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Role of Wood Apple (Limonia Acidissima L.) in Herbal Drug Development and Nutraceutical Applications

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Abstract : *Wood apple (Limonia acidissima L.), a hardy Rutaceae tree of the Indian subcontinent, is valued as both a food and a traditional medicine. This review aims to evaluate its role in herbal drug development and nutraceutical applications. A curated set of 17 publications from 2005 to 2025, comprising review articles and primary experimental studies, was examined, and data on botany, nutrition, phytochemistry, pharmacology, safety and applications were extracted and organised. The plant supplies carbohydrates, fibre, vitamins and minerals together with phenolics, flavonoids, coumarins, tannins, terpenoids and polysaccharides. Experimental studies report antioxidant, antimicrobial, antidiabetic, antihyperlipidemic, hepatoprotective, wound-healing and larvicidal activities, and leaf extract has served as a reducing agent for silver and zinc oxide nanoparticles. Fruit powder has been used to fortify bakery products. Most evidence, however, is preclinical, standardisation is incomplete, toxicological data are limited and clinical trials are lacking. Wood apple therefore shows considerable promise as a source of herbal medicines and functional foods, but progress depends on chemical standardisation, mechanistic and safety studies, and well-designed human trials*

Keywords: *Limonia acidissima*; wood apple; herbal drug development; nutraceuticals; phytochemistry; antioxidant.

I. INTRODUCTION

Plants have supplied medicines to humankind for as long as records exist, and a large share of modern drugs trace their origin to plant-derived leads. Interest in herbal products has grown because many people prefer treatments perceived as natural, because chronic lifestyle diseases need long-term low-toxicity options, and because the boundary between food and medicine has been blurred by the idea of the nutraceutical: a food or food-derived product that offers health benefits beyond basic nutrition. In this setting, under-utilised fruits that are both edible and medicinal are attractive, since they can be developed as foods, supplements and drug leads at the same time.

Wood apple (*Limonia acidissima* L., synonym *Feronia limonia*; family Rutaceae) is a good example. It grows wild and is cultivated across the Indian subcontinent, is inexpensive, tolerates dry conditions, and is eaten fresh or as beverages, jams, chutneys and sweets. Several review articles have gathered its traditional and pharmacological profile [1-3,5,6,9,10,17], and primary studies have examined its nutrition, antioxidant power, antimicrobial effect, antidiabetic activity, liver protection and wound healing [4,7,11-16]. A newer line of work uses its leaf extract to synthesise metal nanoparticles [8]. These reports, however, are scattered across journals of very different standards, and no single account links the botanical, chemical, pharmacological and technological findings to the practical question of product development.

The purpose of this review is therefore to critically summarise the existing knowledge on wood apple and to evaluate its role in herbal drug development and nutraceutical applications. The specific objectives are to describe the botanical

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identity and ethnomedicinal background of the plant; to present its nutritional and phytochemical profile; to review the pharmacological activities supported by experimental evidence; to examine its use in green nanoparticle synthesis and functional foods; and to discuss safety, quality control and the challenges that must be overcome before commercial and clinical use. The working premise is that the plant combines enough nutritional value and bioactive chemistry to justify a structured development programme, provided that standardisation, safety and clinical evidence are strengthened.

II. METHODOLOGY

Data sources

This narrative review is based on a curated set of 17 publications on *L. acidissima* (including its synonym *F. limonia*) published between 2005 and 2025 in pharmaceutical, phytochemical, food-science and biological journals. The set comprises review articles and primary experimental or descriptive studies and is listed in the References section. No claims were drawn from sources outside this set unless they are general botanical or pharmacological background stated without numerical data.

Study selection

Publications were retained when they dealt specifically with the botany, nutrition, phytochemistry, pharmacology, toxicology, food use or technological use of the plant. Work on other species of the genus or family was not considered. Reviews were used to build the overall picture, while primary studies were used to support individual activities and applications.

Data extraction and synthesis

For each publication, the plant part, type of extract, experimental model, main outcome and any stated limitation were noted. The findings were then grouped under botanical, nutritional, phytochemical, pharmacological, technological, safety and development themes and combined in a qualitative synthesis. Because the studies differ widely in design, extracts and outcomes, no quantitative pooling or meta-analysis was attempted.

III. RESULTS AND DISCUSSION

3.1 Overview of the evidence

The reviewed literature links plant parts, chemical constituents, biological activities and possible applications in a chain that is summarised in Figure 1. The sections below follow this chain from botany to development.

3.2 Taxonomy and botanical description

The plant is a slow-growing, medium-sized tree, usually 9 to 12 metres tall, with rough greyish bark, sharp spines on the branches and a spreading crown. The leaves are pinnately compound with small leaflets and give off an aniseed-like or citrus-like odour when crushed, owing to their volatile oil. Flowers are small, reddish or greenish, in loose clusters. The fruit is a large, round, woody-shelled berry, grey to brownish, which must be cracked open to reveal a brown, sticky, aromatic pulp holding many small whitish seeds. The tree also exudes a gum from the stem, used traditionally as an adhesive and soothing agent [1,2,5]. The botanical profile is summarised in Table 1.

3.3 Distribution and ethnomedicinal uses

The species is native to India and Sri Lanka and has spread to Bangladesh, Myanmar, Thailand, Cambodia, Vietnam, Java and other warm regions, where it is grown in home gardens and found in the wild [2,5,6]. Because it withstands drought and poor soils, it is regarded as a useful species for dryland agriculture and food security in marginal areas.

Ayurveda, Siddha and folk practice use different parts of the plant for different ends. The ripe pulp is considered cooling and is taken as a digestive and a remedy for sore throat and hiccups. The unripe fruit is used as an astringent in diarrhoea and dysentery. Leaves are used for indigestion, flatulence and skin complaints, while bark and gum are used for wounds and as a tonic [1,3,10,17]. Table 2 summarises these uses together with the type of modern evidence that relates to each.

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3.4 Nutritional composition

For a plant to serve as a nutraceutical it must first be a good food, and wood apple qualifies. The edible pulp supplies carbohydrates, mainly sugars, along with protein, small amounts of fat and a notable amount of dietary fibre. It carries vitamins, particularly vitamin C and members of the B group, and minerals such as calcium, phosphorus, iron and potassium. Analyses also show organic acids, which give the fruit its characteristic tang, and a good level of phenolic compounds [7,11]. Because the exact proportions depend on cultivar, maturity, soil and method of analysis, reported figures vary between studies, and Table 3 therefore describes the relative contribution of each component rather than fixed values.

The description of the fruit as a versatile and nutritious food of India [11] reflects the range of products already made from it, including fresh pulp beverages, squash, jam, jelly, toffee, chutney and powders. A study in which fruit powder was used to fortify biscuits and produce a phenolic-enriched bakery product [4] shows that the pulp withstands processing and can raise the antioxidant value of a common food, which is the essence of nutraceutical development.

3.5 Phytochemistry

The pharmacological interest in wood apple rests on its chemistry. Preliminary phytochemical screening of the fruit, leaves, bark and other parts has repeatedly revealed several classes of secondary metabolites [7,13]. Reviews list coumarins, flavonoids, phenolic acids, tannins, terpenoids and triterpenoids, saponins, alkaloids, sterols, volatile oil components, fatty acids and polysaccharides such as gum [1,2,10,17]. Coumarins, which are typical of the Rutaceae, and tannins are especially characteristic (Table 4).

Two points deserve emphasis. First, most reports are screening-level: a class is detected by a colour reaction or a chromatographic profile, but individual compounds are seldom isolated, quantified and tested for activity. Second, the content of each class varies with plant part, extraction solvent, season and geography, so the chemistry of one batch may not match another. These limits are the main obstacles to standardisation (Section 3.12).

3.6 Pharmacological activities

The experimental literature covers a wide spectrum of biological effects. Most of the work was done in vitro or in rodents, and each activity is described below in the light of what the supporting studies show. Table 5 gives a summary.

Antioxidant activity

Oxidative stress, an imbalance between reactive oxygen species and the body's defences, underlies ageing, diabetes, liver injury, inflammation and many other disorders. Plant phenolics and flavonoids are among the best-known natural antioxidants. Pulp, leaf and bark extracts of wood apple show radical-scavenging and reducing activity in chemical assays, and the antioxidant capacity tracks with the phenolic content of the extract [7,14,16]. The same property has been reported in animal models, where fruit pulp raised antioxidant defences in tissues examined during wound healing and liver injury [14,16]. Antioxidant action is probably the most unifying mechanism in the plant, since it plausibly contributes to its protective effects on liver, skin and metabolism.

Antimicrobial activity

Plant parts have been tested against Gram-positive and Gram-negative bacteria and, in some cases, fungi. Preliminary studies of leaf, bark, fruit and other parts demonstrated antibacterial activity linked to their phytochemical content, and the choice of solvent and plant part strongly influenced the result [7,13]. The activity is generally attributed to tannins, coumarins, phenolics and volatile oils, which can damage microbial membranes, precipitate proteins and interfere with enzymes. Silver and zinc oxide nanoparticles prepared with leaf extract also showed antibacterial action [8]. These findings support the traditional use of the plant in diarrhoea, dysentery and infected wounds, though minimum inhibitory concentrations, mechanisms and activity against resistant strains still require rigorous work.

Antidiabetic and antihyperlipidemic activity

Diabetes and dyslipidaemia are among the commonest long-term conditions in India, and plant-based adjuncts are of obvious interest. In alloxan-induced diabetic rats, alcoholic and aqueous stem bark extracts lowered raised blood glucose and improved the lipid profile, which points to both antidiabetic and antihyperlipidemic effects [15]. Possible mechanisms discussed in the literature include protection of pancreatic beta cells through antioxidant action, improved

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glucose utilisation, and reduced intestinal absorption of sugars and fat helped by dietary fibre and saponins [1,10,17]. Because the evidence comes from a chemically induced animal model, the results show promise but do not establish clinical efficacy.

Hepatoprotective activity

The liver is the principal organ of drug metabolism and is vulnerable to toxins. Fruit pulp has been evaluated for hepatoprotective and antioxidant effects, with results indicating protection of liver tissue and improvement in biochemical markers of liver function under experimental injury [16]. Reviews describe liver protection as a recurring theme in the plant's pharmacology, usually explained by free-radical scavenging and stabilisation of cell membranes [2,5,17].

Wound-healing activity

Wound repair requires inflammation control, cell proliferation, collagen deposition and protection against infection. Fruit pulp showed wound-healing and antioxidant activities in rats [14], an outcome consistent with the combined astringent, antimicrobial and antioxidant character of the pulp. Tannins in particular promote contraction and drying of wounds, while antioxidants limit tissue damage at the wound site. This activity suggests topical formulations such as gels, creams and dressings as a development path.

Larvicidal and insecticidal activity

Mosquito-borne diseases remain a major public-health problem, and plant-derived larvicides offer biodegradable alternatives to synthetic chemicals. Leaf extract was effective against the larval stages of *Culex quinquefasciatus*, a vector of filariasis [12]. This result links the plant to vector control, an area of herbal science that is separate from medicine but important for public health.

Other reported activities

Reviews also record anti-inflammatory, analgesic, antipyretic, anticancer, antiulcer, antidiarrhoeal, antifungal, antiviral, cardioprotective and anthelmintic effects [1-3,5,6,9,10,17]. Many of these claims rest on a single study or on crude extracts and should be treated as hypotheses.

3.7 Green nanotechnology and pharmaceutical applications

Nanotechnology and herbal science meet at two points: plant extracts can be used to manufacture nanoparticles, and nanocarriers can be used to improve the delivery of plant actives. In the first case, polyphenols, flavonoids and other reducing compounds in an extract convert metal salts to nanoparticles and then stabilise them, avoiding harsh chemicals. Wood apple leaf extract has been used in this way to prepare silver and zinc oxide nanoparticles that displayed antibacterial activity [8]. Such particles may be useful in antimicrobial coatings, wound dressings and topical products, although their safety and long-term fate need to be established.

The second point is more an opportunity than an accomplishment. Many phenolic and terpenoid constituents dissolve poorly in water, are unstable and are poorly absorbed, which limits the benefit of oral extracts. Carrier systems such as phytosomes, nanoemulsions, liposomes, and polymeric and lipid nanoparticles are widely studied for other herbal products and could in principle be applied to standardised wood apple fractions. Likewise, the natural gum of the plant may be investigated as a binder, thickener or matrix former in tablets and gels, a use mentioned in the review literature [1,5,9]. Applications of this kind are still largely at the proposal stage and call for experimental work.

3.8 Nutraceutical and functional food applications

The nutraceutical value of wood apple arises from the union of its nutrient content with its bioactive phytochemicals. Foods are the easiest vehicles. Pulp can be processed into beverages, squash, jam, jelly, sauces, dried powder and confectionery, and the powder can be mixed into staple foods. Fortification of biscuits with fruit powder improved their phenolic content, demonstrating practical feasibility [4]. Reviews of the fruit's nutritional and pharmacological aspects also point to ready-to-drink formulations, fibre-rich supplements and antioxidant-rich capsules or powders [5,6,9,11]. Possible product types are listed in Table 6.

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For a product to be marketed as a nutraceutical, health claims must be supported by evidence, and at present such evidence for wood apple is largely preclinical. The agenda should therefore combine product development with human studies of glycaemic response, antioxidant status and lipid profile.

3.9 Toxicity and safety considerations

A long history of eating the fruit suggests that normal food quantities are well tolerated. Concentrated extracts are a different matter, however, and safety work has not kept pace with efficacy work. A recent review focused on the ethnobotanical significance, pharmacology and toxicological profile of the plant [17], reflecting growing acknowledgement that toxicology deserves attention. Points to be considered include acute and sub-chronic toxicity of defined extracts, the effect of alkaloids and coumarins at high doses, the possibility of herb-drug interactions (for example with antidiabetic agents, where additive glucose lowering could occur), contamination with heavy metals, pesticides and microbes, and the safety of nanoparticles prepared from plant extracts. Until such data exist, use of concentrated products in pregnancy, lactation, children and patients on regular medication should be cautious and medically supervised.

3.10 Pathway to herbal drug development

The route from a traditional plant to a dependable herbal medicine or nutraceutical follows a series of stages (Table 7, Figure 2). Wood apple has completed some of them and is at an early point on others. In practice the plant is strongest in bioactivity screening and animal proof of concept and weakest in standardisation, safety evaluation and clinical testing. Closing these gaps will determine whether wood apple remains a folk remedy or becomes a trusted product.

3.11 Strengths and limitations of the evidence

The principal strength of the available literature is its consistency: several independent groups, working with different plant parts and models, report related effects that fit the antioxidant and astringent chemistry of the plant. The principal limitations are chemical variability caused by geography, season and plant part; the heavy reliance on crude extracts without identified active compounds; single-model, small-group animal experiments; scarcity of bioavailability data; and the absence of clinical trials. This review is itself limited by being a narrative synthesis of a defined set of 17 publications rather than an exhaustive systematic search.

3.12 Challenges and future perspectives

Cultivation is mostly informal, and organised supply chains, post-harvest handling and shelf-life improvement are needed if large-scale products are planned. The following directions appear most useful:

- bioassay-guided isolation and structural characterisation of the principal active compounds, with development of marker-based quality standards;
- modern analytical fingerprinting and metabolomics to compare cultivars, plant parts and regions;
- mechanistic studies on antioxidant, antidiabetic and hepatoprotective pathways, including enzyme inhibition and gene expression;
- systematic toxicology, including interaction studies with common drugs;
- formulation research on nanocarriers, phytosomes, topical gels and wound dressings, and on the natural gum as an excipient;
- optimisation of food products, shelf-life studies and sensory evaluation, followed by small human trials of glycaemic and antioxidant effects; and
- sustainable cultivation, conservation of germplasm and fair sourcing to protect rural communities that depend on the tree.

IV. CONCLUSION

Wood apple is an uncommon combination of an affordable, nutritious fruit and a chemically rich medicinal plant. Its pulp, leaves, bark and gum have a long record of folk use, and laboratory and animal studies lend support to several of those uses, notably antioxidant, antimicrobial, antidiabetic, hepatoprotective, wound-healing and larvicidal effects. Early work on green nanoparticle synthesis and on enriched foods shows that the plant is also relevant to modern

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pharmaceutical and food technology. At the same time, the evidence base is uneven: standardisation is weak, active compounds are mostly unidentified, safety data are limited and human trials are lacking. With careful authentication, chemical standardisation, mechanistic and toxicological study, and well-designed clinical research, wood apple has real potential to move from a traditional fruit to a validated ingredient in herbal drugs and nutraceuticals.

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Table 1. Botanical profile of wood apple.

Feature	Description
Botanical name	*Limonia acidissima* L. (syn. *Feronia limonia* (L.) Swingle; *Feronia elephantum*)
Family	Rutaceae (citrus family)
Common names	Wood apple, elephant apple, monkey fruit, curd fruit; *kaith* or *kavath* (Hindi, Marathi), *vilvam* (Tamil)
Habit	Deciduous, spiny, slow-growing tree
Leaves	Pinnate, aromatic, with small leaflets
Fruit	Globose, hard woody rind, brown aromatic pulp with seeds
Parts of medicinal interest	Fruit pulp, unripe fruit, leaves, bark, seeds, gum, roots
Habitat	Dry deciduous forests, plains and waste lands of tropical regions

Note: the plant should not be confused with the bael tree (*Aegle marmelos*), a related Rutaceae species with a similar-looking woody fruit.

Table 2. Ethnomedicinal uses of wood apple and corresponding scientific support.

Plant part	Traditional use	Modern evidence available
Ripe pulp	Digestive, cooling tonic, throat and hiccup remedy	Antioxidant and nutritional analysis [7,11]; hepatoprotective and wound-healing studies [14,16]
Unripe fruit	Astringent in diarrhoea and dysentery	Tannin-rich phytochemistry; antibacterial screening [13]
Leaves	Carminative, skin disorders, insect control	Larvicidal activity [12]; antibacterial and nanoparticle studies [8,13]
Stem bark	Tonic; diabetic and lipid disorders in folk use	Antidiabetic and antihyperlipidemic effects in rats [15]
Gum	Adhesive, binder, soothing agent	Reported as a natural excipient in reviews [1,5]
Seeds	Oil used in folk medicine	Reported in pharmacognostic studies [10]

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Table 4. Major phytochemical classes reported in wood apple and their biological relevance [1,2,7,10,13,17].

Phytochemical class	Typical plant part	Biological relevance
Phenolic acids and flavonoids	Fruit pulp, leaves	Free-radical scavenging, metal chelation, anti-inflammatory potential
Tannins	Unripe fruit, bark, leaves	Astringency, antimicrobial action, wound contraction
Coumarins	Leaves, bark, fruit	Antimicrobial, anti-inflammatory and insect-deterrent roles
Terpenoids and triterpenoids	Leaves, bark, seeds	Antimicrobial, hepatoprotective and metabolic actions
Saponins	Pulp, bark	Surfactant effects, cholesterol-lowering potential
Alkaloids	Leaves, bark	Diverse bioactivities; require careful safety assessment
Volatile oils	Leaves, fruit	Aroma, antimicrobial and larvicidal effects
Polysaccharides and gum	Pulp, stem exudate	Dietary fibre, binder and thickener, mucilage-type protective action

Table 5. Summary of experimentally supported activities of wood apple.

Activity	Plant part and model	Key outcome	Ref.
Antioxidant	Fruit pulp; chemical assays and rat tissue	Radical scavenging linked to phenolic content	[7,14,16]
Antimicrobial	Several parts; bacterial screening	Inhibition of bacterial growth	[7,13]
Antidiabetic / antihyperlipidemic	Stem bark extracts; alloxan-diabetic rats	Lower glucose and improved lipids	[15]
Hepatoprotective	Fruit pulp; rat model	Protection of liver function markers	[16]
Wound healing	Fruit pulp; rats	Improved healing with antioxidant effect	[14]
Larvicidal	Leaf extract; *Culex quinquefasciatus* larvae	Larval mortality	[12]
Nanoparticle synthesis	Leaf extract	Silver and zinc oxide nanoparticles with antibacterial effect	[8]

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Table 6. Possible nutraceutical and functional food products from wood apple.

Product type	Concept	Intended health claim
Fortified bakery items	Fruit powder in biscuits and cereal products [4]	Higher dietary phenolics and antioxidants
Beverages and squash	Pulp-based drinks, sometimes blended with other fruits	Hydration, vitamins, digestive comfort
Dried pulp powder	Spray- or shade-dried powder for reconstitution	Convenient source of fibre and antioxidants
Standardised extract capsules	Extract with marked phenolic content	Antioxidant, glycaemic and liver support (to be proven clinically)
Jams, jellies and sweets	Use of pectin-rich pulp	Traditional nutritious product with long shelf life

Table 7. Stages of herbal drug and nutraceutical development and the status of wood apple.

Stage	What is needed	Status for wood apple
1. Authentication and collection	Correct botanical identity, voucher specimens, defined harvest time and part	Pharmacognostic studies exist [10]; harmonised standards lacking
2. Standardisation	Marker compounds, fingerprints (HPTLC, HPLC), moisture, ash, extractive values, contaminant limits	Largely incomplete
3. Extraction and fractionation	Reproducible solvent systems and scalable processes	Mostly laboratory-scale crude extracts
4. Bioactivity screening	In vitro assays against clear targets	Many assays reported [7,13]
5. In vivo proof of concept	Validated animal models with dose-response	Present for diabetes, liver, wounds [14-16]
6. Safety evaluation	Acute, repeated-dose and special toxicity studies	Limited [17]
7. Formulation	Dosage forms, stability, delivery systems	Early; food products [4] and nanoparticles [8]
8. Clinical evaluation	Controlled human trials	Essentially absent
9. Regulation and commercialisation	Compliance with AYUSH, food-safety and nutraceutical regulations; sustainable sourcing	Not yet addressed

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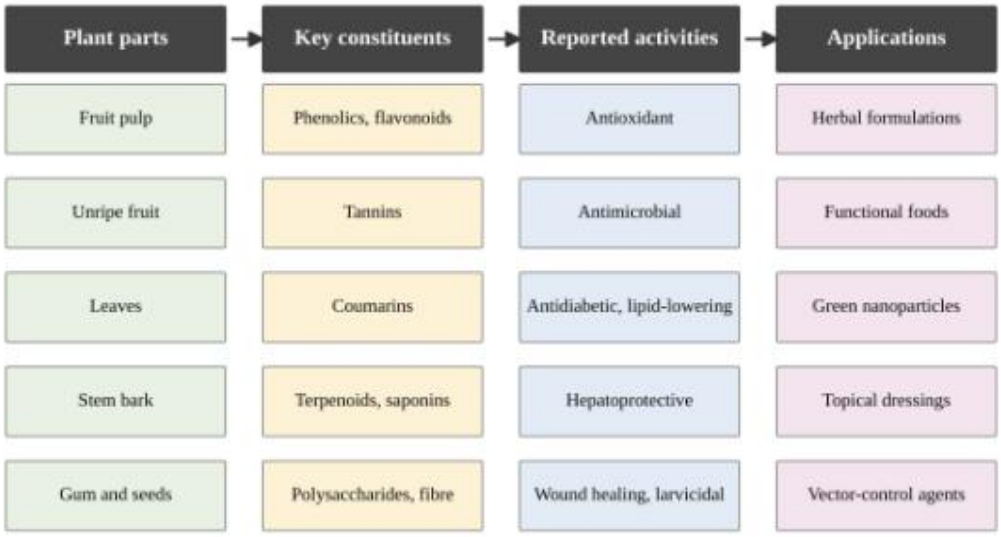


Figure 1. Schematic overview linking plant parts, key constituents, reported activities and possible applications of wood apple.

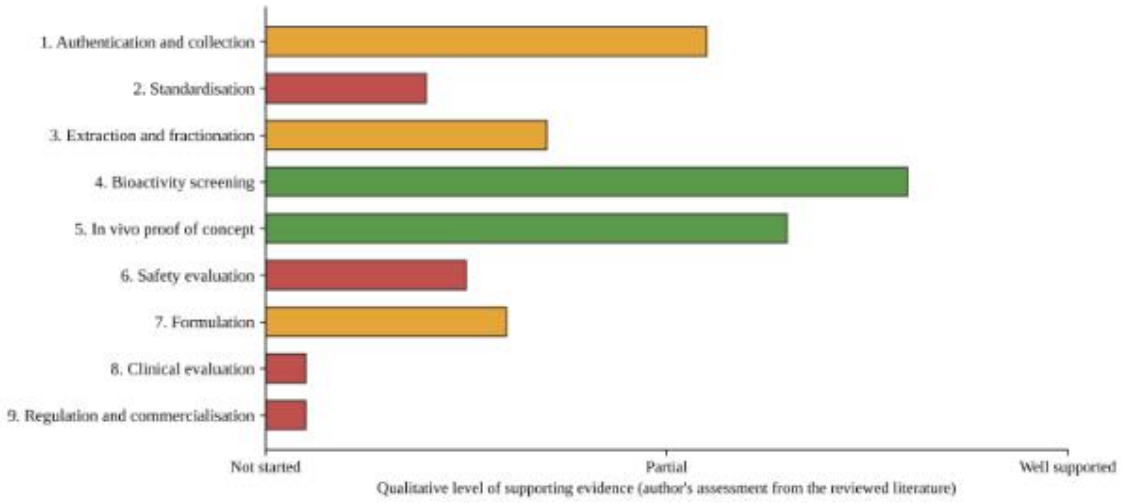


Figure 2. Qualitative status of the evidence at each stage of herbal drug and nutraceutical development for wood apple (author's assessment based on the reviewed literature; see Table 7)

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