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Phytochemistry and Pharmacological Analysis of Gerbera Jamesonii: A Review

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ABSTRACT

One high-profile ornamental plant in the Asteraceae family that has come under intense scientific attention is *Gerbera jamesonii A reg. Hook.f.*, which now is being studied not only owing to its horticultural and economical potential but also owing to its dense phytochemical and pharmacological profile. In addition, the plant contains abundant flavonoid, coumarin, phenolic acid, and sterol and exhibits strong antioxidant, anti-inflammatory, anti-microbe, and anti-proliferative effects, highlighting the potential of using the plant in pharmaceutical concern development. New developments in floriculture, including nanotechnology-based curing, trendy and beneficial biostimulatory microorganisms, and optimisation of long-term light qualities, have augmented stress persistence, growth, and after-harvest permanence, further enforcing the commercial interest of the vegetable. Nevertheless, additional limitations to translational opportunities, including the unclinical validation, standard protocols, and mechanistic research, are hindering. Based on a synthesis of the phytochemical, pharmacological, and horticultural data, this paper presents a case that G. jamesonii is a viable agricultural crop

suitable for ornamental use and a potential wellspring of bioactivity portfolios in agricultural and biomedical innovation.

Keywords: Gerbera jamesonii, phytochemicals, pharmacological activities, floriculture, nanotechnology, postharvest management.

INTRODUCTION

Gerbera jamesonii Bolus ex Hook.f., also called Transvaal daisy or Barberton daisy, is a perennial herbaceous plant and a member of the family Asteraceae. A native South African, the species has also become one of the most valuable ornamental crops in the world. It is extremely popular because of its dramatic colour in flowers, large inflorescences, and a tremendously long vase life. These characteristics ensure that G. jamesonii produces a market-class product and continues to be one of the five most sold cut flowers in the world, after roses (Rosa spp.), carnations (Dianthus caryophyllus), chrysanthemums (Chrysanthemum morifolium), and tulips (Tulipa spp.) (Cioć et al., 2022). The extent of its importance to the economy is manifested by massive production in the Netherlands, where the yearly output totalled over 420 million cut stems, of which the annual market value was close to 67 million euros (Cioć et al., 2022). Other significant global players in the market include Canada, Mexico, Indonesia and Japan, where stem-cut and potted varieties have gained large coverage to satisfy consumer demands (Cioć et al., 2022).

G. jamesonii is not only economically significant as an ornament. This species is also cultured commercially, and the process is dependent on state-of-the-art tissue culture and in vitro propagation methods. Such biotechnological methods are essential to the sustainability of the production of high-quality disease-free propagules at scale, as well as supporting genetic enhancement and preservation of elite stuff (Cioć et al., 2022). Along with the propagation approaches, research activities in the postharvest area have been used to enhance the storage life and shelf life of cut flowers. It was recently revealed that the post-treatment with melatonin-capped copper nanoparticles has a substantial beneficial effect on stem strength, senescence and post-harvest quality via regulating the lignin biosynthesis pathways and the related biochemical characteristics (Katoch et al., 2025). With their implications being significant as to the sustenance of the commercial interest of the gerbera industry over time under increasingly competitive environments of the floriculture industry.

Although G. jamesonii cultivation is widely known and used economically and horticulturally, its phytochemical potential has gained currency, as well as the ability of targeting its phytochemical resources for pharmacological use. The study of its chemical composition allowed determining a great number of secondary metabolites, such as flavonoids (e.g., apigenin, kaempferol, quercetin, and rutin), coumarins (gerberinside, gerberin), phenolic acids (protocatechuic acid), and sterols (stigmasterol, daucosterol) (El-Dein et al., 2022). Such interest, in particular, lies in the various biological functions of these bioactive compounds, namely, in terms of antioxidant, anti-inflammatory, and cholesterol-lowering properties. The extracts of G. jamesonii flowers obtained have shown strong free radical scavenging potential with low IC50 values as well as high cholesterol-degrading efficacy in vitro (El-Dein et al., 2022). It is worth mentioning that some fractions of gerbera extracts have indicated antiproliferative properties toward human cancer cell lines with superior effects to conventional drugs and very low cytotoxicity to normal cells (El-Dein et al., 2022). These results indicate that G. jamesonii can be used as a prospective source of plant-derived therapeutics.

In addition to antioxidant and anticancer properties, the use of G. jamesonii has been shown to have antibacterial properties, which apply to numerous other pharmacological studies. The identification of rutin and luteolin found in its flowers has been found to confer excellent protection against the pathogenic Escherichia coli O78 infections in dietary poultry; hence, the practical application of this plant in human medicine and veterinary practice as well (El-Dein et al., 2024). This evidence can enable the use of gerbera-derived compounds as a natural alternative to synthetic antibiotics and anti-inflammatory agents against the wider trend to push towards alternative therapeutics with a focus on safety and sustainability.

G. jamesonii is also agronomically useful due to resistance to abiotic stress, namely drought. Silicon as a biostimulant has been proved to improve the physiological and biochemical mechanisms of the plants facing water-deficit conditions, and it was found to increase certain biochemical and physiological traits the plant has, like the range of chlorophyll stability, its water-use efficiency, and plant vitality (Ahsan et al., 2023). The results have meaningful implications on sustainable floriculture as well as overall agricultural practices faced with increasing variance in climate and resource constraints.

Collectively, G. jamesonii is a unique plant species that cuts across ornamental, economic and medicinal sectors. Its status as a major ornamental crop, however, is not disputed, but emerging evidence also proves its phytochemical/therapeutic potential. It is thus high time to review its phytochemistry in detail and its pharmacological properties. This will gather the available knowledge and patch the knowledge gaps necessary in the future research on the dual significance of this species as a floricultural and pharmacognostic plant. By combining the knowledge of plant biotechnology, postharvest science, and medicinal chemistry, G. jamesonii potentially transforms not only into a representation of beauty but also provides humans and animals with medicinally potential plant-based interventions.

Fig: *Gerbera jamesonii* Plant

Plant Description

Gerbera jamesonii Bolus ex Hook.f., or Transvaal daisy, or Barberton daisy, is a flowering perennial herb in the family Asteraceae native to South Africa. It is popularly grown as a decorative plant and produces large colourful flower heads comprising a central disc framed by brightly coloured ray flowers of red, orange, yellow, pink and white colour. The stem is usually 30-45 cm high with a basal rosette of hairy lobed leaf. The flowers grow in isolation on long scapes which are leafless and are commonly of the system of composites. The plant grows best in well-drained fertile soils with full sun and is grown primarily via seed or via tissue culture. Other than its decorativeness, G. jamesonii is very rich in bioactivity, including flavonoid, phenolic and terpenoid compounds. These are the metabolites that give it its reported antioxidant, antibacterial, and anti-inflammatory properties, which are why it may be of significance in medicinal and phytochemical studies.

Kingdom	**Plantae**
Phylum	Tracheophytes
Subphylum	Angiosperms
Class	Asterids
Order	Asterales
Family	Asteraceae
Genus	Gerbera
Species	Jamesonii

Source: Integrated Taxonomic Information System

PHYTOCHEMICAL PROFILE OF *GERBERA JAMESONII*

The phytochemical content of Gerbera jamesonii has attracted great attention not only as an ornamental and horticultural plant but also for its potential action in pharmaceutical and agricultural fields. Recent mounting literature has demonstrated this species to possess a rich, chemically diverse presence of secondary metabolites and phytohormones that bring to its antioxidant activity, antibacterial activity, stress tolerance and the common denominator – therapeutic potential. These results indicate that G. jamesonii, a plant long used only as an ornamental plant, has potential as a source of compounds with health-promoting properties as well as a model plant in plant biochemical research.

Flavonoids

Flavonoids form one of the most well-researched phytochemicals in G. jamesonii, as they are well-known polyphenolic compounds with antioxidant and anti-inflammatory properties. Research into the flower extracts of G. jamesonii revealed that apigenin, kaempferol, quercetin, rutin and dihydroquercetin (taxifolin) are major compounds in it (El-Dein et al., 2022). These are compounds that have been identified to attack free radicals, alleviate oxidative stress and regulate the pathways of inflammation, thus preventing the occurrence of chronic degenerative ailments. Besides these aglycones, glycosylated compounds like quercetin-4-O-D-beta-glucopyranoside and rutin have also been identified, which also form a great variety of flavonoid content in this plant (El-Dein et al., 2022). The significant antioxidant activity of extracts of G. jamesonii flowers is mainly explained by these flavonoids, which have high scavenging free radical activity as well as low IC50 values in vitro. These findings highlight their effectiveness in the neutralisation of reactive oxygen species that is core business in biosystems oxidative damage. In addition to health effects, flavonoids can have pigmentation, UV protection and herbivore/pathogen defences.

Coumarins

Coumarins form another special group of compounds that are present in G. jamesonii. The flowers are also interesting in that they have structurally novel coumarin derivatives, including gerberinside and gerberin (El-Dein et al., 2022). In one instance, these compounds are of particular interest because of their rarity or novelty in the Asteraceae family, and thus G. jamesonii differs quite significantly from other ornamental plants. Coumarins are pharmacologically linked to antimicrobial, antioxidant, anti-inflammatory and anticoagulant activities, and preliminarily the coumarins in G. jamesonii are presumed to have the same effects. Their chemical heterogeneity adds value to the chemical core of plants, and their bioactivities offer promising horizons of therapeutic applications.

Phenolic Acids

Phenolic acids like the protocatechuic acids (3,4-Dihydroxybenzoic acid) may also be present in the flowers of G. jamesonii (El-Dein et al., 2022). It is already well known that they possess antimicrobial and antioxidant properties. Protocatechuic acid forms part of the direct increment of the radical scavenging of gerbera extracts, as well as the activity in the plant's defence against biotic and abiotic stresses. It is conceivable that the presence of phenolic acids makes G. jamesonii more pharmacologically and agronomically valuable due to their well-documented role in plant responses to UV light, drought and pathogen attack.

Sterols

G. jamesonii flower extracts have been characterised to contain stigmasterol and daucosterol (3-O-beta-D-glucopyranoyl-sitosteryl) (El-Dein et al., 2022). These compounds have a high affinity with cholesterol lowering in human beings and have been identified as inhibiting the intestinal absorption of dietary cholesterol. The presence of sterols in G. jamesonii is a factor associated with the experimentally induced in vitro anti-cholesterol activity, thus confirming the potential of its application in the prevention of cardiovascular diseases. Sterols are noted to be of benefit to cell membrane stability and stress tolerance in plants, which further increases their significance beyond pharmacology.

Table: List of Phytochemicals identified in *Gerbera jamesonii*

Phytochemical Class	Representative Compounds	Molecular Formula	Reported Biological Relevance	References
Flavonoids	Quercetin	$C_{15}H_{10}O_7$	Antioxidant, anti-inflammatory, anticancer	El-Dein et al., 2022
	Rutin (Quercetin-3-O-rutinoside)	$C_{27}H_{30}O_{16}$	Antioxidant, anti-inflammatory, vascular protection	El-Dein et al., 2022
	Kaempferol	$C_{15}H_{10}O_6$	Antioxidant, anticancer, antimicrobial	Mucha et al., 2021
	Apigenin	$C_{15}H_{10}O_5$	Anti-inflammatory, antioxidant	Mucha et al., 2021
	Luteolin	$C_{15}H_{10}O_6$	Antioxidant, neuroprotective	Mucha et al., 2021
Coumarins	Gerberinside	$C_{15}H_{16}O_9$	Antioxidant, cytotoxic potential	El-Dein et al., 2022
	Gerberin	$C_{10}H_6O_3$	Anti-inflammatory,	El-Dein et al.,

			antioxidant	2022
	Umbelliferone	$C_9H_6O_3$	Antioxidant, hepatoprotective	El-Dein et al., 2022
Phenolic acids	Protocatechuic acid	$C_7H_6O_4$	Antioxidant, antimicrobial	Ben Ammar, 2023
	Caffeic acid	$C_9H_8O_4$	Antioxidant, cholesterol-lowering	Ben Ammar, 2023
	p-Coumaric acid	$C_9H_8O_3$	Antioxidant, anti-inflammatory	Ben Ammar, 2023
Sterols	Stigmasterol	$C_{29}H_{48}O$	Cholesterol degradation, anti-inflammatory	El-Dein et al., 2022
	Daucosterol (β-sitosterol glucoside)	$C_{35}H_{60}O_6$	Antioxidant, hypoglycemic effects	El-Dein et al., 2022
	β-Sitosterol	$C_{29}H_{50}O$	Cholesterol-lowering, anti-inflammatory	El-Dein et al., 2022
Terpenoids	Triterpenes (general)	Variable (e.g., $C_{30}H_{48}O$)	Antiproliferative, cytotoxic	Hassanein et al., 2020
Anthocyanins	Cyanidin-3-glucoside	$C_{21}H_{21}O_{11}^+$	Pigmentation, antioxidant	Pawłowska et al., 2018
	Pelargonidin derivatives	$C_{15}H_{11}O_5^+$	Pigmentation, antioxidant	Pawłowska et al., 2018
Sugars & Polysaccharides	Inulin-like carbohydrates	$(C_6H_{10}O_5)_n$	Prebiotic, metabolic regulation	Rolnik & Olas, 2021
	Soluble sugars (glucose, fructose, sucrose)	$C_6H_{12}O_6$; $C_6H_{12}O_6$; $C_{12}H_{22}O_{11}$	Energy metabolism	Rolnik & Olas, 2021

Analytical Approaches for Phytochemical Identification

Extraction, purification, and analytical tools are necessary in the identification and characterisation of phytochemicals in G. jamesonii that involves the use of a number of recent technologies. Usually, crude extracts with the highest concentration of secondary metabolites are extracted using ethanol or methanol (El-Dein et al., 2022). The crude extracts are then subjected to chromatography processes with column chromatography and high-performance liquid chromatography (HPLC) to purify. Nuclear magnetic resonance (NMR) spectroscopy and mass spectrometry (MS) are routinely used to elucidate a structural basis and provide a detailed molecular structure and chemical fingerprint. To further analyse phytochemicals, specifically phytohormones and other small molecules, a high-resolution separation and quantification can be achieved via the use of an ultra-high-performance liquid chromatography (UHPLC) (Cioć et al., 2022). The combination of these approaches has both validated existing identification of bioactives but has also been able to reveal novel compounds specific to gerbera.

Endogenous Phytohormones

Besides the secondary metabolites, the content of the endogenous phytohormones of G. jamesonii has also been described, especially in various environmental and light conditions. In numerous studies, the phytohormone analysis afforded by UHPLC-based techniques has been utilised successfully to determine a variety of different hormones, including cytokinins, auxins, gibberellins, and stress-induced compounds like salicylic and benzoic acids (Cioć et al., 2022). The phytohormones are vital in optimising the developmental cycle of the plant, floral development and abiotic stress disposition. Of particular interest, phytohormone levels in G. jamesonii were found to vary greatly when exposed to light of different quality, and this affected axillary bud proliferation as well as overall plant habit (Cioć et al., 2022). These results show that the environment can be used to regulate the biochemical network of the plant and apply to both crop cultivation strategies and production of secondary metabolites.

Influence of Biostimulants and Nanomaterials

Outside of intrinsic phytochemistry, there are external manipulations, like biostimulants and nanomaterials, that have been demonstrated to alter the metabolic profile of G. jamesonii. When exogenous melatonin-capped copper nanoparticles are applied to the leaves, in addition to increasing the postharvest quality through improving the stem strength, it also modified the physio-chemical profile and the pathway of lignin biosynthesis of the plant (Katoch et al., 2025). In the same way, application of nanochitosan-encapsulated melatonin caused petal senescence retardation, and there is the demonstration of how nanotechnology can increase flower longevity by controlling biochemical and antioxidant processes (SeyedHajizadeh et al., 2024). A more conventional element, silicon supplementation, has also demonstrated the ability to increase drought tolerance via modulation of antioxidant enzymes and phenolic compounds (Ahsan et al., 2023), whereas a combined foliar application of L-glutamic acid, nitrogen and potassium elicited a significant growth stimulatory effect with improved mineral intake and floral quality (Farahmandi et al., 2021). Taken together, these findings demonstrate that exogenous intervention can have a positive effect to further the physiological abilities and phytochemical contents of G. jamesonii to prop up the horticultural and pharmacological possibilities of the plant further.

PHARMACOLOGICAL ACTIVITIES OF GERBERA JAMESONII

The pharmacological importance of Gerbera jamesonii has recently been a subject of growing interest as research and surveys indicate the varied treatment potential of the bioactive compounds entailed by it. The biological activity of the flavonoids, coumarins, phenolic acids and sterols has a biochemical basis, since there is a broad range of biological effects, including antioxidant and anti-inflammatory effects, as well as antiproliferative, anticancer and antimicrobial properties. In conjunction with these widely conducted studies, new findings also indicate cholesterol-lowering and possible neuroprotective properties that indicate the therapeutic dexterity of the said ornamental species.

Antioxidant Activity

Antioxidant property is one of the most researched pharmacological properties of G. jamesonii. Oxidative stress that occurs because of excess production of reactive oxygen species (ROS) is associated with chronic diseases like cancer, cardiovascular diseases, and neurodegenerative disease. G. jamesonii flower extracts have shown an extraordinarily high free radical scavenging activity, including the highest level of efficacy as antioxidants of 94.4-99.3 per cent at a concentration of 16.7 mg/ml. Furthermore, the extracts have low IC50 values (3-7 mg/ml), which proves their potent ability in inhibiting oxidative damage (El-Dein et al., 2022).

It is believed that the antioxidant property of G. jamesonii is due largely to flavonoid and coumarin content, or quercetin, rutin and greedin. These molecules inactivate ROS and RNS, thus inhibiting peroxidation of lipids, oxidative destruction of DNA and modification of proteins. Mechanically, an activation of the Keap1/Nrf2/ARE signalling axis that represents a crucial cellular protective defence mechanism against oxidative stress is known to be activated by flavonoids and coumarins (Hassanein et al., 2020). On activation, nuclear factor erythroid 2-related factor 2 (Nrf2) is translocated to the cell nucleus and induces the expression of genes encoding endogenous antioxidant defence enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). This up-regulation of intrinsic protective mechanisms confers cytoprotection to oxidative stress.

The results of the efficacy of G. jamesonii extract in the radical scavenging assay resemble their phytochemical diversity and imply their possible adherence in dealing with oxidative stress-related diseases. Noteworthy, the combination of maximum antioxidant activity along with minimal cytotoxic activity against normal cells as in vitro evidence indicates G. jamesonii as a potential nutraceutical and pharmaceutical product.

Anti-inflammatory Effects

Inflammation is a two-sided principle of biological reaction: it should be caused by host defence, and it becomes destructive when it is immoderate, resulting in a long-lasting condition arthritis, heart diseases, and metabolic disorders. Anti-inflammatory G. jamesonii secondary metabolites have mainly been demonstrated to be flavonoids and, in particular, rutin (El-Dein et al., 2022). At low concentrations, rutin has an efficient suppressing influence on the release of pro-inflammatory mediators, which include tumour necrosis factor-alpha (TNF-alpha), interleukin-6 (IL-6) and nitric oxide.

The modes of action of G. jamesonii compounds include inhibition of nuclear factor kappa B (NF-kB), a transcription factor with critical roles relating to inflammation. This is done by blocking the activity of NF-kB, which lessens the expression of inflammatory mediators and chemokines, including iNOS and COX-2 (Ben Ammar, 2023). On one hand, flavonoids and coumarins activate the Nrf2 pathway to enhance the production of antioxidant enzymes to form an anti-inflammatory cellular microenvironment (Hassanein et al., 2020).

This combination of inhibition of NF-κB and activation of Nrf2 provides a reasonable therapeutic approach to the balancing of the effects of chronic inflammation. These effects can indicate possible uses of G. jamesonii extracts in the treatment of inflammatory disease states, such as arthritis, inflammatory bowel disease and cardiovascular inflammation.

Antiproliferative and Anticancer Properties

G. jamesonii has shown antiproliferative activity against many cancer cell lines; hence, it has (HepG-2) cells, including complete (100%) tumour cell growth inhibition at a relatively low dose of 1 mg (El-Dein et al., 2022). Amazingly, the selected fractions show a much better growth inhibition activity in comparison to orthodox chemotherapeutic agents such as doxorubicin but with minimal loss of normal cells, making them have a comfortable margin of tolerance referred to as the therapeutic index.

The anticancer mechanisms behind the G. jamesonii phytochemicals affect various cellular pathways. Quercetin and rutin have shown apoptotic induction via the intrinsic way (mitochondrial pathway) that involves the upregulation of pro-apoptotic proteins (e.g., Bax, etc.) and the downregulation of the anti-apoptotic protein (e.g., Bcl-2, etc.) and the eventual occurrence of apoptosis mediated by caspase activation (Mucha et al., 2021). These compounds also inhibit the cycle progression of cells by halting at a checkpoint in the cell cycle, like the G1 checkpoint or the G2/M checkpoint, preventing the proliferation of cancer cells. Coumarins can also potentiate antineoplastic action through the regulation of angiogenesis signal transduction, diminishing blood supply and the metastasising ability of a cancer.

Cumaruonic hydrazide G. jamesonii has high anticancer activity, which is due to the synergy of flavonoids and coumarins. Notably, the deprivation of the cytotoxicity of normal cells indicates that the extracts might be used to produce gentler derivatives or adjunctive with current chemotherapeutic agents. The efficacy and safety, therefore, are unique and make the combination of the two appealing as a future source of an anticancer agent worthy of future investigations.

Antimicrobial and Veterinary Applications

One other relevant pharmacological characteristic of G. jamesonii is its antimicrobial effects, which may be relevant even to veterinary practices. Flavonoids that have shown exciting protective effects against a common causative pathogen, Escherichia coli O78, which causes enteric diseases in poultry, are purified flavonoids, such as rutin and luteolin. These were either phage-killing or phage-reducing and capable of increasing the survival rates of the avian subjects and ameliorating clinical manifestations suggested in the avian subjects infected with these infections (El-Dein et al., 2024).

It is believed that the mechanism of action of the antimicrobials encompasses the interference of the nucleic acid synthesis, disruption of the cell membrane and the modulation of the immune response of the host. Other than the antibacterial property, flavonoids and coumarins can be antifungal and antiviral, but they are yet to be confirmed through clinical studies.

The possible applications of G. jamesonii-derived products as alternatives to antibiotics are especially promising against the background of the global crisis of antimicrobial resistance. The integration of such compounds into veterinary practices has the potential of alleviating the use of synthetic antimicrobials and hence limiting the emergence of resistant strains, contributing to animal health and food safety.

Other Biological Activities

Besides antioxidant, anti-inflammatory, anticancer, and antimicrobial properties, G. jamesonii has other properties. Remarkably, the flower extracts have a cholesterol-degradation capacity, whereby the extracts degrade cholesterol by up to 65-70 per cent within 96 hours (El-Dein et al., 2022).

The fact that sterols, stimulated by a wide range of phenolic compounds, influence this phenomenon largely is attributable to the synergetic effect of sterols (stigmasterol and daucesterol). Such phytochemicals help with cardiovascular protection and metabolic health in general by lowering the cholesterol. Despite direct experimental evidence pointing toward neuroprotective or antidepressant effects of G. jamesonii being rare, its flavonoid and coumarin content can be used as a foundation upon which such effects are possible. The closely related compounds in other plants have been shown to cross the blood-brain barrier, decrease inflammation of the nervous system, and improve cognition, leading to a study on G. jamesonii as a potentially exciting candidate in the research on neurodegenerative diseases and psychiatric disorders (Hassanein et al., 2020).

Also, the anti-inflammatory and antioxidant action of G. jamesonii could be synergistic since chronic diseases linked to oxidative and inflammatory toxicity are avoided. All these multifurcated domains echo its usefulness as a multipurpose medicinal plant and necessitate a research translation between prospective research and practical therapeutic implications.

ADVANCEMENTS IN FLORICULTURE AND POSTHARVEST TECHNOLOGY FOR *GERBERA JAMESONII*

Besides its ornamental and pharmacological importance, Gerbera jamesonii has evolved into a centre of concern in floriculture-related research, with special emphasis being given to postharvest technologies and sustainable cultivation methods. As the market demand for superior cut flowers is growing globally, so also has the interest in prolonged vase life of cut flowers, fibre strength, pigmentation and anti-senescence of flowers increased. New developments such as nanotechnology, biostimulant formulations, and optimised culture and lighting conditions are changing preharvest management and postharvest management approaches to Gerbera. Such methods do not only enhance the economical efficiency of the production process but also support the environmentally friendly and sustainable farming methodologies.

Nanotechnology Applications

Nanotechnology has become a promising currency to improve the life and quality of flowers. The prospective action can be the foliar application of melatonin-capped copper nanoparticles (MT-CuNPs). Recently, it has been shown that MT-CuNP significantly ameliorated physiological and biochemical characteristics of G. jamesonii. An increase in photosynthetic rates, diameter and lignin content of stems helps to make stems stronger and more resilient. At the cellular level, MT-CuNPs increase the thickness of xylem walls to make water transport efficient and slow senescence (Megha Katoch et al., 2025).

The soluble sugar levels and phenolic compound levels, directly associated with the flower durability and stress tolerance, are increased by MT-CuNPs in addition to structural changes. Most importantly, the vase life of the treated flowers was extended by six days over the untreated controls, which demonstrates the potential usefulness of such an intervention in the cut-flower market. At the molecular level, it can be seen that MT-CuNPs induce the expression of lignin biosynthetic genes, a mechanistic connection between nanoparticles and enhanced stem rigidity. These findings demonstrate that nanotechnology can be applied to strengthen the physical structure and chemo resilience in the same.

Besides copper-based nanostructures, iron, silver, and cobalt nanoparticles added to culture media have a positive influence on in vitro growth and multiplication. These nanoparticles induce rooting, enhance the rate of shoot growth, and improve the vigour of the plantlet (Bui Van The Vinh et al., 2024; Tung et al., 2022). It is believed to affect their action by the enhanced uptake of nutrients and conditioning the phytohormone signalling pathways. The combination of these results advocates the use of nanotechnology as an all-purpose technology to boost the preharvest capability and prolong the preservation stage of Gerbera.

Biostimulants and Eco-friendly Preservatives

In parallel with nanotechnology, there has been an increasing adoption of the use of biostimulants and postharvest-preserving, eco-friendly products as a method to enhance postharvest stability on a more sustainable level. Protein hydrolysates, which are mixtures of amino acids and peptides, have been quite useful when used pre-harvest. When used with calcium, these hydrolysates enhance nutrient absorption levels and flower firmness, and they maintain pigment levels during the vase life (Ciriello et al., 2024). The benefit of such treatments is to increase ornamental value and diminish the need to use synthetic chemical preservatives by impacting metabolic resilience.

Encapsulation of melatonin with nanochitosan has also become a potential preservative agent for cut flowers. This formulation increases stabilisation of membranes, inhibits pigment degradation, and promotes the retention of high antioxidant enzyme activity throughout the postharvest storage period. The flowers coated with nanochitosan-melatonin showed a maximum of 12 days of vase life, which outstripped the ordinary preservative solutions (SeyedHajizadeh et al., 2024). The encapsulation ensures that the release of melatonin is controlled, which is known to regulate stresses related to oxidation, providing prolonged senescence resistance.

The use of biostimulants is not only functional but also strongly beneficial to the environment. With protein hydrolysates and nanochitosan-based formulations, the alternative solutions to act as sustainable and biodegradable additions to the horticultural industry appear inevitable as concerns towards chemical preservatives continue to dominate the ecological and health arena. This shift is part and parcel of a general shift within the floricultural industry to more environmentally friendly production systems in which performance and environmental protection are equalised.

Influence of Light and Culture Conditions

Quality of light is a key regulator of plant physiology and an important moderator of in vitro propagation and postharvest results. Studies on G. jamesonii have demonstrated that the red spectrum and red:blue spectrum are most optimum in terms of the effects on several growth parameters, such as shoot multiplication, root formation and photosynthetic pigment accumulation. A balanced red-to-blue light ratio of 7:3 seems particularly beneficial in immune regulation and stress resistance as well as normal morphogenesis (Pawłowska et al., 2018; Cioć et al., 2021).

Besides the capacity to improve morphogenetic processes, precise LED systems represent an outstanding opportunity to increase the efficiency of photosynthesis. With red:blue light regimes, there are enhancements in chlorophyll synthesis, carbohydrate accumulation, and energy requirements but in plantlets due to more robust axillary shoots (Meng et al., 2019). These are also observed in postharvest scenarios, as these encourage a physiologically hardy condition upon propagation. Notably, the carbon footprint of setting up this technology also decreases the production cost of LED technology, thus enhancing the sustainability of Gerbera production.

Nanoparticle supplementation to culture media combined with optimised lighting is potentially a synergistic way of maximising growth potential. By matching physical conditions with biochemical improvements, these techniques are used to generate a homogeneous and high-end propagation to satisfy both commercial and environmental demands.

Toward Sustainable Floriculture

Collectively, the innovations in nanotechnology, biostimulant use, and better light conditions offer promised improvements of the floriculture and postharvest technology of G. jamesonii. Nanoparticles allow improving the structural integrity and stress resistance, and biostimulants and natural preservatives prolong vase life due to biochemical control. At the same time, LED-based systems enhance propagation efficiency and sustainability. The multidisciplinary strengths can assist in developing a new paradigm in Gerbera production focusing on quality, durability, and green practices.

Since the current worries are growing stronger with regards to the cultivation of the ornamental vegetation in a naturalistic, sustainable, and top-quality way, Gerbera jamesonii will be an appropriate embodiment that will allow testing the combination of the latest technology and environmental standards. Instead of focusing on the scaling of such interventions and streamlining the economic feasibility of their application, research work might proceed towards also to examine the possible synergies that occur when therapeutic plans are combined. It is these efforts that promise the world that we are going to turn G. jamesonii from a scientific-only phenomenon into a commercial-only venture in the floricultural industry of today.

PHYTOCHEMICAL DIVERSITY-PHARMACOLOGICAL EFFECTS CO-OPTIMISATION IN *GERBERA JAMESONII*: COMPARATIVE AND RESEARCH APPROACHES

Not only is Gerbera jamesonii an appealing ornamental species of high commercial interest; Gerbera jamesonii is also a promising medicinal source, notwithstanding its chemically diversified phytochemical spectrum. Recent descriptions show a range of pharmacological actions (i.e., antioxidant, anti-inflammatory, anticancer, antimicrobial, and cholesterol-lowering effects) that fundamentally stem from the unique and variable phytochemistry. To maximise the potential, it is necessary to connect the phytochemical findings with pharmacological data, place them in context against the rest of the members of the Asteraceae family, and critically evaluate the shortcomings that currently cripple the application to the applied situation.

Integration of Phytochemical Diversity with Pharmacological Effects

In Gerbera jamesonii the flowers are typified by a strong portrayal of flavonoids, coumarins, phenolic acids, and sterols, all related to different portions of biological activities (El-Dein et al., 2022). Apigenin, kaempferol, quercetin, and rutin are members of the flavonoid subgroup of compounds and have long been indicative of antioxidant and anti-inflammatory activity. An example of an effective flavonoid glycoside is rutin, which has been shown to have the capacity of reducing inflammatory pathways, including the NF-κB pathway, and at the same time boosting antioxidant response via the Nrf2/ARE pathway. Likewise, phenolic acids, including protocatechuic acid, are exhibited as strong radical scavengers, which explains the strong free-radical neutralising and low IC_5 energy values observed in the extract of Gerbera results.

Such coumarin-containing substances as gerberinside and gerberin have been of particular interest; they seem rather specific to the member related to other species in the Asteraceae. Some of the unique pharmacological functions of this plant, including but not necessarily limited to the possibility to modulate apoptosis and cholesterol metabolism, could be mediated by these molecules. Such lipid-lowering agents as sterols, such as stigmasterol and stigmasterol daucesterol (among others), also react with cholesterol-metabolism pathways and support the in vitro evidence of cholesterol-degradation rates of up to 70% after 96 h of incubation.

Another key drug dimension would be anticancer properties. Fractions and extracts of Gerbera were found to have selective cytotoxicity against a variety of human cancer cell lines, i.e., HCT-116 (colorectal), MCF-7 (breast), and HepG2 (liver), without toxicity on normal cells (El-Dein et al., 2022). This selective inhibition indicates that the phytochemicals could be used through a specific action, like induction of apoptosis, regulation of p53 signal, or through a blockage of proliferative suppressors, and this places these phytochemicals as therapeutic targets with an enhanced safety profile. Collectively, the phytochemical character of the plant Gerbera jamesonii defines a mechanistic basis for its wide range of pharmacological repertoire.

Comparison with Related Asteraceae Species

The Asteraceae family is one of the largest families of angiosperms, with more than 23,000 known existing species, among which many have been used in the past to treat and nourish people (Rolnik and Olas, 2021). The main similarity characteristic of members of this family is the intensive accumulation of bioactive secondary metabolites, such as polyphenols, flavonoids, phenolic acids, sesquiterpene lactones, and different forms of sterols that combine to mediate antioxidant, anti-inflammatory, hepatoprotective, and antimicrobial effects.

As an example, T. officinale (dandelion) and C. intybus (chicory) have been characterised by their higher levels of inulin and phenolic acid constitutions, thus conferring prebiotic, antioxidant, and liver protective properties. Another Asteraceae member, Cynara scolymus (artichoke), is appreciated as being rich in the phenols caffeoylquinic acids, which have been posited to exert lipid-lowering and hepatoprotective effects. In addition, the frequency of sesquiterpene lactones that is common over the family has anti-inflammatory and cytotoxic properties with potency, and so their permanent relevance in the traditional practice and modern therapeutic uses.

Gerbera jamesonii is known to have the conventional chemical classes typical of the Asteraceae, with the unique exception of coumarins such as gerberinside and gerberin and other distinct flavonoid glycosides. Such unique metabolites have the potential to endow pharmacological potential previously undocumented in related taxa, which may have played a role in the purported cholesterol-lowering properties and targeted anticancer replacement of the reported plant. The chemical singularity behind this species implies that, despite its adherence to an ad hoc of more general phytochemical syntheses of its family, Gerbera, besides a traditional path to such a stretch, provides a structural complement to or a new path to therapeutic exploration.

Limitations of Current Research

In spite of the scope of promising results, the study of G. jamesonii is limited by multiple significant shortcomings. Most of the existing evidence bases on in vitro or preclinical demonstration, with much of the clinical exploration being unfinished. Its pharmacological effect and long-term safety are not yet proven by any human-bottomed study, which is an impediment to progress translationally.

There are also limited studies of comparative phytochemical and pharmacological research on the family Asteraceae. The characteristics of individual specific species are established, such as dandelion [Taraxacum officinale], control weed [Cichorium intybus], and artichoke [Cynara scolymus], but few systematic cross-finger studies are conducted to put into context the comparative potency or uniqueness of Gerbera. The reason is that such studies are required to identify whether the effects of the Gerbera are extraordinary or if they are within the usual scope of activities that are conducted across the family.

The level of mechanistic insight is also in lag behind the pharmacological observations. Even though the antioxidant and anti-inflammatory mechanisms of hotpot, e.g., gerberin, gerberinside, or the target flavonoid glycosides, are a matter of speculation. On the same note, there are no questions on bioavailability, metabolism, and pharmacokinetics in vivo, and the use of these drugs is not certain using cell-culture models. Finally, reproducibility and standardisation present critical challenges. Discrimination in extraction procedure, solvent systems, growing of plants in various conditions, and protocol of assays make disparity between studies. This is unless, without standardised methodologies, there can be no comparison of results or progress towards a pharmaceutical or nutraceutical implementation.

Research Perspectives

The consideration of these importances demands an in-depth approach to this. Clinical studies must be prioritised in order to authenticate the safety profile and therapeutic efficacy of Gerbera extracts or isolated bioactive constituents in human beings. Juxtaposing Gerbera with other taxa in the family Asteraceae would frame Gerbera in the context of family-wide pharmacodynamics, defining where certain and unique pharmacodynamic properties overlap between Linnae. The use of current metabolomic, proteomic, and systems-biological techniques provides the opportunity to identify molecular targets, elucidate mechanistic pathways, and assess pharmacokinetic parameters. Moreover, uniformity of the extraction practices and bioassays would greatly enhance reproducibility and translatability.

Linking its own phylogenetic position with, and bridging gaps in, crucial areas of research deficiency, synthesising its phytotracial phytochemical diversity with pharmacological data, and consolidating it phylogenetically, the state-of-the-art-eris stands a chance to transform the heinous but insufficiently researched ornamental species, Gerbera jamesonii, into an asset with significant pharmacognosy and therapeutic potential.

FUTURE PROSPECTS AND RESEARCH GAPS FOR *GERBERA JAMESONII*: CLINICAL VALIDATION, APPLICATIONS, AND RESEARCH DIRECTIONS

Gerbera jamesonii has continued to receive academic interest as an ornament and as an unexploited reservoir of bioactive molecules with significant agronomic and pharmaceutical potential. However, certain research gaps prevent its application in clinical and industrial practice, as a growing body of evidence demonstrates its antioxidant, anti-inflammatory, antimicrobial, and antineoplastic performance. The systematic investigations of these gaps will fulfil the overall fulfilment of its therapeutic and commercial value.

Need for Clinical Validation and Toxicity Studies

Most of the existing research results on G. jamesonii have been generated in in vitro experiments and preclinical models, in which the extracts and isolated compounds, including rutin, luteolin, and coumarins, have profound bioactivity. This is, however, accompanied by the ominous lack of clinical trials, or standardised toxicity studies, in humans or animal societies with more developed brain systems (El-Dein et al., 2022). The future of Gerbera-derived compounds into evidence-based medicine is a conjecture in the absence of a stringent pharmacokinetic and safety margin and therapeutic window assessment. Clinical validation of findings should be prioritised in future studies since they are designed to assess not only therapeutic efficacy but also long-term safety, possible side effects, or interactions with conventional pharmacotherapies.

Potential for Pharmaceutical and Agricultural Applications

A wide range of pharmacological activities can be attributed to the phytochemical variation of the terpene genus Gerbera jamesonii, which makes the plant a potential source of new drug preparations. The antioxidant and anti-inflammatory activity allows considering its possible use in the treatment of such chronic illnesses related to oxidative stress as arthritis, cardiovascular disorders, and neurodegenerative diseases (El-Dein et al., 2022). Furthermore, the selective anti-proliferative action of the selective cause of action on several kinds of cancer cells in extracts of the plant of interest, the Gerbera, enhances the application of the plant extracts in the discovery of anticancer drugs.

In other areas of life other than human wellbeing, there are some promising developments indicating its use in agriculture. As an example, the gerbera-based plant extracts like rutin and luteolin have also been positively utilised in poultry feed as protective nutrients against infection by Escherichia coli O78, as a natural substitute to antibiotics, and are thus involved in the fight against antimicrobial resistance (El-Dein et al., 2024). In floriculture, technological developments in the fields of biotechnology and plant biotechnology, such as in vitro polyploidy induction, show the potential of improving plant horticultural characteristics (flower size, colour intensity, stress resistance, etc.) (Khalili et al., 2019). These developments collectively open dual avenues for Gerbera jamesonii as both a medicinal resource and an economically valuable agricultural species.

RECOMMENDATIONS FOR FUTURE RESEARCH DIRECTIONS

Clinical and Toxicological Studies

Six-month-long in vivo and clinical studies would be necessary in order to define the safety profile, effective dose levels, and PK disposition of Gerbera jamesonii extracts and single constituent compounds. These studies will provide the critical evidence foundation that may subsequently be utilised by regulation and practice.

Mechanistic Investigations

Whereas a comprehensive overview of pharmacological activities has been reported, the nature of the exact molecular mechanisms that can prompt these activities has not yet been clearly established. Explanations of pathways that utilise NF-κB, Nrf2-ARE, apoptotic signalling and cholesterol metabolism will elucidate modes of therapy and enable compound optimisation.

Comparative Efficacy

It would require comparative studies on the alternatives of Gerbera jamesonii itself (with other species in the Asteraceae family, e.g., dandelion, chicory, and artichoke) and the conventional pharmaceuticals to put in perspective its inherent strengths and weaknesses or benefits. These comparative studies would help in guiding a priority with which to develop the drug and apply it to agriculture.

Disease Management in Cultivation

In horticulture, Fusarium stem and root rot weed bane Gerbera plants. Integrated disease management, which involves designing resistant cultivars and the use of biocontrol agents, should be part of the future studies (Chen et al., 2021).

Postharvest and Preservation Research

The extension of the life of the vases and the reduction in the process of microbial spoilage are pivotal issues in the floriculture sector. Emerging preservation methods, such as the use of titanium ions and sustainable preservative solutions, should be the focus of future research because it has the potential to improve the quality of postharvest (Li et al., 2018).

CONCLUSION

Gerbera jamesonii is a highly commercial and highly reputed ornamental species that is globally important and whose importance is increasingly being acknowledged in scientific fields in general. Novel studies have not only led to better understanding of its physiology, stress pathology, propagation and postharvest control but have also demonstrated promising proof of positive pharmaceutical use.

Improvements in stress tolerance represent a substantive advance. Beneficial fungal colonisation, including that of a root symbiont like Piriformospora indica, improves growth rate and photosynthetic efficiency and salinity tolerance by maintaining chlorophyll content and stabilising ions. In a similar manner, supplementation of silicon improves drought resistance and leads to an increment of the leaf area and an increase in flower size and antioxidant activity. The results are long-term solutions to growth within harsh environmental conditions.

Improvements in propagation technologies have also been made, especially with the introduction of light-emitting diode lighting (LEDs), in which adjustments in the red wavelength and blue wavelength enhance multiplication of the shoots, rooting and pigmentation build in the shoots. This technology facilitates the low-cost mass rearing of robust and standardised plants, which helps in the stabilisation of the floriculture industries across the world.

Postharvest studies point to nanotechnology as a revolutionary finding towards long flowering life. Nanochitosan-logo-melatonin and copper-nanoparticles-logo-melatonin nanoparticles improve stem integrity, delay senescence events, and maintain biochemical integrity, providing green solutions to more commonly available preservatives. The strategies are needed in order to meet the needs of the supply chain and reduce ecological footprints.

In addition to use in the horticulture domain, Gerbera jamesonii exhibits a substantial phytochemical activity flow, including flavonoids, coumarins, and sterols that have been shown to possess the properties of antioxidants, anti-inflammatories, and anti-cancers. Though in preclinical studies, results are encouraging, the lack of clinical trials, as well as comprehensive toxicology studies, is a major limitation. Future studies need to strictly prove efficacy and safety before taking the next step of therapeutic use.

In total, advances in biotechnology, postharvest preservation, plant physiology, and phytochemistry demonstrate Gerbera jamesonii as a species beyond an ornamental one. It serves as a model organism that connects floriculture and sustainable agriculture on the one hand and pharmaceutical innovation on the other hand with interesting prospects of improving economic success and health at the same time.

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