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MULTIFUNCTIONAL POTENTIAL OF *CICHORIUM INTYBUS*: A REVIEW ON PHYTOCHEMICAL DIVERSITY, PHARMACOLOGICAL EFFICACY, AND FUTURE PROSPECT

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ABSTRACT

Chicory, or *Cichorium intybus* L., is a widely used industrial and medicinal plant that is prized for its extensive pharmacological potential and rich phytochemical makeup. Its bioactive components, which include inulin, phenolics, flavonoids, and sesquiterpene lactones, have been used traditionally as a liver tonic, digestive aid, and anti-inflammatory treatment. Its traditional medical usage has been supported by recent studies that have demonstrated its antioxidant, hepatoprotective, antidiabetic, antibacterial, and anti-inflammatory properties. New understandings of its metabolic pathways and genetic regulation have been made possible by developments in biotechnological and genomic study. Genes linked to inulin and phenolic biosynthesis have been identified by genetic transformation and omics-based techniques, while in vitro culture systems, such as callus and hairy root cultures, have been modified for increased metabolite production. Large-scale industrial applications and metabolic engineering are made possible by these advancements. Although more clinical validation and standardization are required, toxicological assessments show that *C. intybus* is generally safe at therapeutic dosages. Chicory may become a sustainable source of phytopharmaceuticals and nutraceuticals through future research that combines molecular breeding, biotechnological innovation, and pharmacological validation. All things considered, this study offers a thorough summary of the phytochemistry, pharmacology, and biotechnological developments in *Cichorium intybus*, highlighting its importance as a link between conventional medicine and contemporary scientific advancement.

Keywords: *Cichorium intybus*; chicory; phytochemicals; inulin; pharmacological activities; antioxidant; hepatoprotective; prebiotic; biotechnology; medicinal plant.

INTRODUCTION

Chicory, or *Cichorium intybus* L., is a perennial herb that is a member of the Asteraceae family. Originally from Europe and Western Asia, it is currently grown all over the world in temperate and subtropical climates for its nutritional and therapeutic qualities (Janda et al., 2020). The plant is well-known for its deep taproot, which is a major source of inulin, a naturally occurring fructan-type polysaccharide with important prebiotic and industrial use, as well as its bright blue blooms and bitter flavor. *C. intybus* has long been used to treat liver conditions, digestive issues, inflammation, and metabolic illnesses including diabetes in a variety of traditional medical systems, including Ayurveda, Unani, and European folk medicine (Mudannayake et al., 2022). Because of its extensive phytochemical profile, scientific research on *C. intybus* has accelerated over the past few decades. Numerous bioactive substances, including sesquiterpene lactones (lactucin, lactucopicrin), phenolic acids (caffeic and chlorogenic acids), flavonoids (quercetin, rutin), coumarins, tannins, and alkaloids, are found in the plant. Its wide range of pharmacological effects, including as antioxidant, hepatoprotective, anti-inflammatory, antibacterial, and antidiabetic qualities, are attributed to these secondary metabolites. (Riaz et al.,2024). The root extract's hepatoprotective and hypoglycemic properties, in particular, have been thoroughly investigated, supporting its traditional usage in liver and metabolic illnesses (Khan et al., 2024). *C. intybus* has become a significant industrial crop in addition to its medical use (Bais et al., 2001). The inulin-rich roots are frequently used as a coffee alternative and as a component of dairy products, functional meals, and dietary supplements (Birsa and Sarbu 2023). Chicory-derived inulin is known to have prebiotic properties that improve digestive health by fostering the development of advantageous gut bacteria. Additionally, the plant's bioactive components have been used in pharmaceutical, nutraceutical, and cosmetic formulations, demonstrating its diverse commercial significance (Naveed., 2017).

The biosynthesis of chicory's useful metabolites can now be better understood thanks to recent developments in molecular biology and plant biotechnology (Akram et al., 2025). To increase the production of inulin and other pharmacologically active substances, research has been conducted using tissue culture, callus induction, and genetic transformation. (Kalashnikova et al., 2023). Key genes involved in secondary metabolite biosynthesis have been further clarified by transcriptomic and proteomic investigations, opening the door to metabolic engineering and large-scale manufacturing. (Guo et al., 2025)

Despite these important discoveries, there are still unanswered questions about how phytochemical diversity and pharmacological efficacy are related, as well as how to carry out thorough clinical trials to confirm preclinical findings. Furthermore, issues like standardization of extracts, safety assessment, and variation in phytochemical content caused by genetic and environmental variables must be addressed. Thus, the goal of this review is to provide a thorough analysis of Cichorium intybus's phytochemical composition, pharmacological potential, nutritional importance, and recent biotechnological developments. Additionally, it identifies current research gaps and future directions for transforming this traditional herb into a commercially viable and scientifically verified medicinal plant.

CICHORIUM INTYBUS'S PHYTOCHEMICAL COMPOSITION

The numerous pharmacological and nutraceutical qualities of Cichorium intybus are attributed to its large reservoir of varied secondary metabolites (Girelli et al., 2021) The plant's roots, leaves, blossoms, and seeds all contain different amounts of inulin, sesquiterpene lactones, phenolic acids, flavonoids, coumarins, tannins, and alkaloids. The bitter flavor and medicinal properties of the plant are caused by these compounds. *C. intybus* is a crucial model species for the investigation of natural product production in medicinal plants due to its chemical variety (Alamgir., 2018).

PRIMARY METABOLITES: Inulin, a naturally occurring fructan-type polysaccharide present in large quantities in the root (up to 68% of dry weight), is the main primary metabolite in C. intybus. Inulin is well known for its prebiotic role in promoting the growth of good intestinal flora like Lactobacillus and Bifidobacterium. (Mudannayake et al., 2022). It also acts as an energy store for the plant. The plant tissues also include proteins, carbohydrates, and trace amounts of fatty acids, all of which add to their nutritional worth. (Bais and Ravishankar, 2001).

Secondary Metabolites

Sesquiterpene Lactones: These are C. intybus's distinctive bitter chemicals, which are mostly present in the latex and roots. The three main sesquiterpene lactones are 8-deoxylactucin, lactucin, and lactucopicrin. They have strong antioxidant, anti-inflammatory, and antiparasitic qualities. By altering the NF-κB and COX-2 pathways, these substances lessen oxidative stress and inflammation. (Birsa and Sarbu 2023).

Phenolic Acids: Chicory leaves and roots are primarily composed of phenolic acids, including ferulic acid, p-coumaric acid, caffeic acid, and chlorogenic acid. (Covaet al., 2021). These substances have potent free radical scavenging properties, which support the plant's hepatoprotective and antioxidant properties. Additionally, phenolic acids shield plant tissues from oxidative stress and UV-induced damage (Stevanovic et al., 2019). Another significant class of bioactive substances found in *C. intybus* are flavonoids. Quercetin, rutin, apigenin, and luteolin are the primary flavonoids

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found. These substances are well-known for their cardioprotective, antibacterial, and anti-inflammatory properties. They work in concert with phenolic acids to increase the plant extracts' antioxidant potential (Qangule., 2016).

Coumarins And Other Compounds: The plant's antibacterial and vasodilatory properties are attributed to coumarins such esculetin and cichoriin. There have also been reports of minor components such tannins, saponins, and alkaloids that may support the pharmacological activity and defense mechanisms of the plant (Beik Mahdavi et al., 2024).

Analytical Techniques For Phytochemical Characterization: The phytochemicals of *C. intybus* may now be thoroughly profiled thanks to recent developments in analytical chemistry (Khatami et al., 2018). To precisely identify and measure bioactive components, methods including High-Performance Liquid Chromatography (HPLC), Liquid Chromatography–Mass Spectrometry (LC–MS), Gas Chromatography–Mass Spectrometry (GC–MS), and Nuclear Magnetic Resonance (NMR) are frequently used. Additionally, these techniques aid in standardizing extracts for use in industry and pharmacology (Maliket al., 2016).

Table 1. Major phytochemical classes and their biological activities in *Cichorium intybus*

Phytochemical class	Major compounds	Plant part	Reported biological activities
Polysaccharides	Inulin	Root	Prebiotic, hypoglycemic, hypolipidemic
Sesquiterpene lactones	Lactucin, Lactucopicrin, 8-Deoxylactucin	Root, latex	Anti-inflammatory, analgesic, antimalarial
Phenolic acids	Chlorogenic acid, Caffeic acid, Ferulic acid	Leaf, root	Antioxidant, hepatoprotective
Flavonoids	Quercetin, Rutin, Luteolin, Apigenin	Leaf, flower	Antimicrobial, cardioprotective, antioxidant
Coumarins	Esculetin, Cichoriin	Root, leaf	Vasodilatory, antimicrobial
Tannins and saponins		Root, seed	Antioxidant, immunomodulatory

Pharmacological And Therapeutic Activities Of *Cichorium Intybus*

Cichorium intybus is widely used in traditional medicine due to its wide range of pharmacological actions (El-Sayed Raghda et al., 2024). The various bioactive components, including flavonoids, coumarins, phenolic acids, inulin, and sesquiterpene lactones, work either alone or in concert to provide therapeutic benefits. Many of its conventional use have been confirmed by contemporary pharmacological research, both in vitro and in vivo, demonstrating its potential as a source of natural medications and functional food ingredients (Sun and Shahrajabian, 2023)

Antioxidant Activity: Phenolic acids and flavonoids are the main components of C. intybus's antioxidant potential, which has been extensively documented. In DPPH, ABTS, and FRAP tests, extracts from roots and leaves show notable free radical scavenging activity (Azad et al., 2024). By neutralizing reactive oxygen species (ROS), phenolic substances like caffeic acid and chlorogenic acid function as hydrogen donors, lowering oxidative stress. This antioxidant characteristic is essential for preventing oxidative damage linked to diabetes, cardiovascular disease, and liver illnesses (Marzbanet al., 2024).

Hepatoprotective Activity: Chicory has long been used as a liver tonic in traditional medicine. Its hepatoprotective potential has been validated in models of chemically induced liver injury (e.g., carbon tetrachloride, paracetamol). The ethanolic and aqueous root extracts restore the normal histological architecture of liver tissue and lower serum levels of AST, ALT, and ALP. Hepatic cell membranes are stabilized and antioxidant enzymes like SOD and catalase are improved by sesquiterpene lactones and phenolic acids. (Lupanova. et al 2022).

Antidiabetic And Hypolipidemic Activity: By increasing glucose tolerance and lowering fasting blood glucose levels, *C. intybus* demonstrates exceptional antidiabetic qualities. By inhibiting α-amylase and α-glucosidase, the inulin-rich extracts improve insulin sensitivity and regulate the metabolism of carbohydrates. Furthermore, lower serum cholesterol, triglycerides, and LDL levels in diabetic rats suggest its hypolipidemic impact. Chlorogenic acid, flavonoids, and inulin work together to mediate these effects. (Pushparaj et., al 2007).

Anti-Inflammatory And Analgesic Activity: The main cause of C. intybus's anti-inflammatory properties is its sesquiterpene lactones (lactucin, lactucopicrin), which reduce pro-inflammatory cytokines like TNF-α and IL-6 and block the NF-κB signaling pathway. (Moujir, et al., 2020). animal models have demonstrated the analgesic and anti-edematous properties of both root and leaf extracts. These results support the historic use of chicory to treat inflammatory diseases like arthritis. (Krepkova et al., 2023).

-**Antimicrobial And Antiparasitic Activity:** The broad-spectrum antibacterial activity of *C. intybus* extracts against both Gram-positive and Gram-negative bacteria, such as Pseudomonas aeruginosa, Escherichia coli, and Staphylococcus aureus, has been shown in a number of studies (Pandey et al., 2021). Because phenolics, flavonoids, and coumarins work in concert, the ethanolic and methanolic extracts have strong antibacterial and antifungal properties. Sesquiterpene lactones also exhibit encouraging efficacy against protozoan parasites, indicating their possible application in antiparasitic compositions. (Azman et al., 2020). Antiparasitic, antibacterial, antioxidant, and cytotoxic activities of six Malaysian medicinal plants and identification of their active constituents (Doctoral dissertation, University of Nottingham).

Anticancer Activity:
According to new research, *C. intybus* may have anticancer properties through inducing apoptosis and preventing the growth of cancer cells. (Imam et al., 2019). Hepatic, breast, and colon carcinoma cells are among the cancer cell lines against which phenolic and sesquiterpene lactone-rich extracts have demonstrated cytotoxicity. (Gospodinova et al., 2015) These effects are thought to be caused by downregulating oncogenic pathways and modulating oxidative stress. Comprehensive molecular and clinical research is still scarce, nevertheless.

Prebiotic And Gastroprotective Effects: One of the main carbohydrates in chicory root, inulin, acts as a natural prebiotic, promoting the growth of good gut bacteria like Lactobacillus and Bifidobacterium. (Khoobani et al., 2019). Improved immunity, greater mineral absorption, and better digestion are all facilitated by this. Additionally, by lowering stomach ulcers and boosting mucosal defense, the plant's mucilage and polyphenols have gastroprotective action. (Naveed., 2017).

Additional Activities Reported: In addition to the actions listed above, *C. intybus* has immunomodulatory, diuretic, cardioprotective, and nephroprotective properties (Kumari., 2024). Its extracts enhance renal function, lower blood pressure, and stop lipid peroxidation. Its potential as a multipurpose medicinal plant is further highlighted by these diverse actions.

4. NUTRITIONAL AND INDUSTRIAL APPLICATIONS OF *CICHORIUM INTYBUS*

Because of its rich nutrient makeup, useful bioactives, and several commercial uses, Cichorium intybus is not only a medicinal herb but also a lucrative industrial crop and nutraceutical. The plant is a commercially valuable species for the food, pharmaceutical, and cosmetic sectors since nearly every portion of it root, leaf, and seed has nutritional or industrial use (Aldahak et al., 2021).

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Table 2. Pharmacological activities of *Cichorium intybus* and their bioactive constituents

Pharmacological Activity	Active Compounds / Extracts	Proposed Mechanism	Model / System
Antioxidant	Chlorogenic acid, Caffeic acid, Quercetin	Free radical scavenging, ROS inhibition	In vitro assays
Hepatoprotective	Sesquiterpene lactones, Phenolic acids	Restoration of hepatic enzymes, antioxidant enzyme activation	CCl_4, paracetamol models
Antidiabetic / Hypolipidemic	Inulin, Flavonoids, Chlorogenic acid	α-Amylase inhibition, insulin sensitization, lipid metabolism modulation	STZ-induced diabetic rats
Anti-inflammatory / Analgesic	Lactucin, Lactucopicrin, Quercetin	NF-κB inhibition, cytokine suppression	Carrageenan-induced edema models
Antimicrobial / Antiparasitic	Phenolic acids, Coumarins, Flavonoids	Cell wall disruption, enzyme inhibition	Bacterial and protozoal strains
Anticancer	Sesquiterpene lactones, Phenolics	Apoptosis induction, oxidative stress modulation	Cancer cell lines
Prebiotic / Gastroprotective	Inulin, Polyphenols	Gut microbiota modulation, mucosal protection	Human and animal models

Nutritional Composition: Numerous vital nutrients and bioactive elements can be found in the roots and leaves of chicory. Up to 68% of the root's dry weight is made up of inulin, a dietary fiber with low calorie content and prebiotic properties. (Kadiri et al., 2025). Apart from inulin, the plant also includes minerals (Ca, K, Mg, Fe, Zn), proteins (8–10%), carbs (15–20%), and trace levels of vitamins (B-complex, C, and E). Because of their high polyphenol and flavonoid content, the leaves have antioxidant potential and can be used in salads and herbal teas. (Nwafor., 2017). Chicory root is a great dietary supplement for those with diabetes and obesity because of its low glycemic index and cholesterol-lowering qualities. (Katiyar. et al., 2015) Its traditional use as an appetizer and digestive tonic is supported by the presence of naturally occurring bitter chemicals such sesquiterpene lactones, which improve bile secretion and digestion.

Functional Food And Beverage Industry: *C. intybus* is most commonly used commercially in the food industry, mainly as a functional food ingredient and coffee substitute. In order to lower caffeine consumption, roasted chicory root powder is frequently mixed with coffee to add a nice scent and bitterness. The root's inulin is used in baked goods, dairy products, and confections as a low-calorie sweetener, fat substitute, and texturizing agent. (Wang and Cui, 2011). Chicory inulin, which is added to yogurts, cereal bars, and baby formulae, has become well-known throughout the world as a prebiotic fiber in recent years. (Singla and Chakkaravarthi 2017). By specifically promoting good gut microorganisms, it enhances immunity and nutrition absorption, improving gut health. Chicory oligosaccharides are also utilized in nutraceutical formulations and functional drinks intended for gastrointestinal health.

Pharmaceutical And Nutraceutical Uses: *C. intybus* is a viable raw material for the herbal and nutraceutical sectors due to its pharmacological characteristics. (Wang and Cui 2011). Formulations that target digestive diseases, diabetes, and liver disorders use standardized extracts of chicory root and leaves. Hepatoprotective and anti-aging supplements contain the antioxidant-rich phenolic components. Additionally, inulin is being studied as a drug carrier matrix to increase the bioavailability of chemicals that are encapsulated. Additionally, syrups, tonics, and capsules sold for lipid control, weight management, and liver detoxification contain chicory extracts. The commercial market for chicory-based nutraceuticals has grown due to consumers' increasing demand for natural, plant-based health products.

Cosmetic And Personal Care Industry: *C. intybus* has been used in cosmetic compositions because of its antibacterial, anti-inflammatory, and antioxidant qualities. Hair care products, anti-aging serums, and skin-soothing creams all contain extracts from the roots and leaves. By preserving the natural microbiota balance, inulin and polyphenols enhance skin hydration and elasticity. The plant is becoming more and more popular as an ingredient in natural skincare products because of its bioactive ingredients, which also lessen skin damage caused by oxidative stress. (Kęsik and Klimowicz 2024).

Industrial and Agricultural Applications: Chicory has potential as an industrial crop in addition to its nutritional value. (Barry., (1998). Because of their high carbohydrate content, the dried roots are utilized to produce biomass and bioethanol. Following inulin extraction, the plant wastes can be used into animal feed, providing a sustainable by-product. Chicory is grown as a feed crop in agriculture because of its high protein content and livestock-friendliness.

C. intybus is a promising option for bio-based economy efforts because to the growing demand for sustainable and multipurpose crops that combine industrial, nutritional, and therapeutic benefits. (Hughes et al., 2017).

5. BIOTECHNOLOGICAL AND GENOMIC ADVANCES IN *CICHORIUM INTYBUS*

The biotechnological and genetic study of *C. intybus* has advanced significantly in recent decades with the goal of increasing the synthesis of its beneficial metabolites, especially inulin and sesquiterpene lactones. Developments in molecular biology, genetic engineering, and plant tissue culture have made it possible to use secondary metabolism on an industrial scale and have yielded important insights into its regulation. (Maroufi., 2010).

Tissue Culture And In Vitro Propagation: In vitro culture methods have been effectively used for *C. intybus* secondary metabolite production, germplasm conservation, and quick clonal multiplication. (Samridha and Chandra 2024). Using different combinations of growth regulators such 2,4-D (2,4-dichlorophenoxyacetic acid) and BAP (6-benzylaminopurine), callus and suspension cultures have been produced from root, leaf, and petiole explants. (Chaâbani et al., 2015In comparison to wild-type plants, adventitious root cultures and hairy root cultures caused by Agrobacterium rhizogenes infection have demonstrated a notable buildup of inulin, phenolics, and sesquiterpene lactones. Regardless of changes in the environment, these systems offer a regulated and sustained foundation for metabolite production. (Hanafy et al., 2018

Table 3. Major nutritional and industrial applications of *Cichorium intybus*

Application Area	Utilized Part	Key Components	Commercial / Functional Significance
Functional foods & beverages	Root	Inulin, oligosaccharides	Coffee substitute, prebiotic fiber, fat replacer
Nutraceuticals & herbal formulations	Root, leaf	Phenolics, sesquiterpene lactones	Hepatoprotective, antidiabetic supplements
Cosmetics & personal care	Root, leaf	Inulin, flavonoids	Anti-aging, moisturizing, antimicrobial creams
Agriculture & animal feed	Whole plant, residue	Proteins, carbohydrates	Forage crop, feed additive
Bioenergy production	Root residue	Carbohydrates	Bioethanol and biomass generation

Additionally, studies have shown that elicitors including chitosan, salicylic acid, and jasmonic acid can improve the manufacture of secondary metabolites. Target compound yield and stability have been further enhanced by optimizing precursor feeding, light conditions, and culture media.

Genetic Transformation And Metabolic Engineering: Targeted modification of C. intybus's metabolic pathways is now possible thanks to developments in genetic transformation techniques. (Mahdavi et al.,2024). Genes important in inulin production (1-SST, 1-FFT) and the control of the phenylpropanoid pathway have been introduced using the Agrobacterium-mediated transformation technique.Transgenic lines that express the genes for 1-SST (sucrose:sucrose 1-fructosyltransferase) and 1-FFT (fructan:fructan 1-fructosyltransferase) exhibit improved carbohydrate metabolism and increased inulin content. Although research is still in its early phases, CRISPR/Cas9-mediated genome editing is being investigated as a novel strategy for gene function analysis and metabolic enhancement in chicory. (Bernard et al., 2019). The commercial production of valuable chemicals like inulin and sesquiterpene lactones in controlled systems is possible with these molecular engineering techniques.

Molecular Marker Development And Genetic Diversity Studies: Crop development and germplasm conservation depend on an understanding of genetic heterogeneity within *C. intybus* populations. To evaluate genetic diversity, cultivar identification, and phylogenetic relationships, a number of molecular marker systems, including RAPD (Random Amplified Polymorphic DNA), AFLP (Amplified Fragment Length Polymorphism), ISSR (Inter Simple Sequence Repeat), and SSR (Simple Sequence Repeat), have been used.These results show significant genetic variation between wild and farmed populations, which can be used in breeding initiatives to improve stress tolerance, yield, and inulin content.(El-Taher et al., 2023).

Omics Approaches And Functional Genomics: Our knowledge of the metabolic and regulatory networks in *C. intybus* has greatly increased with the recent integration of omics technology. Important genes linked to phenolic biosynthesis, stress response pathways, and fructan metabolism have been found by transcriptomic analysis. Proteomic research has identified defense-related proteins and enzymes involved in inulin buildup that are triggered by elicitor therapies. A thorough picture of metabolic fluxes has been made possible by metabolomic profiling employing LC-MS and GC-MS, which has aided in the correlation of metabolite accumulation with patterns of gene expression. (Draga et al., 2023). When combined, these omics-based methods have made it possible to understand chicory at the systems level and to tailor its metabolism for use in pharmaceutical and nutraceutical products.

Future Prospects: The integration of biotechnology and genetics in *C. intybus* research is still developing, despite notable advancements. The development of high-throughput transformation technologies for stable gene insertion should be the main emphasis of future research. Using metabolic engineering based on CRISPR to precisely regulate pathways. Identifying important regulatory hubs for targeted breeding by combining genomic, transcriptomic, and metabolomic datasets; establishing bioreactor-scale hairy root cultures for industrial metabolite synthesis. These methods will increase the commercial potential of Cichorium intybus as a model industrial and medicinal crop and support the sustained large-scale production of important metabolites.

Conclusion: Chicory, or Cichorium intybus L., is a useful industrial and medicinal plant with a variety of phytochemicals that contribute to its broad range of pharmacological effects, including inulin, phenolics, and sesquiterpene lactones. Its antioxidant, hepatoprotective, antidiabetic, antibacterial, and anti-inflammatory qualities have been proven by numerous investigations. New insights into its metabolic pathways and genetic variety have been made possible by recent developments in biotechnology, genomics, and metabolomics, opening the door to crop enhancement and large-scale metabolite manufacturing. Despite the plant's outstanding safety profile, more toxicological and clinical research is needed to confirm its medicinal usefulness in people. Its nutraceutical and medicinal potential will be further enhanced by the future combination of metabolic engineering, molecular breeding, and sustainable growing techniques. All things considered, *C. intybus* is a promising model species that connects conventional wisdom with cutting-edge biotechnological innovation.

Table 4. Summary of biotechnological and molecular studies on *Cichorium intybus*

Biotechnological Approach	Objective	Key Findings / Outcomes	References*
Callus & suspension culture	Metabolite production	Enhanced phenolics and lactones accumulation	Mamdouh and Smetanska (2022).
Hairy root culture (*A. rhizogenes*)	Stable metabolite synthesis	High inulin yield, rapid biomass growth	(Tabatabaee, et al., 2021).
Genetic transformation	Pathway modification	Overexpression of 1-SST and 1-FFT genes	(Suárez-González et al., 2014)
Molecular markers (RAPD, ISSR, SSR)	Genetic diversity analysis	High intra-species variation, useful for breeding	(Debajit et al., 2015)
Transcriptomics / Proteomics	Functional gene discovery	Identified genes for inulin and phenolic metabolism	(Farabegoli et al., 2023).

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