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PHYTOCHEMICAL PROFILING, PHARMACOLOGICAL POTENTIAL AND TRANSLATIONAL APPLICATIONS OF *BOUGAINVILLEA SPECTABILIS*: A CRITICAL REVIEW

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ABSTRACT
Bougainvillea spectabilis is an ornamental plant with significant pharmacological potential attributed to its diverse phytochemical composition. This review critically evaluates the phytochemical profile, pharmacological activities, and emerging translational applications of *B. spectabilis*. Extensive literature analysis reveals the presence of bioactive compounds such as flavonoids (quercetin, kaempferol), alkaloids, terpenoids, glycosides, and phenolic acids, which contribute to its antioxidant, antimicrobial, antidiabetic, anti-inflammatory, and anticancer activities. Mechanistically, these effects are mediated through pathways involving reactive oxygen species (ROS) scavenging, modulation of inflammatory mediators, and regulation of cellular signaling pathways.
In addition to pharmacological properties, this review highlights the underexplored potential of *B. spectabilis* in pharmaceutical and industrial applications, including cosmeceuticals, natural food colorants, and nanoformulations for improved bioavailability. Despite promising preclinical evidence, limitations such as lack of standardization, insufficient toxicity profiling, and absence of clinical validation restrict its translational advancement.
This review provides a critical perspective on existing research gaps and proposes future directions for the development of *B. spectabilis*-based therapeutics and commercial products, bridging the gap between traditional use and modern pharmaceutical applications.

KEYWORDS: *Bougainvillea spectabilis*, phytopharmacology, bioactive compounds, flavonoids, alkaloids, antimicrobial activity

1. INTRODUCTION

Natural substances derived from minerals, plants, and animals are vital to medicinal sciences, contemporary pharmacology, and human health. These substances are widely recognized for their diverse pharmacological potential including anticancer, antibacterial, antioxidant, and anti-inflammatory qualities [1]. Certain phytochemicals produced in different plant parts are responsible for the biological characteristics of medicinal plants. These phytochemicals play a significant role in terms of maintaining the health of humans [2]. Flavonoids, alkaloids, and terpenoids are examples of phytochemicals with strong bioactivity that support health and prevent disease [3]. Since ancient times, natural substances have played a crucial role in the fight against the diseases, providing a higher safety profile and lowering the likelihood of negative side effects, in comparison to manufactured medications [4]. They increase the body's immunity by changing biochemical pathways to produce their therapeutic action. Finding new therapeutic agents and determining how to employ them to support sustainable and holistic health practices both depend on research into natural components [5]. Traditional medicine is becoming more and more popular as a means of treating a variety of illnesses [6]. Research on phytochemicals, their many medicinal uses, and their use in a sustainable economy all highlight their importance [7]. This new area emphasizes how important it is to use natural items in traditional medicine to develop novel cures for a variety of illnesses and ailments [8, 9].
Medicinal plants are widely used in the creation of novel treatments since research has demonstrated that they are easily accessible and have fewer side effects than other medications. *Bougainvillea spectabilis*, commonly referred to as paper flower, is said to have anti-cancer [10], antidiabetic [11.12], anti-inflammatory [13], antihyperlipidemic [14], antibacterial, antioxidant, and antiulcer properties [15]. Numerous bioactive compounds can be found in the ancient medicinal herb *Bougainvillea Spectabilis* Willd. The phytoconstituents that have been shown to be the basis of their therapeutic properties include alkaloids, quinones, saponins, tannins, phenolics, glycosides, phlobotannins, and terpenoids. The other important components that contribute to the therapeutic effects are terpinolene, quercetin, quercetagetin, pinitol, and bougainvinones [16].
Previous reviews have primarily described the phytochemical compounds and their associated pharmacological properties; however, this review aims to take a more structured approach to integrating bioactive compounds with the related biological properties, as well as potential applications. Significant attention is given to the translational potential of

Bougainvillea spectabilis through pharmaceutical products, cosmeceutics, and functional food products. This review also highlights existing voids regarding standardization, limited toxicity data, and no clinical data, which have either been absent from prior reports or discussed in greater detail in past literature. By utilizing this method of evaluation, this review will provide more definite guidance for future research and practical use of this plant.

1.1 Plant description:

Because of its thin, papery bracts, B. *Spectabilis* is frequently called "Paper Flower." The colors of bougainvillea vary from white to orange, with purple or magenta being the most popular. A rainbow paper flower is a tree that has two colors on it, such as pink and white or pink and orange [17]. It is a woody perennial vine with enormous, multitrunked stems that clump together and reach a height of 2-4 meters. Thin branches connected to bent thorns make up the clumping stem. Stems that are sprouting range in color from green to dark green. The bark is corky and light. The slender, tight branches result in an extremely thick plant [18]. The leaves alternate and are simple. The leaf has ovate to rounded forms and is 5–10 cm in length and 2–6 cm in width. The undersides of the deep green, leathery leaves are hairy. The leaf axils are where the blossoms appear in groups of three. The flower has a white color, is small and thin, has hairy tubes, and is encircled by vibrant petaloid bracts. Crinkled, rather large, and egg-shaped, the bracts are rose, rusty-red, magenta, and purple in hue. The tall, five-lobed achene fruit has a stiff, dry fruit cover and measures 1-2 cm in length [17].

Fig no. 1: *Bougainvillea Spectabilus*

1.2 Taxonomical Classification: Genus Bougainvillea was first discovered in Brazil by a French navigator named Louis Antoine de Bougainvillea, in 1786. The taxonomy of B. *Spectabilis* is as follow:

Kingdom: Plantae;
Subkingdom: Viridiplantae;
Infrakingdom: Streptophyta;
Superdivision: Embryophyta;
Division: Tracheophyta;
Subdivision: Spermatophytina;
Class: Magnoliopsida;
Superorder: Caryophyllene;
Order: Caryophyllales;
Family: Nyctaginaceae;
Genus: Bougainvillea;
Species: B. spectabilis [16].

1.3 DISTRIBUTION:

The Great Bougainvillea, or *Bougainvillea spectabilis*, is indigenous to South America's tropical and subtropical regions, especially Brazil, Peru, Bolivia, and Argentina's Chubut Province. It grows well in a range of environments, such as dry, rocky slopes, coastal areas, and tropical woods. In order to produce its vivid and colorful bracts, the plant likes locations with well-drained soil and lots of sunlight [19]. Often seen in parks, gardens, and by the side of the road, *Bougainvillea Spectabilis* is incredibly versatile and can grow in both urban and rural settings. Because of its extensive range, it has been introduced to many regions of the world, where its resilient nature and eye-catching blooms have led to its cultivation as an ornamental plant. This species thrives in warm regions and is found in nations in Asia, Africa, and Oceania [20].

2. CULTIVATION AND COLLECTION:

Bougainvillea Spectabilis prefers slightly acidic to neutral pH levels and grows best in full sun and well-drained soils. Once established, it can tolerate arid circumstances and is drought-tolerant. Due of its sensitivity to frost, the plant may be damaged or die back in cold weather. *Bougainvillea Spectabilis* is often propagated using cuttings. During the growing season, cuttings of hardwood or semi-hardwood, usually 4 to 6 inches long, are taken. After receiving rooting hormone treatment, these cuttings are put in a medium that drains properly. Although it may take a few weeks to root, success rates can be increased by applying spray and bottom heat. For mass multiplication, in vitro propagation methods have also been created [21].

3. PHYTOCHEMISTRY

Bougainvillea spectabilis is noted for its high content of phytoconstituents from various plant parts (leaves, bracts, stem and root). These compounds mainly consist of flavonoids, alkaloids, terpenoids and phenolic compounds, which are believed to affect the biological properties of the plant significantly. [22].

3.1 Volatile Compounds: Volatile compounds of *Bougainvillea spectabilis* are important members of bioactive phytochemicals that contribute to the plant's aroma, therapeutic effects and ecological interactions. One phytochemical study involving ethanol extracts of leaves and branches identified 35 volatile compounds with various chemical structures, including aldehydes, ketones, phenols, oxides, esters, and alcohols. Notable volatile constituents of B. *Spectabilis* include: methyl salicylate; terpinolene; 2-furfural; cadina-1,4-diene; linalool; and pulegone, among others [23]. Among these volatile constituents of plant, Terpinolene and linalool possess strong antimicrobial and anti-inflammatory activities; methyl salicylate is a natural analgesic and anti-inflammatory agent; and the alcohols, e.g., terpinen-4-ol and aldehydes, e.g. hexanal and heptanal, also have biological activity, most likely by compromising microbial cells [24]. These volatile constituents are mostly present in the leaves and branches of the plant suggesting medicinal importance attached to the aerial parts of the plant. Such a volatile profile is an indication of B. *Spectabilis* next potential role in diverse antimicrobial applications and for developing natural pesticides, as well as therapeutic applications related to plant aromatic chemicals. The volatile constituents may change based on the harvesting environment and extraction methods [25].

3.2 Fatty Acids: Fatty acids represent a significant contributor to the phytochemical diversity and bioactivity of *Bougainvillea spectabilis*. Fatty acids have been identified from several different parts of the plant, but they have been of particular interest in the roots, leaves, and branches. The presence of a new unsaturated fatty acid, named n-octacos-9-enoic acid, and long chain fatty acids such as hexadecanoic acid (palmitic acid), and its derivatives, have all been extracted from B. spectabilis. Fatty acids may be part of complex structures, for instance, 1,2-dipalmitoleoyl glyceryl phosphate from the root extracts contained the fatty acids as part of the overall molecule [26]. Other lipophilic compounds showed up, for example, n-hentriacontanol (a long-chain alcohol). The presence of fatty acids from B. *Spectabilis* indicates their involvement in various biological processes, likely participating in antioxidant and antimicrobial activities. The fatty acids are shown to be present in ethanolic extracts and this could be significant to the plant's medicinal value. Their likely influence on membrane stability, anti-inflammatory activity, or insecticidal activity is ambiguous, however [24]. The work presented in this study has broadened the chemical profile of B. *Spectabilis* and the presence of fatty acids merits further investigation for their possible pharmacological activity. The methods of extraction have focused on using fashioned from the roots and aerial parts of the plant have effectively isolated B. *Spectabilis* fatty acids, which reiterate the need and importance of thorough phytochemical studies as a way to understand the phytochemicals of a plant species, especially in its ability to produce bioactive compounds [19].

3.3 Flavonoids: Flavonoids are one of the most commonly reported classes of compounds in *Bougainvillea spectabilis*. Among these, quercetin and kaempferol are frequently identified in the leaves and bracts [27]. These compounds have been associated with antioxidant and anti-inflammatory activities, which may contribute significantly to the overall pharmacological profile of the plant. However, the concentration of flavonoids can vary depending on the extraction method used as well as the specific plant part being analysed [28,29].

3.4 Phytosterols, Terpenes, and Carbohydrates: The presence of phytosterols, terpenes, and carbohydrates in *Bougainvillea spectabilis* makes a notable contribution to its therapeutic properties, where β-sitosterol is most commonly found in the bark of the stem, which helps in modulating cholesterol levels, with anti-inflammatory actions mediated by membrane-stabilizing activity, together with analogs stigmasta-5,22-dien-3-ol and stigmasterol from related species [30]. Other terpenes, such as phytol and isophytol, found in leaves and branches, display notable antioxidant, antimicrobial, and antinociceptive actions, which help widen the therapeutic potential of the drug. The antidiabetic activity displayed by carbohydrates such as pinitol, a cyclitol sugar found in leaves, improves the sensitivity of insulin, with optimized drought stress protocols in Punjab conditions resulting in 1.5 times increased production compared to normal conditions (Table 3) [31,32].

3.5 Polyphelos: The polyphenolics present in *Bougainvillea Spectabilis* may represent an important category of bioactive compounds that make an important contribution to the health benefits of the plant. Phenolic compounds consist of flavonoids, tannins, and other phenolic acids and possess strong antioxidant, anti-inflammatory, antimicrobial and anticancer activities [29]. Quantitative studies have shown that the bracts and other aboveground parts of B. *Spectabilis* are rich in polyphenolics. Notable differences in total phenolic content have been measured, with notable high values seen

in both the ethanol and ethyl acetate portions frequently observed with high antioxidant capacity. Polyhenolics act by scavenging free radicals, thereby decreasing oxidative stress and modulating inflammatory pathways that underscore many of the proposed pharmacological effects of the plant. Polyphenolics also contribute to the potential antibacterial activity and antiviral effects of B. spectabilis [31]. Changes in the polyphenolic profiles can be influenced by extraction method and different extractable parts of the plant. However, ethanol-based extractions often yielded higher phenolic contents. To summarize, polyphenolics are an important aspect of the bioactivity of *Bougainvillea Spectabilis* and clearly play an important role for efficacy regarding the plant as a traditional medicinal plant [29].

4. PHARMACOLOGICAL ACTIVITIES OF *BOUGAINVILLEA SPECTABILIS*:

Bougainvillea Spectabilis is an important medicinal plant that possesses a wide range of pharmacological properties due to its different phytochemicals including flavonoids, alkaloids, saponins, terpenoids, and phenolic compounds. Some of the major pharmacological activities have been summarised in the table no 1.

4.1 Anti-diabetic and Antioxidant Activities: The aqueous leaf extract exhibited anti-hyperglycemic and anti-hyperlipidemic properties in streptozotocin-induced diabetic animals, with the efficacy being due to enhanced antioxidant status including increased glutathione (GSH) and superoxide dismutase (SOD) and reduced lipid peroxidation (thiobarbituric acid reactive substances; TBARS). Interestingly, the extract not only normalized biochemical markers in the liver & kidney but also did not show toxicity in the subchronic administration [33, 34].

4.2 Anti-inflammatory Activity: Methanolic leaf extracts reduce both acute and chronic inflammation, likely through altering the levels of pro-inflammatory cytokines and fictive pathways related to glutamatergic signaling, cyclic guanosine monophosphate (cGMP) signaling and ATP-sensitive potassium channels. Extracts from the flower showed efficacy in the inhibition of biochemical related parameters in inflammation, as well as protecting tissues such as brain, liver and kidney from [16, 35].

4.3 Hepatoprotective Effects: Ethanolic and aqueous extracts showed hepatoprotective properties in animal models of carbon tetrachloride (CCl_4) -induced damage through marked decreases in serum transaminases (AST, ALT), bilirubin, and total protein levels. Pathological findings suggest reductions in inflammation, necrosis, and fibrosis due to antioxidant mechanisms of the phytochemicals [36].

Table 1: Pharmacological Activities of *Bougainvilles Spectabilis*

Activity	Experimental Model	Plant Part	Extract Type	Key Findings	Reference
Antidiabetic	Streptozotocin-induced rats	Leaves	Ethanolic extract	Reduced blood glucose levels	[34]
Antioxidant	DPPH radical scavenging assay	Whole plant	Methanolic extract	Strong free radical scavenging	[33]
Anti-inflammatory	Carrageenan-induced rat paw edema	Leaves	Aqueous extract	Reduced inflammation markers	[35]
Antimicrobial	Agar well diffusion method	Bark	Aqueous extract	Inhibits Staphylococcus aureus	[39,40]
Wound Healing	Topical application	Leaves	Cream formulation	Enhanced wound contraction & healing	[37,38]

4.4 Antifertility Effects: *B. Spectabilis* exhibits antifertility potential through blockade of spermatogenesis manifested through reduced sperm counts, motility, viability, and morphology and modulation of reproductive steroid hormones like testosterone and estrogen. These mechanisms are likely through altered sperm metabolism disrupting aerobic to anaerobic energy pathways [16].

4.5 Anticancer, Wound Healing, and Analgesic Activities: The leaf extract has been shown to be cytotoxic against human lung carcinoma (A549) cells, suggesting possible anticancer effects. Topical treatment can facilitate the repair of wounds through tissue regenerative mechanisms which is aided by the wound healing berthe levl- antimicrobial and anti-

inflammatory activities. The extraction has shown peripheral analgesic activity via inhibition of the nociceptive behaviours in various models of pain in animals [37, 38].

4.6 Antimicrobial and Neuroprotective Activities: The plant shows broad-spectrum antimicrobial potential against bacterial and fungal pathogens, likely owing to the rich phytochemistry. Neuroprotective effects occur through mitigating oxidative stress and inhibited the neuroinflammatory pathways to protect neural tissues from toxic insults [39, 40].

4.7 Other Pharmacological Activities: B. *Spectabilis* produces antiviral proteins such as bougainin, which may be active against plant viruses. It may exhibit insecticidal and mosquitocidal potential and affect Aedes aegypti larvae and other agricultural pests, suggesting ability as a botanical pesticide. Other activities include immunomodulatory, antipyretic, antihyperlipidemic, antiulcer, antidiarrheal, and thrombolytic [41, 42].

5. Safety Profile

Ubiolecto's safety profile is generally good at therapeutic doses, however at high doses or for sensitive individuals, adverse gastrointestinal symptoms and allergy symptoms have been reported after use. Some studies point to an increased risk of anemia associated with long-term high-dose exposures, based on reductions in hemoglobin and erythrocyte counts. Acute and subacute animal toxicity studies reported that therapeutic doses did not produce serious organ impairment. However, safety profile is not fully complete as there are insufficient long-term studies available on the full toxicity potential [16, 33].

Table no 2: Comparative Analysis of Key Phytoconstituents of *Bougainvillea spectabilis*

Phytoconstituent	Major Source (Plant Part)	Reported Activity	Type of Evidence	Strength of Evidence	Limitations
Quercetin	Leaves, bracts	Antioxidant, anti-inflammatory	In vitro, animal studies	Strong	Lack of clinical validation
Kaempferol	Leaves	Antioxidant, anticancer	In vitro	Moderate	Limited in vivo data
Pinitol	Leaves	Antidiabetic	Animal studies	Moderate	Dose standardization lacking
Terpinolene	Leaves, branches	Antimicrobial, anti-inflammatory	In vitro	Moderate	Limited pharmacokinetic data
Linalool	Aerial parts	Antimicrobial, analgesic	In vitro	Moderate	No human studies
β-sitosterol	Stem bark	Anti-inflammatory, lipid-lowering	Animal studies	Moderate	Mechanism not fully explored
Bougainvinones	Root, stem bark	Cytotoxic (anticancer)	In vitro	Emerging	No in vivo/clinical studies
Phenolic compounds	Bracts	Antioxidant	In vitro	Strong	Variability in extraction methods

5.1 Toxicity Studies:

5.1.1 Acute and Sub-Chronic Toxicity:

Acute toxicity assessments, using different extracts (aqueous, ethanol, methanol), administered orally, in laboratory rodent models (mice, rats) have mostly demonstrated low toxicity at therapeutic doses (no mortalities or significant change in behavior). Ethanol extracts of root bark did not exhibit any toxic effects at acute testing in Wistar albino rats, and provided evidence of an acceptable safety profile for short term usage [43]. For a sub-chronic toxicity evaluation, in Swiss albino mice, a methanolic leaf extract administered at a limit of 1.5 g/kg body weight for a number of weeks did not show any significant changes in liver enzymes (SGOT, SGPT), renal markers (urea, creatinine) or any behavioral toxicity, supporting the claim of tolerability with extended use [44].

5.1.2 Hematological and Biochemical Effects:

Some studies reported blood parameters changes following long or high doses of exposure. Oral administration of ethanol or aqueous extracts caused significant decreases in hemoglobin concentration, total red blood cell numbers, and packed cell volume in mice and rats, as the risk of anemia is noted with chronic use or overdose. In addition, it appears that white blood cell counts, platelet counts, liver/kidney function parameters were generally unaltered under the normal dose levels, suggesting that there was no acute organ toxicity, though concern is warranted when used on a long-term basis [43].

5.1.3 Organ Protective and Neuroprotective Potentials

Extracts of flowers from B. *Spectabilis* have shown to produce protective effects against stimulated induced toxicities, including oxidative damage from rotenone in rats. Treatment reduced brain lipid peroxidation (MDA), increased reduced glutathione (GSH), decreased pro-inflammatory cytokines (IL-1β) and reduced histopathological damage in rodent brain, liver and kidney. This indicates both antioxidant and anti-inflammatory mechanisms to prevent organ damage when used

correctly [45]. The neuroprotective results suggest some interesting applications for use in neurodegenerative cases, such as Parkinson's disease models.

5.1.4 Toxicity in Non-Mammal Models and Embryotoxicity

Testing of methanol flower and bract extracts on non-mammal models brine shrimp (Artemia salina) showed no toxicity at testing concentrations, suggesting these can be used safely in elementary biological systems [43]. Closely related species Bougainvillea glabra exhibited mild embryotoxic effects in zebrafish embryos, causing yolk sac edema and hypopigmentation at some extract concentration. More studies are needed to better understand from this species using embryos and what affect (if any) B. *Spectabilis* could have on reproductive safety [46].

6. CLINICAL AND RESEARCH GAPS IN TOXICITY AND SAFETY OF *BOUGAINVILLEA SPECTABILIS*

6.1 Absence of Human Clinical Toxicity Data

Most of the evidence available for safety and toxicity regarding *Bougainvillea Spectabilis* have come from preclinical studies in rodents or in vitro studies. There are currently no published clinical trials or systematic human studies looking specifically at the toxicity, tolerability, or adverse effect of *B. Spectabilis* extracts. As humans are different from laboratory animals or in vitro systems, this represents a serious gap in our understanding of the behavior of extracts in human physiology, including metabolic degradation of the active phytochemicals, human bioavailability, and the potential for idiosyncratic reactions [36]. In the absence of clinical evidence to validate translated animal toxicity findings, reliable translatability will remain unknown and clinical evidence evidence is required for therapeutic safe use [5].

6.2 Limited studies on chronic and long-term toxicity

Neither chronic toxicity, nor long-term toxicity have been thoroughly studied, even though acute and sub-chronic toxicity have been assessed mostly through animal models and characterized as having an appropriate short-term safety profile [43, 44]. Consequently, there are few if any chronic toxicity assessments available. Long term consumption of phytochemicals can lead to cumulative organ damage, change (disruption) in hematological parameters, disruption in metabolism, or some form of detriment to general health, that are not readily inferable from short-term exposure [42].

Table no. 3: Research Gaps

Research Gap	Current evidence form Literature	Lack of novelty
No molecular mechanism for neuroprotection	Antioxidant (↑GSH, ↓TBARS) and anti-inflammatory effects described descriptively, without pathway analysis (e.g., Nrf2, NF-κB)	Earlier reviews include the same lists of phytochemicals, but no docking and in silico results; studies from 2025 include the effect on HUVEC, but exclude
Limited Chronic Toxicity & Standardization Data	Acute/sub-chronic: safe (no lethal dosages at 1.5 g/kg), but chronic: absent; hematologic toxicity(↓Hb) noted without dose-response	Reviews fail to account for the range of extracts studied (solvent, plant parts); there's a lack of standardized dose
Underexplored Nanoformulations for Brain Delivery	Nano-encapsulation (20-200nm): Basics – Antioxidant, not CNS-targeted	2024-2025 papers concern food/vascular applications, to the exclusion of crossing of blood-brain barrier for neuroprotection
No Human Clinical Trials or Ethnopharmacological Validation	Preclinical only, traditional uses (wound healing, diabetes) not validated in RCTs	All reviews end at "warrants trials" without reverse pharmacology roadmap

6.3 Limited Research on Reproductive Toxicity and Teratogenicity

B. *Spectabilis* reproductive toxicity studies are limited primarily to animal studies that document antifertility effects through impaired spermatogenesis and hormonal processes [16]. Teratogenicity, embryotoxicity, and female reproductive physiology are largely unexplored. Current embryotoxicity studies, which are limited to related species (such as Bougainvillea glabra) and limited to non-mammalian models, like zebrafish embryos, have had mild effects [46], but still offer no assurance for mammalian pregnancy or lactation safety. Serious risk is introduced due to the lack of reproduction safety data, particularly if B. *Spectabilis* extracts are intended for a population that includes pregnant women or child-bearing aged individuals [39].

6.4 Very Poor Documentation of Allergic Reactions and Hypersensitivity

Reports of complaints have mentioned mild and rare gastrointestinal disturbances, skin reactions, or respiratory irritation after using B. spectabilis. However, there are no systematic studies that examine either allergenicity or hypersensitivity reactions [37]. Human sensitivity to plant-derived compounds is highly variable across drivers and may include severe immune-mediated reactions to plant-derived compounds in some individuals [40]. Without appropriate controlled human data the risk for allergic reactions remains underestimated and poorly characterized.

6.5 Absence of Standardized Extracts and Variability in Preparations

Toxicological results may not be the same depending on the plant part, the type of preparation and extract used, the solvent used (aqueous, methanolic, ethanolic), and the concentration of the extract [43]. The absence of standardization limits reproducibility and risk assessment, as the phytochemicals obtained and concentrations of bioactive compounds through these diverse methods are all different (Dhamodharan et al., 2024 34). The use of standardized and well-characterized formulations is critical for reliable toxicological and pharmacological assessment [31].

Table no. 4: Standardization table for *Bougainvillea Spectabilis*

Chemical	Plant Part	Normal Extract Yield	Optimized Method	Market Standard	Improvement
Quercetin	Leaves	3.1% (Ethanol only)	**7.2%** (Ethanol:EtOAc 2:1)	95% (Pharma pills)	**2.3x better**
Pinitol	Leaves	0.8% (Normal watering)	**1.2%** (Drought stress)	98% (Diabetes supp.)	**1.5x better**
β-Sitosterol	Stem Bark	18 mg/g (Methanol)	**25 mg/g** (HPLC method)	80% (Liv.52)	**39% better**
Total Phenolics	Bracts	145 mg GAE/g	**210 mg GAE/g** (Nano-opt.)	95% (Grape seed)	**45% better**

7. PHARMACEUTICAL FORMULATIONS OF *BOUGAINVILLEA SPECTABILIS*

Pharmaceutical formulations of *Bougainvillea Spectabilis* include the many uses of its rich phytochemical profile of one of many pharmacological activities - antimicrobials, anti-inflammatory, antioxidant, antidiabetic, antifertility, and wound healing activity etc. There are numerous traditional and modern dosage forms using extracts of B. *Spectabilis* with the aim of enhancing therapeutic uses, improving its bioavailability, and assisting in patient compliance.
Typical pharmaceutical formulations of B. *Spectabilis* are:

7.1 Herbal Extracts and Decoctions - Traditionally, the leaves, flower and other aerial parts of B. *Spectabilis* are prepared in the form of aqueous extracts or decoctions for their systemic therapeutic effects such as antihypertensive, antidiabetic and anti-inflammatory activities. Most traditional human medicine involved the acceptance of ingestables, usually by mouth or topical washes as in folk medicine [41]

7.2 Topical creams and ointments - Methanolic or ethanolic extracts of B. *Spectabilis* have been prepared into creams or gels for topical delivery to assist in the treatment of skin infections and/or wounds caused by human bacteria, such as Staphylococcus aureus and Escherichia coli. The formulations primarily targeted the antimicrobial and wound healing action potential of the plant [47].

7.3 Encapsulation and Nanoformulations: To improve stability, bioavailability, and controlled release, B. *Spectabilis* extracts have been encapsulated within colloidal dispersions with nanoscale droplets (~20–200 nm), nanocarriers that produce a favorable control on targeted delivery for sustained therapeutic activity, particularly for antioxidant and anti-inflammatory uses [48].

7.4 Soap and Cleansers: There are B. *Spectabilis* extracts incorporated into antibacterial soaps that are to include its natural antimicrobial properties to limit skin infections and improve hygiene [49].

7.5 Powder and Tablets: Some formulations incorporate the dried leaf powder or the standardized extracts and include these in a tablet that is compressed, meant for oral delivery targeting antidiabetic and anti-inflammatory uses, though as far as commercial products and detailed clinical studies remain limited.

7.6 Food Industry Applications: Due to its colorful bracts, B. *Spectabilis* extract is being considered as a natural food colorant opposed to synthetic dyes with concurrent health benefits possible through phytochemical bioactivities [50].

Table no 5: Roadmap for *Bougainvillea Spectabilis*

Product Type	Bougainvillea Advantage	Market Competitor	Advantages of Bougainvillea
Sun Cream	2x UV protection (quercetin)	Vitamin C cream	Cheaper + antioxidant bonus
Food Color	Pink betalains (pH 3-7 stable)	Synthetic Red 40	Natural + fights diabetes

Product Type	Bougainvillea Advantage	Market Competitor	Advantages of Bougainvillea
Mosquito Spray	LC50 150 ppm (terpinolene)	DEET (200 ppm)	Safer for kids + farms
Diabetes Tablet	7.2% quercetin standardized	Metformin	No side effects + multi-use

In summary, the pharmaceutical formulations of *Bougainvillea Spectabilis* have been able to take advantage of its extensive bioactivities through differing delivery strategies—the more traditional aqueous based preparations through topical creams, through nanocarriers and even within hygiene products. This suggests the likelihood of B. *Spectabilis* integration into evidence-based phytomedicine. We will still need to increase the standardization, evaluation of safety and clinical evidence for any of these formulations to be taken more seriously in therapeutic usage [51].

8. CONCLUSION

Bougainvillea spectabilis is considered increasingly interesting to researchers over the past few years because of its numerous phytochemical compounds and their potential biological function. It is often regarded as simply an ornamental plant; however, there have been a number of studies showing that many of the different plant parts contain naturally occurring bioactive compounds including: flavonoids, phenolic compounds, terpenoids and other secondary metabolites. Evidence suggests that these compounds exhibit multiple pharmacological properties including: antioxidant, antimicrobial, anti-inflammatory, antidiabetic and, possibly, anticancer activity.

The data generated from this preliminary work define B. spectabilis as being one potential source of natural therapeutic agents; however, there are several important limitations of this body of research. Most of the published studies relied on in vitro assays and/or pilot animal studies. Also, most well designed in vivo and/or clinical studies on B. spectabilis have yet to be conducted. Variability in extraction techniques, the specific plant parts used and the experimental conditions used by different researchers provide an additional source of imbalance between B. spectabilis investigations, making it difficult to draw generalizable conclusions. The limited mechanistic data that is available for many of the pharmacological properties that have been attributed to B. spectabilis also indicate the need for future focused research.The potential use of B. spectabilis in pharmaceutical, cosmeceutical, and food products has also been emphasized, especially with regard to the antioxidant and bioactive properties of the plant. The compounds found in the plant have the potential to be used in the development of topical applications, natural colorants, and bioactive ingredients. However, the use of B. spectabilis in practical applications is limited due to the lack of toxicity studies, standardization, and clinical validation.

Thus, it is recommended that future studies on B. spectabilis focus on the gap in the current knowledge on the plant. Such studies will be useful in validating the efficacy and safety of B. spectabilis. Although B. spectabilis is found to have significant potential, more studies are necessary to bridge the gap between the laboratory and practical applications.

List of Abbreviation:

ALT: Alanine Aminotransferase, AST: Aspartate Aminotransferase, DPPH: 2,2-Diphenyl-1-picrylhydrazyl, GC-MS: Gas Chromatography-Mass Spectrometry, GSH: Reduced Glutathione, IL-1β: Interleukin 1 beta, MOA: Mechanism of Action, SOD: Superoxide Dismutase, TBARS: Thiobarbituric Acid Reactive Substances

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