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Review Article

Hydrogel Microsphere Based Delivery of *Panax quinquefolius L*. for Targeted Gut Microbiome Modulation with Design Strategies, Mechanistic Insights, and Therapeutic Prospects

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Abstract

Introduction: *Kiwifruit (Actinidia deliciosa) is a nutrient-dense fruit that has gained considerable scientific attention due to its diverse nutritional composition and potential health-promoting properties. It contains several bioactive constituents that may contribute to its functional and nutraceutical significance.*

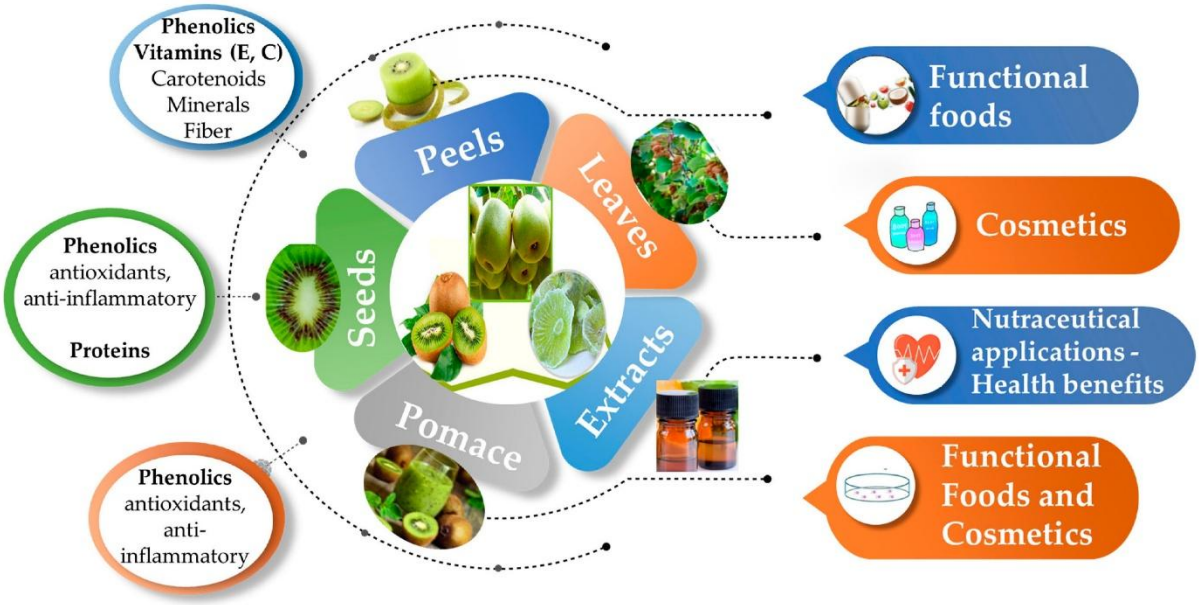
Methods: *This review examines the botanical characteristics, nutritional composition, phytochemical constituents, pharmacological activities, nutraceutical applications, and safety considerations of kiwifruit, with particular emphasis on its biologically active compounds and their reported physiological effects.*

Results: *Kiwifruit contains vitamins, minerals, dietary fiber, organic acids, carotenoids, polyphenols, flavonoids, and proteolytic enzymes. Important constituents include vitamin C, chlorogenic acid, caffeic acid, quercetin derivatives, catechin, and actinidin. Experimental findings suggest that these constituents exhibit antioxidant, anti-inflammatory, antimicrobial, cardiometabolic, and gastrointestinal health-promoting activities. Dietary fiber and actinidin may contribute to digestive health, whereas polyphenolic compounds may help regulate oxidative stress and inflammatory responses. Furthermore, kiwifruit offers potential applications in the development of functional foods and nutraceutical products.*

Conclusion: *Kiwifruit represents a promising natural source of bioactive compounds with potential nutritional and therapeutic relevance. However, further research is required to establish the bioavailability, mechanisms of action, dose-dependent effects, and long-term clinical efficacy of its individual constituents. A better understanding of these aspects may facilitate the development of evidence-based nutraceutical applications and functional food products.*

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Graphical Abstract

1. Introduction

The increasing interest in natural products and food-derived bioactive molecules has encouraged research into fruits as potential sources of health-promoting ingredients. Fruits provide essential nutrients and contain secondary metabolites that may influence physiological processes beyond their basic nutritional functions. Kiwifruit, commonly known as Chinese gooseberry, belongs to the family Actinidiaceae and the genus Actinidia. It is widely consumed because of its characteristic flavor, refreshing taste, and nutritional richness. The green-fleshed commercial Kiwifruit is commonly associated with *Actinidia deliciosa*, although several other species, including Actinidia chinensis and Actinidia arguta, are also commercially important. The nutritional significance of Kiwifruit is associated with its high vitamin C content, dietary fiber, potassium, folate, and diverse phytochemicals. Its chemical composition includes phenolic acids, flavonoids, carotenoids, organic acids, polysaccharides, and proteolytic enzymes. These components have been investigated for their antioxidant, anti-inflammatory, antimicrobial, and gastrointestinal effects(1) . Recent research has also highlighted the potential value of kiwi peel, seeds, and other processing by-products as sources of bioactive ingredients. Therefore, Kiwifruit may have applications extending beyond conventional fruit consumption into functional foods, dietary supplements, and nutraceutical formulations. The present review provides an integrated discussion of the phytochemical composition, pharmacological properties, and nutraceutical significance of Kiwifruit, with particular emphasis on scientific evidence and opportunities for future research(2) .

2. Botanical description and classification



Fig.1 : Fruit, flowers leaf of the *Actinidia deliciosa*

Botanical parameter	Description
Common name	Kiwi / Kiwifruit
Scientific name	*Actinidia deliciosa*
Family	Actinidiaceae
Genus	Actinidia
Plant type	Perennial climbing vine
Fruit type	Fleshy berry
Edible portion	Primarily pulp; peel is also edible
Major commercial forms	Green and gold Kiwifruit
Important constituent	Vitamin C and actinidin

Kiwifruit plants are perennial climbers with woody stems and broad leaves. The fruit is generally oval, with brown, hairy skin and green or yellow flesh containing numerous small edible seeds. Fruit characteristics, nutrient concentration, and phytochemical composition vary with cultivar, maturity, environmental conditions, and post-harvest handling Fig 1(3) .

3. Nutritional composition

Kiwifruit provides a combination of macronutrients, micronutrients, and functional food components. Its nutritional contribution is influenced by the cultivar, ripening stage, and growing conditions(4) .

Table 1. Major nutritional components of Kiwifruit

Nutritional component	Biological significance
Carbohydrates	Provide dietary energy
Dietary fibre	Supports bowel regularity and gut health
Vitamin C	Collagen synthesis and antioxidant defence
Vitamin E	Protects lipid structures against oxidation
Vitamin K	Participates in normal blood coagulation
Folate	Required for DNA synthesis and cell division
Potassium	Supports normal cardiovascular and neuromuscular functions
Magnesium	Involved in enzymatic and metabolic processes
Carotenoids	Contribute to antioxidant activity
Organic acids	Influence flavour and fruit acidity

Exact nutritional values should be reported using a specified cultivar, edible portion, and food-composition database rather than assuming that all Kiwifruit varieties have identical composition(5) .

4. Phytochemical constituents of Kiwifruit

Phytochemicals are important contributors to the biological properties of Kiwifruit. Their distribution differs between the pulp, peel, seeds, and other plant tissues. The major phytochemical groups include phenolic acids, flavonoids, carotenoids, terpenoids, polysaccharides, and proteins Fig 2(6) .

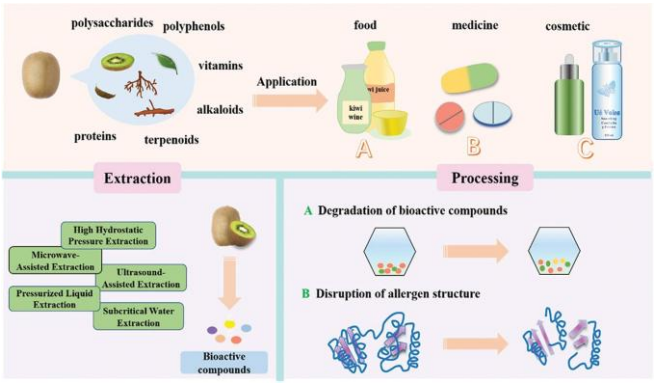


Fig.2: Phytochemical constituents of Kiwifruit

4.1 Phenolic acids

Phenolic acids are important secondary metabolites that contribute to the antioxidant properties of Kiwifruit. They can interact with reactive oxygen species and influence oxidative processes. Kiwifruit (*Actinidia deliciosa*) contains several important phenolic acids that contribute to its phytochemical composition and potential biological activities. These include gallic acid, caffeic acid, chlorogenic acid, ferulic acid, p-coumaric acid, protocatechuic acid, and syringic acid. These compounds belong to different classes of phenolic acids and are recognized for their potential antioxidant properties. They may contribute to the neutralization of reactive oxygen species and protection of cellular components against oxidative damage. Furthermore, certain phenolic acids have been investigated for their anti-inflammatory and other health-promoting effects, highlighting their potential significance in the nutraceutical applications of Kiwifruit. The occurrence and concentration of these compounds may vary depending on the cultivar, fruit maturity, growing conditions, extraction method, and plant fraction analyzed(7) .

4.2 Flavonoids

Flavonoids constitute an important group of polyphenolic compounds associated with antioxidant and inflammation-modulating activities. Kiwifruit (*Actinidia deliciosa*) contains several flavonoids, including quercetin and its glycosides, catechin, epicatechin, rutin, and kaempferol derivatives. These compounds belong mainly to the flavanol and flavan-3-ol subclasses of flavonoids and contribute to the fruit's diverse phytochemical profile.

They are recognized for their potential antioxidant activity, as they may help neutralize reactive oxygen species and protect cellular components from oxidative damage. In addition, certain flavonoids have been investigated for their anti-inflammatory, cardioprotective, and other health-promoting properties. The composition and concentration of these compounds may vary depending on the Kiwifruit cultivar, maturity stage, growing conditions, fruit tissue, and extraction method(8) .

4.3 Carotenoids

Carotenoids are lipid-soluble pigments that contribute to the color and antioxidant characteristics of different Kiwifruit cultivars. Kiwifruit (*Actinidia deliciosa*) contains several carotenoids, including lutein, β-carotene, zeaxanthin, and other xanthophylls. These pigments contribute to the fruit's characteristic color and nutritional properties. Lutein and zeaxanthin are oxygen-containing carotenoids that are particularly important for their potential role in maintaining eye health, whereas β-carotene acts as a precursor of vitamin A and contributes to normal vision and immune function. In addition, carotenoids exhibit antioxidant properties and may help protect cells against oxidative stress by neutralizing reactive oxygen species. The type and concentration of carotenoids in Kiwifruit may vary according to cultivar, fruit maturity, growing conditions, and analytical methods used(9) .

4.4 Vitamin C and other vitamins

Vitamin C is one of the most important nutritional constituents of Kiwifruit. It participates in collagen synthesis, supports normal immune function and contributes to the maintenance of antioxidant defence systems. Vitamins E, K, folate and several B-group vitamins also contribute to its nutritional value(10) .

4.5 Actinidin

Actinidin is a cysteine protease naturally present in Kiwifruit, particularly green-fleshed varieties. It facilitates the breakdown of dietary proteins and has been investigated for its potential role in gastrointestinal protein digestion(11) .

4.6 Dietary fibre and polysaccharides

Kiwifruit contains soluble and insoluble dietary fibers. These components contribute to stool bulk, water retention, and intestinal transit. Its fiber content makes it a potential ingredient in functional food formulations Table 2 (12) .

Table 2. Phytochemical constituents and their potential biological significance

Phytochemical	Chemical class	Potential biological significance
Gallic acid	Phenolic acid	Antioxidant activity
Caffeic acid	Phenolic acid	Antioxidant and inflammation-modulating potential
Chlorogenic acid	Phenolic acid	Antioxidant and metabolic effects
Ferulic acid	Phenolic acid	Protection against oxidative damage
Quercetin	Flavonoid	Antioxidant and anti-inflammatory potential
Catechin	Flavan-3-ol	Radical-scavenging activity
Epicatechin	Flavan-3-ol	Vascular and antioxidant effects
Rutin	Flavonoid glycoside	Antioxidant potential
Lutein	Carotenoid	Protection against oxidative stress
β-Carotene	Carotenoid	Provitamin A activity
Actinidin	Proteolytic enzyme	Protein digestion
Dietary polysaccharides	Carbohydrate	Gastrointestinal health

5. Pharmacological activities of Kiwifruit

Yuan et al. (2021) investigated the protective effects of Kiwifruit polyphenol extract (KPE) against high-fat diet-induced intestinal barrier damage and inflammation in rats. The extract, obtained from Kiwifruit peel, contained approximately 65.40% total polyphenols, with protocatechuic acid identified as its major constituent. Supplementation with KPE at doses of 50 and 100 mg/kg body weight improved intestinal barrier integrity by increasing the expression of tight-junction proteins, including claudin-1, occludin, and zonula occludens-1 (ZO-1)(13) . Furthermore, KPE modulated gut microbial composition by increasing the relative abundance of beneficial bacteria, particularly Lactobacillus and Bifidobacterium, while reducing certain potentially harmful bacterial populations. The treatment also demonstrated anti-inflammatory effects, as indicated by increased interleukin-10 (IL-10) and decreased expression of Toll-like receptors (TLR-2 and TLR-4), tumor necrosis factor-alpha (TNF-α), and interleukin-1 beta (IL-1β). These findings suggest that Kiwifruit-derived polyphenols may help maintain intestinal barrier function and regulate gut microbiota-associated inflammation, highlighting their potential as functional nutraceutical ingredients for gastrointestinal health. However, these findings are based on an animal model and require further validation through human clinical studies Fig 3(14) .

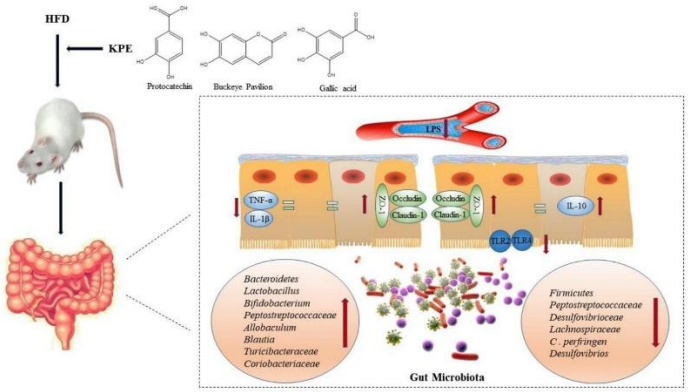


Fig.3: Pharmacological activities of Kiwifruit

5.1 Antioxidant activity

Oxidative stress occurs when the production of reactive oxygen species exceeds the capacity of endogenous antioxidant defence mechanisms. Excessive oxidative stress can damage cellular lipids, proteins, and nucleic acids. Kiwifruit contains several antioxidant components, particularly vitamin C, vitamin E, carotenoids, and polyphenolic compounds. These substances may contribute to the neutralization of reactive species and protection against oxidative damage(15) .

The antioxidant potential of Kiwifruit *(Actinidia deliciosa*) and its extracts can be evaluated using several standard in vitro assays. These include the 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay, which measures the ability of antioxidants to neutralize stable free radicals, and the 2, 2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical-cation decolorization assay, which determines antioxidant activity through the reduction of ABTS radical cations. The Ferric Reducing Antioxidant Power (FRAP) assay evaluates the reducing capacity of the extract by measuring the conversion of ferric (Fe^{3+}) ions into ferrous (Fe^{2+}) ions, whereas the Oxygen Radical Absorbance Capacity (ORAC) assay measures the ability of antioxidants to inhibit oxidative damage caused by peroxyl radicals. In addition, total phenolic content (TPC) is commonly determined using the Folin–Ciocalteu method to estimate the overall concentration of phenolic compounds, which is generally expressed as gallic acid equivalents (GAE). Collectively, these methods provide complementary information about the antioxidant capacity and phenolic composition of Kiwifruit extracts(16) .

5.2 Anti-inflammatory activity

Inflammation is a complex biological response involving inflammatory mediators, immune cells, and intracellular signalling pathways. Phenolic acids and flavonoids present in Kiwifruit have been investigated for their potential to modulate inflammatory processes. Experimental findings suggest that certain kiwi-derived extracts may influence inflammatory mediators and oxidative pathways. The antioxidant potential of Kiwifruit (*Actinidia deliciosa*) and its extracts can be evaluated using several standard in-vitro assays(17) . These include the 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay, which measures the ability of antioxidants to neutralize stable free radicals, and the 2, 2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical-cation decolorization assay, which determines antioxidant activity through the reduction of ABTS radical cations. The Ferric Reducing Antioxidant Power (FRAP) assay evaluates the reducing capacity of the extract by measuring the conversion of ferric (Fe^{3+}) ions into ferrous (Fe^{2+}) ions, whereas the Oxygen Radical Absorbance Capacity (ORAC) assay measures the ability of antioxidants to inhibit oxidative damage caused by peroxyl radicals. In addition, total phenolic content (TPC) is commonly determined using the Folin–Ciocalteu method to estimate the overall concentration of phenolic compounds, generally expressed as gallic acid equivalents (GAE). Collectively, these methods provide complementary information about the antioxidant capacity and phenolic composition of Kiwifruit extracts(18) .

5.3 Gastrointestinal and digestive health

Gastrointestinal health is one of the most promising areas of Kiwifruit research. Kiwifruit (*Actinidia deliciosa*) contains several important dietary components that contribute to gastrointestinal health and digestive function. Its dietary fiber content supports bowel regularity, promotes intestinal motility, and may help prevent constipation. Kiwifruit also contains actinidin, a naturally occurring cysteine protease enzyme that facilitates the digestion of dietary proteins by breaking them down into smaller peptides. Furthermore, its fermentable carbohydrates and dietary fiber may act as substrates for beneficial intestinal microorganisms, thereby influencing gut microbial composition and metabolic activity. Collectively, these components highlight the potential role of Kiwifruit in supporting digestive health, maintaining bowel function, and promoting a balanced gut microbiota(19) .Human dietary studies have investigated Kiwifruit consumption in relation to constipation, stool frequency, and gastrointestinal comfort. The evidence for digestive benefits is more developed than that for several proposed systemic therapeutic effects(20) .

5.4 Antimicrobial activity

Plant-derived phenolics and other secondary metabolites have been examined for their antimicrobial properties. Kiwifruit extracts and selected constituents have been investigated against different microbial organisms. The proposed mechanisms include interference with microbial

membranes, oxidative processes, and cellular enzyme functions(21) .

5.5 Cardiovascular benefits

Kiwifruit (*Actinidia deliciosa*) contains several nutrients and bioactive compounds that may contribute to cardiovascular health. Its potassium content supports normal blood pressure regulation by maintaining electrolyte balance and counteracting the effects of excessive sodium intake. The polyphenols present in Kiwifruit exhibit antioxidant properties that may help reduce oxidative stress and protect vascular cells from oxidative damage. Furthermore, dietary fiber may support healthy lipid metabolism by influencing cholesterol absorption and contributing to the maintenance of normal blood lipid levels. Kiwifruit is also a rich source of vitamin C, which is essential for collagen synthesis and helps maintain the normal structure and function of blood vessels and vascular connective tissues. Collectively, these nutritional and phytochemical properties suggest that regular Kiwifruit consumption may support cardiovascular health as part of a balanced diet. Some dietary intervention studies have explored blood pressure and cardiometabolic parameters. Nevertheless, the clinical evidence is not sufficient to establish Kiwifruit as a treatment for cardiovascular disease(22) .

5.6 Antidiabetic and metabolic potential

Polyphenols, dietary fibers, and other constituents of Kiwifruit have attracted interest in metabolic research. Potential mechanisms being investigated include modulation of glucose absorption, insulin sensitivity, oxidative stress, and lipid metabolism. These activities require careful differentiation between the findings from isolated compounds, animal models, and human dietary trials(23) .

5.7 Anticancer potential

The potential anticancer effects of Kiwifruit *(Actinidia deliciosa)* and its bioactive constituents have been investigated through several cellular and molecular mechanisms. These possible mechanisms include the regulation of apoptosis, which may promote programmed cell death in abnormal or cancerous cells; modulation of oxidative stress through antioxidant activity, which may help protect cellular components from oxidative damage; and alteration of cell-cycle progression, which may influence the uncontrolled proliferation of cancer cells. Furthermore, Kiwifruit-derived phytochemicals, particularly polyphenols and flavonoids, are being studied for their ability to regulate different cell-signalling pathways involved in cell growth, proliferation, survival, and inflammation. Collectively, these mechanisms suggest the potential role of Kiwifruit bioactive compounds in cancer prevention and management. However, these effects remain under investigation, and further mechanistic, preclinical, and clinical studies are required to establish their therapeutic significance(24) .

5.8 Immunomodulatory potential

Vitamin C and other nutritional components contribute to the normal functioning of the immune system. Polyphenols have also been investigated for their interactions with inflammatory and immune-regulatory pathways. The potential immunomodulatory effects of Kiwifruit require further research to establish the contribution of individual compounds and their physiological availability Table 3(25) .

Table 3. Pharmacological activities and proposed mechanisms

Activity	Potential active components	Proposed mechanism / effect	Evidence status
Antioxidant	Vitamin C, phenolics, carotenoids	Radical scavenging and reduction of oxidative stress	In vitro and nutritional evidence
Anti-inflammatory	Flavonoids, phenolic acids	Modulation of inflammatory signalling	Mainly preclinical
Gastrointestinal	Fibre, actinidin	Bowel regularity and protein digestion	Human dietary and mechanistic evidence
Antimicrobial	Phenolics and other extracts	Potential microbial growth inhibition	Mainly laboratory evidence
Cardioprotective	Potassium, fibre, polyphenols	Potential effects on vascular and metabolic health	Limited human evidence
Antidiabetic	Polyphenols and fibre	Possible modulation of glucose metabolism	Mainly preclinical
Anticancer	Selected Actinidia metabolites	Experimental effects on proliferation and apoptosis	Preclinical
Immunomodulatory	Vitamin C and	Support of immune	Nutritional and

	polyphenols	function and modulation of inflammation	preliminary experimental evidence

6. Nutraceutical applications

Nutraceuticals are food-derived products that contain nutrients or biologically active compounds and are intended to promote health, support normal physiological functions, and potentially reduce the risk of certain diseases. Kiwifruit (*Actinidia deliciosa*) possesses considerable potential for nutraceutical development owing to its rich nutritional composition and diverse bioactive constituents. It provides essential vitamins, minerals, dietary fiber, polyphenols, flavonoids, carotenoids, and digestive enzymes such as actinidin. These components contribute to its antioxidant, digestive, anti-inflammatory, and other health-promoting properties. Consequently, Kiwifruit can be explored as a functional food ingredient and as a source of bioactive compounds for the development of nutraceutical formulations, dietary supplements, and health-promoting food products(26) .

6.1 Functional food development

Kiwifruit (*Actinidia deliciosa*) can be incorporated into a wide range of functional foods and nutraceutical products because of its rich nutritional composition, dietary fiber, and bioactive phytochemicals. It can be utilized in the preparation of functional beverages and fruit juices to provide vitamins, minerals, and antioxidant compounds. Its pulp and extracts may also be added to fortified yoghurt and fermented products, enhancing their nutritional value and functional properties. Furthermore, Kiwifruit can be processed into fruit-based dietary supplements, high-fiber food products, and nutritional powders and concentrates for convenient consumption and improved nutrient delivery. These applications highlight the versatility of Kiwifruit as a functional food ingredient and its potential for the development of value-added nutraceutical products(27) .

6.2 Development of kiwi-based extracts

Standardized extracts can be developed from different parts of Kiwifruit (*Actinidia deliciosa*), including the pulp, peel, and seeds, to obtain bioactive compounds for nutraceutical and pharmaceutical applications. The selection of an appropriate extraction technique depends on the physicochemical properties, polarity, stability, and intended use of the target compound. Conventional methods, such as maceration and Soxhlet extraction, are commonly employed to recover phenolic compounds using suitable solvents for extraction. Advanced techniques, including ultrasound-assisted and microwave-assisted extraction, may improve extraction efficiency, reduce processing time, and enhance the recovery of selected phytochemicals. Supercritical fluid extraction, particularly using carbon dioxide, can be explored for the recovery of specific lipophilic constituents, whereas aqueous extraction is suitable for obtaining water-soluble nutrients and bioactive compounds. The optimization and standardization of these extraction procedures are essential for ensuring the consistent phytochemical composition, quality, safety, and reproducibility of Kiwifruit-derived extracts(28) .

Extraction technique	Potential application
Maceration	Extraction of phenolic compounds
Soxhlet extraction	Conventional solvent extraction
Ultrasound-assisted extraction	Improved extraction efficiency
Microwave-assisted extraction	Rapid extraction
Supercritical fluid extraction	Recovery of selected lipophilic compounds
Aqueous extraction	Recovery of water-soluble constituents

6.3 Utilisation of kiwi processing waste

Peels and seeds are potentially valuable sources of phytochemicals and other functional ingredients. Their utilization can support sustainable food processing and reduce the amount of organic waste generated by the fruit-processing industry. Recent studies have reported antioxidant and other biological properties in extracts obtained from Kiwifruit by-products(29) .

7. Extraction, isolation and characterisation of bioactive compounds

The isolation of bioactive constituents is essential for understanding the relationship between chemical composition and biological activity Fig 4(30) .

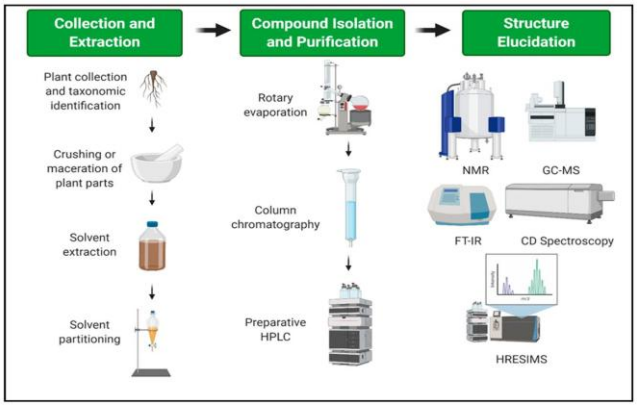


Fig.4: Extraction, isolation and characterisation of bioactive compounds

A systematic extraction and analytical workflow is essential for the identification, characterization, and evaluation of bioactive constituents present in Kiwifruit (*Actinidia deliciosa*). The proposed research process begins with the collection and botanical authentication of fresh Kiwifruit, followed by the separation of different fruit fractions, including pulp, peel, and seeds. These fractions are subsequently dried under controlled conditions and converted into fine powders for further processing. Extraction is then performed using suitable solvents, such as water, ethanol, or hydroalcoholic mixtures, depending on the polarity and stability of the target compounds(31) . The resulting extracts undergo preliminary phytochemical screening, followed by the quantitative estimation of total phenolic and flavonoid contents. Further phytochemical characterization is carried out using chromatographic techniques, including thin-layer chromatography (TLC), high-performance thin-layer chromatography (HPTLC), and high-performance liquid chromatography (HPLC). Advanced analytical techniques, particularly liquid chromatography–tandem mass spectrometry (LC-MS/MS) and nuclear magnetic resonance (NMR) spectroscopy, may be employed for the identification and structural elucidation of individual compounds. Finally, the extracts and isolated constituents are evaluated for their antioxidant and relevant pharmacological activities to establish their potential nutraceutical and therapeutic applications(32) .

Table 4. Analytical techniques for Kiwifruit phytochemical investigation

Technique	Purpose
Preliminary phytochemical screening	Detection of major phytochemical groups
UV-visible spectroscopy	Estimation of selected phytochemical contents
TLC	Preliminary separation and identification
HPTLC	Fingerprinting and marker-based standardisation
HPLC	Separation and quantification of phenolic compounds
LC-MS/MS	Identification and characterisation of metabolites
FTIR	Identification of characteristic functional groups
NMR	Structural elucidation of isolated compounds

8. Safety, toxicity and limitations

Although Kiwifruit (*Actinidia deliciosa*) offers considerable nutritional and nutraceutical benefits, certain safety aspects must be considered before its incorporation into functional foods and commercial nutraceutical formulations. Allergic reactions may occur in susceptible individuals, with actinidin, a cysteine protease enzyme present in Kiwifruit, recognized as an important allergenic protein. Some individuals may experience oral allergy syndrome, characterized by itching, tingling, or swelling of the lips, tongue, and oral cavity following consumption. Cross-reactivity may also occur in individuals sensitive to latex and certain other plant-derived allergens because of the similarities between allergenic proteins. Furthermore, excessive consumption may cause gastrointestinal discomfort, including abdominal pain, bloating, or diarrhea, particularly in sensitive individuals(33) . From a manufacturing perspective, product standardization is essential because the concentrations of bioactive compounds may vary depending on cultivar, fruit maturity, growing conditions, storage, and extraction procedures. Additionally, contaminant control is necessary to ensure product safety and quality, with particular attention to pesticide residues, heavy metals, and microbial contamination during raw-material processing, extraction, formulation, and storage. Therefore, appropriate quality-control procedures, allergen labelling, standardization, and safety assessments are essential for the development of reliable Kiwifruit-based nutraceutical products(34) .

9. Research gaps and future perspectives

Despite the increasing recognition of Kiwifruit (*Actinidia deliciosa*) as a functional food and potential source of nutraceutical ingredients, several research gaps remain to be addressed to establish its therapeutic relevance and commercial applications. Further investigations are required to improve the understanding of its phytochemical composition, biological activities, bioavailability, and long-term safety(35) .

9.1. Identification of Active Metabolites: Comprehensive metabolomic and phytochemical investigations are needed to identify, characterize, and quantify the bioactive constituents present in different Kiwifruit cultivars and fruit fractions. Advanced analytical approaches, such as LC-MS/MS and NMR spectroscopy, may facilitate the identification of previously uncharacterized metabolites(36) .

9.2. Bioavailability and Metabolism: Further studies are required to understand the absorption, distribution, metabolism, and excretion of individual phenolic compounds, flavonoids, and other bioactive constituents. Investigating their bioaccessibility during digestion and their interactions with intestinal microbiota will provide valuable information regarding their physiological significance(37) .

9.3. Mechanistic Pharmacological Studies: Future research should focus on establishing the molecular mechanisms responsible for the biological activities of

Kiwifruit-derived phytochemicals. Particular attention should be given to their interactions with cellular signalling pathways associated with oxidative stress, inflammation, apoptosis, and gastrointestinal health(38) .

9.4. Clinical Validation: Although several preclinical studies indicate promising health-related effects, well-designed randomized controlled clinical trials are necessary to establish the efficacy, effective dietary quantities, and long-term safety of Kiwifruit and its derived nutraceutical products in humans(39) .

9.5. Development of Standardized Formulations: There is considerable scope for developing standardized Kiwifruit extracts with defined phytochemical markers, consistent composition, and reproducible biological activity. Appropriate extraction procedures, analytical validation, and quality control parameters are essential for ensuring batch-to-batch consistency(40) .

9.6. Sustainable Utilization of Fruit By-products: Kiwifruit peel and seeds represent potentially valuable sources of phenolic compounds, dietary fiber, antioxidants, and other functional constituents. Their systematic investigation may support the development of value-added ingredients for pharmaceutical, nutraceutical, and food applications while promoting the sustainable utilization of fruit-processing waste. The peel and seed fractions should be investigated as potential sources of value-added ingredients for pharmaceutical, nutraceutical, and food applications in the future(41) .

10. Conclusion

Kiwifruit (*Actinidia deliciosa*) is a promising natural source of nutritional and bioactive compounds with potential applications in functional foods and nutraceutical development. Its chemical composition includes vitamin C, dietary fiber, phenolic acids, flavonoids, carotenoids, and the proteolytic enzyme actinidin. These constituents contribute to the nutritional value of the fruit and provide a scientific basis for investigating its antioxidant, anti-inflammatory, digestive, and other biological properties. Among its potential applications, gastrointestinal health and antioxidant nutrition are particularly relevant areas of investigation. The availability of bioactive compounds in different fruit fractions also creates opportunities for developing standardized extracts and utilizing processing by-products.

Author Contributions:
Sudeep Gautam; Shivanshu; Shobhit Singh; Shivansh Tripathi; Shivani Yadav; Sakshi: Writing – Original Draft, Investigation, Data Curation, and Formal Analysis.
Dr. Alok Kumar Shukla: Supervision, Conceptualization, and Project Administration.

Conflict of Interests

The authors declare that there is no conflict of interest.

Ethics approval and consent to participate

Not applicable

Source of Funding

No funding was available to conduct this study.

Data Availability

The information cited and examined in this review comes from earlier publicly accessible published works and can be found in databases, repositories, and cited journals. No original datasets were generated for this work.

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