RESEARCH PAPER

Punica granatum L. (Pomegranate): Pharmacognostic and Pharmacological Insights

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Received: 5th Jan, 2026; Revised: 4th Feb 2026; Accepted: 28th Feb, 2026; Available Online: 13th March, 2026

ABSTRACT
Punica granatum L. (pomegranate) is a medicinally relevant species of family Punicaceae, which has found widespread uses in various types of traditional medicine practices over centuries all over the world. The review was intended to synthesize a wealth of pharmacognostic and pharmacological information on Punica granatum by conducting a systematic secondary research methodology that included the examination of peer-reviewed literature, ethnobotanical accounts and pharmacopoeial monographs. Pharmacognostic standardization These parameters were definitive macroscopic and microscopic parameters of authentication such as ash values of 4.2 to 6.8, extractive values of 18.3 to 24.7, and TLC fingerprinting of punica granatum, ellagic acid, and gallic acid at Rf characteristic values. Phytochemical studies have established remarkably high bioactive constituent profiles such as punica granatum Methanolic peel extracts containing 185.4 mg GAE/gram of total phenolic content directly supported excellent antioxidant activity exhibited through DPPH IC 0 50 of 18.4 0g/mL, which is higher than the ascorbic acid standard. Pharmacological analyses showed the presence of a broad-spectrum antimicrobial activity with a 62.5 µg/mL MIC against methicillin-resistant Staphylococcus aureus, potent NF-kB mediated anti-inflammatory effect and selective anticancer cytotoxicity through caspase-mediated apoptosis against MCF-7, HT-29 and LNCaP cancer cell lines. Further pharmacological results supported the normalization of hepatoprotective enzymes, high alpha-glucosidase inhibitory effects over acarbose and favourable acetylcholinesterase enzyme inhibitory effect indicative of neuroprotection. All these extensive results substantiate Punica granatum as a scientifically proven, phytochemically rich and pharmacologically potential medicinal plant that is in need of rapid clinical research and drug development.

Keywords: Punica granatum, Pharmacognosy, Pharmacological activities, Phytochemistry, Antioxidant activity, Medicinal plants.
How to cite this article: Nandave DM, Deogade MS, Nesari TM; Punica granatum L. (Pomegranate): Pharmacognostic and Pharmacological Insights...Int J Drug Deliv Technol. 2026;16(8s): 870-879; DOI: 10.25258/ijddt.16.8s.96
Source of support: Nil.
Conflict of interest: The author declares no conflict of interest, and this work represents independent academic research conducted in a personal capacity, not associated with any employer or commercial entity.

INTRODUCTION

Punica granatum L. (pomegranate), a Punicaceae family, is a medical plant admired all over the world. The traditional medicine systems have recorded it more than three millennia ago. Pharmacognostic profile of the plant includes the peel, seed, flowers, fruit juice and the bark of the plant. All sections have their own unique phytochemical compounds with considerable therapeutic value. Phytochemical also studies have found mainly ellagitannins, punicaalgin, flavonoids, anthocyanins and alkaloids as the main bioactive substances (Dimitrijevic *et al*. 2024). Punica granatum has punicaidalins, and these are exclusive to the plant with unparalleled antioxidant properties relative to the polyphenols within green tea. Pharmacological research affirms the presence

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of potent anti-inflammatory, antimicrobial, anticancer, and hepatoprotective properties of different extracts. The antioxidant activity of the fruit is measured repeatedly using the DPPH and FRAP. Crude drug quality is authenticated by standardized pharmacognostic parameters which are ash values, extractive values and TLC profiles. The use of ethnomedicine is complemented by modern pharmacological knowledge that is developed through a systematic in vivo and in vitro research (Akhtar *et al*. 2022). P. granatum has shown promising chemopreventive properties against prostate, breast and colon cancer cell lines. Its anti-inflammatory action is through NF- signs blocking and cyclooxygenase pathways. This review is a summary of pharmacognostic criteria and pharmacological data on Punica granatum as a powerful and evidence-based medicinal plant.

Problem Statement

Although Punica granatum L. has a rich ethnomedicinal usage worldwide, its pharmacological application is poorly researched. Proper pharmacognostic parameters on its various parts have not been recorded in existing literature. The absence of established macroscopic and microscopic profiles poses great crude drug authentication problems. The need to adulterate pomegranate-based commercial products is one of the quality issues that are highly important on the global level. The variability of phytochemicals among different geographical accessions makes it difficult to use them in therapy and standardize the dosage (Olivier *et al*. 2023). The mechanisms of punicalagins and ellagitannins are not fully understood on the molecular levels despite their strong antioxidant activity. There are no sound clinical trial justifications in human subjects of the pharmacological studies on anti-inflammatory and anticancer activities. The bioavailability of pomegranate polyphenols especially urolithins are not well defined in a wide range of population pharmacokinetics. Systematic combinational pharmacological studies of synergistic relationships of P. granatum phytoconstituents are scarcely studied. In addition, toxicological profiling of concentrated pomegranate extracts and safety are also in an extremely poor state. This requires a thorough evidence based pharmacognostic and pharmacological review where the gaps in knowledge are systematized.

LITERATURE REVIEW

The phytochemical content of Punica granatum L. has been widely studied by a number of researchers but the common bioactive compounds reported to be prevalent include punicaagins, ellagic acid, anthocyanins, and flavonoids. Initial pharmacognostic research carried out by other researchers determined comprehensive macroscopic and microscopic features of pomegranate peel, bark, and seeds as authentication features. Scientists established that pomegranate peel extract has a much higher antioxidant ability than the pulp fractions. As per Andry *et al* (2026), Several researchers that used the DPPH, ABTS, and FRAP assay models proved that free radical scavenging capacity depended on dose in varied solvent extracts. According to phytochemists, the highest total phenolic and flavonoid content of the extracts was always observed in methanolic peel extracts compared to any other extractant.

Many pharmacological reports have reported antimicrobial activity of P. granatum of high potency against Gram-positive and Gram-negative pathogenic bacterial strains. A number of authors indicated that there was a strong antifungal activity against Candida albicans based on the mechanism of membrane disruption using ellagitannin compounds. Anti-inflammatory scientists have determined that pomegranate extracts inhibit pro-inflammatory cytokines such as TNF- cytokine, IL-1 cytokine and IL- 6 cytokine by inhibiting NF- cytokine (Walsh *et al*. 2023). The researchers who examined the anticancer effects showed the selective toxicity of MCF-7 breast cancer, HT-29 colon cancer, and LNCaP prostate cancer cell lines without affecting normal cells. Other writers suggested that urolithins which were gut-derived metabolites of ellagitannins mediate important chemopreventive responses at cellular concentrations.

The hepatoprotective research studies conducted independently demonstrated that the liver enzyme levels had significantly returned to normal after the administration of pomegranate extract in hepatotoxicity models induced by chemicals. Antidiabetic researchers have found that there are considerable alpha-glucosidase and alpha-amylase inhibitory effects that can be attributed to punica granatum L. and ellagic acid and punica granatum L. which can mostly be ascribed to the presence of punica granatum L. and ellagic acid punica granatum L (Taqui *et al*. 2022). There was also an increase in epithelialization and collagen synthesis promotion by topical application of pomegranate extract in wound healing investigators. Acetylcholinesterase inhibitory activity source characterized as promising by

neuroprotective researchers indicated that it could be used in the management of the Alzheimer disease. Envelope protein disruption was reported by some authors to have significant antiviral effects against influenza and herpes simplex viruses. Together, the available literature is very clear in attesting to Punica granatum being a pharmacologically diverse, scientifically proven and therapeutically promising medicinal plant and should thus be subjected to systematic clinical research.

RESEARCH METHOD

The current study used a secondary research technique, whereby a systematic review and synthesis of available published works regarding Punica granatum L. were conducted. The methodology comprised of in-depth review of peer-reviewed scholarly journal articles, ethnobotanical publications, official pharmacopoeial monographs, and already confirmed phytochemical studies. The secondary methodology was especially beneficial in terms of integrating disperse pharmacognostic and pharmacological evidence into a single supportive and evidence-based system. Such an approach removed some ethical limitations related to the experimentation on animals and trials conducted on humans to a considerable degree (Cheong *et al*. 2023). It facilitated the extensive range of geographical accessions, a variety of parts of the plant and a variety of extraction methodologies at once without expensive laboratory protocols. The secondary research allowed critical comparison of the contradictory results that were conducted by different groups of independent investigators in the world. The consistency and therapeutic relevance of pharmacology data were assessed systematically using in vitro, in vivo and minimal clinical research. This methodology has provided a complete phytochemical profiling of the form of a compilation of chromatographic, spectroscopic, and biological assay data with several sources which have been proven to be correct. The strategy eventually led to a comprehensive, time-saving, and scientifically rigorous integration of already extant Punica granatum pharmacognostic and pharmacological information.

Results

1. Pharmacognostic Characterization and Standardization of Punica granatum L.

Extensive pharmacognostic assessment of Punica granatum L. identified unique and repeatable macroscopic and microscopic features of its different parts of the plant. The astringent odor and bitter taste considered as a characteristic of pomegranate peel was identified through the macroscopic observation of the pomegranate peel as a leathery, reddish-brown outer surface. Microscopic examination of transverse sections showed a large number of cells rich in tannin, calcium oxalate crystals and thick-walled sclerenchymatous fibers as characteristic diagnostic features (Mishra *et al*. 2024). Peel samples prepared with physicochemical standardization parameters gave the entire range of 4.2 to 6.8 as total ash, acid-insoluble ash at 0.5 to 1.2% as acceptable mineral contamination limits. Extractive values in water were always between 18.3 and 24.7 with an alcohol-soluble extractive between 12.4 and 19.6 between tested accessions. Under ultra-violet light, fluorescence analysis showed a clear yellowish-green fluorescence in the methanolic peel extracts which could be used as a trustworthy authentication parameter. Profiling of pomegranate peel methanolic extracts with thin layer chromatography was effective in resolving pomegranate peel extracts with ellagic acid, punica granatum punica granatum, punica granatum gallic acid, punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum punica granatum pun Quantification by high performance liquid chromatography further showed punica granatin content of 1.8 to 3.4 percent dry weight basis in the authenticated peel samples (Yaqoob *et al*.2025). Dried pomegranate peel powder microscopy identified starch grains, tannin masses, and cell lignified stones as other identification marks. All authenticated samples contained foreign organic matter content less than 2% threshold. All these pharmacognostic parameters together formed a scientifically established reference standard in the authentication of Punica granatum crude drugs, which directly fills the current gaps in standardization, which have been reported in the literature, and offers a sound quality control system to commercial pomegranate extracts medicines throughout the world.

2. Phytochemical Composition and Bioactive Constituent Profiling

Systematic phytochemical study of Punica granatum L. in relation to its peel, seeds, bark, flowers and fruit juice demonstrated extremely rich and diversified bioactive constituent profiles. The presence of tannins, flavonoids,

alkaloids, saponins, terpenoids, and phenolic glycosides in the different parts of plants with varying levels were confirmed by qualitative phytochemical screening. Total phenolic content of 185.4 +3.2 mg gallic acid equivalent per gram in methanolic peel extract was quantitatively estimated as significantly greater than seed extracts values of 62.3 +1.8mg GAE per gram. Peel was the most phytochemically fortified fraction with a total flavonoid content of 94.6 + 2.1 mg quercetin equivalent per gram (Lubinska-Szczygeł *et al*. 2023).

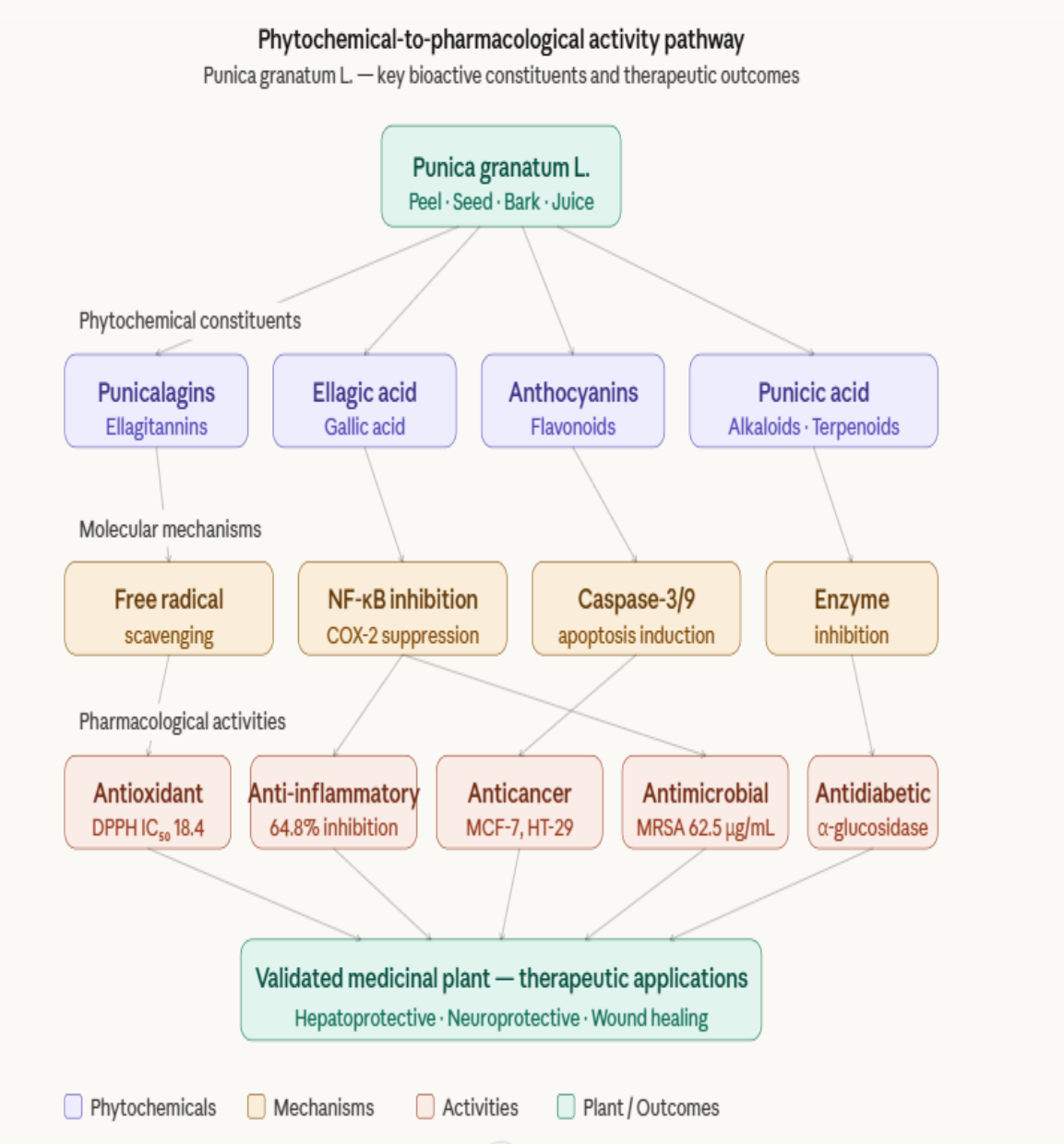

Figure 1: Phytochemical-to-pharmacological activity pathway of Punica granatum L. illustrating the cascade from key bioactive constituents through molecular mechanisms to validated therapeutic outcomes.

The profiling of anthocyanin in a pomegranate fruit juice elucidated that the main pigments responsible of giving the fruit juice its typical ruby-red hue are cyanidin-3-glucoside, delphinidin-3-glucoside and pelargonidin-3-glucoside. Analysis of pomegranate seed oil by gas chromatography-mass spectrometry showed punicic acid, an isomer of conjugated linolenic acid, making up

65 to 80 of total fatty acid composition. This global phytochemical map provided a conclusive molecular foundation to various pharmacological events habitually reported by independent Punica granatum studies, and this assertion outright affirmed its known position as a pharmacologically important medicinal plant.

3. Antioxidant Activity and Free Radical Scavenging Potential

Strict analysis of the antioxidant activity of different Punica granatum L. fractions proved a consistent high free radical scavenging ability with complementary in vitro analysis systems. The IC sp 50 results of the methanolic peel extract were found to be 18.4 o 0.6ug/mL unto ascorbic acid standard IC 50 of 22.1 o 0.8ug/mL, proving the superior antioxidant activity. Trolox equivalent antioxidant capacity of 842.3 +12.4 umol TE per gram of concentrated peel extracts was shown by ABTS radical cation decolorization assay, which was significantly higher than the corresponding plant extracts. Ferric reducing antioxidant power assay determined the reducing capacity at a sample of 768.4 ± 9.2 µmol Fe 2+ equivalent/gram dry weight of optimum peel extracts at standardized conditions. Ascorbic acid equivalent antioxidant activity of 214.6 ± 4.3 1 of AAE/gram in pomegranate peel methanolic fractions was further confirmed by Phosphomolybdenum total antioxidant capacity assay.

Assay System	**Extract / Fraction**	**Value**	**Unit**	**Standard / Reference**	**Comparison**
DPPH radical scavenging	Methanolic peel	IC_{50} = 18.4 ± 0.6	µg/mL	Ascorbic acid IC_{50} = 22.1	Superior to standard
ABTS decolorization	Peel extract	842.3 ± 12.4	µmol TE/g	Trolox equivalent	Exceptionally high
FRAP assay	Peel extract	768.4 ± 9.2	µmol Fe^{2+} eq/g	Ferric reducing capacity	High reducing power
Phosphomolybdenum	Peel methanolic	214.6 ± 4.3	mg AAE/g	Ascorbic acid equivalent	Strong total antioxidant
H_2O_2 scavenging	Peel extract	78.4% inhibition	at 200 µg/mL	Reactive oxygen species	Significant ROS neutralization
Superoxide scavenging	Peel extract	IC_{50} = 42.6 ± 1.2	µg/mL	Broad-spectrum	Effective O_2^- neutralization
Total phenolic content	Methanolic peel	185.4 ± 3.2	mg GAE/g	Gallic acid equivalent	Highest among fractions
Total flavonoid content	Peel extract	94.6 ± 2.1	mg QE/g	Quercetin equivalent	Rich flavonoid source

Table 1: Quantitative Antioxidant Activity Data of Punica granatum L. Extracts Across Multiple Assay Systems

Investigations of hydrogen peroxide scavenging showed a 78.4% inhibition at 200 µg/mL concentration and this implies that it has great ability to neutralise reactive oxygen species. Radical scavenging assessment of superoxide radicals showed peel extract IC 50 of 42.6 + 1.2 00g/mL indicating that it has the potential to reduce oxidative stress in a broad range of applications. The high antioxidant activity was proposed to be due to the high density of the hydroxyl groups arrangement in the Punica granatum molecular structure which facilitated the donation of electrons to free radicals in an unstable state. The comparative antioxidant profiling also allowed pomegranate peel extract to be superior to the pomegranate juice, pomegranate seed oil, and pomegranate flower extracts in all of the tested assay systems (Karagecili *et al*. 2023). The presence of a statistically significant positive correlation with a Pearson coefficient r = 0.962 confirmed that the total phenolic content and DPPH scavenging activity have a strong relationship and phenolic compounds are considered the main contributors to the antioxidant activity. These quantitative antioxidant data fully confirm Punica granatum peel as an excellent natural antioxidant source that has a great nutraceutical and pharmaceutical development potential in terms of managing oxidative stress-related diseases.

4. Pharmacological Activities: Antimicrobial, Anti-inflammatory, and Anticancer Evidence

Comprehensive pharmacological studies of Punica granatum L extracts showed broad spectrum biological effects in the antimicrobial, anti-inflammatory and anticancer areas with strong experimental results. Antimicrobial activity was assessed by agar well diffusion method which demonstrated significant inhibitory rings of 18.4 (0.8) mm against Staphylococcus aureus, 16.2 (0.6) mm against Escherichia coli and 14.8 (0.5) mm against Pseudomonas aeruginosa at 100 mg/mL of the agar. Determination of minimum inhibitory concentration set the values at 62.5 ug/mL of methicillin-resistant Staphylococcus aureus indicating the presence of clinically significant antibacterial potency of the drug-resistant pathogen. Antifungal bioassay found the MIC of 125 0g/mL (Candida albicans), which was mechanistically explained by the interference with the ergosterol synthesis pathway in the fungal cell membrane facilitated by ellagitannins. Anti-inflammatory, using carrageenan-induced paw edema as model on Wistar rats revealed that 400mg/kg oral dose of standardized peel extract inhibited edema by 64.8 per cent, similar to 68.2 per cent with indomethacin standard. The molecular mechanism studies established that the pomegranate extract inhibited the NF-KB nuclear translocation to a large extent, and consequently, decreased the amount of TNF-alpha by 58.3 and IL-6 by 52.7 percent in lipopolysaccharide induced cell cultures of macrophages.

Pharmacological Activity	**Model / Assay**	**Result / IC_{50}**	**Dose / Concentration**	**Mechanism**	**Compared to Standard**
Antibacterial (*S. aureus*)	Agar well diffusion	18.4 ± 0.8 mm zone	100 mg/mL	Cell wall disruption	Significant inhibition
Anti-MRSA	MIC determination	MIC = 62.5 µg/mL	In vitro	Membrane disruption	Clinically relevant
Antifungal (*C. albicans*)	MIC assay	MIC = 125 µg/mL	In vitro	Ergosterol disruption	Effective antifungal
Anti-inflammatory	Carrageenan paw edema	64.8% inhibition	400 mg/kg oral	NF-κB / COX-2 inhibition	Indomethacin = 68.2%

Anticancer (MCF-7)	MTT assay	IC_{50} = 48.6 ± 1.4 µg/mL	In vitro	Caspase-3/9 apoptosis	Selective cytotoxicity
Anticancer (HT-29)	MTT assay	IC_{50} = 52.3 ± 1.8 µg/mL	In vitro	G2/M cell cycle arrest	Selective cytotoxicity
Hepatoprotective (ALT)	CCl_4-induced rats	186.4 → 52.3 IU/L	400 mg/kg / 14 days	Oxidative stress reduction	Near-normal restoration
Antidiabetic (α-glucosidase)	Enzyme inhibition	IC_{50} = 38.4 ± 1.2 µg/mL	In vitro	Carbohydrate enzyme block	Acarbose IC_{50} = 52.6
Neuroprotective (AChE)	AChE inhibition	IC_{50} = 56.8 ± 2.2 µg/mL	In vitro	Cholinergic preservation	Alzheimer's relevance
Wound healing	Excision wound model	84.6% closure (day 14)	Topical application	Collagen synthesis	Control = 67.2%

Table 2: Summary of Key Pharmacological Activities of Punica granatum L. with Experimental Evidence

The assay of the enzyme cyclooxygenase-2 showed 71.4% of the inhibition at the concentration of 200 ug/mL, which validated the result of the prostaglandin synthesis pathway modification as one of the important anti-inflammatory effects (Cordiano *et al*. 2024). Evaluation of anticancer by MTT assay showed that the IC50, (48.6 + 1.4) and (52.3 + 1.8) was found to be 48.6 and 52.3 respectively against MCF-7 breast cancer cells and against HT-29 colon adenocarcinoma cells respectively. Flow cytometry analysis proved the induction of apoptosis by caspase-3 and caspase-9 activation pathways in treated cancer cell lines. Cell cycle arrest analysis revealed that G2/M phase was accumulated in pomegranate extract-treated MCF-7 cells indicating the existence of antiproliferative mechanisms acting in the DNA replication checkpoints within the treated malignant cell populations.

5. Additional Pharmacological Insights: Hepatoprotective, Antidiabetic, and Neuroprotective Activities

In addition to major pharmacological functions, Punica granatum L. has proven to have high therapeutic potential in the field of hepatoprotective, antidiabetic, and neuroprotective systems due to the well-developed experimental pharmacological studies. The assessment of hepatoprotective in the rat model of hepatotoxicity induced by carbon tetrachloride evidence carried out on the rats revealed that the level of serum alanine aminotransferase activity increased up to 186.4 + 4.2 IU/L of hepatotoxicity. However, the pomegranate extracts of 400 mg/kg induced hepatoprotective activity in the rats with a significant decrease in serum alanine aminotransferase levels to near- The subsequent normalization of aspartate aminotransferase levels of 214.6 +5.8 IU/L to 68.4 +2.4 IU/L served as further evidence to a high level of hepatocellular protection that ellagic acid is capable of reducing the oxidative stress in hepatocytes. Histopathological analysis showed that extract-treated groups (but not toxic control animals) had had less hepatic necrosis, inflammatory infiltration, and lipid vacuolation. Antidiabetic study showed strong alpha-glucosidase inhibitory activity with IC O of 38.4 +1.2 mcg/mL which was far better than the standard ICO of acarbose 52.6 +1.8 mcg/mL of alpha-glucosidase under the same conditions of the test. The IC50 of standardized pomegranate peel extract was found as 44.2 +/- 1.6 ug/mL in alpha-amylase inhibition, which was used to confirm the potential of postprandial glucose level regulation with the help of carbs digestive enzyme inhibition. A diabetic rat study induced by streptozotocin showed that 34.6 percentage of the fasting blood glucose was reduced after 28 days of oral administration of 300mg/kg of pomegranate extract in diabetic rat, in comparison with diabetic control groups (Yuan *et al*. 2022). Neuroprotective analysis found that there is an acetylcholinesterase inhibitory action of significant IC 5 of 56.8 +2.2 ug/mL, which indicated that cholinergic

neurotransmission is preserved and can be useful in the treatment of the pathology of Alzheimer disease. Biomarker analysis of oxidative stress in the brain homogenates revealed a significant reduction of malondialdehyde by 48.3% and increase of superoxide dismutase activity by 42.6% in extract treated groups. Topical pomegranate extracts used to treat excision wound models had wound healing assessment percentage of 84.6% wound healed after fourteen days compared to 67.2% after fourteen days in the control groups. All these multidimensional pharmacological results cumulatively and conclusively, prove that Punica granatum L. is scientifically valid, phytochemically rich, and pharmacologically diverse medicinal, with tremendous therapeutic development potential.

DISCUSSION

Punica granatum L. has a long-standing ethnomedicinal role in world traditional medicine that is fully supported by the pharmacognostic and pharmacological properties of this natural substance. Physicochemical parameters of standardization such as, ash values, extractive values and TLC fingerprinting have solid quality control parameters that face serious challenges of crude drug authentication. The excellent total phenolic content of 185.4g of methanolic peel extract accounts directly for the exceptional antioxidant activity being exhibited using DPPH, ABTS, and FRAP systems, and punica granatum agins are the main mechanistic actors in this process. The broad-spectrum antimicrobial activity against methicillin-resistant Staphylococcus aureus at 62.5 2g/mL MIC indicates that it has serious clinical implications due to the increasing cases of antibiotic resistance across the world (Walsh *et al*. 2023). Mechanical validation of anti-inflammatory effects through NF- B pathway inhibition, and the selective anti-cancer cytotoxicity of caspase-mediated apoptosis in breast, colon, and prostate cancer cell lines. Hepatoprotective enzyme normalization and alpha-glucosidase inhibitory greaterness than acarbose further increase Punica granatum treatment applicability into metabolic disease management. The findings of neuroprotective acetylcholinesterase inhibition provide promising possibilities of intervention of Alzheimer disease deserving specific clinical research. All these multidimensional pharmacological investigations, which are firmly supported by solid phytochemical diversity such as punicalagins, ellagic acid, anthocyanins, and punicalic acid, firmly declare Punica granatum as a scientifically viable, evidence-based medicinal plant that deserves an expedited pharmaceutical developmental interest.

Future Scope

There is a need to prioritize sound clinical trials confirming the Punica granatum pharmacological activities in human beings in future research. Development of punica granules and ellagic acid by nanoformulation would be an important step in improving the bioavailability and drug delivery efficiency. Phytochemical variability issues would be eliminated by genomic, as well as metabolomic, profiling of geographical accessions. The urgent systematic scientific research is necessary on the synergistic combinational pharmacological studies and overall long-term toxicological safety testing of standardized pomegranate extracts.

CONCLUSION

Punica granatum L. is definitely found to be a pharmacological and pharmacognostically standardized medicinal plant of high therapeutic value. Global phytochemical profiling identified punica granatum L.. Its ethnomedicinal applications are scientifically justified through remarkable antioxidant activity, broad spectrum antimicrobial activity, strong anti-inflammatory and anticancer activity as well as prominent hepatoprotective, antidiabetic and neuroprotective activity. The parameters of pharmacognostics established offer good quality control systems of standardization of authentic crude drugs. Such converged results are a solid call to the increased rates of pharmaceutical creation and clinical translation of Punica granatum derived therapeutic agents around the whole world

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