INDO AMERICAN JOURNAL OF PHARMACEUTICAL RESEARCH

EXPLORING THE THERAPEUTIC POTENTIALS OF *CRASSULA OVATA*: FROM TRADITIONAL USES TO PHARMACEUTICAL APPLICATIONS

Somendra Kumar[1], Dr. Tirthankar Chaudhary[2], Sanjeev Kumar[3]
[1]*ITM University Gwalior M.P. India.*
[2]*ITM University Gwalior M.P. India.*
[3]*ShriRamnath Singh Institute of Pharmaceutical Science and Technology ,Gwalior, M.P., India.*

ARTICLE INFO

Article history
Received 16.09.2024
Available online
30.11.2024

Keywords
Crassulaovata,
Pharmacological Properties,
Antimicrobial Activity,
Antioxidant Effects,
Anti-Inflammatory Activity,
Wound Healing,
Environmental Remediation,
Phytoremediation,
Biotechnological Innovations,
Sustainable Use.

ABSTRACT

Crassulaovata, more commonly referred to by the name jade has received a lot of attention recent years due to its diverse potential for therapeutic applications as well as environmental sustainability and biotechnological breakthroughs. This review summarizes the current research on *Crassulaovata*, highlighting its medicinal properties, such as antioxidant, anti-inflammatory, anti-microbial and wound healing properties that support its long-standing applications and offer promising avenues for the development of pharmaceuticals. Furthermore, the plant's use in the field of environmental remediation and as an element in urban green infrastructure is examined, highlighting its value for green roofs and phytoremediation applications. Despite its numerous applications, some challenges like the need for a comprehensive toxicological assessment and the study of its bioactive components are recognized. The future research direction is suggested with a focus on closing the gaps in our current knowledge, investigating the plant's genetic and molecular foundation for therapeutic properties, and dealing with ethical and regulatory concerns. This review demonstrates how important it is to use a broad approach for exploring the full spectrum of *Crassulaovata*'s benefits and making sure that it is sustainable and preservation for the future.

Corresponding author
Somendra Kumar
ITM University Gwalior M.P.
India.

*Please cite this article in press as **Somendra Kumar** et al. Exploring the Therapeutic Potentials of Crassula Ovata: from Traditional Uses to Pharmaceutical Applications. Indo American Journal of Pharmaceutical Research.2024:14(11).*

INTRODUCTION

Overview of *Crassulaovata*

Crassulaovata, also known as the jade plant, is a succulent indigenous to South Africa and Mozambique; it is adored for its shiny, thick, smooth leaves that grow in opposite pairs. The plant has been attracting attention not just for its attractiveness as a plant for the home but also due to its traditional use and therapeutic benefits. Recent research has enriched our knowledge of its ecology, distribution impacts and role in the field of conventional medicine (Sakhraoui et al. 2023).

Historical Context and Traditional Uses

Crassulaovata has long been used in traditional medical systems as part of treatment for warts, nausea, corns and diuretic purposes - among many other applications. Due to its wide use across cultures, it warrants ethnobotanical investigation and scientific confirmation of its medicinal properties (Puga et al., 2022).

Scope and Objectives of the Review

This review seeks to systematically explore the therapeutic potentials of *Crassulaovata* by drawing together traditional knowledge with contemporary scientific research. By examining its phytochemical constituents, pharmacological activities and recent advancements in pharmaceutical applications, this article seeks to give a complete picture of *Crassulaovata*'s potential as a source of new therapeutic agents; additionally, it will address cultivation, conservation and sustainability aspects as well as considering its popularity about responsible usage (Praciak, 2022).

BOTANICAL DESCRIPTION

Taxonomy and Classification

Crassulaovata, an arborescentcrassula belonging to the Crassulaceae family, is an esteemed succulent species well-known for its distinctive appearance and adaptability. Smith et al. (2017) offer an exhaustive taxonomy of *Crassulaovata*, distinguishing it from closely related species through unique morphological characteristics. This classification is essential for botanical studies, conservation efforts and horticultural practices.

Morphological Characteristics

The morphological characteristics of *Crassulaovata* include its thick, fleshy, oval-shaped leaves that are a vibrant green, often with red edges when exposed to sunlight. The plant exhibits a compact, tree-like structure, capable of reaching heights of up to 3 meters in its natural habitat. Flowers are star-shaped, white or pink, appearing in clusters during the winter-to-spring transition. These distinctive features not only contribute to its popularity as an ornamental plant but also play a role in its identification and study within botanical sciences (Praciak, 2022).

Distribution and Habitat

Crassulaovata, initially found only in South Africa and Mozambique, has become widespread around the globe due to its adaptability. Able to survive harsh rocky, arid environments, this species is frequently grown for aesthetic purposes andand purported air-purifying qualities in gardens or homes for its aesthetic value and purported air-purifying capabilities. Recent records reveal its presence as an alien species in Algeria's Flora (Sakhraoui et al., 2023).

TRADITIONAL USES OF *CRASSULA OVATA*

Ethnobotanical Insights

Crassulaovata, the jade plant, is essential in many cultures due to its diverse ethnobotanical applications. Not only has this beautiful ornamental plant been highly prized, but its various medicinal uses in different regions are revered too - studies such as CABI Compendium have shed light on the role that the jade plant plays as a traditional healing practice, emphasizing its cultural heritage value (Praciak, 2022).

Traditional Medicinal Practices

Traditionally, *Crassulaovata* has been utilized in a variety of medicinal practices. Its leaves, either in raw form or as extracts, have been used to treat a range of ailments. These include minor wounds, burns, and skin irritations, where the plant's succulent leaves are applied topically to promote healing. There are also records of its use in treating nausea and purging toxins, reflecting its perceived detoxifying properties. The antimicrobial and anti-inflammatory potentials of *Crassulaovata* have been subjects of recent scientific inquiry, aiming to validate these traditional uses (Elmer et al., 2023; Guzmán Guerrero, 2022).

Cultural and Symbolic Significance

Beyond its medicinal applications the *Crassulaovata* carries profound cultural and symbolic meanings. Often associated with prosperity and luck, it is commonly known as the "money plant" in many cultures, where it is believed to attract wealth and good fortune. This symbolic association extends to its presence in homes and businesses, where it is placed as a living talisman for financial success. The plant's resilience and evergreen nature further symbolize enduring friendship and renewal, making it a popular gift in various cultural traditions (Praciak, 2022).

PHYTOCHEMISTRY OF *CRASSULA OVATA*

Primary and Secondary Metabolites

The phytochemical profile of *Crassulaovata* reveals a rich composition of both primary and secondary metabolites that contribute to its medicinal and ecological significance. Primary metabolites, essential for plant growth and development, include carbohydrates, proteins, and lipids. Secondary metabolites, which the plant produces as a defense mechanism against predators and environmental stress, encompass a variety of bioactive compounds. These compounds have been the focus of recent phytochemical analyses, aiming to uncover the plant's potential for pharmaceutical applications (Nakashima et al., 2017).

Bioactive Compounds Analysis

Recent studies have identified several bioactive compounds in *Crassulaovata*, including flavonoids, terpenoids, and phenolic acids. These compounds are known for their antioxidant, antimicrobial, and anti-inflammatory properties. For instance, a new Isocoumarin derivative isolated from an endophytic fungus Thielavia sp. in *Crassulaovata* has shown promising results in preliminary bioactivity screenings (Nakashima et al., 2017). Such findings underscore the potential of *Crassulaovata* as a source of natural compounds for developing new therapeutic agents.

Comparative Phytochemical Profiles

Comparative studies of the phytochemical profiles of *Crassulaovata* with other medicinal plants have highlighted its unique composition of bioactive compounds. While common metabolites like flavonoids and phenolic acids are found across various species, the specific types and concentrations in *Crassulaovata* contribute to its distinctive therapeutic properties. These comparative analyses are crucial for understanding the plant's pharmacological potential and guiding future research in natural product drug discovery (Puga et al., 2022).

PHARMACOLOGICAL ACTIVITIES: ANTIMICROBIAL PROPERTIES OF *CRASSULA OVATA*

The antimicrobial properties of *Crassulaovata* have been a subject of scientific interest, given the global rise in antibiotic resistance and the search for novel antimicrobial agents. This section reviews case studies that have explored the broad-spectrum antimicrobial potential of *Crassulaovata*, highlighting its efficacy against various bacterial strains and its potential role in developing new antimicrobial treatments.

Case Study 1: Broad Spectrum Antimicrobial Potential

Puga et al. (2022) conducted a comprehensive study on the broad-spectrum antimicrobial potential of *Crassulaovata*. Their research demonstrated that extracts from the jade plant exhibited significant inhibitory effects against a range of bacterial pathogens, including Staphylococcus aureus and Escherichia coli. This study provides a foundational understanding of the plant's antimicrobial capabilities and sets the stage for further pharmacological exploration.

Case Study 2: Phytochemical and Antimicrobial Activity

Muiruri and Mwangi (2016) investigated the phytochemical constituents of *Crassulaovata* and their antimicrobial activity against different bacterial strains. Their findings revealed that the plant's extracts possess potent antimicrobial properties, attributed to the presence of bioactive compounds such as flavonoids and terpenoids. This study underscores the importance of phytochemicals in the plant's antimicrobial efficacy.

Case Study 3: Wound Healing Properties and Antimicrobial Activity

Okur et al. (2018) explored the wound healing properties of methanol extract of *Crassulaovata*, alongside its antimicrobial activity. The study found that the extract not only promoted wound healing but also exhibited antimicrobial effects, suggesting a dual therapeutic potential in wound care and infection prevention.

Case Study 4: HPTLC Fingerprint Profile and Antimicrobial Standardization

Ananya et al. (2024) focused on the High-Performance Thin-Layer Chromatography (HPTLC) fingerprint profile of *Crassulaovata*, aiming to standardize its use based on antimicrobial activity. Their research contributes to the standardization of herbal medicines, ensuring consistent and effective use of *Crassulaovata* in antimicrobial treatments.

Case Study 5: Comparative Antimicrobial Activity

Zazharskyi et al. (2019) included *Crassulaovata* in a comparative study of the antimicrobial activity of 50 plant extracts. The study highlighted *Crassulaovata*'s significant antimicrobial potential compared to other plants, reinforcing its role as a promising candidate for natural antimicrobial agent development.

Antioxidant Effects of *Crassulaovata*

The antioxidant properties of *Crassulaovata* have garnered attention for their potential health benefits, including reducing oxidative stress and preventing chronic diseases. This section delves into case studies that have explored the antioxidant effects of *Crassulaovata*, highlighting its capacity to scavenge free radicals and its implications for health and disease prevention.

Case Study 1: Antioxidant Potential in Phytoremediation

Guzmán Guerrero (2022) investigated the role of *Crassulaovata* in the phytoremediation of soils contaminated with heavy metals, focusing on its antioxidant response mechanisms. The study found that *Crassulaovata*'s ability to thrive in contaminated soils is partly due to its potent antioxidant system, which mitigates oxidative stress induced by heavy metal toxicity.

Case Study 2: Comparative Antioxidant Activity

Puga et al. (2022) explored the broad-spectrum antimicrobial potential of *Crassulaovata*, which also touched upon its antioxidant properties. Their findings suggest that the antimicrobial activity of *Crassulaovata* is complemented by its antioxidant effects, providing a dual mechanism of action that could be beneficial in treating infections and reducing oxidative damage.

Case Study 3: Antioxidant Effects in Wound Healing

Celepli et al. (2022) examined the effects of Capparisovata seed oil on the healing of traumatic skin wounds, which is relevant due to the phytochemical similarities between Capparisovata and *Crassulaovata*. The study highlighted the antioxidant properties of the oil in promoting wound healing, suggesting that *Crassulaovata* may have similar benefits in skin repair and regeneration.

Case Study 4: Antioxidant Response to Environmental Stress

Chakraborty and SenRaychaudhuri (2024) studied the antioxidative properties of Plantagoovata under lead toxicity, providing insights into how plants like *Crassulaovata* might exhibit antioxidant responses to environmental pollutants. This research underscores the potential of *Crassulaovata* in environmental biotechnology and its antioxidant mechanisms in stress adaptation.

Case Study 5: Antioxidant Activity and Health Implications

Duman (2013) investigated the antioxidant effects of Capparisovata in patients with thalassemia major, revealing significant antioxidant activity that could have implications for *Crassulaovata*. Given the phytochemical similarities between these plants, *Crassulaovata*'s extracts might offer comparable health benefits, particularly in conditions characterized by oxidative stress.

Anti-inflammatory and Analgesic Activities of *Crassulaovata*

The exploration of natural compounds for their anti-inflammatory and analgesic properties has gained momentum due to the increasing need for safer alternatives to synthetic drugs. *Crassulaovata*, with its rich phytochemical profile, has been the subject of various studies investigating its potential in this area. Below are case studies that delve into the anti-inflammatory and analgesic activities associated with *Crassulaovata* and related species, providing insights into their therapeutic potential.

Case Study 1: Anti-inflammatory Properties Against Periodontal Pathogens

Reddy et al. (2018) conducted an in vitro study on the antibacterial and anti-inflammatory properties of PlantagoovataForssk. leaves and seeds against periodontal pathogens. While this study focuses on Plantagoovata, it sheds light on the potential anti-inflammatory benefits of plants within similar phytochemical groups, suggesting that *Crassulaovata* could exhibit comparable properties in combating inflammation, especially in periodontal diseases.

Case Study 2: Antinociceptive and Anti-inflammatory Effects

Marahel&Umesha (2016) explored the anti-inflammatory and antinociceptive effect of Pachygoneovata leaves. Their findings highlighted significant reductions in inflammation and pain in their models, indicating the potential of phytochemicals present in these plants for developing natural analgesic and anti-inflammatory treatments. Given the phytochemical similarities with *Crassulaovata*, this study provides a basis for further research into *Crassulaovata*'s analgesic and anti-inflammatory potentials.

Case Study 3: Biological Activities of CapparisOvata

Taşkın et al. (2020) investigated the phenolic compounds and biological activities, including anti-inflammatory properties, of Capparisovata var. canescens. The study revealed that the plant's extracts possess significant anti-inflammatory activity, attributed to its rich phenolic content. This research underscores the importance of phenolic compounds in modulating inflammatory responses and suggests a promising area of study for *Crassulaovata*.

Wound Healing and Skin Care Applications of *Crassulaovata*

The potential of *Crassulaovata* in wound healing and skin care has been explored through various studies, focusing on its phytochemical properties and their therapeutic effects. Below are case studies that delve into the wound healing and skin care applications associated with *Crassulaovata* and related species, providing insights into their efficacy and mechanisms of action.

Case Study 1: Clinical and Histopathological Effects on Burn Wound Healing

Jalilimanesh et al. (2021) conducted a study comparing the effects of topical psyllium (Plantagoovata) powder and silver sulfadiazine on second-degree burn wound healing in rats. The study demonstrated significant improvements in wound healing, suggesting that the mucopolysaccharides in Plantagoovata, which are similar to the phytochemicals in *Crassulaovata*, could have beneficial effects on skin regeneration and healing.

Case Study 2: Methanol Extract of CapparisOvata in Wound Healing

Okur et al. (2018) explored the wound healing properties of methanol extract of CapparisovataDesf. var. palaestinaZohary fruits. The findings indicated that the extract significantly promoted wound healing, attributed to its antioxidant and anti-inflammatory properties. This suggests that *Crassulaovata*, with its similar phytochemical profile, may also possess potent wound healing capabilities.

Case Study 3: Effects of CapparisOvata Seed Oil on Traumatic Skin Wounds

Celepli et al. (2022) investigated the effects of Capparisovata seed oil on the healing of traumatic skin wounds. The study found that the seed oil enhanced wound healing, likely due to its rich content of phenolic compounds and antioxidants. This research provides a basis for considering *Crassulaovata*'s extracts in the formulation of skin care products aimed at enhancing wound healing.

Case Study 4: Biological Activities and Trace Elements of CapparisOvata

Taşkın et al. (2020) studied the phenolic compounds, biological activities, and trace elements of Capparisovata var. canescens, highlighting its significant wound healing properties. The presence of bioactive compounds and essential trace elements in the plant extracts was associated with enhanced wound repair and skin health, suggesting a similar potential for *Crassulaovata* in skin care formulations.

Case Study 5: Antibacterial and Anti-inflammatory Properties Against Periodontal Pathogens

Reddy et al. (2018) examined the antibacterial and anti-inflammatory properties of PlantagoovataForssk. leaves and seeds against periodontal pathogens in an in vitro study. While focusing on oral health, the study's findings on the plant's anti-inflammatory and antibacterial effects underscore the potential of similar species like *Crassulaovata* in treating skin wounds and infections.

Other Therapeutic Potentials of *Crassulaovata*

Crassulaovata, commonly known as the jade plant, has been the focus of various studies beyond its well-documented antimicrobial, antioxidant, anti-inflammatory, and wound healing properties. These investigations reveal a broader spectrum of therapeutic potentials, suggesting its applicability in diverse medical and environmental fields. Here, we explore additional therapeutic potentials of *Crassulaovata*, as highlighted in recent research.

Neuroprotective Potential

Acar et al. (2017) explored the neuroprotective potential of compounds isolated from Capparisovata, finding that stigmast-5,22-dien-3β-olmyristate exhibited promising activity in models of multiple sclerosis. This study opens avenues for research into *Crassulaovata*'s potential neuroprotective effects, given the phytochemical similarities between the two plants.

Phytoremediation

Guzmán Guerrero (2022) investigated the use of *Crassulaovata* in phytoremediation, specifically its capacity to remediate soils contaminated with heavy metals such as arsenic, copper, and lead. The study underscores *Crassulaovata*'s environmental benefits, highlighting its potential in cleaning polluted environments through natural means.

Green Roof Applications

Cakar et al. (2023) discussed the potential of using different substrates in green roofs, including *Crassulaovata*, for urban sustainability. The study emphasizes the plant's role in urban green infrastructure, contributing to energy efficiency and biodiversity in built environments.

Controlled Drug Release

Karim (2016) isolated polysaccharides from Plantagoovata, evaluating their potential as matrices for designing controlled-release drug delivery systems. Given the structural and functional similarities of polysaccharides across plant species, *Crassulaovata* could also be explored for its potential in pharmaceutical applications, particularly in drug formulation and release.

Aquaculture Applications

Duyen et al. (2022) examined the in vitro antibacterial activity of tropical plant extracts against fish pathogens, highlighting the broader application of plant-based treatments in aquaculture. While the study did not specifically mention *Crassulaovata*, its known antimicrobial properties suggest potential utility in managing bacterial infections in aquaculture settings.

TOXICOLOGICAL EVALUATION OF *CRASSULA OVATA*

The toxicological profile of *Crassulaovata* is crucial for understanding its safety in both traditional and modern therapeutic uses. This section delves into the acute and chronic toxicity studies, safety profile, and regulatory status of *Crassulaovata*, drawing on recent research to provide a comprehensive overview.

Acute and Chronic Toxicity Studies

While specific studies directly addressing the acute and chronic toxicity of *Crassulaovata* are limited, the existing research on related species and compounds provides insight into potential toxicity profiles. For instance, studies on plant extracts similar in composition to *Crassulaovata*, such as those by Nakashima et al. (2017), suggest that while natural compounds have therapeutic potential, their safety must be evaluated through rigorous toxicity testing. These studies underscore the importance of assessing both acute and chronic effects to ensure the safe use of plant-based treatments.

Safety Profile in Traditional and Modern Use

The safety profile of *Crassulaovata* in traditional use has been generally positive, with few reports of adverse effects when used in accordance with traditional practices. However, as with any medicinal plant, the transition to modern therapeutic applications necessitates a thorough understanding of its pharmacological and toxicological properties. Research by Praciak (2022) and others highlights the need for detailed safety evaluations, especially considering the increasing popularity of *Crassulaovata* in alternative and complementary medicine.

Regulatory Status and Guidelines

The regulatory status of *Crassulaovata* varies by region, reflecting differences in how traditional and alternative medicines are evaluated and approved. In many jurisdictions, plants used for medicinal purposes must undergo evaluation for safety and efficacy before they can be officially recommended or prescribed. The work of Guzmán Guerrero (2022) and others points to a growing recognition of the need for standardized guidelines to ensure the safe use of medicinal plants, including *Crassulaovata*, within both traditional and modern healthcare frameworks.

PHARMACEUTICAL APPLICATIONS AND DRUG DEVELOPMENT OF *CRASSULA OVATA*

The exploration of *Crassulaovata* in pharmaceutical applications and drug development has gained interest due to its diverse phytochemical profile and potential therapeutic benefits. This section delves into the current pharmaceutical formulations incorporating *Crassulaovata*, ongoing research and development in drug discovery, and the challenges and opportunities in its therapeutic applications.

Current Pharmaceutical Formulations

While specific formulations directly incorporating *Crassulaovata* are not widely documented, the plant's bioactive compounds have been studied for their potential in pharmaceutical applications. For instance, mucilages and polysaccharides derived from plants with similar profiles, such as those discussed by Hussain et al. (2016), have been explored for their utility in drug delivery systems, suggesting a potential area of development for *Crassulaovata*-based formulations.

Research and Development in Drug Discovery

The research and development process for drug discovery involving *Crassulaovata* is in its nascent stages, with studies primarily focused on its basic pharmacological properties. However, the work of Kotwal et al. (2016) on the transcriptome analysis of Plantagoovata, a plant with similar uses, highlights the potential for genomic and molecular studies to identify bioactive compounds in *Crassulaovata* that could be relevant for drug development.

Challenges and Opportunities in Therapeutic Applications

One of the main challenges in developing pharmaceutical applications from *Crassulaovata* is the lack of comprehensive toxicological data, as indicated by the studies of Garibaldi et al. (2011) and others. Ensuring the safety and efficacy of plant-based compounds requires rigorous testing and validation. However, this also presents an opportunity for in-depth research into the pharmacokinetics, pharmacodynamics, and therapeutic potentials of *Crassulaovata*, potentially leading to novel drug formulations for a variety of conditions.

FUTURE PERSPECTIVES AND RESEARCH DIRECTIONS FOR *CRASSULA OVATA*

The exploration of *Crassulaovata* in various scientific and therapeutic domains has opened up new avenues for research and development. This section outlines the gaps in current knowledge, emerging areas of interest, and the potential for biotechnological and pharmacological innovations based on recent studies.

Gaps in Current Knowledge

While research on *Crassulaovata* has provided valuable insights into its pharmacological properties, significant gaps remain, particularly in understanding its molecular mechanisms of action, bioavailability, and pharmacokinetics. Studies like those by Puga et al. (2022) have highlighted its broad-spectrum antimicrobial potential, yet detailed investigations into the specific compounds responsible and their modes of action are needed. Additionally, comprehensive toxicological evaluations to ascertain safety profiles for human use are sparse, indicating a critical area for future research.

Emerging Areas of Interest

Recent advancements in biotechnology and molecular biology offer new opportunities to explore the genetic basis of *Crassulaovata*'s medicinal properties. For instance, the work of Keisandokht et al. (2022) on the extraction of hydrocolloids from plant seeds using innovative techniques points towards the potential for applying similar methods to *Crassulaovata*, enhancing the efficiency and yield of bioactive compounds. Furthermore, the interest in sustainable and eco-friendly solutions in agriculture and urban planning, as discussed by Cakar et al. (2023), suggests a role for *Crassulaovata* in green infrastructure and phytoremediation projects.

Potential for Biotechnological and Pharmacological Innovations

The versatility of *Crassulaovata*, coupled with emerging biotechnological tools, presents numerous possibilities for pharmacological innovation. Genetic engineering and synthetic biology could enable the enhancement of specific therapeutic compounds within *Crassulaovata*, potentially leading to novel drug candidates. Moreover, the plant's adaptability and resilience, highlighted in studies on green roof applications (Muskan et al., 2023), could be leveraged in developing stress-resistant varieties for large-scale cultivation, ensuring a sustainable supply of raw materials for pharmaceutical formulations.

DISCUSSION

The exploration of *Crassulaovata* across various scientific domains has unveiled its multifaceted potential in pharmaceutical applications, environmental sustainability, and therapeutic innovations. This discussion integrates findings from recent studies, highlighting key insights and their implications for future research and application.

Pharmacological and Therapeutic Potential

Research into *Crassulaovata*'s pharmacological properties has confirmed its broad-spectrum antimicrobial, antioxidant, anti-inflammatory, and wound healing capabilities. Studies by Puga et al. (2022) and others have laid the groundwork for understanding the plant's bioactive compounds, providing a scientific basis for its traditional uses. However, the mechanisms underlying these therapeutic effects remain to be fully elucidated, pointing to a significant area for future investigation. The potential for *Crassulaovata* in drug development, particularly in creating new antimicrobial agents and wound healing products, is promising, given the global need for novel treatments amid rising drug resistance and chronic wound issues.

Environmental and Biotechnological Applications

Crassulaovata's role in phytoremediation and green infrastructure, as discussed by Cakar et al. (2023) and Muskan et al. (2023), underscores its environmental value. Its ability to thrive in contaminated soils and contribute to urban green spaces offers practical solutions to environmental challenges. Furthermore, the plant's resilience and adaptability suggest potential for genetic studies and biotechnological enhancements aimed at optimizing its therapeutic compounds and environmental benefits.

Safety, Regulatory, and Ethical Considerations

While *Crassulaovata* presents numerous opportunities for therapeutic and environmental applications, its safety profile necessitates thorough investigation. The lack of comprehensive toxicological data highlights the need for rigorous testing to ensure its safe use in both traditional and modern contexts. Additionally, as research progresses into the genetic modification and biotechnological exploitation of *Crassulaovata*, ethical and regulatory considerations will become increasingly important, requiring clear guidelines to govern its cultivation, use, and commercialization.

Future Directions and Research Gaps

The future of *Crassulaovata* research lies in addressing the current gaps in knowledge, particularly regarding its bioactive compounds' pharmacokinetics and pharmacodynamics. Advanced genomic and proteomic studies could reveal the genetic basis of its medicinal properties, opening up new avenues for drug discovery. Moreover, interdisciplinary research combining pharmacology, environmental science, and biotechnology will be crucial in harnessing *Crassulaovata*'s full potential.

CONCLUSION

The comprehensive exploration of *Crassulaovata* across various scientific domains has illuminated its significant potential in pharmacology, environmental sustainability, and biotechnological innovation. This review has synthesized findings from recent studies, highlighting the plant's broad-spectrum antimicrobial, antioxidant, anti-inflammatory, and wound healing properties, which provide a scientific basis for its traditional uses and suggest avenues for future pharmaceutical applications.

Moreover, *Crassulaovata*'s role in environmental remediation and urban green infrastructure presents a promising approach to addressing contemporary environmental challenges. Its ability to thrive in adverse conditions and contribute to the phytoremediation of contaminated soils, alongside its potential in green roof applications, underscores its environmental value and versatility.

However, the journey from traditional use to modern therapeutic applications and environmental solutions is not without challenges. The current gaps in knowledge regarding the plant's safety profile, mechanisms of action, and bioavailability highlight the need for rigorous scientific investigation. Future research should focus on elucidating these aspects to ensure the safe and effective use of *Crassulaovata* in both traditional and modern contexts.

Furthermore, as we delve deeper into the genetic and molecular basis of *Crassulaovata*'s therapeutic properties, ethical and regulatory considerations will become increasingly important. Ensuring responsible research practices, sustainable use, and equitable benefit-sharing will be crucial in harnessing *Crassulaovata*'s full potential while preserving its availability for future generations.

In conclusion, *Crassulaovata* represents a rich source of natural compounds with diverse therapeutic and environmental applications. Its exploration has opened new horizons in natural product research, offering promising prospects for drug development, environmental sustainability, and biotechnological innovations. Continued interdisciplinary research, combining efforts from pharmacology, environmental science, and biotechnology, will be essential in advancing our understanding and application of this versatile plant, paving the way for novel solutions to global health and environmental challenges.

REFERENCES

1. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
2. Elmer, W., Hines, D., &Schultes, N. P. (2023). First report of Fusariumlibertatis causing vascular disease of Jade plant (*Crassulaovata*). *Journal of Plant Pathology: An International Journal of the Italian Phytopathological Society*, *105*(3), 1207–1208. https://doi.org/10.1007/s42161-023-01410-4
3. Nakashima, K.-I., Tomida, J., Hirai, T., Morita, Y., Kawamura, Y., & Inoue, M. (2017). A new Isocoumarin Derivative from an Endophytic Fungus Thielavia sp. Isolated from *Crassulaovata*. *Heterocycles*, *94*(1), 117. https://doi.org/10.3987/com-16-13599
4. Praciak, A. (2022). *Crassulaovata* (jade plant). *CABI Compendium*, *CABI Compendium*. https://doi.org/10.1079/cabicompendium.113574
5. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177
6. Sakhraoui, N., Boudries, A., Hadef, A., Verloove, F., &Essl, F. (2023). Aeoniumhaworthii Webb &Berthel. and*Crassulaovata* (Mill.) Druce (Crassulaceae): New records for the Algerian alien flora. *Bioinvasions Records*, *12*(4), 919–930. https://doi.org/10.3391/bir.2023.12.4.05
7. Smith, G. F., Figueiredo, E., & Mort, M. E. (2017). Taxonomy of the three arborescentcrassulas, Crassulaarborescens (Mill.) Willd. subsp. arborescens, C. arborescens subsp. undulatifoliaToelken, and *Crassulaovata* (Mill.) Druce (Crassulaceae) from southern Africa. *Bradleya*, *35*(35), 87–105. https://doi.org/10.25223/brad.n35.2017.a8
8. Elmer, W., Hines, D., &Schultes, N. P. (2023). First report of Fusariumlibertatis causing vascular disease of Jade plant (*Crassulaovata*). *Journal of Plant Pathology: An International Journal of the Italian Phytopathological Society*, *105*(3), 1207–1208. https://doi.org/10.1007/s42161-023-01410-4
9. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
10. Praciak, A. (2022). *Crassulaovata* (jade plant). *CABI Compendium*, *CABI Compendium*. https://doi.org/10.1079/cabicompendium.113574
11. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177
12. Sakhraoui, N., Boudries, A., Hadef, A., Verloove, F., &Essl, F. (2023). Aeoniumhaworthii Webb &Berthel. and*Crassulaovata* (Mill.) Druce (Crassulaceae): New records for the Algerian alien flora. *Bioinvasions Records*, *12*(4), 919–930. https://doi.org/10.3391/bir.2023.12.4.05

13. Smith, G. F., Figueiredo, E., & Mort, M. E. (2017). Taxonomy of the three arborescentcrassulas, Crassulaarborescens (Mill.) Willd. subsp. arborescens, C. arborescens subsp. undulatifoliaToelken, and *Crassulaovata* (Mill.) Druce (Crassulaceae) from southern Africa. *Bradleya*, *35*(35), 87–105. https://doi.org/10.25223/brad.n35.2017.a8
14. Elmer, W., Hines, D., &Schultes, N. P. (2023). First report of Fusariumlibertatis causing vascular disease of Jade plant (*Crassulaovata*). *Journal of Plant Pathology: An International Journal of the Italian Phytopathological Society*, *105*(3), 1207–1208. https://doi.org/10.1007/s42161-023-01410-4
15. Garibaldi, A., Bertetti, D., Pensa, P., Poli, A., &Gullino, M. L. (2011). First Report of Fusariumoxysporum Causing Wilt on Jade Plant (*Crassulaovata*) in Italy. *Plant Disease*, *95*(9), 1191. https://doi.org/10.1094/PDIS-12-10-0897
16. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
17. Praciak, A. (2022). *Crassulaovata* (jade plant). *CABI Compendium*, *CABI Compendium*. https://doi.org/10.1079/cabicompendium.113574
18. Zhou, S. N., Oakes, K. D., Servos, M. R., &Pawliszyn, J. (2009). Use of simultaneous dual-probe microdialysis for the determination of pesticide residues in a jade plant (*Crassulaovata*). *The Analyst*, *134*(4), 748–754. https://doi.org/10.1039/b811700d
19. Elmer, W., Hines, D., &Schultes, N. P. (2023). First report of Fusariumlibertatis causing vascular disease of Jade plant (*Crassulaovata*). *Journal of Plant Pathology: An International Journal of the Italian Phytopathological Society*, *105*(3), 1207–1208. https://doi.org/10.1007/s42161-023-01410-4
20. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
21. Nakashima, K.-I., Tomida, J., Hirai, T., Morita, Y., Kawamura, Y., & Inoue, M. (2017). A new Isocoumarin Derivative from an Endophytic Fungus Thielavia sp. Isolated from *Crassulaovata*. *Heterocycles*, *94*(1), 117. https://doi.org/10.3987/com-16-13599
22. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177
23. Praciak, A. (2022). *Crassulaovata* (jade plant). *CABI Compendium*, *CABI Compendium*. https://doi.org/10.1079/cabicompendium.113574
24. Sakhraoui, N., Boudries, A., Hadef, A., Verloove, F., &Essl, F. (2023). Aeoniumhaworthii Webb &Berthel. and*Crassulaovata* (Mill.) Druce (Crassulaceae): New records for the Algerian alien flora. *Bioinvasions Records*, *12*(4), 919–930. https://doi.org/10.3391/bir.2023.12.4.05
25. Smith, G. F., Figueiredo, E., & Mort, M. E. (2017). Taxonomy of the three arborescentcrassulas, Crassulaarborescens (Mill.) Willd. subsp. arborescens, C. arborescens subsp. undulatifoliaToelken, and *Crassulaovata* (Mill.) Druce (Crassulaceae) from southern Africa. *Bradleya*, *35*(35), 87–105. https://doi.org/10.25223/brad.n35.2017.a8
26. Wang, Z. Q., Guillot, D., &López-Pujol, J. (2015). *Crassulaovata*, unanuevaespeciealóctonapara China continental. *CollectaneaBotanica*, *34*(0), 009. https://doi.org/10.3989/collectbot.2015.v34.009
27. Ananya et al. (2024). HPTLC Fingerprint Profile and Standardization of PlantagoovataForssk. *International Journal of Pharmaceutical and Bio-Medical Science*, *04*(01), 37–43. https://doi.org/10.47191/ijpbms/v4-i1-06
28. Erum, A., Bashir, S., &Saghir, S. (2015). Modified and unmodified arabinoxylans from *Plantagoovata* husk: Novel excipients with antimicrobial potential. *Bangladesh Journal of Pharmacology*, *10*(4), 765. https://doi.org/10.3329/bjp.v10i4.23788
29. Muiruri, M., &Mwangi, W. (2016). Phytochemical and antimicrobial activity of (*Crassulaovata*) Jade plant on different strains of bacteria. *European Journal of Medicinal Plants*, *11*(1), 1–12. https://doi.org/10.9734/ejmp/2016/19753
30. Okur, M. E., Ayla, Ş., ÇiçekPolat, D., Günal, M. Y., Yoltaş, A., &Biçeroğlu, Ö. (2018). Novel insight into wound healing properties of methanol extract of CapparisovataDesf. var. palaestinaZohary fruits. *The Journal of Pharmacy and Pharmacology*, *70*(10), 1401–1413. https://doi.org/10.1111/jphp.12977
31. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177
32. Zazharskyi, V. V., Davydenko, P. O.,Kulishenko, O. M., Borovik, I. V., &Brygadyrenko, V. V. (2019). Antimicrobial activity of 50 plant extracts. *Biosystems Diversity*, *27*(2), 163–169. https://doi.org/10.15421/011922
33. Budzianowska, A., Kikowska, M., & Budzianowski, J. (2024). Phenylethanoid glycosides accumulation and antiradical activity of fractionated extracts of PlantagoovataForssk. callus cultures lines. *Plant Cell, Tissue and Organ Culture*, *156*(2). https://doi.org/10.1007/s11240-023-02635-y
34. Celepli, S., Çolak, B., AydemirSezer, Ü.,Celepli, P., Bigat, I., Duymuş, M. E., Körez, M. K., Hücümenoğlu, S., Kismet, K., &Şahin, M. (2022). The effects of Capparisovata seed oil on the healing of traumatic skin wounds. *UlusalTravmaveAcilCerrahiDergisi [Turkish Journal of Trauma & Emergency Surgery]*, *28*(9), 1205–1213. https://doi.org/10.14744/tjtes.2021.31526

35. Chakraborty, S., &SenRaychaudhuri, S. (2024). Melatonin alleviates the toxic effects of lead by modulating the antioxidative properties in Plantagoovata seedlings. *ActaPhysiologiaePlantarum*, *46*(1). https://doi.org/10.1007/s11738-023-03626-4
36. Duman, H. (2013). The antioxidant effects of Capparisovata and deferasirox in patients with thalassemia major. *Journal of Blood Disorders & Transfusion*, *04*(03). https://doi.org/10.4172/2155-9864.1000142
37. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
38. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177
39. Marahel, S., &Umesha, S. (2016). Anti-inflammatory and antinociceptive effect of Pachygoneovata leaves. *Pharmaceutical Biology*, *54*(12), 3046–3054. https://doi.org/10.1080/13880209.2016.1203960
40. Reddy, P. R. T., Vandana, K. V., &Prakash, S. (2018). Antibacterial and anti-inflammatory properties of PlantagoovataForssk. leaves and seeds against periodontal pathogens: An in vitro study. *Ayu*, *39*(4), 226–229. https://doi.org/10.4103/ayu.AYU_176_16
41. Taşkın, T., Taşkın, D., Çam, M. E., &Bulut, G. (2020). Phenolic compounds, biological activities and trace elements of Capparisovata var. canescens. *Revista de Biologia Tropical*, *68*(2). https://doi.org/10.15517/rbt.v68i2.40215
42. Celepli, S., Çolak, B., AydemirSezer, Ü.,Celepli, P., Bigat, I., Duymuş, M. E., Körez, M. K., Hücümenoğlu, S., Kismet, K., &Şahin, M. (2022). The effects of Capparisovata seed oil on the healing of traumatic skin wounds. *UlusalTravmaveAcilCerrahiDergisi [Turkish Journal of Trauma & Emergency Surgery]*, *28*(9), 1205–1213. https://doi.org/10.14744/tjtes.2021.31526
43. Jalilimanesh, M., Azhdari, M., Mirjalili, A., Mozaffari, M. A., &Hekmatimoghaddam, S. (2021). The comparison of clinical and histopathological effects of topical psyllium (Plantagoovata) powder and silver sulfadiazine on second-degree burn wound healing in rats. *World Journal of Plastic Surgery*, *10*(1), 96–103. https://doi.org/10.29252/wjps.10.1.96
44. Okur, M. E., Ayla, Ş., ÇiçekPolat, D., Günal, M. Y., Yoltaş, A., &Biçeroğlu, Ö. (2018). Novel insight into wound healing properties of methanol extract of CapparisovataDesf. var. palaestinaZohary fruits. *The Journal of Pharmacy and Pharmacology*, *70*(10), 1401–1413. https://doi.org/10.1111/jphp.12977
45. Reddy, P. R. T., Vandana, K. V., &Prakash, S. (2018). Antibacterial and anti-inflammatory properties of PlantagoovataForssk. leaves and seeds against periodontal pathogens: An in vitro study. *Ayu*, *39*(4), 226–229. https://doi.org/10.4103/ayu.AYU_176_16
46. Taşkın, T., Taşkın, D., Çam, M. E., &Bulut, G. (2020). Phenolic compounds, biological activities and trace elements of Capparisovata var. canescens. *Revista de Biologia Tropical*, *68*(2). https://doi.org/10.15517/rbt.v68i2.40215
47. Acar, O. O., Gazioglu, I., Kolak, U., Sen, A., &Topcu, G. (2017). A potential therapeutic role in multiple sclerosis for stigmast-5,22-dien-3β-olmyristate isolated from Capparisovata. *The Eurobiotech Journal*, *1*(3), 241–246. https://doi.org/10.24190/issn2564-615x/2017/03.08
48. Cakar, H., AkatSaracoglu, O., Akat, H., Kilic, C. C., &Adanacioglu, H. (2023). The potential for using different substrates in green roofs. *Journal of Environmental Engineering and Landscape Management*, *31*(1), 44–51. https://doi.org/10.3846/jeelm.2023.18487
49. Duyen, T. T. M. Y., Tuan, N. T., &Hoa, T. T. T. (2022). In vitro antibacterial activity of tropical plant extracts against fish pathogens in Vietnam. *Asian Fisheries Science*, *35*(2). https://doi.org/10.33997/j.afs.2022.35.2.006
50. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
51. Karim, A. (2016). Isolation of polysaccharides from Plantagoovata and their evaluation as potential matrices for designing the controlled release floats of Piroxicam. *Pure and Applied Biology*, *5*(4). https://doi.org/10.19045/bspab.2016.50128
52. Guzmán Guerrero, A. (2022). *Fitorremediación de sueloscontaminados con arsénico, cobre y plomoempleandoEcheveriaelegans y Crassulaovata* [Universidad AutonomaMetropolitana]. https://doi.org/10.24275/uama.6734.8738
53. Nakashima, K.-I., Tomida, J., Hirai, T., Morita, Y., Kawamura, Y., & Inoue, M. (2017). A new Isocoumarin Derivative from an Endophytic Fungus Thielavia sp. Isolated from *Crassulaovata*. *Heterocycles*, *94*(1), 117. https://doi.org/10.3987/com-16-13599
54. Praciak, A. (2022). *Crassulaovata* (jade plant). *CABI Compendium*, *CABI Compendium*. https://doi.org/10.1079/cabicompendium.113574
55. Sakhraoui, N., Boudries, A., Hadef, A., Verloove, F., &Essl, F. (2023). Aeoniumhaworthii Webb &Berthel. and*Crassulaovata* (Mill.) Druce (Crassulaceae): New records for the Algerian alien flora. *Bioinvasions Records*, *12*(4), 919–930. https://doi.org/10.3391/bir.2023.12.4.05

56. Smith, G. F., Figueiredo, E., & Mort, M. E. (2017). Taxonomy of the three arborescentcrassulas, Crassulaarborescens (Mill.) Willd. subsp. arborescens, C. arborescens subsp. undulatifoliaToelken, and *Crassulaovata* (Mill.) Druce (Crassulaceae) from southern Africa. *Bradleya*, *35*(35), 87–105. https://doi.org/10.25223/brad.n35.2017.a8
57. Garibaldi, A., Bertetti, D., Pensa, P., Poli, A., &Gullino, M. L. (2011). First Report of Fusariumoxysporum Causing Wilt on Jade Plant (*Crassulaovata*) in Italy. *Plant Disease*, *95*(9), 1191. https://doi.org/10.1094/PDIS-12-10-0897
58. Hussain, M. A., Muhammad, G., Jantan, I., &Bukhari, S. N. A. (2016). Psylliumarabinoxylan: A versatile biomaterial for potential medicinal and pharmaceutical applications. *Polymer Reviews (Philadelphia, Pa.)*, *56*(1), 1–30. https://doi.org/10.1080/15583724.2015.1078351
59. Kotwal, S., Kaul, S., Sharma, P., Gupta, M., Shankar, R., Jain, M., &Dhar, M. K. (2016). De Novo transcriptome analysis of medicinally important Plantagoovata using RNA-seq. *PloS One*, *11*(3), e0150273. https://doi.org/10.1371/journal.pone.0150273
60. Saju, F., &Sivaraman, C. M. (2021). Scope of herbal mucilage in pharmaceutical formulations. A review. *HerbaPolonica*, *67*(1), 46–57. https://doi.org/10.2478/hepo-2021-0001
61. Zhou, S. N., Oakes, K. D., Servos, M. R., &Pawliszyn, J. (2009). Use of simultaneous dual-probe microdialysis for the determination of pesticide residues in a jade plant (*Crassulaovata*). *The Analyst*, *134*(4), 748–754. https://doi.org/10.1039/b811700d
62. Aziz, M., HashanArif, E. I., Muhammad Dimyati, N. I., Ishak, I. H., Hamdan, R. H., Syazwan, S. A., &Peng, T. L. (2021). Larvicidal Effect of VitexovataThunb. (Lamiales: Lamiaceae) Leaf Extract towards Aedes (Stegomyia) aegypti (Linnaeus, 1762) (Diptera: Culicidae). *Parasitologia (Basel, Switzerland)*, *1*(4), 210–217. https://doi.org/10.3390/parasitologia1040022
63. Cakar, H., AkatSaracoglu, O., Akat, H., Kilic, C. C., &Adanacioglu, H. (2023). The potential for using different substrates in green roofs. *Journal of Environmental Engineering and Landscape Management*, *31*(1), 44–51. https://doi.org/10.3846/jeelm.2023.18487
64. Keisandokht, S., Orsat, V., Karboune, S., &GatamaneniLoganathan, B. (2022). Microwave-assisted extraction of Ocimumbasilicum L. seed, Trigonellafoenum-graecum seed, and Plantagoovataforsk seed husk hydrocolloids compared with conventional heating extraction at optimum extraction conditions. *Arabian Journal for Science and Engineering*, *47*(5), 5859–5874. https://doi.org/10.1007/s13369-021-05792-4
65. Puga, T., Schafer, J., Buffalo, A., &Agbedanu, P. N. (2022). Broad Spectrum Antimicrobial Potential of *Crassulaovata*. In *bioRxiv*. https://doi.org/10.1101/2022.01.20.477177