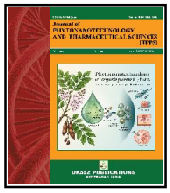
Journal of Phytonanotechnology and Pharmaceutical Sciences 6(3): 129-138, 2026

Online ISSN:2583-0376

http://jpps.ukaazpublications.com

DOI: http://dx.doi.org/10.54085/jpps.2026.6.3.14

Journal of Phytonanotechnology and Pharmaceutical Sciences



Review Article : Open Access

Bioactive compounds of *Terminalia arjuna* (Roxb. ex DC.) Wight and Arn. and their role in human health: A comprehensive review on nutraceutical and pharmacological properties

M. Sri Venkateshwaran and H. B. Roghan*◆

Department of Forest Products and Utilization, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam-641 301, Tamil Nadu, India

**Department of Agroforestry, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam-641 301, Tamil Nadu, India*

Article Info

Article history

Received 25 July 2026

Revised 29 August 2026

Accepted 30 August 2026

Published Online 30 September 2026

Keywords

Terminalia arjuna (Roxb. ex DC.) Wight and Arn.

Arjunolic acid

Triterpenoids

Tannins

Cardioprotective

Pharmacological properties

Abstract

Terminalia arjuna (Roxb. ex DC.) Wight and Arn., a member of the family Combretaceae, is one of the most extensively used medicinal trees of the Indian subcontinent, traditionally valued in Ayurveda for cardiac disorders (Hridroga) and referenced in classical texts such as the Charaka Samhita. The bark, leaves, fruit and roots of the tree contain a rich and structurally diverse array of phytochemicals, including pentacyclic triterpenoids (notably arjunolic acid, arjunic acid, arjungenin and arjunetin), hydrolysable tannins (punicalagin, punicalin, casuarinin, castalagin, terchebulin), flavonoids (luteolin, quercetin, arjunolone), phenolic acids (gallic acid, ellagic acid, ferulic acid), phytosterols, saponins and volatile constituents. This review synthesizes current scientific literature on the phytochemical composition of *T. arjuna* and its associated antioxidant, anti-inflammatory, antidiabetic, antimicrobial, cardioprotective, hepatoprotective, anticancer and gastroprotective properties. Particular emphasis is placed on arjunolic acid, the tree's most intensively studied constituent, which has demonstrated activity across multiple experimental models of cardiovascular and metabolic disease. The review also considers the plant's role in nutraceutical and functional-product development, its safety profile, and the research gaps that remain, including the need for phytochemical standardization, larger and more rigorously designed clinical trials, and cultivar- or provenance-specific chemical profiling. Overall, *T. arjuna* represents a scientifically supported example of a traditional medicinal plant with substantial, and still incompletely realized, potential in preventive and therapeutic healthcare.

1. Introduction

Terminalia arjuna (Roxb. ex DC.) Wight and Arn., is a large, deciduous tree, native to the Indian subcontinent, commonly found along riverbanks and in moist deciduous forests across India, Sri Lanka, Myanmar and Bangladesh. It belongs to the Combretaceae family, which also includes other medicinally important species such as *T.chebula* and *T.bellirica*, with which it is sometimes combined in classical Ayurvedic formulations. Unlike many medicinal plants that owe their reputation largely to folk use, *T. arjuna* occupies an unusual position in Indian pharmacognosy: it is named directly in the Charaka Samhita and other classical texts for the treatment of Hridroga, a term broadly encompassing cardiac disorders, and this specific, disease-focused traditional indication has been substantially corroborated by more than seven decades of modern pharmacological and clinical investigation (Dwivedi, 2007; Dwivedi and Chopra, 2014).The bark of *T. arjuna* is the plant part most widely used in traditional and modern preparations, although the leaves, fruit and root bark have also been investigated for bioactive content. Traditional Ayurvedic use of the stem bark, generally as a decoction or powder (churna), has historically extended beyond cardiac indications to include applications for wound healing, urinary disorders, diarrhoea, and as a general tonic, reflecting the plant's broad phytochemical richness (Amalraj and Gopi, 2017). Modern interest in *T. arjuna* has intensified alongside the global rise in cardiovascular disease, which remains the leading cause of mortality worldwide. The Global Burden of Disease analysis estimated that cardiovascular disease accounted for roughly 18.6 million deaths in 2019, and that the burden has continued to climb, particularly in low- and middle-income countries. This trend has been accompanied by a parallel resurgence of interest in plant-derived agents for managing oxidative stress, dyslipidaemia, hypertension and myocardial dysfunction. Natural products and their derivatives have historically been a major source of approved therapeutic agents (Newman and Cragg, 2020), and cardiovascular medicine has its own well-known examples, which helps explain why traditionally used cardiotonic plants attract systematic study.Since the mid-1990s, a series of small clinical studies have examined standardized bark extracts in patients with chronic stable angina and refractory heart failure, reporting improvements in anginal frequency, exercise tolerance and measures of left ventricular function (Bharani *et al.*,1995; Bharani *et al.*,2002). Earlier work had already suggested antianginal and cardioprotective effects of bark powder in patients with coronary artery disease (Dwivedi and Agarwal, 1994). These clinical observations, together with an extensive body of experimental work on the plant's principal triterpenoid, arjunolic

Corresponding author: Mr. H. B. Roghan

Department of Agroforestry, Forest College and Research Institute, Mettupalayam-641 301, Tamil Nadu, India

E-mail: roghanbalu@gmail.com

Tel.: +91-87788 21013

Copyright © 2026 Ukaaz Publications. All rights reserved.

Email: ukaaz@yahoo.com; Website: www.ukaazpublications.com

acid, have made *T. arjuna* one of the more thoroughly investigated cardioprotective botanicals in the phytomedicine literature (Dwivedi and Udupa, 1989; Amalraj and Gopi, 2017; Kapoor *et al.,*2014). Beyond cardioprotection, contemporary phytochemical and pharmacological research have revealed that *T. arjuna* possesses a considerably wider spectrum of biological activity than its classical reputation alone would suggest. Its bark polyphenols (tannins, flavonoids and phenolic acids) contribute significant antioxidant, anti-inflammatory, antimicrobial, hepatoprotective and gastroprotective effects, while arjunolic acid and related triterpene glycosides have shown antidiabetic and anticancer activity in a range of experimental models (Maheshwari *et al.,*2013; Kumar *et al.,*2023). At the same time, much of this evidence base is derived from preclinical models or small, methodologically limited clinical trials, and a lack of phytochemical standardization across studies complicates direct comparison of results (Gaikwad and Jadhav, 2018). A consolidated review of *T. arjuna*'s phytochemistry and pharmacology is therefore timely, both to summarize what is scientifically well supported and to clarify where further standardized and clinically rigorous research is still required.This review brings together current literature on the botanical and traditional background, phytochemical composition, antioxidant mechanisms and principal pharmacological activities of *T. arjuna*. It further discusses safety and toxicological data, nutraceutical applications, quality and sustainability considerations, and outstanding research gaps, with the aim of providing an integrated scientific account of the plant's therapeutic relevance and its potential in nutraceutical and functional-product development.

2. Botanical background and traditional uses

T. arjuna is a large tree in the Combretaceae family, commonly found along riverbanks in India where it serves key ecological and cultural roles. It is identifiable by its smooth grey bark, winged fruit, and thick, tannin-rich bark that is harvested sustainably for medicinal use. In Ayurveda, bark decoctions and powder are primarily used to treat cardiac ailments, as well as wounds and digestive issues due to its natural astringent properties.

2.1 Taxonomy, distribution and habitat

Terminalia arjuna (Roxb. ex DC.) Wight *and* Arn. is placed in the family Combretaceae, a large family of trees, shrubs and lianas of tropical and subtropical regions. The genus *Terminalia* comprises a substantial number of species, several of which, including *T. chebula*, *T. bellirica* and *T. catappa*, are used medicinally or economically. In India, *T. arjuna* is widely distributed in the sub-Himalayan tracts, the Gangetic plains and the peninsular region, where it characteristically grows beside streams, rivers and dry water courses. The species is also widely planted as an avenue and shade tree, and it has long held cultural and religious associations in parts of South Asia.The tree tolerates a range of soil conditions but performs best in moist, alluvial and well-drained soils with access to seasonal water. Its occurrence along riparian corridors also gives it ecological importance in bank stabilization.

2.2 Morphology and the medicinal plant parts

T. arjuna is a large tree, often reaching considerable height, with a distinctive smooth, grey-to-white outer bark that flakes off in large, irregular plates. The bark, which is the principal source of the plant's bioactive constituents, is thick and fibrous, and its collection for medicinal use is typically carried out without felling the tree, since regrowth of bark occurs over subsequent seasons. The leaves are simple and arranged sub-oppositely, the flowers are small and borne in panicles, and the tree bears winged, woody fruit with characteristic longitudinal wings, features that are typical of the Combretaceae family.Pharmacognostic descriptions of the drug (Dwivedi and Udupa, 1989) emphasize the macroscopic appearance of the bark, its astringent taste, and its characteristic microscopic features, including abundant calcium oxalate crystals. These physical characters have historically been used in raw-drug identification and remain relevant to quality control, given the adulteration and substitution problems that affect many traded medicinal barks.

2.3 Traditional uses in Ayurveda and other systems

Within the Ayurvedic system, *T. arjuna* bark decoction (Arjuna kwath) and bark powder are among the most frequently prescribed preparations for cardiac weakness, palpitations and related complaints, and the plant continues to be included in numerous polyherbal cardiotonic formulations sold across South Asia. Another traditional preparation is the milk decoction of the bark, in which the powdered bark is simmered in milk and water and consumed once the water has evaporated. This concentrated, disease-specific traditional application, in contrast to the broader, tonic-type reputations of many other medicinal plants, has been a significant factor motivating sustained scientific interest in isolating and characterizing the plant's active constituents (Amalraj and Gopi, 2017). Beyond cardiac disease, classical and folk sources describe use of the bark in wounds and ulcers, bleeding disorders, diarrhoea and dysentery, urinary complaints, bone and joint conditions, and as an astringent tonic (Dwivedi, 2007; Amalraj and Gopi, 2017). Many of these uses are consistent with the high tannin content of the bark: astringency, antimicrobial activity and the ability to tighten tissue and reduce secretions are classic properties of tannin-rich drugs. The convergence of traditional indications with the chemistry of the bark is one of the reasons *T. arjuna* is often cited as a case in which ethnopharmacological leads have been supported by laboratory findings.

3. Phytochemical constituents of *T. arjuna*

The phytochemical profile of *T. arjuna* is dominated by triterpenoids and hydrolysable tannins, with substantial contributions from flavonoids, phenolic acids, phytosterols and, in the essential oil fraction, aromatic volatiles. The relative abundance of these classes differs among plant parts, with the bark being particularly rich in tannins and triterpene glycosides (Table 1). The chemistry of the bark has been reviewed repeatedly over several decades, and the picture that emerges is of a chemically complex drug in which no single constituent is likely to account for the entirety of the observed pharmacological activity (Dwivedi and Udupa, 1989; Kumar *et al.,*2023).

3.1 Triterpenoids and arjunolic acid

Pentacyclic triterpenoids constitute the pharmacologically most significant class of compounds in *T. arjuna*, and arjunolic acid in particular has become the plant's signature constituent in the phytomedicine literature. First isolated from the bark, arjunolic acid is an oleanane-type triterpene bearing multiple hydroxyl groups and a carboxylic acid, a structure that gives it amphiphilic character and underlies both its biological activity and its utility as a chemical

scaffold. It has been the subject of extensive mechanistic study encompassing antioxidant, cardioprotective, antidiabetic, hepatoprotective and anticancer activity, and has also served as a starting material for the synthesis of semi-synthetic derivatives evaluated for enhanced pharmacological potency (Ghosh and Sil, 2013). Related triterpene glycosides, including arjunic acid, arjungenin, arjunetin, and the arjunoside and arjunolic acid glucoside series, contribute further to the bark's bioactivity, and several novel oleanane-type triterpene glycosides have continued to be isolated and characterized from the plant in recent years. Oleanane derivatives from the bark have also been reported to modulate the respiratory burst of phagocytic cells, which links the triterpenoid fraction to antioxidant and anti-inflammatory activity (Pawar and Bhutani, 2005). The glycosides are generally considered to be more polar than the free aglycones and may differ in absorption and biological behaviour, a point that has received little systematic investigation.

Table 1: Major phytochemical classes identified in *T. arjuna* (Dwivedi and Udupa, 1989; Mandal *et al.*, 2013; Kumar *et al.*, 2023; Tahir *et al.*, 2025)

Phytochemical class	Representative compounds	Primary plant part	Reported biological activity
Triterpenoids/saponins	Arjunolic acid, arjunic acid, arjungenin, arjunetin, arjunoside I-II, terminic acid	Bark, fruit	Cardioprotective, antidiabetic, anticancer, antioxidant
Hydrolysable tannins	Punicalagin, punicalin, casuarinin, castalagin, terchebulin, terflavin C, casuariin	Bark	Antioxidant, antimicrobial, nitric-oxide-mediated vasorelaxation
Flavonoids	Luteolin, quercetin, arjunolone	Bark, leaves	Cardioprotective, anti-inflammatory, lipid-lowering
Phenolic acids	Gallic acid, ellagic acid, ferulic acid, 7-methyl gallate	Bark	Antioxidant, hepatoprotective
Phytosterols	β-sitosterol	Bark	Cholesterol-lowering
Essential-oil volatiles	Carvacrol, thymol, furfural, isoeugenol	Bark, leaves	Antimicrobial
Minerals	Calcium, magnesium	Bark	Cardiotonic support (traditional attribution)

3.2 Tannins

T. arjuna bark is unusually rich in hydrolysable tannins, with approximately fifteen distinct tannin-related compounds reported from the bark, including punicalagin, punicalin, casuarinin, castalagin, terchebulin and terflavin C (Tahir *et al.,*2025). These compounds contribute substantially to the bark's antioxidant capacity and have also been linked to a distinctive vasoactive mechanism: tannins from *T. arjuna* have been reported to enhance nitric oxide synthesis and to relax vascular smooth muscle segments pre-contracted with norepinephrine, a mechanism directly relevant to the plant's traditional cardiovascular use (Tahir *et al.,* 2025). Casuarinin, one of the bark's principal tannins, has additionally demonstrated protective activity against hydrogen-peroxide-induced oxidative and DNA damage in cultured renal epithelial cells (Chen *et al.,*2004).

Tannins are also the principal reason for the pronounced astringency of the bark. From a pharmacological perspective, high-molecular-weight tannins are poorly absorbed intact, and their systemic effects may depend substantially on hydrolysis products and on metabolism by the gut microbiota.

3.3 Flavonoids

Flavonoid constituents of *T. arjuna*, principally luteolin and quercetin, contribute to the plant's cardioprotective and lipid-modulating activity and have been implicated, together with tannins, in the bark's long-recognized anticancer properties (Tahir *et al.,*2025). Flavonoid-rich fractions of the bark have also demonstrated antioxidant and anti-inflammatory effects in experimental assays, complementing the activity of the tannin and triterpenoid fractions. Arjunolone, a flavonoid characteristic of the bark, is among the compounds that distinguish the chemistry of this species.

3.4 Phenolic acids

Gallic acid and ellagic acid derivatives are prominent phenolic constituents of *T. arjuna* bark and are considered major contributors to its antioxidant capacity (Tahir *et al.,*2025). Related simple phenolics, including 7-methyl gallate, have also been characterized from the bark and evaluated for toxicological safety at high doses without evidence of adverse effect (Kumar *et al.,*2023). Because gallic and ellagic acids are also released on hydrolysis of gallotannins and ellagitannins, their measured content in an extract depends on both the native content and the extraction and storage conditions. Phenolic compounds as a class are well recognized as dietary antioxidants with potential relevance to chronic disease (Pandey and Rizvi, 2009; Shahidi and Ambigaipalan, 2015).

3.5 Essential oil and volatile constituents

Essential oils obtained from *T. arjuna* by steam distillation, hydrodistillation or solvent extraction contain aromatic compounds such as carvacrol, thymol, furfural and isoeugenol, which are associated with the plant's antimicrobial potential. Carvacrol in particular is a well-characterized natural phenolic monoterpenoid with broad antimicrobial activity, and its presence in *T. arjuna* essential oil is consistent with the plant's traditional use in wound care and its demonstrated *in vitro* antibacterial effects (M¹czka *et al.,* 2023). The oil represents a minor fraction of the drug by mass, but it has attracted interest as a potential natural antimicrobial ingredient.

3.6 Phytosterols, minerals and other constituents

In addition to the classes above, the bark contains phytosterols such as β-sitosterol, which is widely recognized for its association with reduced intestinal cholesterol absorption, along with saponins and appreciable levels of minerals, notably calcium and magnesium. The

high calcium content, largely present as calcium oxalate, has been noted in pharmacognostic descriptions of the drug and has sometimes been invoked in traditional explanations of its cardiotonic effect, although this attribution remains speculative and is not supported by direct mechanistic evidence (Dwivedi and Udupa, 1989).

3.7 Variation in chemical composition

The phytochemical content of *T. arjuna* is not fixed. Reported variation arises from the plant part used, the age of the tree, the season and place of collection, drying and storage conditions, and the solvent and method used for extraction. Polar solvents such as water, methanol and ethanol favour recovery of tannins, phenolic acids and glycosides, whereas less polar solvents preferentially extract triterpenoid aglycones and sterols. Consequently, an aqueous decoction, an ethanolic extract and a chloroform fraction of the same bark may differ markedly in composition and in observed activity (Mandal *et al.,*2013; Tahir *et al.,*2025).This variability has direct practical consequences. Studies that describe the material tested only as "bark extract" cannot be reliably compared, and the biological activity attributed to arjunolic acid or to tannins in one report may not translate to a commercial product in which these constituents are present at very different levels. Systematic characterization of geographical and seasonal variation remains limited.

3.8 Extraction and analytical methods

Conventional approaches to obtaining bioactive fractions from the bark include maceration, Soxhlet extraction, decoction and reflux with solvents of increasing polarity. More recent work has evaluated ultrasound-assisted, microwave-assisted and other intensified extraction methods that may improve yield and reduce solvent use and processing time (Tahir *et al.,*2025). Extraction conditions influence not only yield but also the chemical integrity of heat-labile tannins.For characterization and quality control, chromatographic methods have been the mainstay. Reversed-phase liquid chromatography methods for the simultaneous determination of oleanane derivatives in the bark were developed to support standardization (Singh *et al.,*2002), and high-performance thin-layer chromatography and liquid chromatography coupled to mass spectrometry have since been applied to profile triterpenoids and polyphenols. Adoption of a common set of marker compounds, such as arjunolic acid and selected tannins, would considerably strengthen comparability across studies and products.

4. Antioxidant properties of *T. arjuna*

Oxidative stress, arising from an imbalance between reactive oxygen and nitrogen species (ROS/RNS) and the body's endogenous antioxidant defences, is a central pathological mechanism in cardiovascular disease, diabetes, hepatic injury and carcinogenesis (Sies, 2015). The antioxidant capacity of *T. arjuna* is one of its most consistently demonstrated properties across *in vitro* and *in vivo* models, arising from the combined action of its tannins, flavonoids, phenolic acids and triterpenoids.

4.1 *In vitro* antioxidant activity

Bark extracts of *T. arjuna* have shown strong free-radical-scavenging and reducing activity in standard *in vitro* antioxidant assays, with phytochemical analysis linking this activity to the extract's high total phenolic and tannin content (Mandal *et al.,*2013). The bark's antioxidative potential has additionally been shown to coincide with antimicrobial activity in the same extracts, suggesting that the plant's polyphenolic constituents act through overlapping mechanisms of radical neutralization and microbial membrane disruption (Mandal *et al.,* 2013). Chemical radical-scavenging tests are useful for ranking extracts and for quality control, but they do not by themselves demonstrate an antioxidant effect in living systems, where absorption, metabolism and cellular localization determine whether a compound can act at the relevant site. The *in vivo* evidence summarized below is therefore more informative regarding physiological relevance.

4.2 *In vivo* antioxidant mechanisms

In vivo studies have provided considerable evidence that arjunolic acid, specifically, restores endogenous antioxidant status under conditions of induced oxidative stress. In a rat model of experimental myocardial necrosis, arjunolic acid was shown to influence platelet aggregation, coagulation parameters and antioxidant status, supporting a mechanistic basis for the compound's cardioprotective effects (Sumitra *et al.,*2001). In carbon-tetrachloride-induced cardiac oxidative stress, *T. arjuna* extract administration was associated with protective effects on cardiac tissue consistent with restoration of antioxidant defences (Manna *et al.,*2007).Comparable protective effects have been reported in other organs and against other toxicants. An aqueous bark extract attenuated hepatic and renal injury induced by carbon tetrachloride, with improvement in markers of oxidative damage (Manna *et al.,*2006), and the bark extract protected mouse hearts against sodium-fluoride-induced oxidative stress (Sinha *et al.,*2008). Arjunolic acid also mitigated acetaminophen-induced renal injury through effects on oxidative stress and the production of tumour necrosis factor-alpha (Ghosh *et al.,*2010). Taken together, these reports describe a consistent pattern in which the bark or its principal triterpenoid supports enzymatic and non-enzymatic antioxidant defences, including glutathione and antioxidant enzymes, while reducing lipid peroxidation markers. Arjunolic acid and ascorbic acid derived from the plant have also been reported to arrest depletion of key components of the antioxidant system, including α-tocopherol and reduced glutathione, under conditions of chemical carcinogen exposure, indicating a protective role against environmentally induced oxidative.

4.3 Contribution of tannins and phenolics

The bark's tannin fraction, comprising compounds such as punicalagin and casuarinin, contributes both direct radical-scavenging activity and the vasoactive nitric-oxide-mediated effects described above (Tahir *et al.,*2025). Gallic acid and ellagic acid derivatives further reinforce the bark's reducing capacity, consistent with the well-established antioxidant behaviour of hydrolysable tannins and their phenolic hydrolysis products generally (Pandey and Rizvi, 2009). Tannins may additionally chelate transition metals that catalyze radical formation, providing an indirect route to antioxidant protection. Because polyphenols can also act as pro-oxidants under certain conditions, particularly at high concentrations or in the presence of free transition metals, the net effect of a complex extract *in vivo* should not be assumed from chemical assays alone. The consistent protective effects seen in animal models nevertheless suggest that, at doses used experimentally, the antioxidant contribution predominates.

5. Pharmacological activities of *T. arjuna*

The pharmacological profile of *T. arjuna* spans cardioprotective, anti-inflammatory, antidiabetic, antimicrobial, hepatoprotective, anticancer and gastroprotective activity, with cardioprotection remaining both the most historically prominent and the most clinically investigated of these properties (Table 2).

Table 2: Pharmacological activities of *T. arjuna* and associated mechanisms

Activity	Bioactive components	Reported evidences
Cardioprotective	Arjunolic acid, tannins, flavonoids	Antioxidant defence, anti-ischemic and inotropic effects, improved angina symptoms and exercise tolerance in clinical studies
Antioxidant	Tannins, phenolic acids, arjunolic acid	Free radical scavenging, restoration of glutathione/α-tocopherol status
Anti-inflammatory	Flavonoids, tannins, oleanane triterpenoids	Reduced inflammatory markers in experimental assays; suppression of phagocyte oxyburst
Antidiabetic	Arjunolic acid	Reduced oxidative/nitrosative stress in pancreatic and renal tissue, improved glycaemic parameters in animal models
Antimicrobial	Tannins, essential-oil volatiles (carvacrol, thymol)	Disruption of microbial membranes, enzyme inhibition, activity against oral and enteric pathogens
Hepatoprotective	Flavonoids, phenolics	Normalization of ALT/AST/ALP after hepatotoxin challenge
Anticancer	Arjunolic acid, tannins, flavonoids	ROS generation, membrane disruption, apoptosis induction in cancer cell lines
Gastroprotective	Tannins, bark extract	Reduced NSAID-induced gastric mucosal damage

5.1 Cardioprotective effect

Cardioprotection remains the best-substantiated pharmacological property of *T. arjuna*, supported by both experimental and clinical evidence. The evidence is discussed below in three parts: experimental models of myocardial injury, mechanistic findings, and human studies.

5.1.1 Experimental evidence

In rodent models, chronic treatment with bark powder or extract improved functional recovery of isolated hearts subjected to ischaemia and reperfusion (Gauthaman *et al.,*2001), and an alcoholic bark extract reduced myocardial injury in an *in vivo* model of ischaemia-reperfusion, with improvements in antioxidant status and reduced tissue damage (Karthikeyan *et al.,*2003). In isoproterenol-induced chronic heart failure in rats, bark extract was reported to improve markers of cardiac function and reduce oxidative and structural changes, providing mechanistic clues for its cardioprotective effect (Parveen *et al.,*2011). Arjunolic acid has demonstrated protective effects against platelet aggregation and coagulation abnormalities in a rat model of induced myocardial necrosis (Sumitra *et al.,*2001), while bark-derived preparations have shown cardioprotective activity against carbon-tetrachloride-induced oxidative stress in cardiac tissue (Manna *et al.,*2007).

5.1.2 Proposed mechanisms

Several complementary mechanisms have been proposed. First, the antioxidant activity described in Section 4 reduces oxidative damage to myocardial membranes, proteins and DNA. Second, tannin-mediated stimulation of nitric oxide synthesis and vasorelaxation may lower vascular tone and improve perfusion (Tahir *et al.,*2025). Third, effects on platelet aggregation and coagulation may reduce thrombotic tendency (Sumitra *et al.,*2001). Fourth, inotropic and anti-ischaemic effects have been described in experimental and clinical work, and the bark has been reported to have a hypolipidaemic effect that may contribute to anti-atherosclerotic activity (Shaila *et al.,*1998). These mechanisms are not mutually exclusive, and it is plausible that the overall effect reflects the combined action of several constituent classes.

5.1.3 Clinical evidence

In a clinical study of patients with severe refractory heart failure, *T. arjuna* bark extract was associated with a salutary clinical effect (Bharani *et al.,*1995), and a subsequent clinical evaluation in patients with chronic stable angina reported improved efficacy outcomes with bark extract administration (Bharani *et al.,*2002). An earlier study of bark powder in coronary artery disease reported antianginal and cardioprotective effects (Dwivedi and Agarwal, 1994). A randomized, placebo-controlled trial of bark powder examined antioxidant and cholesterol-lowering effects in a small group of participants (Gupta *et al.,*2001). A broader review of the ethnopharmacological, preclinical, clinical and safety literature in coronary artery disease concluded that the available data are encouraging but that more rigorous trials are needed (Kapoor *et al.,*2014). Collectively, these findings support the traditional Ayurvedic characterization of *T. arjuna* as a cardiotonic agent, although reviewers have consistently noted that many of the underlying clinical trials are small in scale and limited in methodological rigor, and that phytochemical standardization of the extracts used across studies has often been inadequate (Gaikwad and Jadhav, 2018). The plant should therefore be regarded as a promising adjunct candidate rather than a replacement for established cardiovascular therapy, and patients should not discontinue prescribed medicines in favour of herbal products.

5.2 Anti-inflammatory properties

The flavonoid and tannin fractions of *T. arjuna* bark contribute to demonstrated anti-inflammatory activity in experimental models. Bark powder produced anti-inflammatory, immunomodulatory and antinociceptive effects in mice and rats (Halder *et al.,*2009), and oleanane triterpenoids from the bark suppressed the respiratory

oxyburst of phagocytes (Pawar and Bhutani, 2005). Aqueous bark extracts in particular have shown pronounced anti-inflammatory effects in protein-denaturation-based assays, alongside antimicrobial activity against common oral pathogens, a combination of properties that has generated interest in the plant's potential use in periodontal therapy and local herbal drug-delivery systems. Given that chronic low-grade inflammation and oxidative stress are intertwined in cardiovascular and metabolic disease, the anti-inflammatory activity may also contribute to the plant's cardioprotective profile.

5.3 Antidiabetic activities

Arjunolic acid has been investigated for antidiabetic potential in the streptozotocin-induced diabetic rat model, in which the compound was shown to mitigate the oxidative and nitrosative stress, elevated pro-inflammatory cytokine levels, and disrupted mitochondrial signalling associated with pancreatic tissue damage, when administered both before and after diabetes induction (Ghosh and Sil, 2013). In the same model, arjunolic acid also protected against diabetic renal injury by modulating the polyol pathway and oxidative-stress-responsive signalling cascades (Manna *et al.,*2009). Consistent with this preclinical evidence, a clinical study comparing *T. arjuna* with the standard antidiabetic agent sitagliptin in patients with type 2 diabetes mellitus was undertaken to formally evaluate the plant's antihyperglycaemic efficacy and safety, reflecting a longstanding but comparatively underexplored traditional attribution of antidiabetic activity to the bark. At present, the antidiabetic claims rest predominantly on animal work, and adequately powered human trials with glycaemic endpoints such as glycated haemoglobin are needed.

5.4 Antimicrobial and antifungal properties

T. arjuna extracts exhibit antimicrobial activity attributable to their tannin and essential-oil content. Aqueous and ethanolic bark extracts have shown notable antimicrobial activity against oral pathogens including *Staphylococcus aureus*, *Pseudomonas* species and *Escherichia coli*, supporting the plant's potential application as a local antimicrobial agent in periodontal care. Proposed mechanisms of tannin antimicrobial action include inhibition of microbial enzymes, complexation with cell-wall proteins, deprivation of essential metal ions and disruption of membranes (Scalbert, 1991; Cowan, 1999).The essential-oil constituent carvacrol, identified in *T. arjuna* oil, is independently recognized as a broad-spectrum natural antimicrobial phenolic compound (M¹czka*et al.,* 2023), reinforcing the plausibility of the whole-plant extract's observed antibacterial effects. Most reports are based on *in vitro* diffusion or dilution assays, and comparison with standard antibiotics under uniform conditions, together with assessment of activity against resistant clinical isolates, would strengthen the evidence.

5.5 Hepatoprotective activities

T. arjuna leaf and fruit extracts have demonstrated hepatoprotective activity in experimental models of drug-induced liver injury. In mice challenged with acetaminophen, administration of *T. arjuna* fruit and leaf extract restored disturbed haematological and serological markers of liver damage, including alkaline phosphatase (ALP) and aspartate aminotransferase (AST), in a dose-dependent manner, supporting a protective role against hepatotoxin-induced injury. Aqueous bark extract likewise protected against carbon-tetrachloride-induced hepatic damage in rats (Manna *et al.,*2006). The proposed basis is the antioxidant action of phenolics and flavonoids, which limits lipid peroxidation and preserves hepatocellular membrane integrity.

5.6 Anticancer potential

Arjunolic acid has demonstrated cytotoxic and pro-apoptotic activity against multiple cancer cell lines. In Ehrlich ascites carcinoma and Dalton's lymphoma cell lines, arjunolic acid induced substantial cell death primarily through membrane disruption, while against MCF-7 and HeLa cell lines the compound showed significant anticancer activity with comparatively low toxicity toward normal lymphocytes, with fluorescence-based assays indicating that arjunolic acid disrupts redox balance in cancer cells through generation of reactive oxygen species (Ghosh and Sil, 2013). Independent isolation of cancer cell growth inhibitory constituents from *T. arjuna* has further supported the plant's relevance to anticancer drug discovery (Pettit *et al.,*1996). Tannins and flavonoids in the bark have separately been implicated as the primary contributors to the plant's traditionally recognized anticancer properties, potentially acting through carcinogen-trapping and antimutagenic mechanisms. It is important to stress that these findings are preclinical. Cytotoxicity in cell culture, or activity in a transplantable tumour model, is far removed from demonstrated benefit in patients, and the selectivity for malignant over normal cells observed in some assays requires confirmation in more physiologically relevant systems. No clinical evidence currently supports the use of *T. arjuna* as an anticancer treatment.

5.7 Gastroprotective effects

T. arjuna bark has demonstrated gastroprotective activity in a rat model of diclofenac-sodium-induced gastric ulceration, in which bark administration was associated with reduced gastric mucosal damage (Devi *et al.,*2007), consistent with the plant's traditional use in digestive and ulcer-related complaints and with the antioxidant and anti-inflammatory activity of its polyphenolic constituents. Astringent tannins may additionally form a protective layer over the mucosa, although this has not been directly demonstrated for this species.

5.8 Lipid-modulating and antiatherogenic effects

A hypolipidaemic effect of the bark has been reported in experimentally induced atherosclerosis in cholesterol-fed animals, in which *T. arjuna* was compared with other indigenous drugs (Shaila *et al.,*1998). In humans, a randomized, placebo-controlled study examined the effect of bark powder on antioxidant status and cholesterol levels (Gupta *et al.,*2001). Phytosterols and flavonoids in the bark are plausible contributors, but the human data are limited by small sample size and short duration, and further studies with modern lipid endpoints are warranted.

6. Pharmacokinetics, safety and toxicology

T. arjuna active constituents face absorption challenges due to low solubility, suggesting many effects are mediated by gut metabolites. While animal and clinical data indicate the plant extract is well-tolerated with minimal toxicity, its potential interactions with conventional cardiovascular and diabetes medications warrant clinical caution.

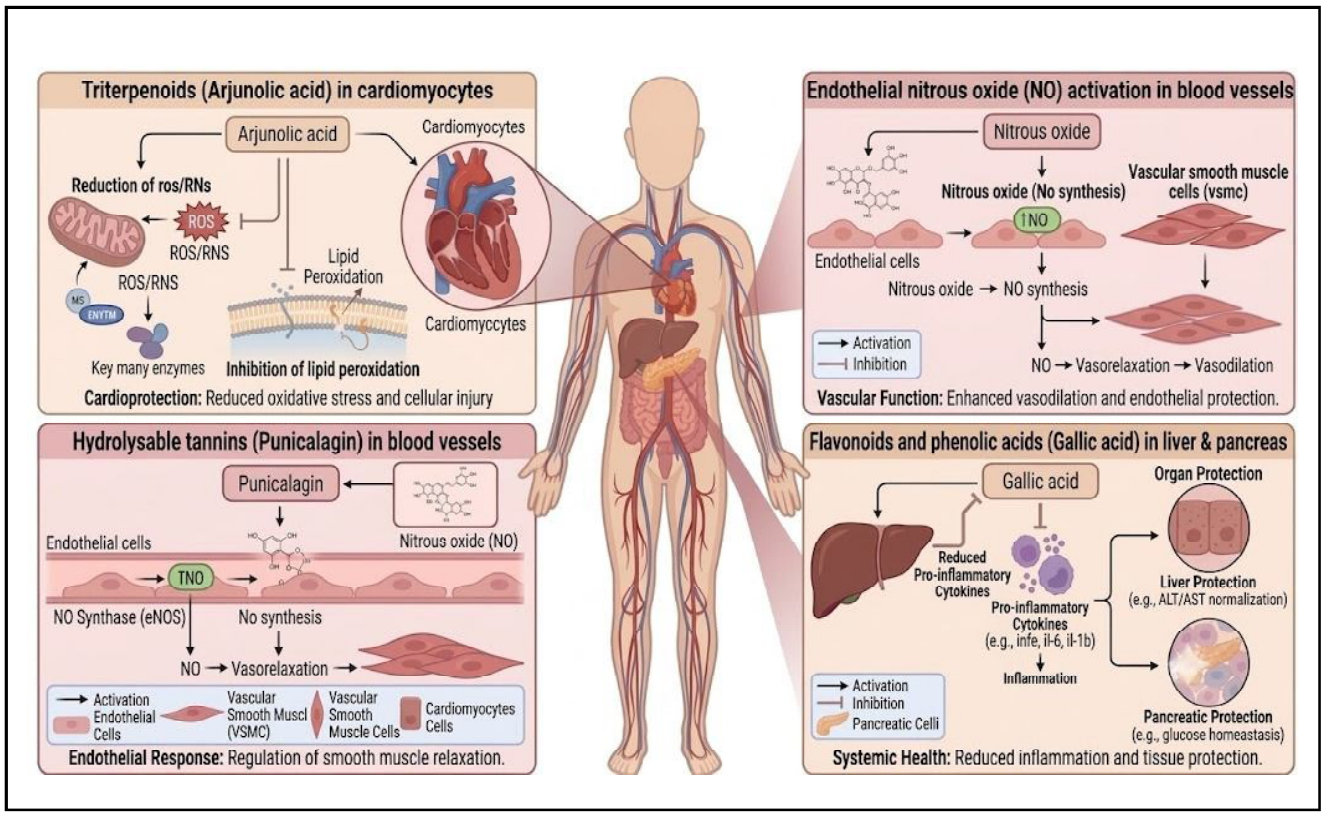


Figure 1: Mechanism of action of *T. arjuna* bioactive compounds in human health.

Table 3: Representative experimental and clinical studies on *T. arjuna*

Model	Material tested	Principal findings	References
Patients with coronary artery disease	Bark powder	Antianginal and cardioprotective effects reported	Dwivedi and Agarwal, 1994
Patients with severe refractory heart failure	Bark extract	Salutary clinical effect reported	Bharani *et al.*,1995
Cholesterol-fed animals (atherosclerosis model)	Bark preparation	Hypolipidaemic effect reported	Shaila *et al.*,1998
Isolated ischaemic-reperfused rat heart	Bark, chronic treatment	Improved recovery after ischaemia	Gauthaman *et al.*, 2001
Randomized, placebo-controlled human study	Bark powder	Antioxidant and cholesterol-related parameters examined	Gupta *et al.*, 2001
Rat model of myocardial necrosis	Arjunolic acid	Effects on platelet aggregation, coagulation and antioxidant status	Sumitra *et al.*, 2001
Patients with chronic stable angina	Bark extract	Improved efficacy outcomes reported	Bharani *et al.*,2002
Rat myocardial ischaemia-reperfusion	Alcoholic bark extract	Cardioprotection, improved antioxidant status	Karthikeyan *et al.*, 2003
CCl_4-induced hepatic/renal injury	Aqueous bark extract	Protection against oxidative organ damage	Manna *et al.*, 2006
Diclofenac-induced gastric ulcer, rat	Bark	Reduced gastric mucosal damage	Devi *et al.*, 2007
STZ-induced diabetic renal injury, rat	Arjunolic acid	Protection *via* polyol pathway and oxidative-stress signalling	Manna *et al.*,2009
Isoproterenol-induced heart	Bark extract failure, rat	Improved cardiac function markers and oxidative status	Parveen *et al.*,2011

6.1 Absorption and bioavailability

Systematic pharmacokinetic data for the constituents of *T. arjuna* in humans are scarce. Arjunolic acid is a lipophilic triterpenoid whose oral absorption may be limited by poor aqueous solubility, while large hydrolysable tannins are expected to be poorly absorbed intact and to undergo extensive transformation in the gut. This raises the possibility that many of the effects seen *in vitro* are mediated *in vivo* by metabolites rather than parent compounds. Formulation strategies designed to improve triterpenoid solubility and absorption, such as nano-formulation and complexation, are an active area of interest in natural-product delivery, but data specific to *T. arjuna* remain limited.

6.2 Toxicological evaluation

Available toxicological data are generally reassuring. Safety data indicate no significant toxicity of bark extract at doses used in clinical study, and acute and subacute toxicity assessments of bark preparations in animals have not shown serious adverse effects at experimentally relevant doses (Kumar *et al.,*2023; Kapoor *et al.,*2014). The simple phenolic 7-methyl gallate has also been evaluated at high doses without evidence of adverse effect (Kumar *et al.,*2023). In clinical studies, the bark has generally been well tolerated, with the most commonly cited adverse effects being mild gastrointestinal complaints.

6.3 Precautions and herb-drug considerations

Despite the generally favourable profile, several precautions are warranted. Because *T. arjuna* is used alongside conventional cardiovascular drugs in practice, potential interactions with antihypertensives, antiplatelet agents, anticoagulants and lipid-lowering drugs cannot be excluded, given the reported effects of the bark on vascular tone, platelet aggregation and lipids. Patients with diabetes using glucose-lowering agents should be aware of possible additive effects. The high tannin content may reduce absorption of co-administered iron or certain drugs, if taken simultaneously. Data on safety in pregnancy, lactation, children and patients with significant renal or hepatic impairment are insufficient, and use in these groups should be supervised by a qualified practitioner. Finally, heavy-metal and microbial contamination of commercial herbal products is a recognized quality concern that is unrelated to the plant itself but affects consumer safety.

7. Nutraceutical applications and by-product utilization

T. arjuna bark, in the form of powders, standardized extracts and decoctions, is already commercialized as a cardiotonic nutraceutical and herbal supplement across South Asia, and is a common constituent of polyherbal cardiovascular formulations. Given the safety data indicating no significant toxicity of bark extract at doses used in clinical study (Kumar *et al.,*2023), and the plant's demonstrated antioxidant, hepatoprotective and antimicrobial properties, there is continuing interest in developing standardized bark-derived nutraceutical products, functional beverage additives and topical antimicrobial formulations.Several product concepts have been proposed. Standardized capsules and tablets could be formulated to contain defined amounts of marker triterpenoids and tannins. Bark tea and instant decoction powders provide a familiar delivery form that mirrors traditional use. Because polyphenols and triterpenoids differ in solubility, combined aqueous and hydroalcoholic extraction may yield fuller-spectrum products. Bark extracts may also find use in oral-care formulations, including mouthwashes and gels, on the basis of their antimicrobial and anti-inflammatory activity. The essential-oil fraction, rich in carvacrol and thymol, further offers potential for natural antimicrobial product development beyond conventional oral supplementation, for example as a natural preservative or in active packaging.Utilization of by-products could add value and improve sustainability. Leaves and fruit, which are renewable and can be harvested without damaging the tree, have shown bioactivity in experimental models and may partly substitute for bark in some applications, provided that their phytochemical profile and safety are adequately established. Residues remaining after extraction may retain fibre and residual polyphenols and could be evaluated for use in feed or materials applications. Any nutraceutical claims must; however, remain within the bounds of the evidence; in most jurisdictions, statements about treating or preventing disease require regulatory approval, and products should be positioned as complementary to, not substitutes for, standard care.

8. Quality control, regulatory aspects and sustainability

Reliable quality control is a prerequisite for translating traditional use into dependable nutraceutical products. Recommended elements include authentication of the botanical source by macroscopic and microscopic characters, chemical fingerprinting by chromatographic methods, quantitation of defined markers such as arjunolic acid and selected tannins (Singh *et al.,*2002), and testing for heavy metals, pesticide residues, aflatoxins and microbial load. Because commercial bark may be adulterated with bark of other species, particularly given the visual similarity of many tree barks, botanical authentication remains a practical concern. Regulatory treatment of herbal products differs among countries, ranging from classification as traditional medicines to dietary supplements or drugs. Harmonized pharmacopoeial monographs with defined marker content would support consistency and consumer confidence. From a sustainability perspective, the demand for bark places pressure on wild populations if collection is unregulated or excessive. Sustainable harvesting practices, including rotational or partial bark removal, cultivation in plantations and agroforestry systems, and exploration of leaf- or fruit-based alternatives, are important to secure supply without depleting natural stands.

9. Future perspectives

Despite the substantial body of literature on *T. arjuna*, several important gaps remain. Clinical studies of the plant's cardioprotective effects have generally involved small patient numbers and inconsistent extract standardization, limiting the strength of conclusions that can be drawn and complicating comparison across trials (Gaikwad and Jadhav, 2018). Phytochemical standardization of commercial bark extracts is inconsistent, meaning that the specific triterpenoid, tannin and flavonoid content of products marketed as *T. arjuna* extractcan vary considerably. Much of the antidiabetic, anticancer and hepatoprotective evidence remains confined to preclinical animal or cell-line models, with comparatively few adequately powered human trials.Further work is also needed to characterize cultivarand provenance-specific variation in phytochemical content, to clarify the pharmacokinetics and bioavailability of arjunolic acid and the bark's tannin constituents in humans, and to establish long-term safety data for chronic use. Priority areas for future research include the following: (i) large, multicentre, randomized, double-blind trials

using well-characterized standardized extracts and clinically meaningful endpoints such as cardiovascular events, functional capacity and quality of life; (ii) systematic herb-drug interaction studies with commonly prescribed cardiovascular and antidiabetic drugs; (iii) identification of the relative contributions of triterpenoids and tannins through bioassay-guided fractionation and combination studies that test for synergy; (iv) investigation of gut-microbiota-derived metabolites of tannins as active species; (v) development and clinical testing of improved delivery systems for arjunolic acid; and (vi) sustainable cultivation and supply-chain traceability. Advances in metabolomics, network pharmacology and other systems-level approaches could also help to explain how a chemically complex drug exerts multi-target effects, and could guide the rational design of standardized combinations. Adoption of reporting standards for botanical research, including full description of plant material, voucher specimens, extraction procedures and chemical profiling, would substantially improve reproducibility.

10. Conclusion

T. arjuna stands as one of the more scientifically substantiated examples of a classical Ayurvedic medicinal plant, with a phytochemical profile, dominated by arjunolic acid and related triterpenoids, hydrolysable tannins, flavonoids and phenolic acids, that provides a coherent mechanistic basis for its long-recognized cardioprotective use. Beyond cardioprotection, the plant's antioxidant, anti-inflammatory, antidiabetic, antimicrobial, hepatoprotective, anticancer and gastroprotective properties broaden its relevance to preventive and therapeutic healthcare considerably beyond its traditional cardiac indication.Nonetheless, the evidence base remains uneven: while the plant's mechanistic and preclinical pharmacology is well developed, clinical validation is comparatively limited in scale and rigor, and phytochemical standardization across studies and commercial products requires improvement. Continued investment in standardized extraction, larger clinical trials, pharmacokinetic characterization and cultivar-specific phytochemical profiling, together with sustainable sourcing, will be essential to fully establish *T. arjuna*'s place as a scientifically validated nutraceutical and therapeutic agent.

Acknowledgements

The authors express their gratitude and credit the researchers behind the original studies whose works are referenced in this review.

Availability of data and material

All data are provided within the manuscript.

Authorship contribution statement

H. B. Roghan: Conceptualization, academic oversight, critical review and validation of scientific content; **M. Sri Venkateshwaran**: Writing, software handling and data curation.

Consent for publication

All authors gave full consent for publication and submission to this journal.

Ethical approval

Not applicable.

Conflict of interest

The authors declare no conflict of interest relevant to this article.

References

Amalraj, A. and Gopi, S. (2017). Medicinal properties of *Terminalia arjuna* (Roxb.) Wight *and* Arn.: A review. J. Trad. Complement. Med.,**7**(1):65-78.

Bharani, A.; Ganguli, A. and Bhargava, K. D. (1995). Salutary effect of *Terminalia arjuna* in patients with severe refractory heart failure. Int. J. Cardiol., **49**:191-199.

Bharani, A.; Ganguli, A. and Mathur, L. K. (2002). Efficacy of *Terminalia arjuna* in chronic stable angina. Indian Heart J., **54**:170-175.

Chen, H. C.; Liu, Z.; Cheng, K.; Fung, L. and Chen, Y. U. (2004). Casuarinin protects cultured MDCK cells from hydrogen peroxide induced oxidative stress and DNA oxidative damage. Planta Med., **70**:1022-1026.

Cowan, M. M. (1999). Plant products as antimicrobial agents. Clin. Microbiol. Rev.,**12**(4):564-582.

Devi, R. S.; Narayan, S.; Vani, G. and Shyamala Devi, C. S. (2007). Gastroprotective effect of *Terminalia arjuna* bark on diclofenac sodium induced gastric ulcer. Chem. Biol. Interact., **167**(1):71-83.

Dwivedi, S. (2007).*Terminalia arjuna* Wight *and* Arn.: A useful drug for cardiovascular disorders. J. Ethnopharmacol.,**114**(2):114-129.

Dwivedi, S. and Agarwal, M. P. (1994). Antianginal and cardioprotective effects of *Terminalia arjuna*, an indigenous drug, in coronary artery disease. J. Assoc. Physicians India, **42**(4):287-289.

Dwivedi, S. and Chopra, D. (2014). Revisiting *Terminalia arjuna*: An ancient cardiovascular drug. J. Tradit. Complement. Med., **4**(4):224-231.

Dwivedi, S. and Udupa, N. (1989).*Terminalia arjuna*: Pharmacognosy, phytochemistry, pharmacology and clinical use: A review. Fitoterapia, **60**(5):413-420.

Gaikwad, D. and Jadhav, N. (2018). A review on biogenic properties of stem bark of *Terminalia arjuna*: An update. Asian J. Pharm. Clin. Res., **11**(8):26-33.

Gauthaman, K.; Maulik, M.; Kumari, R.; Manchanda, S. C.; Dinda, A. K. and Maulik, S. K. (2001). Effect of chronic treatment with bark of *Terminalia arjuna*: A study on the isolated ischemic-reperfused rat heart. J. Ethnopharmacol., **75**(2-3):197-201.

Ghosh, J. and Sil, P. C. (2013). Arjunolic acid: A new multifunctional therapeutic promise of alternative medicine. Biochimie, **95**(2):193-203.

Ghosh, J.; Das, J.; Manna, P. and Sil, P. C. (2010). Acetaminophen induced renal injury via oxidative stress and TNF-alpha production: Therapeutic potential of arjunolic acid. Toxicology, **268**(1-2):8-18.

Gupta, R.; Singhal, S.; Goyle, A. and Sharma, V. N. (2001). Antioxidant and hypocholesterolaemic effects of *Terminalia arjuna* tree-bark powder: a randomised placebo-controlled trial. J. Assoc. Physicians India, **49**:231-235.

Halder, S.; Bharal, N.; Mediratta, P. K.; Kaur, I. and Sharma, K. K. (2009). Anti-inflammatory, immunomodulatory and antinociceptive activity of *Terminalia arjuna* Roxb bark powder in mice and rats. Indian J. Exp. Biol., **47**(7):577-583.

Kapoor, D.; Vijayvergiya, R. and Dhawan, V. (2014).*Terminalia arjuna* in coronary artery disease: Ethnopharmacology, pre-clinical, clinical *and* safety evaluation. J. Ethnopharmacol., **155**(2):1029-1045.

Karthikeyan, K.; Sarala Bai, B. R.; Gauthaman, K.; Sathish Kumar, K. and Niranjali Devaraj, S. (2003). Cardioprotective effect of the alcoholic extract of *Terminalia arjuna* bark in an *in vivo* model of myocardial ischemic reperfusion injury. Life Sci., **73**(21):2727-2739.

Kumar, V.; Sharma, N.; Saini, R.; Mall, S.; Zengin, G.; Sourirajan, A.; Khosla, P. K.; Dev, K. and El-Shazly, M. (2023). Therapeutic potential and industrial applications of *Terminalia arjuna* bark. J. Ethnopharmacol., **310**:116352.

M'czka, W.; Twardawska, M.; Grabarczyk, M. and Wińska, K. (2023). Carvacrol: A natural phenolic compound with antimicrobial properties. Antibiotics, **12**(5):824.

Maheshwari, R.; Singh, A.; Gajbhiye, V. and Soni, M. (2013). Pharmacological activities of *Terminalia arjuna* (Roxb.) Wight *and* Arn: A review. J. Pharmacogn. Phytochem., **1**(6):18-24.

Mandal, S.; Patra, A.; Samanta, A.; Roy, S.; Mandal, A.; Sarkar, T. K.; Chakraborty, R.; Sen, A. and Mandal, V. (2013). Analysis of phytochemical profile of *Terminalia arjuna* bark extract with antioxidative and antimicrobial properties. Asian Pac. J. Trop. Biomed., **3**(12):960-966.

Manna, P.; Sinha, M. and Sil, P. C. (2006). Aqueous extract of *Terminalia arjuna* prevents carbon tetrachloride induced hepatic and renal disorders. BMC Complement. Altern. Med., **6**:33.

Manna, P.; Sinha, M. and Sil, P. C. (2007). Phytomedicinal activity of *Terminalia arjuna* against carbon tetrachloride induced cardiac oxidative stress. Pathophysiology, **14**(2):71-78.

Manna, P.; Sinha, M. and Sil, P. C. (2009). Prophylactic role of arjunolic acid in response to streptozotocin mediated diabetic renal injury: Activation of polyol pathway and oxidative stress responsive signaling cascades. Chem. Biol. Interact., **181**(3):297-308.

Newman, D. J. and Cragg, G. M. (2020). Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. J. Nat. Prod., **83**(3):770-803.

Pandey, K. B. and Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. Oxid. Med. Cell. Longev., **2**(5):270-278.

Parveen, A.; Babbar, R.; Agarwal, S.; Kotwani, A. and Fahim, M. (2011). Mechanistic clues in the cardioprotective effect of *Terminalia arjuna* bark extract in isoproterenol-induced chronic heart failure in rats. *Cardiovasc. Toxicol.,* **11**(1):50-59.

Pawar, S. P. and Bhutani, K. K. (2005). Effect of oleanane triterpenoids from *Terminalia arjuna*: A cardioprotective drug on the process of respiratory oxyburst. Phytomedicine, **12**(5):391-393.

Pettit, G. R.; Hoard, M. S.; Doubek, D. L.; Schmidt, J. M.; Pettit, R. K.; Tackett, L. P. and Chapuis, J. C. (1996). Antineoplastic agents 338. The cancer cell growth inhibitory constituents of *Terminalia arjuna* (Combretaceae). J. Ethnopharmacol., **53**(2):57-63.

Scalbert, A. (1991). Antimicrobial properties of tannins. Phytochemistry, 30(12):3875-3883.

Shahidi, F. and Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects: a review. J. Funct. Foods, **18**:820-897.

Shaila, H. P.; Udupa, S. L. and Udupa, A. L. (1998). Hypolipidemic activity of three indigenous drugs in experimentally induced atherosclerosis. Int. J. Cardiol., 67(2):119-124.

Sies, H. (2015). Oxidative stress: A concept in redox biology and medicine. Redox Biol., **4**:180-183.

Singh, D. V.; Verma, R. K.; Singh, S. C. and Gupta, M. M. (2002). RP-LC determination of oleane derivatives in Terminalia arjuna. J. Pharm. Biomed. Anal., **28**(3-4):447-452.

Sinha, M.; Manna, P. and Sil, P. C. (2008). *Terminalia arjuna* protects mouse hearts against sodium fluoride-induced oxidative stress. J. Med. Food, **11**(4):733-740.

Sumitra, M.; Manikandan, P.; Kumar, D. A.; Nagarajan, A.; Balakrishna, K. and Manohar, B. M. (2001). Experimental myocardial necrosis in rats: role of arjunolic acid on platelet aggregation, coagulation and antioxidant status. Mol. Cell. Biochem., **224**(1-2):135-142.

Tahir, H.; Akhtar, M. N.; Bishoyi, A. K.; Sanghvi, G.; Rasheed, M.; Afzaal, M.; Imran, A.; Saeed, F.; Khare, N.; Ahmed, F.; Sahni, O.; Ateeq, H.; Islam, F. and Kinki, A. B. (2025). Nutritional composition, phytochemical profile, extraction methods of bioactive components, and health benefits of *Terminalia arjuna* bark. eFood, **6**(2).

Citation **M. Sri Venkateshwaran and H. B. Roghan (2026). Bioactive compounds of *Terminalia arjuna* (Roxb. ex DC.) Wight and Arn. and their role in human health: A comprehensive review on nutraceutical and pharmacological properties. J. Phytonanotech. Pharmaceut. Sci., 6(3):129-138, http://dx.doi.org/10.54085/ap.2026.6.3.14.**