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# From Flowers to Stems and Leaves: Whole-Plant Valorization of Hangbaiju Chrysanthemum

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**Abstract** Chrysanthemum is a representative medicinal and edible plant resource in China. Its traditional industry has long focused on the harvesting, processing, and commercialization of flower heads, whereas leaves, stems, and processing residues remain underutilized, resulting in insufficient valorization of whole-plant biomass. Taking Hangbaiju chrysanthemum (*Chrysanthemum morifolium* Ramat.) as an example, this study reviews its production and traditional utilization and systematically evaluates the resource characteristics and valorization potential of its flowers, leaves, and stems. Flowers have an established foundation for the development of herbal teas, medicinal products, and functional foods and should therefore remain at the core of the high-value product chain. Leaves are rich in bioactive compounds, particularly polyphenols and flavonoids, and have potential for development as functional ingredients, natural antioxidant sources, and plant extracts. Stems offer opportunities for both the recovery of phenolic compounds and the production of lignocellulosic materials, making them suitable for a sequential valorization strategy of "extraction first, material utilization second, and recycling thereafter." On this basis, a whole-plant cascade utilization framework is proposed, integrating high-value flower products, functional compounds from leaves, sequential stem valorization, bioconversion of residual biomass, and recycling into agricultural production. Future efforts should strengthen the evaluation of non-floral tissues, promote tiered product development and whole-process standardization, and establish a circular Hangbaiju chrysanthemum industry that integrates cultivation, processing, utilization, and agricultural recycling.
**Keywords** Hangbaiju chrysanthemum; Whole-plant valorization; cascade utilization; Agricultural by-products; Functional compounds; Circular bioeconomy

## 1 Introduction

Hangbaiju chrysanthemum is a distinctive regional medicinal and edible cultivated type of *Chrysanthemum morifolium* Ramat. and an important component of both Zhejiang's traditional specialty agricultural products and the chrysanthemum industry. Its primary commercial organ is the capitulum, which has long been marketed as dried flowers, chrysanthemum tea, and traditional Chinese medicinal material. Over time, a diversified product system has developed that integrates traditional medicinal use, daily consumption, and functional food applications. Hangbaiju chrysanthemum from different geographical origins exhibits distinct variations in stable isotopes, mineral elements, and metabolite profiles, indicating that regional ecological conditions are closely associated with commercial quality and geographical origin authentication (Long et al., 2022). More broadly, studies on medicinal chrysanthemums have demonstrated that the inflorescences of *C. morifolium* are rich in flavonoids, phenolic acids, volatile compounds, polysaccharides, and other phytochemicals and exhibit antioxidant, anti-inflammatory, and various health-related activities. These characteristics collectively provide a scientific basis for the transition of chrysanthemum from a traditional medicinal and edible resource to a modern source of functional plant-derived ingredients (Wang et al., 2022).

However, the traditional Hangbaiju industry has long been characterized by a pronounced flower-centered utilization pattern, in which cultivation, harvesting, processing, and market evaluation are primarily focused on commercial flower heads, while leaves, stems, and other postharvest residues have not yet been incorporated into a utilization system comparable to that established for the flowers. Cross-organ studies of other medicinal chrysanthemums have shown that leaves and stems also contain various flavonoids, phenolic acids, and other

potentially functional compounds, with clear differences in chemical composition and accumulation patterns among plant tissues (Xu et al., 2025). In Hangbaiju chrysanthemum, the leaves and stems remaining after flower harvesting therefore possess a phytochemical basis for further development, suggesting that these non-floral tissues, traditionally regarded as low-value by-products, could potentially be converted into functional raw materials. Studies on the fermentation and resource utilization of chrysanthemum by-products have further demonstrated that postharvest residues can be incorporated into agricultural production and other applications through bioconversion (Ren et al., 2025; Danciu et al., 2026).

Against the background of the continued development of circular agriculture, green processing, and biomass valorization, transforming the conventional linear Hangbaiju production model of "flower harvesting-processing-residue disposal" toward whole-plant valorization has important implications for both resource utilization and industrial development. Research on the valorization of plant-derived by-products has demonstrated that green extraction, bioconversion, material utilization, and agricultural recycling can be integrated into tiered utilization pathways according to the compositional characteristics and economic value of different biomass fractions. In this way, conventional waste streams can be converted into sources of functional compounds, industrial materials, or agricultural inputs. For Hangbaiju chrysanthemum, whole-plant valorization does not imply replacing the established high-value uses of flowers in tea, medicinal, and functional products. Instead, it involves identifying the differentiated value of leaves, stems, and processing residues while maintaining flowers as the core high-value component, and subsequently increasing the overall value generated per unit of biomass through separate processing streams and cascade utilization. Taking Hangbaiju chrysanthemum as a representative case, this study analyzes its conventional flower-centered utilization pattern and the resource characteristics of non-floral tissues, examines the hierarchical value positioning of flowers, leaves, and stems, and proposes a whole-plant cascade utilization framework comprising high-value flower products, functional ingredients from leaves, sequential valorization of stems, and final recycling into agricultural production. The potential resource, environmental, and industrial benefits of this framework, together with its practical constraints, are further evaluated to provide a reference for transforming the Hangbaiju industry from a single flower-oriented commodity system toward a multi-component, circular, and high-value-added industrial system.

## 2 Production and Traditional Utilization Background

### 2.1 Production characteristics

Hangbaiju chrysanthemum (*Chrysanthemum morifolium* Ramat. cv. Hangbaiju) is a representative medicinal and edible chrysanthemum resource in Zhejiang Province, China, where a relatively stable regional system of cultivation, processing, and commercial distribution has developed over time (Figure 1). Hangbaiju produced in different areas of Zhejiang exhibits clear geographical variations in stable isotopes, mineral elements, and other quality-related characteristics. These differences reflect the close relationship between production and regional ecological conditions and also make geographical origin an important factor in quality evaluation and product authentication (Mei et al., 2023). Unlike crops cultivated primarily for their vegetative organs, the principal economic organ of Hangbaiju is the mature capitulum, and harvesting and commercial processing have traditionally centered on the flowers.

Gong et al. (2019) compared 15 commercial Hangbaiju samples, including six Duoju and nine Taiju samples. Taiju is generally harvested in October, when the ray florets have opened but the central tubular florets have not yet fully opened, whereas Duoju is usually harvested in November after the flower heads have reached a more fully opened stage. Clear differences in phenolic composition and antioxidant capacity were observed between these two commercial types. Taiju generally contained higher levels of caffeoylquinic acids and exhibited stronger antioxidant activity, indicating that harvesting at an earlier stage versus after full flowering not only produces products with different appearances but also results in differences in intrinsic quality.

Freshly harvested flowers must also undergo timely stabilization and dehydration. In both traditional and modern production systems, steaming, drying, and related processing methods are commonly used to reduce moisture content and produce dried flowers suitable for storage and distribution. Different drying methods and

temperatures can substantially affect phenolics, flavonoids, and antioxidant components in chrysanthemum flower heads, demonstrating that primary processing not only extends shelf life but also plays an important role in determining the functional quality of the flowers (Yuan et al., 2015). For growers and small-scale processors, Hangbaiju production therefore involves much more than simply cultivating the crop and harvesting all flowers at one time. Commercial grade is determined throughout the production process, from assessment of flowering stage and sequential harvesting to primary processing. The differentiation between Taiju and Duoju according to harvesting stage is one of the most characteristic features of the traditional flower-oriented Hangbaiju industry.

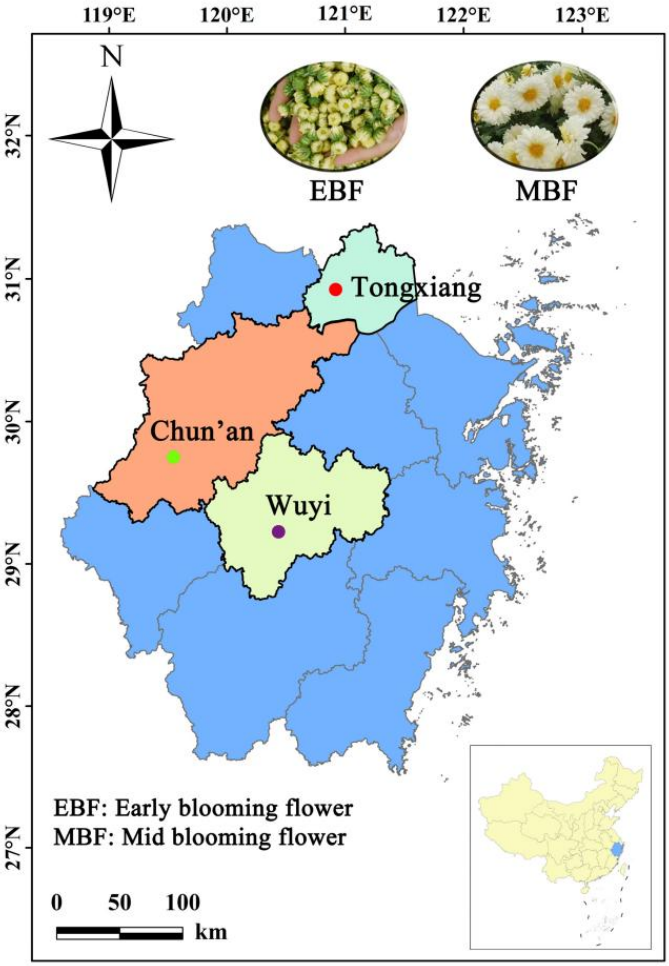



Figure 1 Hangbaiju sampling sites in Zhejiang Province, China (Adopted from Mei et al., 2023)

### 2.2 Traditional flower-based products

The dried capitula of chrysanthemum, known as *Chrysanthemi Flos* (Juhua), have a long history of use as a traditional Chinese medicinal material and are also widely consumed as herbal tea and used as a dietary ingredient. This dual role as both medicine and food has contributed to the development of an established consumption culture and commercial market for chrysanthemum flowers (Yuan et al., 2020). In the Hangbaiju industry, traditional products are not limited to a single category of "dried chrysanthemum flowers." Instead, different commercial types, particularly Taiju and Duoju, have developed according to harvesting time, flower developmental stage, and processing practices. Taiju generally retains a relatively compact flower form and is particularly suitable for the tea market, where intact appearance and infusion quality are important attributes. Duoju, by contrast, is characterized by more fully opened flower heads. Although both products originate from the same Hangbaiju resource, differences in chemical composition associated with harvesting stage indicate that this traditional commercial classification already incorporates a basic form of quality grading.

The regional identity of Hangbaiju products can also be illustrated by the relationship between Hangbaiju and Fubaiju chrysanthemum. A genetic study published in 2024 indicated that Hangbaiju originated in Tongxiang, Zhejiang Province, whereas "Fubaiju," cultivated in Macheng, Hubei Province, was reportedly introduced from Tongxiang in 1968. Evidence from chloroplast genomes, morphological characteristics, and historical records collectively indicates that Hangbaiju and Fubaiju have highly similar genetic backgrounds and may represent the same cultivated resource under different regional names (Yao et al., 2024). The commercial identity of chrysanthemum products is therefore determined not only by genetic background but also by cultivation region, historical dissemination, and the development of local brands.

### 2.3 Underutilization of stems, leaves, and processing by-products

Compared with the well-established commercial system for flowers, stems, leaves, and other plant residues generated during Hangbaiju production have long lacked similarly mature market outlets. Traditional production is economically centered on the harvesting of commercial flowers. Once graded and processed, the flowers can readily enter the tea, traditional medicine, and food markets, whereas non-commercial organs generally lack standardized grading criteria, raw-material specifications, and stable purchasing channels. In particular, Taiju and Duoju can already be differentiated into distinct commercial categories according to harvesting maturity, while no comparable classification system has been established for leaves and stems. This contrast clearly reflects the traditional industrial structure of Hangbaiju production, characterized by a strong emphasis on flowers and limited attention to stems and leaves.

In other chrysanthemum production systems, attempts have been made to return postharvest residues to agricultural production through composting. Organic compost prepared from chrysanthemum harvesting residues combined with fallen leaves can be reused in chrysanthemum cultivation, demonstrating that non-floral biomass is not without utilization value, although this pathway mainly represents relatively low-value agricultural recycling (Arjana et al., 2026). For Hangbaiju, therefore, the fundamental issue is not that stems and leaves have "no use," but rather that they lack clearly defined raw-material grades, purchasing specifications, and established product outlets comparable to those available for Taiju and Duoju. Flower heads can already be directed toward different markets according to maturity and quality, whereas stems and leaves are still largely handled as mixed residual biomass. This disparity in industrial maturity between floral and non-floral tissues provides the practical basis for developing a whole-plant valorization strategy for Hangbaiju chrysanthemum.

## 3 High-Value Utilization of Hangbaiju Flowers

### 3.1 Traditional tea and medicinal uses

The foundation for the high-value utilization of Hangbaiju flowers lies in their long-established dual role as both medicinal and edible resources. Traditional applications have mainly focused on uses associated with dispelling wind and clearing heat, as well as clearing liver heat and improving vision. Over a long history of consumption, chrysanthemum flowers have gradually developed an integrated utilization pattern encompassing traditional medicine, herbal tea, and dietary applications. Modern phytochemical and pharmacological studies have demonstrated that chrysanthemum inflorescences contain diverse flavonoids, phenolic acids, terpenoids, and volatile compounds. These findings provide modern scientific support for traditional uses and establish a basis for extending chrysanthemum from a conventional medicinal material to a source of functional food ingredients (Liu et al., 2024).

For Hangbaiju, the flower head not only serves traditional medicinal purposes but also represents the most commercially developed organ of the plant. Different production areas in Zhejiang have established various commercial forms, including dried Hangbaiju flowers, Taiju, Duoju, and different grades of chrysanthemum tea. Their geographical origin, flower morphology, aroma, and infusion quality collectively contribute to product identity and market recognition (Mei et al., 2023). Current retail markets offer canned, bagged, and gift-boxed products marketed with claims such as "originating from Tongxiang," "Hangbaiju," "Taiju," and "premium Taiju." For example, Hangbaiju products available through major Chinese e-commerce platforms such as JD.com include conventional dried flowers, first-harvest Taiju, premium-grade Taiju, and small portable packages.

Established commercial products such as Shifeng-branded Tongxiang Hangbaiju and Taiju are also available, with package sizes ranging from approximately 40~50 g for Taiju to 150 g for Hangbaiju flowers.

### 3.2 Bioactive compounds in flowers

The high-value potential of Hangbaiju flowers is largely attributable to their rich and diverse phytochemical composition. Inflorescences originating from different production areas contain a range of functionally relevant phenolic acids and flavonoids. Compounds such as chlorogenic acid, rutin, and apigenin-7-*O*-glucoside vary considerably among samples from different geographical origins, indicating that the chemical quality of Hangbaiju flowers is influenced not only by genetic background but also by local ecological conditions (Long et al., 2022). Various luteolin, apigenin, and kaempferol glycosides, together with phenolic acid derivatives such as dicaffeoylquinic acids, have also been detected in Hangbaiju. Collectively, rather than through the action of a single compound, these constituents provide an important chemical basis for antioxidant activity, metabolic regulation, and other potential biological functions (Feng et al., 2025).

Marked differences in chemical composition are also observed among different cultivars and commercial types of chrysanthemum flowers. Comparative studies of various *Chrysanthemi Flos* materials have identified multiple classes of phenolic acids and flavonoids in aqueous extracts, with significant differences among varieties in major marker compounds and associated biological activities. These findings suggest that cultivar selection and chemical fingerprinting could serve as important criteria for the grading of flower-derived products (Chen et al., 2021a). In addition to low-molecular-weight phenolic compounds, polysaccharides represent another important group of functional constituents. Polysaccharides isolated from the flowers of different chrysanthemum varieties vary in molecular weight, monosaccharide composition, and structural characteristics and exhibit different levels of immunomodulatory activity (Wang et al., 2022). From a production perspective, these compositional differences provide a basis for linking chemical quality indicators with different commercial grades and intended uses, such as Taiju, Duoju, ordinary flowers for tea consumption, and flowers specifically produced for extraction, rather than relying solely on external characteristics such as flower size for product grading.

### 3.3 Development of high-value flower products

The key to increasing the value of Hangbaiju flowers is to extend their utilization from traditional intact dried flower products toward standardized, convenient, and function-oriented products (Figure 2). Hangbaiju flavonoids can potentially be incorporated into tea beverages, instant products, nutritional supplements, and other functional foods. Appropriate extraction and formulation technologies can transform bioactive compounds that may be only partially utilized during conventional infusion into more stable product forms with improved convenience and more controllable concentrations (Lu and Liu, 2025). Spectrum–effect relationship studies of edible chrysanthemums have further indicated associations between compounds such as luteolin, acacetin-7-O-glucoside, and apigenin-7-O-glucoside and specific anti-inflammatory activities, providing a basis for establishing relationships among characteristic compounds, functional activities, and product quality (Huang et al., 2023).

Commercial Hangbaiju products are no longer limited to conventionally packaged bulk dried flowers. Public retail channels now offer tea bags, canned Taiju, small portable packages of flower tea, gift boxes, and blended infusion products. Some products combine Hangbaiju with ingredients such as lemon and honeysuckle to provide more convenient options for daily consumption. Although these products generally require relatively simple processing technologies, they are particularly suitable for different types of local agricultural businesses. Family farms can begin with raw-material grading and small-package products, cooperatives can focus on regional branding and gift-box products, while enterprises with greater processing capacity can develop instant powders, concentrates, blended tea beverages, or standardized extracts. Hangbaiju flower valorization can therefore follow a progressive pathway from intact flower products → convenient tea products → blended products → standardized extracts → functional foods.

High-value utilization also depends on effectively preserving functional compounds and sensory quality during harvesting and processing. Studies of chrysanthemum flower heads have demonstrated that developmental stage at harvest and drying method can substantially alter phenolic and flavonoid contents as well as antioxidant capacity,

indicating that the development of high-value products should begin with the establishment of appropriate harvesting stages, drying conditions, and raw-material quality grades (Yuan et al., 2015). Differences in total phenolic content, total flavonoid content, and antioxidant capacity among chrysanthemum varieties and maturity stages further demonstrate that raw-material selection is an important basis for product differentiation. From the broader perspective of functional food development, research on chrysanthemum hybrids of European origin has shown that volatile compounds, phenolic acids, flavonoids, and related enzyme-inhibitory activities in inflorescences can be jointly evaluated to determine their potential as functional beverages and dietary ingredients (Miler et al., 2026). For the Hangbaiju industry, a more practical future strategy would be to establish a tiered product system comprising premium Taiju → conventional flower tea → blended instant beverages → extraction-grade raw materials → functional products, thereby ensuring that flowers of different quality grades can be directed toward appropriate market outlets.

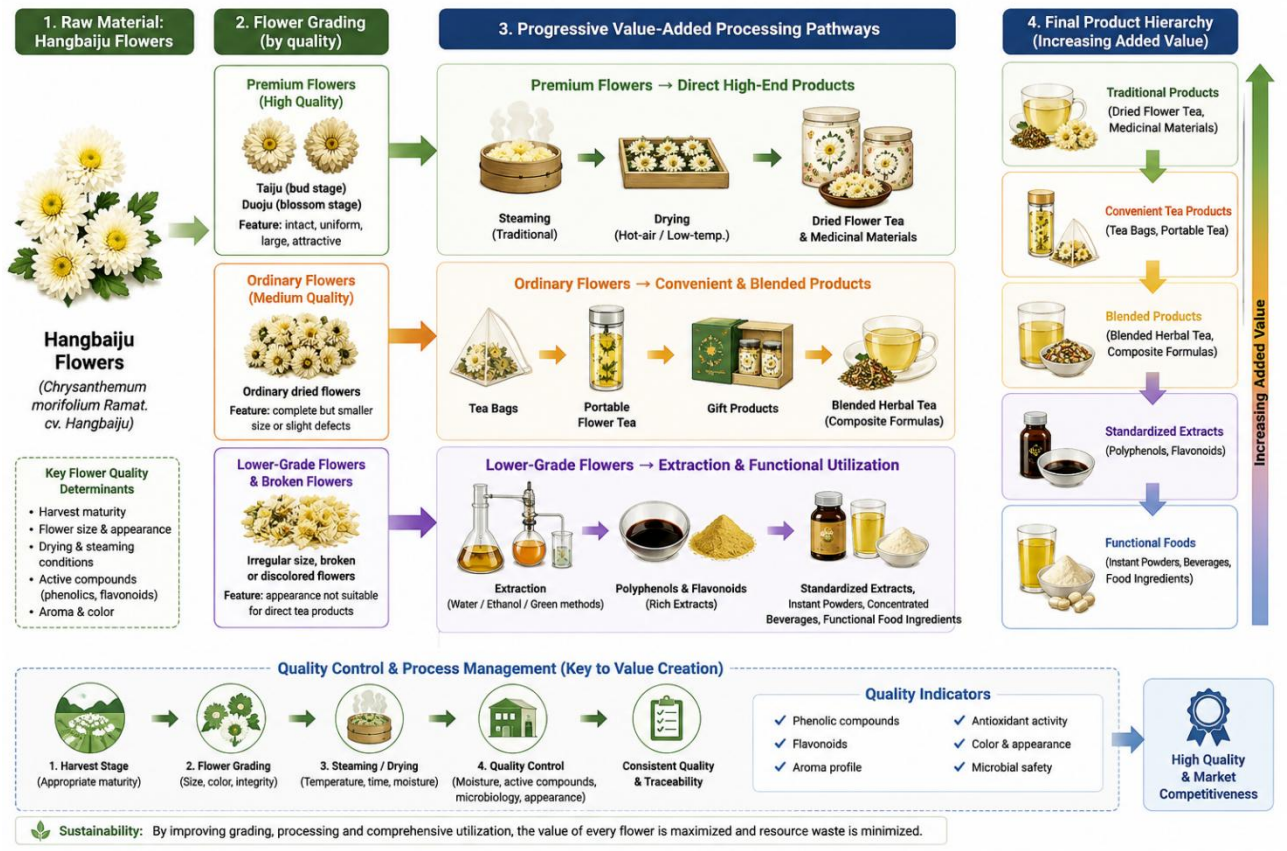



Figure 2 Graded processing and cascade valorization pathways of Hangbaiju flower products

## 4 High-Value Utilization Potential of Hangbaiju Leaves

### 4.1 Nutritional and bioactive compounds in leaves

Compared with the traditional utilization pattern in which inflorescences have long served as the primary research focus and commercial product, the systematic development of Hangbaiju leaves began relatively late. However, these leaves should not be regarded merely as agricultural residues with limited chemical value; rather, they represent a potentially valuable source of phytochemicals. Hangbaiju leaves contain considerable amounts of polyphenols and flavonoids. Following steam explosion (SE) pretreatment, total phenolic and total flavonoid contents are markedly increased compared with those in untreated materials. SE also promotes the release of phytochemicals and improves antioxidant activity and post-digestion bioaccessibility (Yuan et al., 2025). These findings indicate that Hangbaiju leaves contain not only readily extractable bioactive compounds but also a proportion of bound or poorly extractable constituents that can be more effectively released through appropriate pretreatment.

Cross-organ studies of other medicinal chrysanthemum varieties provide additional evidence supporting the utilization of leaves. In Chuju chrysanthemum, the total flavonoid content of leaves reached 51.95 mg/g DW, lower than the 73.99 mg/g DW detected in flowers but substantially higher than the 32.72 mg/g DW found in stems. The leaves also contained representative compounds such as chlorogenic acid, rutin, luteolin-7-O-glucoside, and dicaffeoylquinic acids, with some flavonoids accumulating at relatively high levels in leaf tissues (Miao et al., 2026). Comparisons between flowers and leaves of different *C. morifolium* cultivars have further shown that phenolic compounds such as 3,5-dicaffeoylquinic acid and 4,5-dicaffeoylquinic acid occur at relatively high levels in the leaves of many materials. Leaves from some cultivars also exhibit strong DPPH and ABTS radical-scavenging activities (Doan et al., 2024).

### 4.2 Potential for food and functional product development

The most practical utilization pathway for Hangbaiju leaves is not to replicate conventional flower tea products, but rather to develop them as functional intermediate ingredients for plant extracts, formulated food ingredients, and plant-based beverages. Leaves share some phenolic and flavonoid constituents with flowers, but their status as a by-product of flower harvesting makes centralized extraction and standardized processing more suitable approaches for value addition. Studies using different extraction systems for chrysanthemum materials have demonstrated that aqueous and alcoholic extraction can generate distinctly different chemical profiles. Aqueous extracts tend to be enriched in polysaccharides and other water-soluble constituents, whereas alcoholic extracts generally contain higher levels of flavonoids, polyphenols, and certain phenolic acids and often exhibit stronger antioxidant activity (Chen et al., 2021b). For Hangbaiju leaves, extraction methods could therefore be selected according to the intended end product. Mild aqueous extraction or combined water-based extraction technologies may be prioritized for beverages and water-soluble ingredients, whereas ethanol extraction, ultrasound-assisted extraction, and other green extraction approaches could be explored for natural antioxidants or phenolic-rich functional ingredients.

Another advantage of developing Hangbaiju leaves for functional food applications is that their major phenolic constituents share a chemical basis with compounds for which health-related activities have already been reported in chrysanthemum materials. Studies of different edible chrysanthemums have identified relatively clear spectrum-effect relationships between phenolic compounds such as luteolin, acacetin-7-O-glucoside, and apigenin-7-O-glucoside and anti-inflammatory activity (Huang et al., 2023). Nevertheless, evidence specifically concerning Hangbaiju leaves remains primarily focused on chemical composition, antioxidant activity, and bioaccessibility after simulated digestion. Direct evidence regarding food safety, effects in humans, appropriate intake levels, and mature commercial products remains limited. At present, Hangbaiju leaves are therefore more appropriately positioned as a potential source of functional ingredients rather than as an established functional food. Future incorporation into large-scale food production will require quality-control specifications covering raw-material standards, contaminant limits, stability of bioactive compounds, and compatibility with different processing systems.

### 4.3 Other high-value utilization pathways

Beyond food and nutritional ingredients, Hangbaiju leaves also have potential for development as natural antioxidant sources and functional ingredients for personal-care products. The close association between phenolic content and antioxidant capacity suggests that standardized leaf extracts could potentially serve as plant-derived antioxidant ingredients for food preservation, combined natural antioxidant systems, or other products requiring improved oxidative stability. Extracts from different chrysanthemum varieties have also shown considerable variation in tyrosinase-inhibitory and skin-whitening-related activities, with certain flavonoids and phenolic acids considered potential active constituents (Wang et al., 2024). Therefore, in addition to food applications, phenolic resources derived from chrysanthemum leaves may have potential in cosmetic and personal-care formulations. At present, however, these applications should be regarded as medium- to long-term development opportunities. Quantitative compositional analysis, activity validation, and safety assessment specifically using Hangbaiju leaves will be required before broader industrial applications can be justified.

Another promising direction is the utilization of leaves and their extracts as functional ingredients for non-human food applications or as biological resources. Studies of chrysanthemum stem and leaf by-products have demonstrated that these non-floral tissues contain a variety of bioactive phytochemicals and may have potential applications in animal health and other functional products (Li et al., 2026). Research comparing different extraction methods for other chrysanthemum varieties has further shown that fractions rich in polysaccharides, proteins, phenolics, and other constituents can exhibit different functional characteristics, providing a methodological basis for the fractionated extraction and utilization of chrysanthemum by-products (Gao et al., 2024). From the perspective of the Hangbaiju industry, the most practical sequence for high-value leaf utilization should therefore prioritize polyphenol- and flavonoid-rich extracts and natural antioxidant ingredients, for which the current evidence is relatively strong, followed by formulated food ingredients and plant-based beverages, and subsequently by the exploration of personal-care actives, animal functional ingredients, and other specialized products.

## 5 High-Value Utilization Potential of Hangbaiju Stems

### 5.1 Biomass characteristics of stems

Hangbaiju stems are one of the major non-floral biomass fractions remaining after inflorescence harvesting, and their resource value is first reflected in the relatively large amount generated during production. Non-floral tissues such as chrysanthemum stems and leaves can account for a substantial proportion of total plant biomass, indicating that considerable amounts of potentially usable plant residues remain after flower harvesting. Unlike flowers, which can directly enter the tea, medicinal, and food markets, stems lack well-established grading and commercialization channels in traditional production systems and are therefore commonly treated as low-value agricultural by-products. The significance of stem valorization lies not only in reducing waste but also in redefining this concentrated and relatively stable postharvest biomass as a secondary raw material for downstream processing.

Hangbaiju stems have potential for both phytochemical recovery and lignocellulosic utilization. Studies of Hangbaiju stems have demonstrated the presence of potentially valuable phenolic and flavonoid compounds. Following steam explosion (SE) pretreatment, total phenolic and total flavonoid contents increased by up to 1.64-fold and 8.71-fold, respectively, accompanied by enhanced release of compounds such as 3,5-CQA and linarin. These findings indicate that Hangbaiju stems are not merely structural residues but also possess value as a source of recoverable bioactive compounds (Zhu et al., 2024). Materials research on *Chrysanthemum morifolium* stem fibers has further shown that they possess relatively high crystallinity, low density, and favorable mechanical and thermal stability, making them potential candidates for the development of natural fiber-reinforced materials (Dalmiş et al., 2020). The resource characteristics of Hangbaiju stems therefore differ from those of leaves: stems are more appropriately regarded as a multifunctional biomass resource linking phytochemical extraction with material utilization.

### 5.2 Agricultural recycling

Agricultural recycling represents the most fundamental and technically accessible utilization pathway for Hangbaiju stems. Postharvest residues can be composted together with fallen leaves and other organic materials and subsequently returned to chrysanthemum cultivation, thereby contributing to soil organic matter and nutrient supply while reducing resource losses associated with direct disposal. Low-grade stems and mixed residues that are unsuitable for extraction or material processing can be returned to agricultural systems after composting, decomposition, and appropriate formulation. However, this pathway is more appropriately positioned as the final stage of cascade utilization rather than the primary destination for all stem biomass, because direct incorporation into soil prematurely eliminates opportunities to recover the chemical and structural value still contained in the stems.

A further value-added agricultural pathway is to upgrade chrysanthemum residues from conventional compost into functional biofertilizers. Partial substitution of chemical fertilizers with chrysanthemum-derived residues in combination with beneficial microorganisms can improve soil enzyme activities, rhizosphere microbial communities,

and plant growth under continuous cultivation conditions. These findings suggest that chrysanthemum residual biomass can be transformed from a simple source of organic matter into an agricultural input with potential functions in rhizosphere and soil microbial regulation (Wang et al., 2026) (Figure 3). For Hangbaiju, agricultural recycling should therefore be positioned primarily as the final destination for residues remaining after the recovery of high-value compounds and material fractions. Such applications should also be accompanied by evaluation of compost maturity, salinity, nutrient balance, and long-term effects on soil properties.

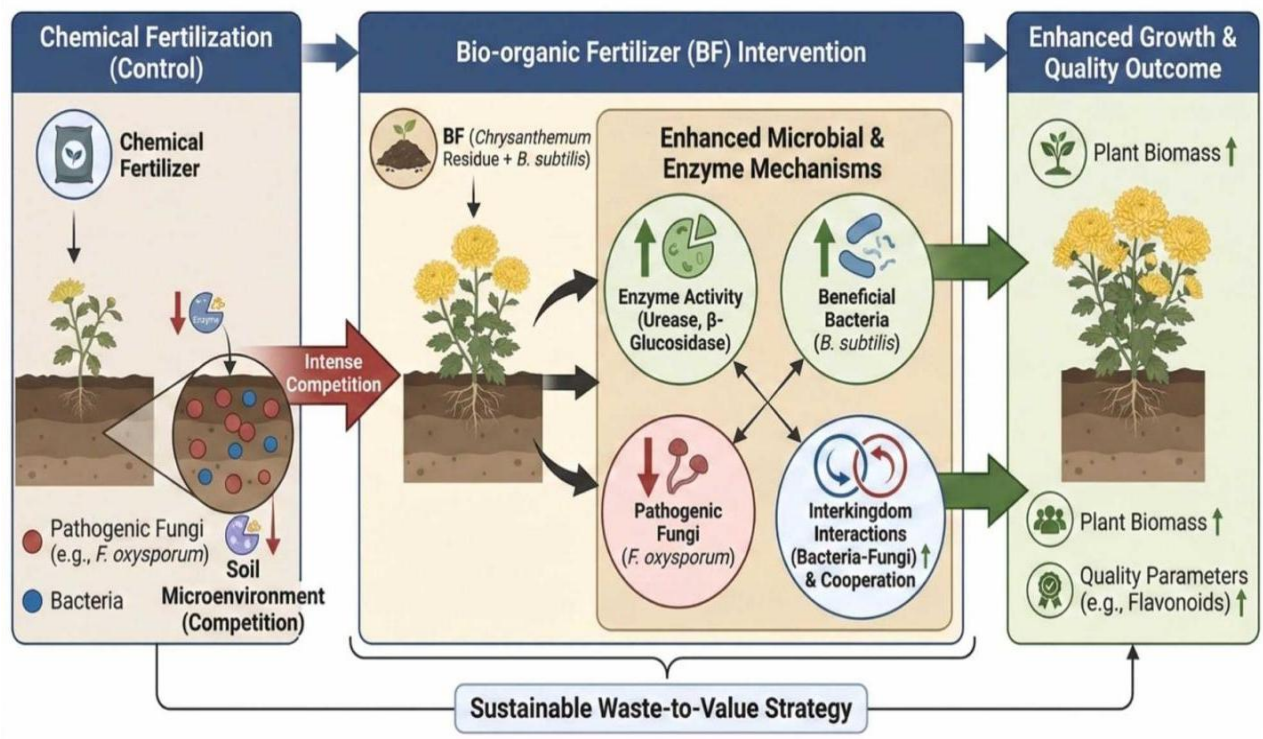



Figure 3 Agricultural recycling of chrysanthemum residues and their rhizosphere regulatory effects

### 5.3 Biomass resources and high-value applications

Compared with direct incorporation into agricultural soils, the conversion of stems into biomaterials and other industrial products offers greater potential for value addition. Studies of other medicinal chrysanthemum varieties have already demonstrated such possibilities. For example, cellulose extracted from Fubaiju stems has been used to produce biodegradable films, and the resulting material properties indicate that the lignocellulosic framework of chrysanthemum stems can serve as a potential feedstock for bio-based materials (Yao et al., 2026). Fibers derived from *Chrysanthemum indicum* stems have also been shown to possess favorable mechanical properties and can be carbonized and activated to produce porous adsorbent materials (Zhao et al., 2021). These findings demonstrate that chrysanthemum stems need not be restricted to combustion or composting; their cellulose, lignocellulosic components, and carbon skeleton can support the development of higher-value products, including composite materials, biodegradable materials, and environmentally functional materials.

In addition to material applications, stems may serve as a source of functional raw materials within mixed by-product utilization systems. Solid-state fermentation of chrysanthemum waste has been reported to improve crude protein content, total flavonoid levels, and amino acid composition, indicating potential for its development as an alternative feed ingredient (Cui et al., 2023). After the extraction of bioactive compounds and utilization of fibrous components, the remaining fractions of Hangbaiju stems may therefore continue to generate value through fermentation and other bioconversion processes. Rather than relying on a single utilization pathway, Hangbaiju stems are better suited to a sequential valorization strategy: first, recover extractable phenolic compounds and flavonoids; second, utilize cellulose and lignocellulosic fractions for material production; and finally, convert the remaining low-value residues through fermentation, fertilizer production, or recycling into agricultural systems.

## 6 Case Study: Tongxiang

### 6.1 Cascade utilization of flowers, leaves, and stems

Whole-plant valorization of Hangbaiju does not mean that flowers, leaves, and stems should be processed in the same way. Instead, a prioritized cascade utilization system should be established according to the commercial maturity, chemical composition, and processing suitability of each organ. Hangbaiju inflorescences have long been used for herbal tea, traditional Chinese medicine, and medicinal and edible products, while their flavonoids, phenolic acids, and other bioactive compounds provide a basis for the further development of standardized extracts and functional foods. Under a whole-plant utilization model, high-quality intact flowers should first enter direct commercial chains as dried flower tea and medicinal materials. Lower-grade flowers or those that fail to meet appearance requirements but retain utilization value can be directed toward extraction and functional food processing. This creates an internal flower-based cascade of "direct commercialization of premium flowers → further processing of lower-grade flowers → reutilization of flower-processing residues," thereby maximizing the value obtained from each unit of floral biomass (Kumar et al., 2025).

In Tongxiang, Zhejiang Province, local Hangbaiju processing enterprises have increasingly adopted steam fixation, hot-air drying, and continuous drying equipment. Some enterprises have independently developed automated steam fixation systems and large tunnel-type continuous drying lines. Publicly available information indicates that these technologies can reduce energy and labor requirements by more than 20%. Tongxiang has also developed contract production models involving enterprises, cooperatives, and farmers, enabling high-quality Hangbaiju to be produced and purchased according to enterprise quality specifications. For small- and medium-sized enterprises, these practices demonstrate that flower valorization does not necessarily need to begin with costly advanced processing. Instead, it can start with harvest grading, standardized steaming, stable drying, and contract-based sales, with premium, ordinary, and lower-grade flowers directed toward different markets to increase the overall value of the same harvest.

Leaf utilization represents an additional step that could be incorporated into this industrial system. Yuan et al. (2025) found that after steam explosion treatment of chrysanthemum leaves, total phenolic and total flavonoid contents reached 26.32 mg CAE/g and 30.72 mg RE/g, respectively, representing increases of more than threefold compared with the untreated material. The treatment also enhanced the release and bioaccessibility of several phenolic compounds. These results demonstrate that leaves remaining after flower harvesting do not necessarily need to be discarded or directly composted. Instead, they can first be collected, cleaned, and dried at the production site and subsequently transferred to enterprises equipped for centralized extraction and processing.

The practical utilization pathway for stems is even more clearly defined. In addition to their potential for bioactive compound recovery and fiber-based material development, Tongxiang has explored an agricultural recycling model linking "Hangbaiju stems → Hu sheep → organic fertilizer → Hangbaiju and other crops." In this system, Hangbaiju stems are integrated with the local Hu sheep industry, while manure and organic fertilizers are subsequently returned to farmland. Stems suitable for industrial processing can be directed toward phenolic extraction or fiber utilization, whereas stems generated far from processing facilities, for which transportation costs are relatively high, can preferentially enter livestock feeding, composting, or other local agricultural recycling pathways. This tiered strategy—directing suitable stems toward extraction and material applications while returning ordinary residues to agricultural cycles—is more compatible with actual production conditions than requiring all stems to undergo high-end material processing. Evidence from related chrysanthemum stem resources further supports their material potential: cellulose content can reach 58.2 ± 2.3%, and the resulting material can be used to prepare biodegradable films with a tensile strength of 23.7 ± 1.8 MPa and a degradation rate of 95 ± 3% after 12 weeks (Yao et al., 2026).

### 6.2 Transition from single flower products to whole-plant utilization: evidence from production practices in Tongxiang

In traditional Hangbaiju production, growers remain primarily concerned with whether their flowers can obtain a favorable market price. Labor requirements are concentrated during the harvesting season, and after intact,

high-grade flowers enter the tea and medicinal markets, stems and leaves generally generate little or no independent income. For small enterprises, whole-plant utilization is difficult to implement if it merely adds new costs for collection, sorting, and transportation without providing stable purchasing and utilization channels. In recent years, the development of Good Agricultural Practice (GAP) production bases and enterprise-led contract systems in Tongxiang has provided a practical approach to addressing this problem. The region has explored a contract farming model involving "leading enterprises + cooperatives + farmers + government," while standardized seedlings, unified agricultural inputs, and standardized technical protocols have been introduced to improve raw-material consistency. In 2024, some GAP production bases supplied virus-free seedlings, botanical pesticides, and microbial agents while providing guidance on standardized cultivation. These measures reportedly increased yield per mu by more than 10% and raised the selling price per kilogram by more than 15% compared with prevailing market levels.

For whole-plant utilization to become operational, a division-of-labor model can be adopted in which farmers are not required to perform all processing, while enterprises are not required to undertake all cultivation activities. Family farms can primarily be responsible for cultivation, standardized harvesting, and preliminary separation of flowers, leaves, and stems. Cooperatives or regional service centers can undertake centralized collection, drying, storage, and transportation. Leading enterprises with appropriate equipment and marketing capacity can then conduct extraction, functional food production, material processing, or fertilizer production. Under this model, premium flowers remain the principal source of cash income for growers, while leaves and stems become additional sources of value.

Whole-plant utilization does not mean that a single mu of Hangbaiju must simultaneously produce a dozen different products. Rather, its practical objective is to create several additional market outlets for biomass fractions that previously generated little or no income. Premium-grade flowers can continue to be sold as tea and medicinal materials, while lower-grade flowers can be supplied to processing enterprises. Leaves can be collected after flower harvesting and sold to extraction facilities, and stems can be locally used for Hu sheep production, organic fertilizer production, or centralized crushing and processing. Agricultural enterprises with more advanced processing capacity can further extend these pathways toward polyphenol extraction, functional ingredients, and bio-based materials.

### 6.3 Integration of cultivation, processing, and by-product utilization: a practical industrial pathway

Tongxiang has established authentic Hangbaiju medicinal production gardens, experimental and demonstration bases, and GAP demonstration bases, together with multi-stakeholder cooperation mechanisms involving villages, enterprises, and testing institutions. GAP production bases implement unified planning, standardized seedlings, coordinated fertilizer and pesticide management, and standardized technical protocols, while also establishing traceability systems. These existing practices already provide a foundation for connecting quality control at the cultivation stage with specific processing and utilization pathways. For whole-plant utilization, the next practical step is therefore to incorporate classification and collection standards for leaf and stem by-products into existing GAP and contract farming systems.

From the perspective of small enterprises, the operational process can be simplified as follows: cultivation is managed according to standardized technical requirements; flowers are harvested in batches during the flowering period according to enterprise orders; commercial-grade flowers, lower-grade flowers, and non-floral biomass are preliminarily separated during harvesting; fresh flowers are rapidly transferred to steaming and drying; leaves are promptly spread for cooling or dried at relatively low temperatures; and stems are collected, crushed, or baled after flower harvesting. Leaves and some lower-grade flowers can be centrally collected by cooperatives and transported to extraction enterprises, while stems can be directed toward feed, organic fertilizer, or advanced processing according to transportation distance, processing costs, and market prices (Figure 4).

The existing "Hangbaiju stems → Hu sheep → organic fertilizer → Hangbaiju and other crops" model in Tongxiang demonstrates that circular utilization does not necessarily require complex processing equipment. For farms located near Hu sheep operations or organic fertilizer enterprises, stems can be utilized locally, thereby

reducing long-distance transportation costs. Larger Hangbaiju processing enterprises, in contrast, can recover bioactive compounds from leaves and stems and convert them into higher-value products. Therefore, there is no single model for commercially feasible whole-plant utilization of Hangbaiju. Instead, utilization pathways should be adapted to the scale and capabilities of different operators through a coordinated division of labor: "preliminary sorting by family farms → centralized handling by cooperatives → advanced processing by enterprises → agricultural recycling of residual biomass."

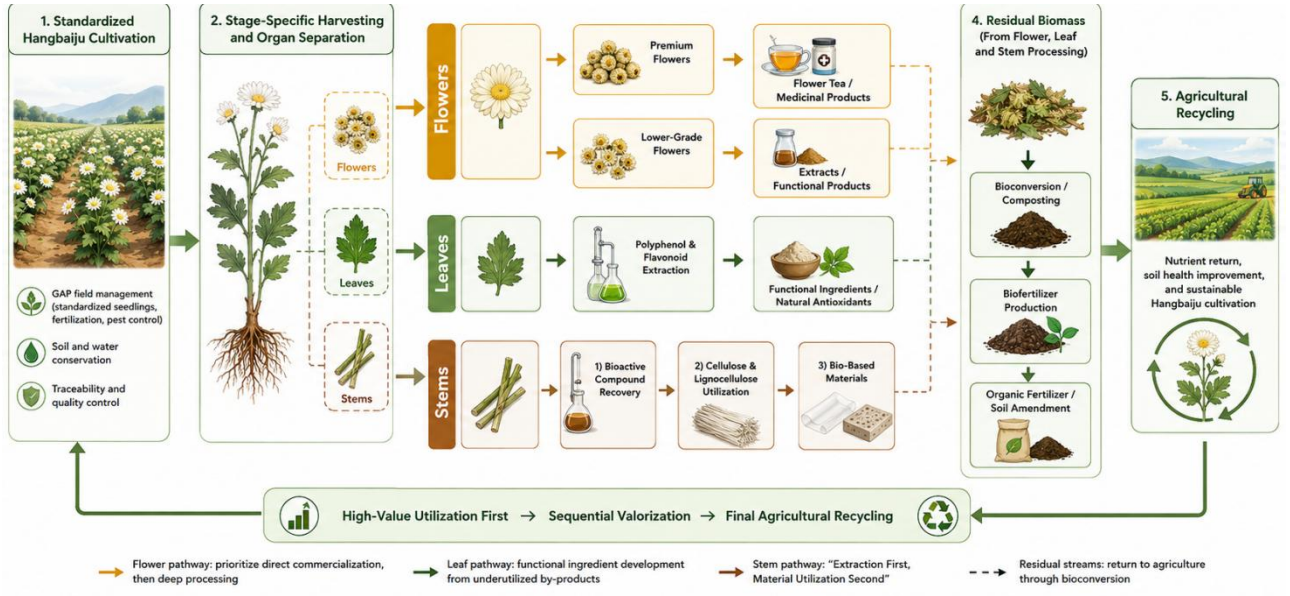



Figure 4 Whole-plant cascade valorization and circular utilization pathway of Hangbaiju chrysanthemum

## 7 Development Pathways and Future Prospects

### 7.1 Strengthening research and development of non-floral tissues

A major priority for future research is to systematically characterize the chemical profiles, biological activities, processing properties, safety, and application boundaries of Hangbaiju leaves and stems. Chrysanthemum research has traditionally focused on inflorescences, whereas stems and leaves, despite accounting for approximately 70%-80% of total plant biomass, are often utilized in low-value applications because of insufficient research and poorly defined end uses. However, stems and leaves are not chemically "poor" tissues. They contain flavonoids, phenolic acids, and other potentially bioactive compounds and have demonstrated biological activities related to antioxidant, anti-inflammatory, and stress-alleviating effects. For example, stem and leaf extracts have been reported to downregulate IL-1β, IL-8, and MMP9 while increasing superoxide dismutase activity in a zebrafish model of inflammatory bowel disease. Under chronic heat stress in fish, these extracts have also been associated with improved intestinal homeostasis, reduced cortisol levels, and alleviation of oxidative stress and inflammation (Li et al., 2022; 2026). Both leaves and stems contain chlorogenic acid, rutin, luteolin-7-O-glucoside, and 3,5-O-dicaffeoylquinic acid. Total flavonoid content in leaves can reach approximately 30%~50% of that in flowers, while certain individual flavonoids may even accumulate at higher levels in leaves than in floral tissues (Miao et al., 2026). Future studies should therefore address organ-specific chemical profiling, comparisons among geographical origins and cultivation conditions, storage stability, toxicological and intake safety, digestive bioaccessibility, and *in vivo* efficacy. Such evidence is essential for transforming leaves and stems from resources with theoretical "potential" into well-defined and commercially viable raw materials.

### 7.2 Development of diversified high-value products

A more practical product development strategy is to establish a hierarchical system in which high-value flower products remain the core, functional utilization of leaves provides additional value, and circular or material-based utilization of stems serves as a complementary pathway. Flowers should continue to dominate the production of herbal teas, traditional Chinese medicinal materials, functional foods, and standardized extracts because *Chrysanthemum morifolium* has a history of medicinal and dietary use extending over 3 000 years, while its

flavonoids, phenolic acids, volatile oils, and terpenoids have been extensively associated with antioxidant, anti-inflammatory, and chronic disease-related biological activities (Liu et al., 2024).

Leaves are more suitable for development into polyphenol- and flavonoid-rich extracts, functional food ingredients, plant-based beverage ingredients, and natural antioxidant sources. Although the overall antioxidant capacity of leaves is generally lower than that of flowers, leaves are available in relatively large quantities as a production by-product, and some cultivars retain high phenolic contents and considerable antioxidant activity. These characteristics support their potential as a stable source of functional raw materials (Doan et al., 2024). Broader research on agricultural by-products also supports this differentiated utilization strategy. Residues rich in polyphenols, dietary fiber, proteins, and other bioactive constituents can be converted through green extraction, fermentation, encapsulation, and formulation technologies into functional foods, nutritional supplements, clean-label additives, and even cosmetic ingredients (Alexandri et al., 2023). Stems, by contrast, are better suited for cellulose recovery, bio-based materials, adsorbent materials, organic fertilizer feedstocks, and other biomass applications. From the broader perspective of lignocellulosic biomass utilization, agricultural residues can be processed through integrated biorefinery systems to produce biofuels, platform chemicals, resins, bioplastics, and composite materials (Mujtaba et al., 2023).

### 7.3 Establishing a standardized whole-plant utilization system

The key to transforming Hangbaiju leaves and stems from agricultural by-products into reliable industrial raw materials is the establishment of a standardized whole-plant utilization system. Research on biomass and industrial crops has repeatedly demonstrated that differences in physical properties, mechanical characteristics, and chemical composition among plant organs can directly affect processing difficulty, conversion efficiency, and product yield. Consequently, heterogeneous biomass should first be graded, separated, and appropriately pretreated rather than processed as a single mixed feedstock (Nguyen et al., 2020). A stable supply of biomass depends not only on harvesting but also on appropriate storage, preservation, preconditioning, and near-source pretreatment, because seasonal harvesting, storage and transportation losses, and microbial degradation can substantially reduce raw-material consistency and increase processing costs.

For Hangbaiju, standardized procedures should therefore be established for flowers, leaves, and stems, covering appropriate harvesting periods, organ separation, drying and storage conditions, stability control, pretreatment before extraction or fiber utilization, quality markers, and end-use grading. Research on Chuju chrysanthemum provides a useful starting point. Chlorogenic acid, rutin, luteolin-7-O-glucoside, and 3,5-O-dicaffeoylquinic acid can be used as quantitative indicators for preliminary comparisons of flavonoid-related quality among different plant organs. However, current quality evaluation remains limited to a relatively small number of marker compounds, and more comprehensive characterization of unidentified constituents and their degradation kinetics is still required. As whole-plant utilization pathways expand, the absence of harmonized standards, supportive policies, and quality-management systems may compromise reproducibility, technological scale-up, and sustainability assessment (Enarevba and Haapala, 2024). Future standardization should therefore move beyond end-product testing toward whole-process quality management covering cultivation, harvesting, separation, storage and transportation, processing, and quality control.

### 7.4 Building a circular Hangbaiju industry

The longer-term goal is to develop Hangbaiju into a circular industry closely integrated with green agriculture, circular farming, and advanced agricultural processing. A fundamental principle of the circular economy is to regard by-product streams as renewable resource flows from the outset. This approach has demonstrated both environmental and industrial value in sugar crops, food waste, and residues from medicinal and edible plants (Ungureanu et al., 2022; Pal et al., 2024). For Hangbaiju, a feasible pathway is to integrate cultivation with downstream processing: flowers can enter tea, medicinal, and functional product chains; leaves can be directed toward extraction and formulated ingredient systems; stems can enter fiber, bio-based material, or other lignocellulosic utilization pathways; and the remaining low-value residues can be returned to agricultural production

through composting, biofertilizer production, substrate development, or biostimulant production, thereby promoting nutrient cycling and potentially reducing dependence on chemical fertilizers (Puglia et al., 2021).

Research on medicinal and aromatic plants and other agricultural residues has shown that biomass generated during harvesting, drying, and processing can be comprehensively utilized through combined valorization strategies and converted into mushroom cultivation substrates, compost, functional additives, adsorbent materials, and other bio-based products (Marcelino et al., 2023; Zotti et al., 2025). Crop production research increasingly emphasizes that raw-material quality is already being shaped during irrigation, nutrient management, environmental stress management, and biomass-flow planning. Therefore, whole-plant valorization of Hangbaiju should integrate cultivation practices, raw-material quality, and intended end uses within a unified framework (García-Parra and Ramírez, 2026).

Future development of the Hangbaiju industry should consequently shift toward an integrated model combining whole-plant fractionation, green extraction, advanced processing, and agricultural recycling. Such a system would maximize resource utilization, minimize residual waste, and progressively transform the traditional flower-tea-centered Hangbaiju industry into a more comprehensive example of the circular bioeconomy.

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The authors conducted this study, including literature review, data analysis, and the drafting and revision of the manuscript. The authors have read and approved the final version of the manuscript.

## Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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