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From Fresh Fruit to Value-Added Products: Production, Processing, and Comprehensive Utilization of Chinese Bayberry

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Abstract Chinese bayberry (*Myrica rubra* Sieb. et Zucc.) is an important specialty fruit crop in southern China, with considerable value for fresh consumption, processing, and the development of functional components. However, the overall economic benefits of the industry are constrained by its concentrated ripening period, soft and damage-prone fruit, short postharvest shelf life, and insufficient utilization of processing by-products. This review summarizes recent advances in Chinese bayberry germplasm resources and fresh fruit quality improvement, postharvest preservation and graded utilization, processed product development, and comprehensive utilization of by-products, and further discusses pathways for industrial upgrading based on practices in major production areas of Zhejiang Province. The Chinese bayberry industry should shift from a yield-oriented production model toward marketable quality improvement. The proportion of marketable fruit and its distribution capacity can be enhanced through appropriate cultivar selection, standardized cultivation, timely harvesting, precooling and grading, protective packaging, and an integrated cold chain. According to fruit quality, a tiered utilization system should be established for premium fresh-market sales, conventional fresh-market sales, and processing, while promoting the development of juice, dried fruit, wine, fruit powder, and high-value-added products derived from anthocyanins, polyphenols, and other valuable components. Meanwhile, processing by-products such as pomace and pits can be further utilized for dietary fiber, kernel oil, and agricultural recycling. In the future, stronger collaboration among growers, cooperatives, processing enterprises, and research and extension institutions is needed to establish an integrated industrial chain encompassing "high-quality production-postharvest preservation-graded utilization-value-added processing-by-product utilization," thereby promoting the standardization, diversification, value addition, and circular utilization of resources in the Chinese bayberry industry.

Keywords Chinese bayberry (*Myrica rubra* Sieb. et Zucc.); Fresh fruit quality; Postharvest preservation; Graded utilization; Value-added processing; Comprehensive utilization of by-products

1 Introduction

Chinese bayberry (*Myrica rubra* Sieb. et Zucc.) has a long history of cultivation and utilization and has established a strong industrial foundation in Zhejiang, Jiangsu, Fujian, Guangdong, Hunan, and other regions of China. Chinese bayberry fruit is characterized by its attractive color and pleasant sweet–sour flavor. In addition to its high value for fresh consumption, the fruit is rich in anthocyanins, flavonoids, phenolic acids, vitamins, and other nutritional and bioactive components, giving it considerable potential for fresh consumption, food processing, and functional food development (Sun et al., 2013). Zhejiang is one of the leading regions in China in terms of Chinese bayberry production and industrial development. Through long-term development, Yuyao, Cixi, Xianju, Linhai, Wenzhou, and other areas have established distinctive local production bases. Major cultivars such as 'Dongkui' and 'Biqi' are not only important local specialty agricultural products but have also become important sources of income for farmers, family farms, and agricultural enterprises in some mountainous areas.

The harvesting and marketing period of Chinese bayberry is highly concentrated. Its soft and juicy fruit is susceptible to water loss, softening, mechanical damage, and microbial decay after harvest, resulting in a very short shelf life under ambient conditions. Even under low-temperature storage, the marketing period remains considerably limited (Saeed et al., 2024). These characteristics indicate that sustainable value enhancement of the Chinese bayberry industry cannot be achieved simply by expanding cultivation area and increasing fruit yield. When large quantities of fruit ripen within a short period, insufficient capacity for harvesting, grading, precooling, packaging, transportation, and marketing can result in the mixed sale of premium- and standard-quality fruit, price

declines caused by concentrated market supply, and substantial fresh fruit losses. Therefore, improving marketable fruit quality at the production stage, reducing postharvest losses, and establishing graded utilization pathways that direct fruits of different quality levels toward premium fresh-market sales, conventional fresh-market sales, and processing represent important strategies for addressing the challenges associated with the short harvesting season, high perishability, and concentrated supply of Chinese bayberry.

Against this background, this review focuses on the extension of the Chinese bayberry value chain from fresh fruit production to high-value-added utilization. Recent research progress in Chinese bayberry production and fresh fruit quality improvement, postharvest handling and preservation, processed product development, and comprehensive utilization of processing by-products is systematically reviewed. Combined with production and industrial practices in major Chinese bayberry-producing areas of Zhejiang Province, feasible pathways for growers, family farms, cooperatives, and agricultural enterprises to participate in value-chain extension are further discussed. This review aims to provide practical references for increasing the proportion of marketable fruit, reducing postharvest losses, diversifying processed products, and improving the utilization efficiency of processing by-products in major Chinese bayberry-producing regions. It also provides guidance for primary producers and agricultural business entities in selecting appropriate development models according to their production scale, financial capacity, and market conditions.

2 Improvement of Fresh Fruit Quality in Chinese Bayberry

2.1 Major production regions and cultivars

Commercial cultivation of Chinese bayberry is mainly concentrated in provinces south of the Yangtze River, including Zhejiang, Jiangsu, Fujian, Guangdong, and Hunan. Differences in climate, soil conditions, altitude, and traditional cultivation practices among production regions have contributed to the development of abundant local cultivars and germplasm resources. Considerable variation exists among Chinese bayberry germplasm in fruit color, size, sugar–acid composition, and other quality traits, providing an important basis for the differentiated utilization of cultivars for fresh consumption, storage and transportation, and processing (Zhang et al., 2024b). At present, ‘Dongkui’ and ‘Biqi’ remain two of the most representative commercial cultivars. ‘Dongkui’ is characterized by its large fruit size and attractive appearance, giving it a competitive advantage in the premium fresh-fruit market. ‘Biqi’, with its relatively strong adaptability, long cultivation history, and wide distribution, has established a solid production base in Zhejiang and other regions.

In Zhejiang Province, Yuyao, Cixi, Xianju, Linhai, Wenzhou, and other areas have developed distinct regional advantages in Chinese bayberry production, with Ningbo, Taizhou, and Wenzhou having long been among the major production areas. The Chinese bayberry industry in Zhejiang is characterized not only by a strong cultivation base and abundant cultivar resources, but also by active research, technology extension, and brand development. A particularly valuable aspect of Zhejiang’s experience is that industrial development has not relied solely on expanding cultivation area. Instead, different production regions have gradually established a development model integrating “local cultivars + standardized production + regional branding,” facilitating the transformation of Chinese bayberry from a traditional mountainous fruit crop into a market-oriented specialty fruit with distinctive regional characteristics.

2.2 Key techniques for high-quality production

Although Chinese bayberry is relatively well adapted to hilly and mountainous environments, the production of high-quality marketable fruit still depends on appropriate soil, nutrient, water, and tree management. Soil management should emphasize the improvement of soil organic matter and adequate drainage, while fertilizer application should be adjusted according to tree age, fruit load, and tree vigor. Excessive nitrogen fertilization should be avoided because it may stimulate excessive vegetative growth and adversely affect fruit quality. For large-scale orchards, regular monitoring of soil conditions and agricultural inputs should also be strengthened. Zhang and Zhou (2020) found that the concentrations of some heavy metals in Chinese bayberry fruit samples from Zhejiang orchards were associated with their levels in orchard soils. This finding indicates that high-quality production should not focus solely on fruit size and sweetness; soil environmental quality and food safety should also be incorporated into long-term orchard management.

Tree training, pruning, and flower and fruit management directly affect fruit size, coloration, and uniformity of ripening. Excessively dense canopies reduce light penetration and may negatively affect fruit coloration and sugar accumulation. Yang et al. (2025a) showed that shading reduced the contents of sugars, vitamin C, flavonoids, and anthocyanins in Chinese bayberry fruit while increasing acidity, indicating that appropriate pruning and improved canopy ventilation and light penetration can directly contribute to fruit quality. This does not necessarily mean that growers need to adopt complicated supplemental lighting systems. Instead, priority should be given to basic orchard practices such as removing overcrowded branches, maintaining an open canopy structure, and controlling excessively vigorous shoots. Orchards with better production facilities may further explore rain shelters, insect-proof systems, and supplemental lighting, but these technologies should be selected according to cultivar characteristics and cost–benefit considerations rather than adopted simply for the sake of technological sophistication.

Pest and disease management and harvest timing are also important determinants of the proportion of marketable fruit. Insect- and rain-proof nets can substantially reduce fruit damage during the ripening period while improving fruit diameter, individual fruit weight, edible portion, and sugar–acid ratio (Yu et al., 2021). For small-scale growers and family farms, the most practical value of such technologies lies in reducing insect-damaged, rain-damaged, and decayed fruit and thereby increasing the proportion of fruit suitable for fresh-market sales. Harvest timing should also vary according to the intended market. Chinese bayberries intended for same-day local sales can be harvested at a relatively advanced stage of maturity to ensure desirable flavor, whereas fruit intended for long-distance transportation requires a balance between maturity and transport tolerance. Selective harvesting in several rounds is therefore preferable to harvesting overripe and optimally ripe fruit together. The objective of high-quality production is not simply to increase total yield, but to maximize the proportion of intact, high-quality, and marketable fruit.

2.3 Transition from a high-yield orientation to a marketable-quality orientation

Chinese bayberry cultivation has traditionally placed considerable emphasis on yield per unit area or per tree. With changes in consumer demand, however, the price that fruit can achieve increasingly depends on its marketable quality. Marketable quality includes external characteristics such as fruit size, color, shape, and physical integrity, as well as internal attributes such as soluble sugar content, acidity, aroma, taste, and nutritional components. Future cultivar selection and orchard management should therefore move beyond the pursuit of simply “large fruit” and “high yield” and instead focus on traits required by specific target markets. Premium fresh fruit places greater emphasis on appearance, eating quality, and physical integrity, whereas fruit intended for processing may be evaluated more strongly according to sugar-acid balance, color, juice yield, and functional components.

Differences in internal quality among cultivars also indicate that Chinese bayberry should gradually shift from evaluating all cultivars according to a single standard toward an “evaluation according to intended use” approach. For growers and other agricultural business entities, not all fruit necessarily needs to enter the same fresh-fruit market. Fruit with attractive appearance, desirable color, and good flavor can be directed toward premium fresh-market sales. Fruit with good flavor but relatively limited storage and transportation tolerance may be more suitable for local or short-distance markets. Cultivars with favorable sugar–acid balance, color characteristics, or functional components for processing can instead be linked with juice, wine, and other processing enterprises.

Ultimately, consumers purchase Chinese bayberry based on their overall perception of quality. Taste and product quality are among the major factors considered by consumers when purchasing Chinese bayberry, while price, packaging, and purchasing convenience also influence consumption but cannot substitute for the intrinsic quality of the fruit (Huang et al., 2026). Future Chinese bayberry production should therefore shift from asking “how many kilograms can be produced?” toward “how many kilograms of high-quality marketable fruit can be produced?” For growers, this transition means that fertilization, pruning, fruit thinning, pest and disease management, and harvesting should all be managed around final marketable quality. For agricultural enterprises, cultivar allocation and raw-material production bases should be planned in advance according to the differing requirements of fresh-market sales, cold-chain distribution, and processing.

3 Postharvest Preservation and Graded Utilization of Fresh Chinese Bayberry

3.1 Causes of postharvest losses

Chinese bayberry fruit is soft and juicy and lacks the relatively tough protective outer layer found in fruits such as apples and citrus. In addition, the fruit remains physiologically active during the ripening period and is therefore highly susceptible to water loss, softening, and flavor deterioration after harvest. Chinese bayberries harvested at different maturity stages show marked differences in respiration, ethylene production, and changes in sugars and organic acids. Although fruit harvested at a more advanced stage of maturity generally has better eating quality, its storability is often lower (Zhang et al., 2005). Comparative studies of multiple Chinese bayberry cultivars have shown that postharvest ethylene changes are closely associated with fruit coloration, texture softening, and shelf life, while low-temperature storage can markedly slow these processes (Saeed et al., 2024).

After harvest, the use of large baskets, repeated transferring of fruit between containers, or excessive vibration during transportation can easily damage the fruit surface. Once fruit tissues are injured, juice leakage may occur and the damaged areas become more susceptible to microbial infection, resulting in localized soft rot that can subsequently spread to other fruit within the same package. Therefore, postharvest loss reduction should begin at the harvesting stage. Fruit should be picked and handled gently, and small containers should be used for field handling to minimize compression among fruit. Particular attention should be paid to harvest timing and handling efficiency after rainfall, when the fruit surface contains more moisture and fruit tissues may be more vulnerable. Damage occurring at this stage cannot simply be compensated for by subsequent preservation treatments.

In addition to visible decay, flavor deterioration is an important cause of the loss of marketability in Chinese bayberry. Gao et al. (2024) examined the storage quality of ‘Dongkui’ Chinese bayberry at different temperatures and found that volatile flavor profiles changed substantially with increasing storage duration, with off-flavors potentially developing before severe visible decay occurred (Figure 1). Consumers evaluate Chinese bayberry not only by appearance but also by its characteristic sweet-sour taste and fresh aroma. Therefore, fruit that still appears visually acceptable but has developed alcoholic, sour, or other undesirable odors may no longer be suitable for sale as a high-quality fresh product.

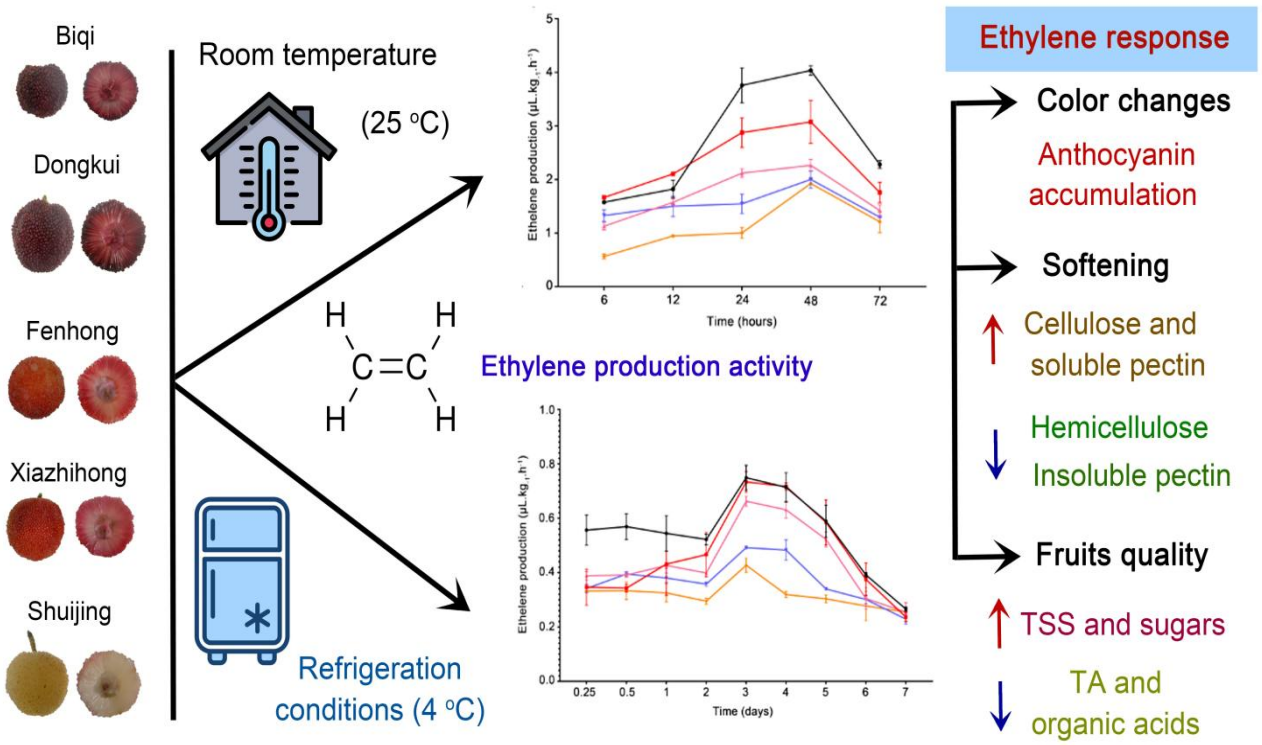


Figure 1 Changes in ethylene production and their effects on postharvest quality of Chinese bayberry fruit under different storage temperatures (Adapted from Gao et al., 2024)

3.2 Grading, packaging, and cold-chain preservation

The first step in postharvest management should be timely grading rather than storing and transporting fruit of different maturity and quality levels together. Practical grading can be based on readily observable characteristics such as fruit size, color, maturity, physical integrity, and the presence or absence of pest, disease, or mechanical damage. Small-scale growers do not necessarily need to adopt sophisticated and expensive equipment at the initial stage; greater product consistency can be achieved through standardized harvesting criteria and manual grading. Larger cooperatives and agricultural enterprises, however, may gradually introduce technologies such as color recognition and machine vision to assist sorting. Zheng et al. (2025) applied image-based technology to identify the maturity of Chinese bayberry and achieved a classification accuracy of more than 95%, indicating that future grading systems may gradually shift from reliance on manual experience toward greater standardization and digitalization.

After preliminary grading, field heat should be removed as quickly as possible. Chinese bayberry generally ripens during periods of relatively high ambient temperature. If harvested fruit remains for prolonged periods in orchards, along roadsides, or in conventional storage facilities, respiration, water loss, and microbial activity can accelerate. Where conditions permit, growers and enterprises should minimize the time between "harvesting-grading-precooling-cold storage." Packaging should primarily address two problems: mechanical compression and the maintenance of appropriate temperature and humidity. Although conventional bulk packaging is inexpensive and convenient for transportation, fruit in the lower layers is easily compressed. Premium fresh Chinese bayberries are therefore more suitable for small packages, layered packaging, or packaging with cushioning structures. Packaging materials with controlled-release antimicrobial properties have been shown to reduce firmness loss and inhibit microbial growth, indicating that packaging is evolving from simply "holding the fruit" into an important means of fruit protection and preservation (Chen et al., 2024).

For Chinese bayberries intended for distant markets, an integrated cold chain is more important than cold storage alone. Emerging packaging technologies have demonstrated further potential for extending shelf life. For example, Tong et al. (2026) developed a cushioning aerogel combined with 1-MCP treatment that extended the marketable shelf life of Chinese bayberry to 18 d at 4 ℃, whereas untreated fruit lost marketability considerably earlier. Although such technologies may currently be relatively costly for ordinary farms, they illustrate a straightforward principle for practical production: Chinese bayberry preservation should not focus solely on temperature control but should simultaneously address mechanical damage, water loss, ethylene activity, and microbial deterioration.

3.3 Graded utilization pathways for fresh fruit

After harvest, not all Chinese bayberries should be marketed in the same way. The first category is premium fresh-market fruit, consisting of fruit with intact shape, relatively uniform size, normal coloration, appropriate maturity, and no obvious pest, disease, or mechanical damage. These fruits have the greatest potential to achieve premium fresh-market prices and should therefore be given priority in the allocation of high-quality packaging and cold-chain resources. They can be supplied to premium fruit retailers, supermarkets, e-commerce platforms, gift markets, and high-end community delivery channels.

The second category is standard marketable fruit. These fruits are safe to eat and have acceptable internal quality but may not meet premium standards in terms of fruit size, color uniformity, or external appearance. They can be marketed through local wholesale markets, farmers' markets, conventional supermarkets, community group purchasing, and other short-distance sales channels. For this category, the priority is not necessarily the use of expensive long-term preservation technologies but rather rapid turnover, ideally following the principle of "harvest today, grade today, and sell as soon as possible." The third category is processing-grade fruit, including fruit with non-uniform size, lower external market grades, or limited suitability for long-distance transportation, provided that it is free from mold, decay, and food safety problems. Such fruit should be rapidly directed toward the production of juice, jam, wine, concentrated juice, and other processed products. Importantly, processing-grade fruit should not be regarded as spoiled fruit. Fruit that has already decayed, become moldy, or developed obvious disease symptoms cannot be made suitable for consumption simply through processing.

Different Chinese bayberry germplasm resources also vary inherently in storability and processing suitability. Liu et al. (2025) compared metabolites, decay resistance, and reprocessing characteristics among different Chinese bayberry resources and found clear differences in appearance, quality retention, and processing potential. For example, cultivars with better transportation tolerance may be prioritized for fresh-market distribution, whereas cultivars with intense coloration, distinctive flavor, or desirable processing characteristics may be more suitable for the processing industry. Freezing can also serve as an intermediate preservation strategy when processing materials need to be stored for a longer period. Appropriate pretreatments before freezing can reduce water loss and textural damage after freeze–thaw cycles, providing a potential approach for processing enterprises to establish reserves of frozen Chinese bayberry raw materials (Kong et al., 2026).

4 Processing and High-Value-Added Development of Chinese Bayberry

4.1 Traditional processed products: from fresh fruit preservation to processing-suitable cultivars and product quality

Because Chinese bayberry has a concentrated harvesting season and a relatively short postharvest storage life, juice, jam, preserves, and dried products have long been major processing approaches for extending its utilization period. Among these products, juice is most directly associated with fresh fruit as a raw material and is also relatively suitable for large-scale production. Tian et al. (2019) compared the juice-processing characteristics of 14 Chinese bayberry cultivars from Zhejiang and found significant differences in juice yield, sugar-acid ratio, polyphenol content, and sensory evaluation. Among them, ‘Zaose’ had the highest juice yield, reaching 84%, while ‘Lizhi’ juice had a relatively high total phenolic content. Considering overall processing quality and consumer sensory preference, ‘Wandao’ and ‘Biqi’ were more suitable as raw materials for juice production. Sensory preference for Chinese bayberry juice was positively correlated with total sugar content and the sugar-acid ratio, but negatively correlated with titratable acidity.

After processing, the ability of the product to retain its original color and flavor is also an important determinant of market value. Wang et al. (2015) compared the effects of high-pressure processing and conventional thermal treatment on the storage quality of Chinese bayberry juice. The retention rates of anthocyanins and ascorbic acid after high-pressure processing reached 96.5% and 89.2%, respectively, which were higher than those obtained after thermal treatment (85.1% and 58.3%, respectively). High-pressure processing also resulted in better color retention.

In addition to juice production, drying is an important method for extending the marketing period of Chinese bayberry. Liu et al. (2022) compared quality changes in ‘Biqi’ and ‘Dongkui’ Chinese bayberries subjected to hot-air drying and freeze-drying. Freeze-dried samples had significantly higher contents of total phenolics, total flavonoids, and total anthocyanins than hot-air-dried samples and exhibited stronger in vitro antioxidant activity and inhibitory activity against enzymes associated with glucose metabolism. The investment and operating costs of hot-air drying equipment are relatively manageable, making this method suitable for the production of conventional dried fruit. Freeze-drying provides better retention of fruit color and bioactive components but is more expensive and is therefore more suitable for premium dried fruit, freeze-dried fruit pieces, or high-end food ingredients.

4.2 Fermented products: extending the marketing period and developing specialty chinese bayberry products

Fermentation is an important approach for addressing the concentrated seasonal supply of Chinese bayberry. Fermented products such as Chinese bayberry wine and fruit vinegar can substantially extend the storage and marketing periods while creating flavors and consumption scenarios that differ from those of fresh fruit. In their review of the nutritional value, processing, and industrial utilization of Chinese bayberry, Zhang et al. (2022) indicated that Chinese bayberry can be processed into products such as fruit wine and vinegar through juicing and fermentation. The production of Chinese bayberry wine generally involves fruit crushing, adjustment of sugar content, yeast fermentation, clarification, and subsequent storage. Anthocyanins, esters, and other compounds in Chinese bayberry wine collectively influence product color and aroma. Therefore, fermentation is not simply a

matter of soaking fresh fruit in alcohol; rather, careful control of raw-material maturity, sugar-acid balance, fermentation conditions, clarification, and product stability is required.

The major value of fermented products lies in their ability to convert large quantities of fruit ripening within a short period into products that can be marketed over a much longer period. However, raw materials used for processing must still meet food safety requirements, and decayed or moldy fruit should not be used for fermentation. A more appropriate approach is to separately grade processing-suitable fruit that has a relatively low external appearance grade but satisfactory maturity and internal quality and then supply it to professional wine or beverage processing enterprises. This approach avoids reducing the market value of premium fresh fruit while providing a stable utilization channel for processing-grade fruit.

Fermentation can also be integrated with the utilization of Chinese bayberry processing by-products. Zhu et al. (2022) used Chinese bayberry pomace for pomace wine fermentation and analyzed the polysaccharides present in the resulting product. The polysaccharides exhibited antioxidant activity and contributed to improvements in the color of pomace wine. Therefore, pomace generated after juice extraction does not necessarily need to be treated immediately as waste; depending on its hygienic condition and available processing facilities, it may be further utilized through fermentation. The industrial value of fermented Chinese bayberry products such as wine and vinegar therefore lies not only in extending the marketing period of the fruit but also in providing additional utilization pathways for processing-grade fruit and certain processing by-products.

4.3 High-value-added products: from selling fruit to utilizing characteristic components

Zhang et al. (2015) compared 17 Chinese bayberry cultivars from Zhejiang and Jiangsu and found substantial differences in soluble sugars, organic acids, total phenolics, flavonoids, and anthocyanins among cultivars. Total phenolic and total flavonoid contents were positively correlated with in vitro antioxidant indices, including DPPH, FRAP, and ABTS. The study also identified multiple anthocyanins and flavonoids. These findings indicate that cultivar differences should also be considered in the high-value-added development of Chinese bayberry. In the future, suitable cultivars could be selected according to specific applications, such as juice, natural colorants, fruit powder, or food ingredients, rather than evaluating cultivar value solely on the basis of fruit size and appearance for fresh consumption.

Anthocyanins are among the characteristic components of Chinese bayberry with considerable development potential. Fu et al. (2025) investigated the green extraction of Chinese bayberry anthocyanins using acidic deep eutectic solvents and found that different extraction systems significantly affected anthocyanin recovery and stability. The optimized acidic deep eutectic solvent system substantially improved anthocyanin extraction efficiency. Whereas Chinese bayberry has traditionally been used mainly for fresh consumption and juice production, processing enterprises could further extract natural colorants and other characteristic components for use as food ingredients, thereby increasing the utilization value of the raw material.

High-value utilization can also extend beyond conventional food products. Yun et al. (2019) incorporated Chinese bayberry anthocyanin extracts into cassava starch films and found that cyanidin-3-O-glucoside accounted for more than 95% of the major anthocyanins in the extracts. The addition of an appropriate amount of Chinese bayberry anthocyanins improved the antioxidant activity, ultraviolet-barrier properties, and mechanical performance of the films. The films also exhibited pH-responsive color changes and could be used to monitor pork freshness. Therefore, the high-value utilization of Chinese bayberry is not limited to processing the fruit into wine or fruit powder but may be further extended to food-industry materials such as natural colorants and active packaging (Figure 2). Nevertheless, for family farms and conventional agricultural enterprises, more mature products such as juice, dried fruit, wine, and fruit powder remain more practical entry points. Technologies such as anthocyanin extraction and intelligent packaging are more suitable for collaborative development involving food-processing enterprises, universities, and research institutions. Accordingly, a progressive product-development pathway can be established from processed fresh-fruit products → fermented products → fruit powders and food ingredients → natural bioactive components and functional materials, thereby gradually increasing the comprehensive utilization value of Chinese bayberry resources.

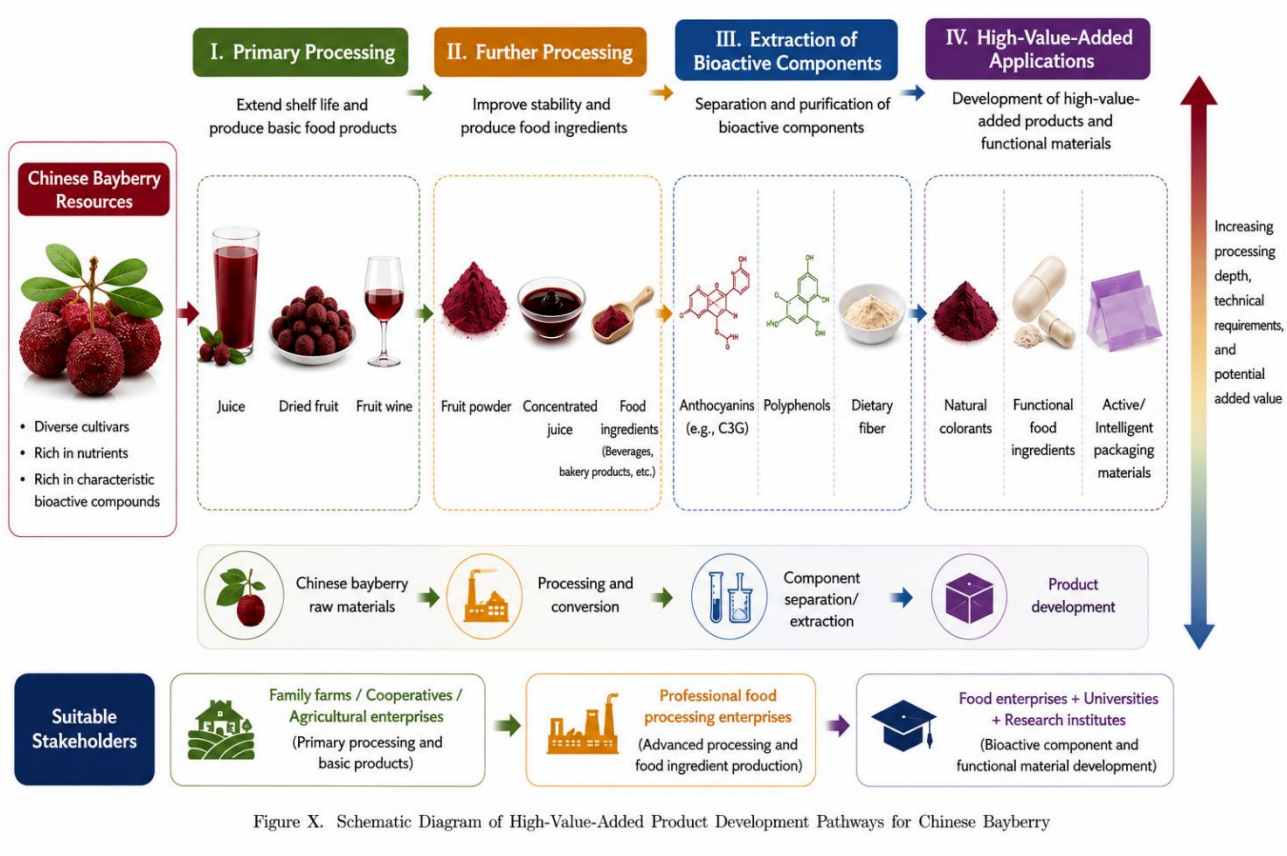


Figure X. Schematic Diagram of High-Value-Added Product Development Pathways for Chinese Bayberry

Figure 2 Development pathways for high-value-added Chinese bayberry products

5 Comprehensive Utilization of Chinese Bayberry By-Products

5.1 Reutilization of Chinese bayberry pomace

The processing of Chinese bayberry into juice, wine, and other products generates a certain amount of pomace. In the past, pomace was often treated simply as processing waste; however, it still retains considerable amounts of potentially valuable components. Zhou et al. (2009) compared the phenolic compounds and antioxidant properties of pomace from five Chinese bayberry cultivars. The predominant anthocyanin in the pomace was cyanidin-3-O-glucoside, with contents ranging from 3 073.3 to 6 219.2 mg/kg DW. The pomace also contained flavonols such as quercetin-3-O-glucoside and various phenolic acids. Significant differences in composition and antioxidant capacity were observed among cultivars. In particular, pomace from ‘Wandao’ showed relatively strong antioxidant activity, which was significantly correlated with total phenolic and total anthocyanin contents. These findings indicate that the pomace remaining after Chinese bayberry juice production is not a valueless residue and that its reutilization potential may vary among cultivars.

The utilization of Chinese bayberry pomace has gradually expanded from the simple recovery of pigments to the development of dietary fiber. Zhang et al. (2024c) used pomace remaining after Chinese bayberry juice extraction as the raw material and modified its dietary fiber through ultrasound-assisted enzymatic treatment. Under optimized conditions, the yield of soluble dietary fiber reached 15.14%, with a water-holding capacity of 54.13 g/g. The modified dietary fiber also showed improvements in water-holding capacity, oil-holding capacity, swelling capacity, and glucose adsorption, together with relatively good in vitro antioxidant activity. Therefore, Chinese bayberry pomace does not need to be treated merely as a source of crude fiber; with appropriate processing, it can potentially be converted into a dietary fiber ingredient with improved processing and functional properties.

5.2 Development and utilization of Chinese bayberry pits and kernels

Compared with pomace, Chinese bayberry pits are more easily overlooked in practical processing. However, the kernels inside the pits have considerable potential for oil development. Yang et al. (2025b) conducted a systematic

investigation of Chinese bayberry kernel oil and found that the kernels had a relatively high oil content. Unsaturated fatty acids accounted for 79.5%~87.2% of the oil, with oleic acid and linoleic acid as the major components. Phytosterols and tocopherols were also detected, with phytosterol contents ranging from 384.67 to 597.14 mg/100 g and tocopherol contents ranging from 632.09 to 1 227.62 μg/100 g. These findings demonstrate that Chinese bayberry pits are not merely hard processing residues; their kernels have potential for further development into plant oils and related food ingredients.

The same study also compared six processing methods, including cold pressing, solvent extraction, ultrasound-assisted extraction, steam-explosion pretreatment, enzymatic extraction, and supercritical fluid extraction. Kernel oil yields ranged from 30.95% to 49.49%. Different extraction methods affected the contents of phytosterols, tocopherols, volatile compounds, and antioxidant activity, whereas the major fatty acid composition remained relatively stable. Therefore, if Chinese bayberry kernel oil is developed into practical products in the future, evaluation should not focus solely on maximizing oil yield. Processing costs, food safety, oil quality, and intended product positioning should also be considered.

Although Chinese bayberry kernel oil has demonstrated promising research and development potential, its industrial development remains far less mature than that of established edible oils such as soybean and rapeseed oils. Further studies are required on large-scale production, processing costs, food safety evaluation, and market acceptance. At present, therefore, Chinese bayberry kernel oil is more appropriately regarded as a potential high-value utilization pathway rather than an already established commercial edible-oil industry.

5.3 Agricultural recycling of processing residues

After valuable components such as anthocyanins, dietary fiber, or oils have been recovered from Chinese bayberry by-products, residual pomace, pit shells, and other organic materials still require appropriate treatment. For materials that are no longer suitable for further food applications, direct disposal should be avoided where possible. Depending on local conditions, a more practical approach is to incorporate these residues into composting, organic fertilizer production, or other agricultural recycling systems. Sayara et al. (2020) systematically reviewed organic-waste composting and its agricultural applications and indicated that composting can convert organic waste into relatively stable organic materials through microbial activity, allowing the resulting compost to be used as a soil amendment in agricultural production. However, composting performance is influenced by raw-material composition, moisture, temperature, aeration, and the degree of maturity. Therefore, agricultural recycling should not simply involve piling processing residues in orchards; appropriate composting and maturation processes are required.

In addition to composting, biochar represents another potential utilization pathway for fruit-processing residues. Zhang et al. (2024a), in a review of the thermochemical conversion of fruit waste, indicated that fruit peels, pits, and other lignocellulosic residues can be converted into biochar through pyrolysis and related processes. The resulting materials have potential applications in areas such as soil amendment. For the Chinese bayberry industry, this approach may be particularly relevant to pit shells and other residues that are difficult to reutilize in food products. At present, however, it is more appropriate to regard biochar production as a potential agricultural recycling pathway rather than an established utilization model specifically for Chinese bayberry residues.

6 Pathways for Upgrading the Chinese Bayberry Industry

6.1 Transition from fresh fruit sales to the integration of fresh-market sales and processing

The first issue that needs to be addressed in the development of the Chinese bayberry industry is the concentrated marketing period of fresh fruit and its poor storability. After harvest, fresh Chinese bayberry fruit is highly susceptible to water loss, softening, and decay, resulting in a short shelf life at room temperature, whereas processing can effectively extend the utilization period of the fruit (Mo et al., 2024). In addition to fresh consumption, Chinese bayberry can now be processed into juice, dried fruit, wine, fruit vinegar, and other products. Anthocyanins, polyphenols, as well as pomace and pits generated during processing also have potential for further development and utilization (Figure 3). Therefore, the Chinese bayberry industry should not simply be regarded as a model of “growing Chinese bayberry and selling fresh fruit.” Instead, different utilization pathways

should be arranged according to fruit quality. High-quality fruit with good appearance and physical integrity should be prioritized for premium fresh-market sales; standard marketable fruit can enter conventional fresh-fruit markets; and fruit that meets food-processing requirements but is unsuitable for premium fresh sales can be directed to juice, wine, jam, and other processing channels.

In Lanxi, Zhejiang Province, the annual processing volume of Chinese bayberry had already exceeded 6,000 t, with products including dried Chinese bayberry, Chinese bayberry wine, and canned Chinese bayberry. Fengyuan Food Technology Co., Ltd. established a Chinese bayberry juice concentrate production line with an annual production capacity of 3 000 t and adopted an “enterprise + farmers” model. Under this arrangement, the company signed fresh-fruit purchase agreements with local growers and provided a guaranteed purchase price of RMB 3.8 per jin (500 g). In 2020, Zhejiang Lansen Food Technology Co., Ltd. and Zhejiang Riyuan Food Co., Ltd. were also introduced into the area, each with an annual fruit-juice processing capacity exceeding 3,000 t.

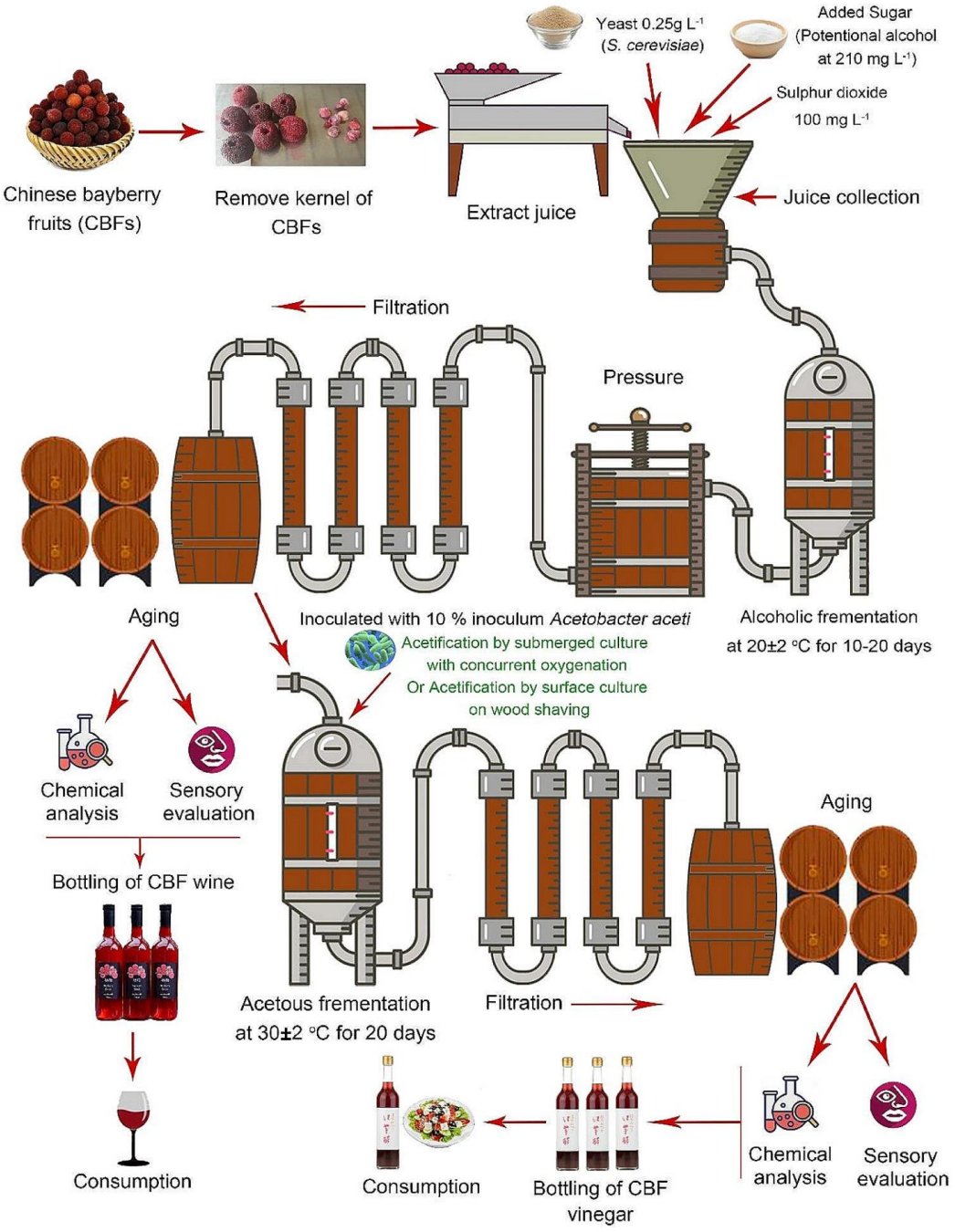


Figure 3 Schematic diagram of wine and vinegar production from Chinese bayberry fruit (Adopted from Mo et al., 2024)

6.2 Rational division of responsibilities between family farms and processing enterprises

Developing the processing sector of the Chinese bayberry industry does not mean that every grower or family farm needs to establish its own processing facility. Huang et al. (2022), in their study of cooperation between family farms and other business entities in agricultural value chains in China, found that stable and long-term cooperation with other business entities can improve the operational performance of family farms. At the same time, insufficient capital and relatively high transaction costs may restrict family farms from independently expanding into downstream segments of the value chain. This situation is consistent with the practical conditions faced by many Chinese bayberry growers. Establishing production lines for Chinese bayberry juice, wine, and other processed products requires equipment for washing, juice extraction, sterilization, filling, and cold storage, while also involving food production management, quality testing, and product marketing. For relatively small family farms, independently establishing a complete set of processing facilities would require substantial investment. Moreover, because Chinese bayberry processing is highly concentrated within a short harvest season, the actual annual utilization rate of such equipment may remain relatively low.

A more suitable model for family farms is therefore "own production + own grading + premium fresh sales + cooperative processing." After harvest, fruit can first be graded according to quality. Premium fruit can be marketed through pick-your-own operations, e-commerce platforms, supermarkets, or premium packaging channels; standard marketable fruit can enter conventional fresh-fruit markets; and fruit suitable for processing can be sold to cooperatives or food-processing enterprises. Fengyuan Food Technology Co., Ltd., for example, established a specialized processing line and purchased Chinese bayberry fruit from local farmers through contractual arrangements. Under this model, farmers do not need to invest in their own processing equipment but can still direct part of their harvest into processing channels.

6.3 Development of the Chinese bayberry industry in Zhejiang: the case of Xianju

One notable change in the Chinese bayberry industry in Zhejiang in recent years has been the gradual shift from focusing mainly on "how much is planted and how much is produced" toward considering "how much high-quality fruit can be produced, how far it can be marketed, and what kinds of products it can be processed into." The use of insect- and rain-proof nets in Chinese bayberry production can reduce damage caused by unfavorable weather and insect pests while improving fruit size, weight, edible portion, and sugar–acid characteristics (Yu et al., 2021). Therefore, industrial upgrading still needs to begin in the orchard. Only by improving production practices and increasing the proportion of intact, large, and high-quality fruit can a solid foundation be established for premium packaging, e-commerce sales, and brand development. After harvest, appropriate postharvest treatments can reduce the microbial load on the fruit surface and delay decay (Suo et al., 2023). Orchard production and postharvest handling should therefore be regarded as a continuous process: the former is responsible for improving fruit quality, while the latter aims to preserve that quality until the fruit reaches consumers.

Some cooperatives in Xianju have already introduced intelligent equipment to grade Chinese bayberry according to indicators such as soluble solids content and fruit size, with machines capable of sorting approximately 500 jin (250 kg) of premium Chinese bayberry per hour. In some mountainous orchards, drones have also begun to undertake fresh-fruit transportation. Manually transporting 100 jin (50 kg) of Chinese bayberry on a round trip from a hillside approximately 80 m high takes about 40 min, whereas a drone can transport the same weight in approximately 3 min. The first phase of the Xianju Chinese Bayberry Cold-Chain Logistics Base, which became operational in 2026, covers an operating area of more than 6 000 m², has a daily handling capacity of 100 000 boxes of Chinese bayberry parcels, operates 30 direct delivery routes across China, and connects with more than 800 village-level collection points throughout the county. Nearly 200 refrigerated vehicles are deployed locally to collect fresh fruit from villages, together with more than 200 refrigerated vehicles for long-distance trunk transportation, enabling Chinese bayberry fruit to reach consumer markets outside the production region more rapidly.

Xianju has also developed a cluster of 22 Chinese bayberry deep-processing enterprises producing a diverse range of products, including Chinese bayberry wine, fruit vinegar, dried fruit, fermented products, brandy, and Chinese bayberry pastries, while further exploring high-value-added products such as Chinese bayberry anthocyanins. Zhejiang Yangbaili Biotechnology Co., Ltd. has adopted a production model of "producing concentrated juice during the peak season and developing finished products during the off-season," thereby converting Chinese bayberry harvested within a short period into intermediate products that can be further processed and marketed throughout the year. The Chinese bayberry wine industry in Xianju has also reached a certain scale. In 2023, major local Chinese bayberry wine enterprises produced 2 575 t of wine, with an output value of RMB 165 million. Products included infused wine, fermented wine, distilled spirits, and blended wine. Chinese bayberry wine products from Gumeishu Winery, Yangbaili, Juxianzhuang, and Meiyuan Agriculture also received gold awards at the 2024 Zhejiang Agricultural Expo. From the perspective of the industry as a whole, the output value of fresh Chinese bayberry fruit in Xianju reached RMB 1.23 billion in 2024, while the output value of the entire industrial chain reached RMB 4.5 billion. By the end of 2025, the total output value of the industrial chain had exceeded RMB 4.8 billion.

7 Conclusions and Future Perspectives

The high-value development of the Chinese bayberry industry should not be limited to increasing fresh fruit production, nor should it simply rely on expanding processing capacity. Instead, considering the concentrated ripening period, poor storability and transportability of Chinese bayberry, as well as the different utilization values of fruits of different grades, production, preservation, marketing, processing, and by-product utilization should be effectively integrated. High-quality production is the foundation for industrial value enhancement. The proportion of marketable fruit can be increased through appropriate cultivar selection, standardized cultivation, and harvesting at the proper maturity stage. After harvest, losses can be reduced through timely precooling, grading and packaging, and cold-chain transportation, while fruits of different quality grades can be directed to premium fresh-market sales, conventional fresh-fruit markets, or processing. Processing can be further extended from traditional products such as juice, jam, and dried fruit to Chinese bayberry wine, fruit vinegar, fruit powder, and high-value products containing anthocyanins, polyphenols, and dietary fiber. Meanwhile, processing by-products such as pomace and pits can be further reutilized. In this way, the Chinese bayberry industry can gradually establish a cascade-utilization model of "high-quality production–postharvest preservation–graded utilization–value-added processing–by-product utilization," enabling fresh fruits of different quality grades and processing residues to enter appropriate utilization pathways.

In the future, greater attention should be given to standardized production, diversified processing, product branding, coordinated operation, and resource recycling in the Chinese bayberry industry. At the production stage, cultivar allocation should be optimized according to different purposes, including fresh consumption, storage and transportation, and processing. Soil, fertilizer, and water management, tree-canopy regulation, environmentally friendly pest and disease control, maturity assessment, and quality-grading standards should be further improved, shifting the production objective from simply increasing yield toward increasing the proportion of high-quality marketable fruit and maintaining stable quality. At the postharvest and distribution stages, production-area precooling, grading and packaging, cold-chain transportation, and e-commerce marketing systems should be further improved to extend the marketing period and geographical reach of high-quality fresh fruit. At the processing stage, products such as juice, wine, fruit vinegar, dried fruit, and fruit powder should be developed according to market demand, while the utilization of characteristic resources such as anthocyanins, polyphenols, dietary fiber, and kernel oil should be steadily promoted. However, high-value development should remain closely linked to actual market conditions, with production costs, food safety, product stability, and consumer acceptance taken into consideration. For pomace, pits, and other residual materials, the principle of "high-value utilization first, followed by recycling" should be adopted, with potential applications including food ingredients, functional ingredients, compost, organic fertilizers, and biochar.

Different business entities should select development approaches suited to their operational scale and financial capacity. Growers should focus primarily on producing high-quality fruit; family farms should strengthen

production, grading, and marketing while extending the industrial chain through cooperative or contract processing; cooperatives should enhance technical services and coordinate production and marketing; and agricultural enterprises with sufficient capacity can further integrate production bases, cold-chain logistics, processing, and branding resources. Cooperation among research institutions, agricultural extension agencies, processing enterprises, and marketing channels should also be strengthened so that new cultivars, technologies, and products can be effectively applied in actual production and business operations. Ultimately, the Chinese bayberry industry should strive to achieve the goals of "high-quality production, effective preservation, accurate grading, efficient processing, comprehensive utilization, and wider market access," enabling Chinese bayberry to gradually develop from a highly seasonal fresh fruit into a distinctive industry supported by fresh-market sales, processing, high-value utilization, and agricultural recycling.

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Conflict of Interest Disclosure

The author affirms 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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