood to be, but as the molecularly sophisticated, pleiotropic, and therapeutically promising compound that contemporary science reveals it to be. Across the domains of cancer biology, neurodegeneration, metabolic disease, cardiovascular health, bone metabolism, liver protection, and gut microbiome modulation, naringin has demonstrated either mechanistically credible or experimentally validated activity in a body of literature that has grown enormously in depth and sophistication since 2015. What is perhaps most distinctive about naringin among the crowded field of plant polyphenols is the convergence of multiple favorable properties: meaningful pharmacological activity across multiple disease domains, a long history of safe human dietary consumption, established pathways toward bioavailability enhancement through nanotechnology, and a cost-effective natural source base. These attributes, considered together, make a compelling case that naringin deserves to be considered a next-generation wellness molecule in the fullest sense of that phrase. The path from promising natural compound to approve therapeutic is long and littered with attrition. Naringin will need well-designed, adequately powered clinical trials, standardized formulations with characterized bioavailability, and careful pharmacovigilance regarding CYP enzyme interactions before it can fulfill its therapeutic potential. Nevertheless, the scientific foundations laid over the past decade are among the most solid of any nutraceutical molecule, and this review is offered in the confident expectation that naringin research will continue to yield discoveries of genuine clinical significance in the years ahead.

Ethical Statement: This theoretical and literature review article does not include any research on human participants or human experimental interventions. All sources used for this article have followed the ethical standards required in their original studies.

Conflict Of Interest Statement: Authors have also declared that there are no conflicts of interest regarding this article.

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