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Phytofabrication of Diverse Nanoparticles Using *Blumea* Species: Synthesis, characterizationand Pharmacological Applications – A Review

[1*]Rupali D. Popeta, [1]Ganesh A. Thakur, [2]Kirti Mhatre, [3]Sandhya Patil

[1*]Department of Chemistry, Mahatma Phule Arts, Science and Commerce College, Panvel, India

[1]Principal, Mahatma Phule Arts, Science and Commerce College, Panvel, India

[2]Department of Biotechnology, Mahatma Phule Arts, Science and Commerce College, Panvel, India

[3]M.Sc. Organic Chemistry Student, Mahatma Phule Arts, Science and Commerce College, Panvel, India

Abstract: *The development of sustainable and biocompatible nanomaterials has gained considerable attention due to limitations associated with conventional physicochemical synthesis methods, including toxicity, high energy consumption and environmental hazards. Plant-mediated green synthesis has emerged as an efficient and eco-friendly approach for nanoparticle production, utilizing phytochemicals as natural reducing and stabilizing agents. The genus Blumea (Asteraceae), widely distributed in tropical and subtropical regions and traditionally recognized for its medicinal properties, contains diverse secondary metabolites such as flavonoids, phenolic compounds, terpenoids and essential oils that play a crucial role in nanoparticle formation. This review comprehensively summarizes recent advances in the phytofabrication of multifunctional nanoparticles using Blumea species, with emphasis on synthesis strategies, mechanistic pathways, physicochemical characterization and biomedical applications. Various nanoparticles synthesized from Blumea extracts, including silver, gold, zinc oxide, copper and iron nanoparticles, are discussed along with key parameters influencing their size, morphology, and stability. Characterization techniques such as UV–visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning and transmission electron microscopy (SEM/TEM) and dynamic light scattering (DLS) are critically evaluated. Furthermore, the biological activities of Blumea-mediated nanoparticles, including antimicrobial, antioxidant, anti-inflammatory, anticancer and wound healing effects, are highlighted, together with toxicity and biocompatibility considerations. Current challenges related to reproducibility, standardization, large-scale production and clinical translation are also addressed. Overall, Blumea species represent a promising yet underexplored resourcefor green nanotechnology, offering significant potential for the development of safe, cost-effective and therapeutically relevant nanomaterials for biomedical applications.*

Keywords*:* Blumea species, Green synthesis, Phytofabrication, Metal nanoparticles, Silver nanoparticles, Phytochemicals, Characterization, Biomedical applications

I. INTRODUCTION

Nanotechnology has emerged as one of the most rapidly advancing interdisciplinary research fields, offering innovative solutions across medicine, agriculture, environmental science and material engineering. Nanoparticles, typically ranging from 1 to 100 nm in size, exhibit unique physicochemical properties such as high surface-to-volume ratio, enhanced catalytic activity, optical behavior and improved biological interactions compared to their bulk counterparts [1]. These distinctive characteristics have enabled nanoparticles to play a crucial role in biomedical applications including drug delivery, diagnostics, antimicrobial therapy, cancer treatment, tissue engineering and biosensing [2].

Among various types of nanomaterials, metal and metal oxide nanoparticles such as silver (Ag), gold (Au), zinc oxide (ZnO), copper oxide (CuO) and iron oxide (Fe_3O_4) nanoparticles have attracted significant attention due to their multifunctional properties and broad therapeutic potential [3].

Conventional methods for nanoparticle synthesis primarily involve physical and chemical approaches, including chemical reduction, thermal decomposition, laser ablation and electrochemical techniques. Although these methods can produce nanoparticles with controlled size and morphology, they often require toxic chemicals, high energy input and expensive instrumentation, which raise concerns regarding environmental safety, biocompatibility and cost-effectiveness [4]. Furthermore, the use of hazardous reducing agents and stabilizers may limit the biomedical applicability of chemically synthesized nanoparticles due to potential toxicity [5]. These limitations have stimulated increasing interest in environmentally friendly and sustainable alternatives, particularly biological or green synthesis methods.

Green synthesis of nanoparticles using biological systems such as microorganisms, enzymes and plant extracts has emerged as a promising approach due to its simplicity, eco-friendliness and scalability [6]. Among biological sources, plant-mediated synthesis has gained considerable attention because plant extracts contain a wide range of phytochemicals capable of acting simultaneously as reducing, stabilizing and capping agents during nanoparticle formation [7]. Secondary metabolites such as flavonoids, phenolic acids, alkaloids, terpenoids, tannins, proteins and polysaccharides play essential roles in the reduction of metal ions into nanoscale particles and stabilization of the synthesized nanostructures [8]. Plant-based synthesis also eliminates the need for sterile culture conditions required in microbial synthesis, making it more practical for large-scale production [9]. Additionally, nanoparticles synthesized using plant extracts often exhibit enhanced biological activities due to synergistic interactions between phytochemicals and nanomaterials [10].

In recent years, medicinal plants have received increasing attention as valuable resources for nanoparticle synthesis because of their rich phytochemical diversity and therapeutic relevance. The genus *Blumea* (family Asteraceae) comprises approximately 100–120 species distributed widely in tropical and subtropical regions of Asia, Africa, and Australia [11]. Several species of *Blumea*, including *Blumea balsamifera*, *Blumealacera*, *Blumeamollis*, and *Blumeaeriantha*, are widely used in traditional medicine systems for the treatment of inflammation, wounds, fever, respiratory disorders, gastrointestinal problems and microbial infections [12]. These plants are known to contain diverse bioactive compounds such as essential oils, flavonoids, sesquiterpenes, diterpenes, phenolic compounds and sterols, which contribute to their pharmacological properties including antimicrobial, antioxidant, anti-inflammatory, hepatoprotective and anticancer activities [13].

The presence of bioactive phytochemicals in *Blumea* species makes them potential sourcefor nanoparticle phytofabrication. Plant metabolites can act as natural reducing agents converting metal salts into nanoparticles, while functional groups such as hydroxyl, carbonyl and amine groups contribute to stabilization and capping of nanoparticles [14]. Recent studies have reported the successful synthesis of various nanoparticles using *Blumea* extracts, particularly silver nanoparticles, which demonstrate potent antimicrobial and antioxidant activities [15]. In addition to silver nanoparticles, other metal and metal oxide nanoparticles synthesized using plant extracts have shown promising applications in wound healing, cancer therapy, drug delivery, and environmental remediation [16]. The integration of phytochemistry and nanotechnology thus provides a novel platform for developing multifunctional nanomaterials with enhanced biological efficacy and reduced toxicity.

Despite increasing research interest, the nanoparticle synthesis potential of *Blumea* species remains relatively underexplored compared to other medicinal plants. Most available studies focus on limited species and specific nanoparticle types and comprehensive information regarding synthesis mechanisms, characterization approaches and biomedical applications is scattered across the literature. Furthermore, challenges related to reproducibility, standardization of plant extracts, optimization of synthesis parameters, large-scale production, and clinical translation remain significant barriers to practical applications [17]. A systematic review integrating phytochemical knowledge with nanotechnology principles is therefore necessary to highlight current progress and identify future research opportunities.

The present review aims to provide a comprehensive overview of the phytofabrication of diverse nanoparticles using *Blumea* species, with emphasis on synthesis strategies, physicochemical characterization techniques and biomedical applications. In addition, the review discusses toxicity considerations, comparative advantages over conventional methods, current limitations and future perspectives for translational research. By integrating botanical, phytochemical and nanotechnological aspects, this work intends to establish *Blumea* species as promising resources for sustainable nanomaterial development and biomedical innovation.

II. SYNTHESIS OF NANOPARTICLE FROM BLUMEASPECIES

2.1 Silver Nanoparticles (AgNPs)

Silver nanoparticles are the most extensively synthesized nanomaterials using *Blumea* species, particularly *Blumea balsamifera*, *Blumealacera*, *Blumeasinuata* and *Blumeamollis*. The synthesis generally involves the reduction of silver ions from silver nitrate solutions using aqueous plant extracts or essential oils rich in phenolic compounds, flavonoids and terpenoids. These phytochemicals donate electrons to silver ions, leading to nucleation and formation of stable nanoparticles while simultaneously acting as capping agents to prevent aggregation. Leaf extracts are the most commonly used plant part due to their high concentration of bioactive metabolites. The efficiency of nanoparticle formation is influenced by parameters such as pH, temperature, metal ion concentration and extract composition. The consistent ability of multiple *Blumea* species to synthesize AgNPs highlights the strong reducing potential of phytoconstituents present within this genus and supports its suitability as a natural nanofactory for eco-friendly nanoparticle production [18]– [21].

2.2 Copper and Copper Oxide Nanoparticles (CuNPs / CuO NPs)

Copper and copper oxide nanoparticles have been synthesized primarily using *Blumea balsamifera* and *Blumealacera* extracts, where plant metabolites facilitate the reduction of copper salts and stabilization of the resulting nanostructures. Compared with silver nanoparticles, copper-based nanoparticles require more controlled synthesis conditions due to their susceptibility to oxidation; however, phytochemicals present in *Blumea* extracts help regulate oxidation states and improve nanoparticle stability. Root extracts of *Blumealacera* have shown particular effectiveness in synthesizing copper oxide nanoparticles, possibly due to the presence of concentrated secondary metabolites in underground plant parts. The ability to produce copper-based nanoparticles using plant extracts demonstrates the versatility of *Blumea* species in mediating the synthesis of different metal nanoparticles through similar phytochemical mechanisms [19], [22], [23].

2.3 Iron Oxide Nanoparticles (Fe_3O_4 NPs)

Iron oxide nanoparticles synthesized using *Blumealacera* root extracts represent an important class of metal oxide nanoparticles produced via plant-mediated green methods. The synthesis typically involves the reaction of iron salts with plant extracts followed by precipitation and stabilization processes driven by phytochemicals containing hydroxyl and carbonyl functional groups. These biomolecules play a crucial role in controlling nucleation and growth while preventing particle agglomeration. The successful synthesis of iron oxide nanoparticles using *Blumea* species suggests that the genus possesses sufficient reducing and chelating capacity to mediate the formation of magnetic nanomaterials, expanding its applicability beyond noble metal nanoparticles [20], [24].

2.4 Polymeric Nanoparticles (Chitosan Nanoparticles)

In addition to metallic nanoparticles, *Blumea balsamifera* extracts have also been used in the preparation of polymeric nanoparticles such as chitosan nanoparticles through ionic gelation techniques. In this process, plant-derived bioactive compounds interact with polymeric matrices, enhancing nanoparticle stability and functional properties. The

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incorporation of plant phytochemicals into polymeric systems demonstrates the broader role of *Blumea* metabolites not only in metal ion reduction but also in nanoparticle stabilization and functionalization. This highlights the potential of *Blumea* species in the development of hybrid nanomaterials combining natural polymers with plant bioactive compounds [21], [25].

Table 1 summarizes the various *Blumea* species utilized for the green synthesis of different types of nanoparticles along with the plant parts employed. The data highlight the versatilityof *Blumea* extracts in producing metallic and metal oxide nanoparticles through eco-friendly approaches. These findings emphasize the potential of *Blumea* species as promising bioresources for sustainable nanoparticle synthesis and biomedical applications.

Table 1. Green synthesis of nanoparticles using *Blumea* species extracts

Sr. No.	Plant Name	Part Used	Nanoparticle Synthesized
1	*Blumea balsamifera*	Leaves	Silver nanoparticles (AgNPs)
2	*Blumea balsamifera*	Leaves	Copper nanoparticles (CuNPs)
3	*Blumea balsamifera*	Leaves/Essential oil	Silver nanoparticles (AgNPs)
4	*Blumea balsamifera*	Leaves	Chitosan nanoparticles
5	*Blumealacera*	Whole plant/ Leaves	Silver nanoparticles (AgNPs)
6	*Blumealacera*	Roots	Iron oxide nanoparticles (Fe_3O_4 NPs)
7	*Blumealacera*	Roots	Copper oxide nanoparticles (CuO NPs)
8	*Blumeasinuata*	Leaves	Silver nanoparticles (AgNPs)
9	*Blumeamollis*	Leaves	Silver nanoparticles (AgNPs)

III. CHARACTERIZATION OF NANOPARTICLES SYNTHESIZED USING *BLUMEA* SPECIES EXTRACTS

Comprehensive physicochemical characterization is a critical step in confirming the successful synthesis of nanoparticles using *Blumea* species extracts and in understanding their structural, morphological and surface properties. Plant-mediated nanoparticles often exhibit unique features due to the presence of phytochemical capping layers, which influence particle size, stability and biological activity. Therefore, multiple analytical techniques are employed to obtain complementary information regarding nanoparticle formation, crystallinity, morphology, surface chemistry and dispersion behavior. Commonly used characterization tools include UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Dynamic Light Scattering (DLS), Energy Dispersive X-ray Analysis (EDX) and zeta potential measurements (Figure 1) [26]–[28].

UV–Visible spectroscopy serves as a rapid and preliminary method for monitoring nanoparticle formation in plant-mediated synthesis systems. Nanoparticles synthesized using *Blumea* extracts typically exhibit distinct surface plasmon resonance (SPR)absorption peaks resulting from collective oscillation of conduction electrons upon interaction with electromagnetic radiation. Silver nanoparticles generally display characteristic SPR bands between 400 and 450 nm, confirming the reduction of Ag^+ ions into metallic silver. Variations in peak position, width and intensity provide valuable information regarding particle size distribution, aggregation state and concentration. Copper and copper oxide nanoparticles synthesized from *Blumea* extracts commonly show absorption bands in the range of 250–350 nm, while iron oxide nanoparticles often exhibit broader absorption spectra due to magnetic interactions and polydispersity. Time-dependent UV–Visible studies are also useful in evaluating nanoparticle growth kinetics and reaction completion [27], [29].

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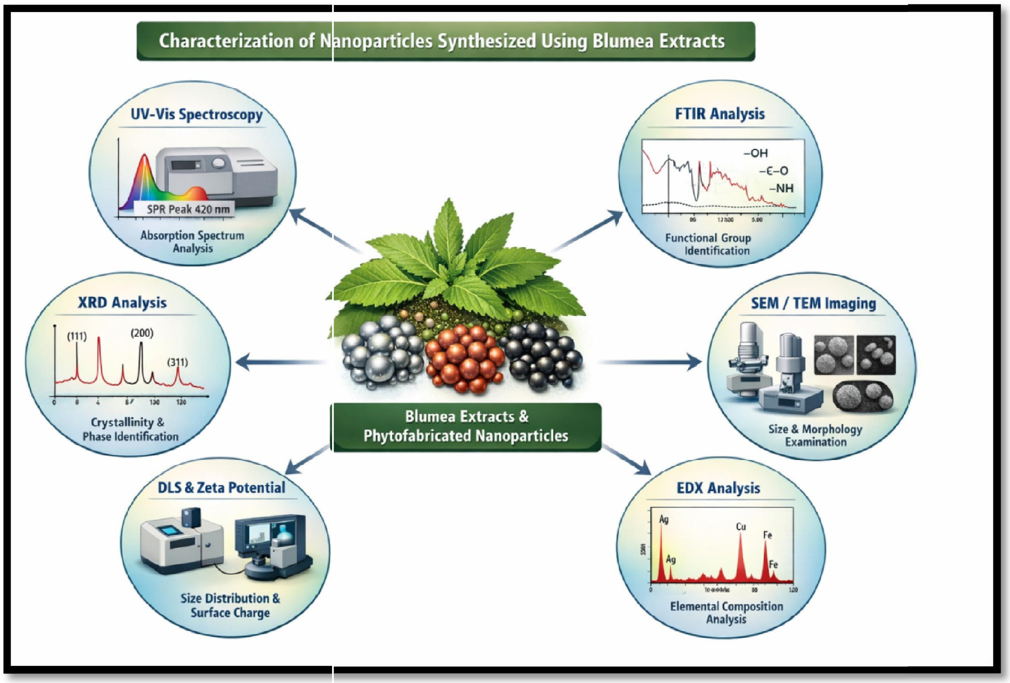

Figure 1: Schematic representation of physicochemical characterization of Plant-derived nanoparticles.

Fourier Transform Infrared Spectroscopy (FTIR) plays a vital role in identifying functional groups present on nanoparticle surfaces and determining the involvement of phytochemicals during synthesis. Plant extracts of *Blumea* species contain diverse biomolecules such as flavonoids, phenolic acids, terpenoids, proteins and polysaccharides, which contribute to metal ion reduction and stabilization processes. FTIR spectra typically reveal absorption bands corresponding to hydroxyl (–OH), carbonyl (C=O), amine (–NH), alkene (C=C) and ether (C–O–C) functional groups. Shifts in peak positions or changes in intensity after nanoparticle formation indicate the interaction of these functional groups with metal ions and nanoparticle surfaces, confirming their role as reducing and capping agents. Such phytochemical coating enhances nanoparticle stability and biocompatibility, which is particularly advantageous for biomedical applications [26], [30].

X-ray diffraction (XRD) analysis provides definitive evidence of nanoparticle crystallinity and phase structure. Nanoparticles synthesized using *Blumea* extracts commonly exhibit well-defined diffraction peaks corresponding to crystalline metallic or metal oxide phases. Silver nanoparticles typically show characteristic Bragg reflections associated with face-centered cubic (FCC) crystal structure at diffraction planes such as (111), (200), (220) and (311). Similarly, copper oxide and iron oxide nanoparticles demonstrate distinct diffraction patterns confirming their respective monoclinic or spinel crystal phases. The Debye–Scherrer equation is frequently applied to estimate average crystallite size from peak broadening, providing insights into nanoscale dimensions and crystallinity. High crystallinity is often associated with improved stability and enhanced functional properties [31], [32].

Microscopic characterization using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) offers detailed visualization of nanoparticle morphology, surface topology and size distribution. Nanoparticles synthesized using *Blumea* species extracts are generally spherical or semi-spherical, although irregular or aggregated structures may also occur depending on synthesis conditions such as pH, temperature and extract concentration. TEM analysis provides higher resolution imaging and allows precise determination of particle size, typically ranging between 10 and 100 nm for metallic nanoparticles synthesized using *Blumea*. In many cases, a thin organic layer surrounding nanoparticles can be observed, indicating phytochemical capping, which contributes to colloidal stability and prevents aggregation [28], [33].

Energy Dispersive X-ray Analysis (EDX), often coupled with SEM or TEM, is used to confirm elemental composition and purity of synthesized nanoparticles. Characteristic energy peaks corresponding to silver, copper, iron or other elements validate successful nanoparticle formation and provide semi-quantitative information about elemental distribution [29].

Dynamic Light Scattering (DLS) analysis is commonly employed to determine the hydrodynamic diameter of nanoparticles in colloidal suspension. The hydrodynamic size is usually larger than the size observed in TEM due to the presence of solvent molecules and surface-bound phytochemicals surrounding nanoparticles. DLS also provides information about particle size distribution and polydispersity index (PDI), which is crucial for assessing uniformity and reproducibility of synthesis [27].

Zeta potential measurement is an important parameter for evaluating nanoparticle stability in suspension. Nanoparticles synthesized using *Blumea* extracts typically exhibit moderate to high negative zeta potential values due to the adsorption of negatively charged phytochemicals such as phenolic compounds on nanoparticle surfaces. Higher absolute zeta potential values indicate stronger electrostatic repulsion between particles, preventing aggregation and improving colloidal stability over time [26], [28].

Overall, characterization studies demonstrate that nanoparticles synthesized using *Blumea* species possess controlled nanoscale dimensions, crystalline structures and enhanced stability attributed to phytochemical capping layers. The integration of multiple analytical techniques is essential for correlating physicochemical properties with biological activities and for ensuring reproducibility, scalability and safety in future biomedical and industrial applications. Detailed characterization also provides mechanistic insights into plant-mediated nanoparticle formation, supporting the development of optimized green synthesis protocols [27], [30].

IV. PHARMACOLOGICAL APPLICATIONS OF NANOPARTICLES SYNTHESIZED USING *BLUMEA* SPECIES EXTRACTS

Nanoparticles synthesized using *Blumea* species extracts have attracted considerable attention due to their enhanced pharmacological potential and biocompatibility. The presence of bioactive phytochemicals such as flavonoids, terpenoids, phenolics and alkaloids in *Blumea* extracts plays a crucial role in the reduction, stabilization and functionalization of nanoparticles, thereby improving their biological activity. These phytogenic nanoparticles exhibit a wide range of pharmacological properties, including antimicrobial, antioxidant, anticancer, anti-inflammatory and wound healing activities (Figure 2). The nanoscale size, high surface area and synergistic interaction between metallic cores and plant-derived compounds contribute to improved cellular uptake, targeted action and therapeutic efficacy compared to crude plant extracts. Consequently, *Blumea*-mediated nanoparticles represent promising candidates for biomedical and pharmaceutical applications, particularly in the development of novel therapeutics and drug delivery systems.

4.1 Antimicrobial Activity

Nanoparticles synthesized using *Blumea* species extracts, particularly silver nanoparticles (AgNPs), demonstrate significant antimicrobial activity against both Gram-positive and Gram-negative bacteria as well as fungal pathogens. The antimicrobial efficacy is primarily attributed to the small particle size, large surface area and the presence of phytochemical capping agents derived from *Blumea* extracts. These nanoparticles interact with microbial cell membranes, causing structural damage, increased membrane permeability and leakage of intracellular components. Additionally, nanoparticles generate reactive oxygen species (ROS), which induce oxidative stress leading to protein denaturation, DNA damage and inhibition of essential metabolic pathways. The synergistic interaction between metallic nanoparticles and plant-derived bioactive compounds enhances antimicrobial potency compared with crude extracts alone. Such properties make *Blumea*-mediated nanoparticles promising source for treating drug-resistant microbial infections and for applications in medical coatings and wound dressings [34]–[36].

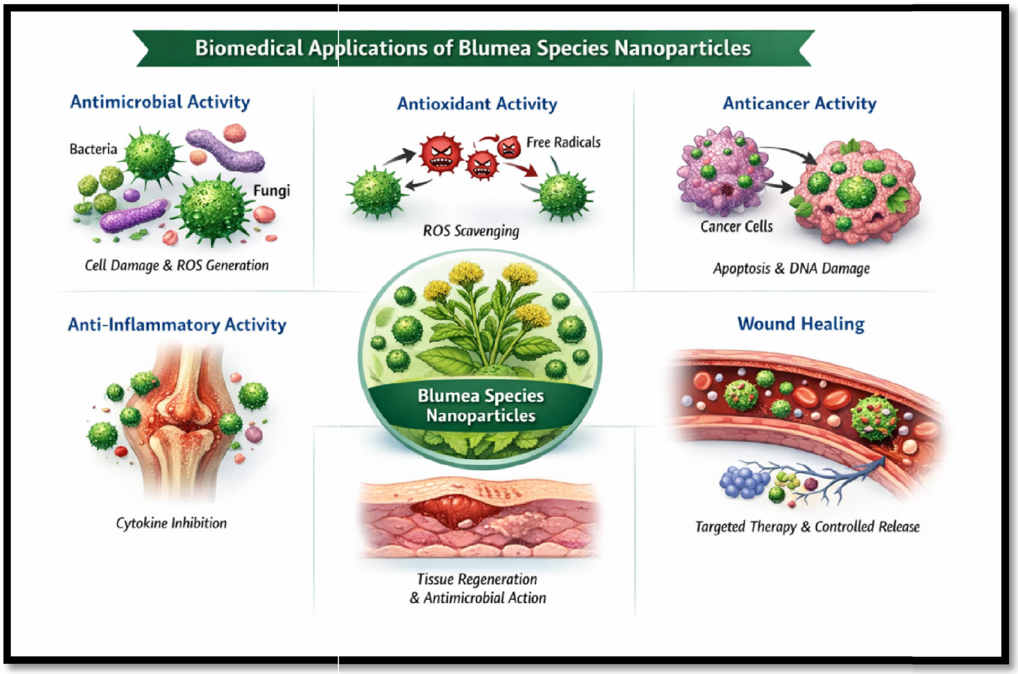

Figure 2: Pharmacological activities of *Blumea* Species–derived nanoparticles.

4.2 Antioxidant Activity

Nanoparticles synthesized using *Blumea* extracts exhibit notable antioxidant properties due to the presence of phenolic compounds, flavonoids and terpenoids attached to nanoparticle surfaces. These phytochemicals possess strong free radical scavenging ability and contribute to reducing oxidative stress by neutralizing reactive oxygen species. The nanoscale size enhances the exposure of active phytoconstituents, resulting in improved antioxidant efficiency compared with plant extracts alone. Antioxidant nanoparticles synthesized from *Blumea* species have potential therapeutic applications in preventing oxidative stress-related disorders such as cardiovascular diseases, neurodegenerative conditions and inflammatory disorders. The stabilization of phytochemicals on nanoparticle surfaces also improves their bioavailability and protects them from degradation [37], [38].

4.3 Anticancer Activity

Nanoparticles synthesized using *Blumea* species extracts have shown promising anticancer potential, particularly metallic nanoparticles such as silver and copper oxide nanoparticles. These nanoparticles induce cytotoxic effects in cancer cells through multiple mechanisms, including oxidative stress generation, mitochondrial dysfunction, DNA fragmentation and activation of apoptosis signaling pathways. The phytochemical molecules present on nanoparticle surfaces may contribute synergistically to anticancer activity by enhancing cellular uptake and targeting cancer cells. Nanoparticles also demonstrate selective toxicity toward cancer cells while exhibiting comparatively lower toxicity to normal cells, making them attractive candidates for cancer therapeutics and drug delivery systems. The nanoscale size facilitates penetration into cancer cell tissues and improves therapeutic efficiency [39], [40].

4.4 Anti-Inflammatory Activity

Nanoparticles synthesized using *Blumea* species extracts also exhibit anti-inflammatory properties due to the presence of bioactive phytochemicals known for their anti-inflammatory effects. These nanoparticles may inhibit inflammatory mediators such as cytokines, prostaglandins, nitric oxide and cyclooxygenase enzymes. The improved stability and bioavailability of phytochemicals when incorporated into nanoparticle systems enhance their therapeutic efficacy compared with conventional formulations. Such nanoparticles may be beneficial in the treatment of inflammatory disorders, arthritis and tissue injury conditions. The combination of nanoparticle-induced modulation of cellular pathways and plant-derived compounds contributes to their anti-inflammatory potential [41], [42].

4.5 Wound Healing Activity

Nanoparticles synthesized from *Blumea* species extracts have demonstrated significant potential in wound healing applications due to their antimicrobial, antioxidant and anti-inflammatory properties. These nanoparticles promote wound contraction, collagen deposition, angiogenesis and epithelialization, which accelerate tissue regeneration. Silver nanoparticles are particularly effective in preventing wound infection while simultaneously enhancing the healing process. The phytochemical coating on nanoparticles further contributes to tissue repair by stimulating fibroblast proliferation and reducing oxidative stress at the wound site. These multifunctional properties make *Blumea*-derived nanoparticles promising materials for biomedical dressings and regenerative medicine applications [43], [44].

4.6 Drug Delivery Applications

Nanoparticles synthesized using *Blumea* extracts can also serve as efficient drug delivery systems due to their nanoscale size, surface functionalization and biocompatibility. Phytochemical molecules present on nanoparticle surfaces improve interaction with biological membranes and enable controlled drug release. Polymeric nanoparticles such as chitosan nanoparticles prepared using *Blumea* extracts further enhance drug encapsulation efficiency, stability and targeted delivery. These systems may reduce drug toxicity, improve therapeutic efficacy and allow sustained release of active compounds, highlighting their importance in nanomedicine and pharmaceutical applications [45], [46].

V. CONCLUSION

Nanoparticles synthesized using *Blumea* species extracts demonstrate significant potential as eco-friendly and cost-effective nanomaterials due to the presence of bioactive phytochemicals that act as reducing and stabilizing agents. Various metallic and metal oxide nanoparticles produced from *Blumea* plants exhibit desirable physicochemical characteristics and diverse pharmacological activities, including antimicrobial, antioxidant, anticancer, anti-inflammatory and wound-healing effects. These biological properties arise from the synergistic interaction between nanoscale features and phytochemical surface functionalization, which enhances therapeutic efficiency and biocompatibility.

However, challenges such as standardization of synthesis methods, large-scale production, toxicity evaluation and clinical validation remain to be addressed. Further mechanistic studies and in vivo investigations are essential to translate laboratory findings into practical biomedical applications. Overall, *Blumea* species represent promising natural resources for the development of sustainable nanotherapeutics and advanced biomedical technologies.

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