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Review

Research Progress on Processing Technology of Refined Betel Nut in China: A Review

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Abstract: Betel nut is a traditional Asian herbal medicine and ranks as the fourth most common addictive substance in the world. Refined betel nut is made from the original fruit of the *Areca catechu* L. tree through complex traditional processes. Betel nut has various pharmacological effects, and the health effects of chewing refined betel nut have sparked significant concern. The optimization of processing techniques is essential in mitigating the harmful effects of refined betel nut products. This article reviews the current procedures, major limiting factors and technological innovations associated with refined betel nut production. Modern softening techniques including enzymatic treatment, steam explosion and microwave technology have been developed in the last two decades to improve the softness of betel nut fiber. To address the microbial contamination of products, automated production and nonthermal sterilization technologies such as irradiation are preferred. To prevent or delay the whitening and returning of the betel nut brine, an enhanced brine reaction, compound additives and strict control of environmental temperature and humidity can be essential. Chemical reagents, low-temperature preservation, modified atmosphere preservation and coating preservation are applied for the storage of fresh betel nuts. It was found that optimized processing methods and stringent regulatory measures are required to control the chemical pollution in betel nut products. The widespread integration of emerging technologies underscores the imperative need to update regulatory measures. Thus, we hope this review will offer research insights and theoretical references for reducing the harm associated with the processing technology, as well as the formulation of updated supervisory measures.

Keywords: betel nut; processing technology; fiber softening; fruit storage; microbial control; brine quality

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1. Introduction

Areca catechu L., also referred to as the betel nut palm, is an evergreen tree belonging to the genus *Areca* of the palm family (Arecaceae) (Figure 1). It is native to Malaysia and primarily distributed in tropical regions of Asia, Africa and Europe [1]. The betel nut palm generally grows in hot and humid tropical rainforests and thrives in environments at low altitudes with a small temperature difference. The optimal temperature for its growth is 25–28 °C. The relative humidity (RH) in its suitable growing regions is around 60–80% with an annual rainfall of 2200–2500 mm [1].

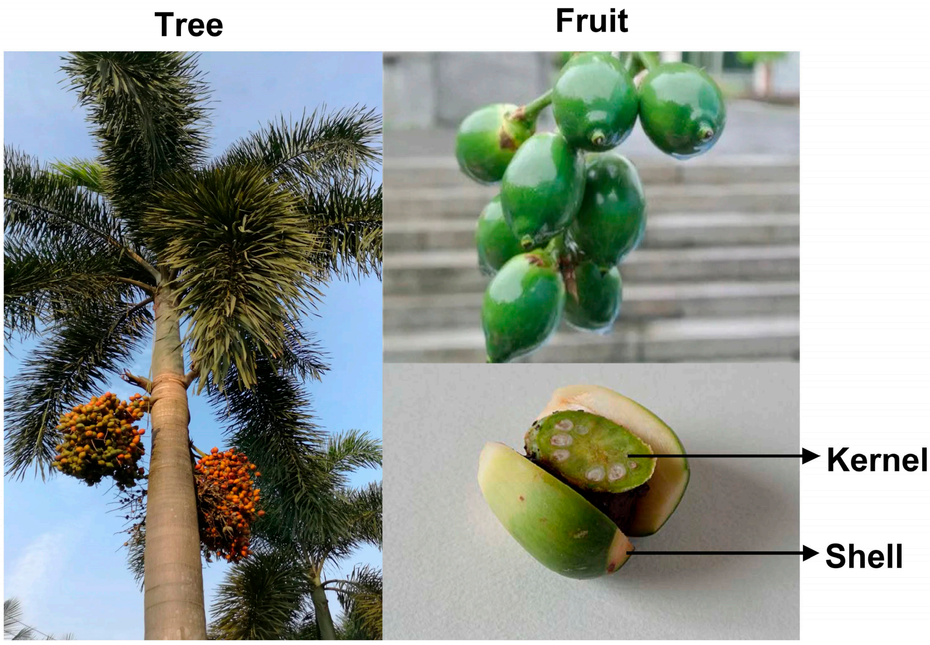

Figure 1. Tree and fruit of *Areca catechu* L.

Betel nut is the fruit of *Areca catechu* L. and has been widely utilized for both medicinal and dietary purposes (Figure 1). Betel nut holds a prominent position among the four renowned traditional medicines in Southern China and ranks as the fourth most widely consumed addictive substance globally, following caffeine, nicotine and alcohol [2]. Approximately 600 million people, primarily residing in the eastern and southern regions of Asia such as China, India, Vietnam, Indonesia, Myanmar and the Pacific regions, are chewing betel nuts for their mild psychoactive effects [3]. There are three primary methods of chewing betel nuts: chewing fresh betel nuts, dried kernels and dried betel nut pericarp. In Southeast Asia, fresh betel nuts are commonly chewed with slaked lime and Laotian leaves or grated tobacco [4,5]. In China, dried betel nut pericarps are usually processed into refined betel nuts, referred to as "Binglang" by local consumers, through complex processing procedures including boiling, flavor addition, brine addition and drying. Betel nut kernels can be sliced into thin pieces, and the dried kernel pieces are commonly utilized in traditional Chinese medicine for the treatment of diseases, such as indigestion and parasitic infection [6].

In China, betel nut is mainly produced in provinces such as Hainan and Yunnan. Among them, Hainan Province contributes to more than 70% of the total betel nut production in China. Betel nut has become the second largest cash crop in Hainan, following rubber, with a gross annual value of RMB 19 billion (USD 2.60 billion) [7,8]. At the end of November 2019, the betel nut cultivation and harvest area in Hainan Province were 0.15 and 0.08 million hectares, respectively. Fresh and dried betel nut fruit production amounted to 600,000 and 272,200 tons, respectively. This crop serves as a crucial source of economic income for 2.30 million farmers in Hainan, constituting 41.37% of the agricultural population in this province [9,10].

Since the 21st century, explosive growth has been observed in the refined betel nut industry. Refined betel nuts have been introduced to various regions, including Guangdong, Hubei, Jiangxi and Guizhou, from the traditional betel-nut-consumption areas such as Hunan and Hainan Provinces [11]. In 2022, there were 127 refined betel-nut-production enterprises in Hunan Province that obtained food-production permits, including seven large-scale enterprises and three enterprises with over 5000 employees. The number of people engaged in betel nut production and sales in Hunan Province exceeded 500,000, and the industry's related gross annual value exceeded RMB 40 billion (USD 5.47 billion) [12].

After centuries of development, the refined betel nut industry in Hunan has transformed from small-scale family workshops to large-scale industrial plants [13].

The potential impact of chewing and ingesting refined betel nuts on health has gradually attracted the attention of researchers. In 2003, the International Agency for Research on Cancer (IARC) classified betel nuts as Group 1 carcinogens [14]. Another study conducted by the IARC classified arecoline as a Group 2B carcinogen [15]. Extensive discussions have focused on the health risks associated with betel nuts and the corresponding control mechanisms. On the other hand, as a traditional Asian herbal medicine, betel nuts possess a range of pharmacological effects such as acting as an insect repellent, being refreshing, promoting gastrointestinal motility and having antioxidant and antidepression properties, and they can also be used to treat diseases such as malaria, depression, hypertension, hyperlipidemia and diabetes [16]. Considering the persistent nature of refined-betel-nut-chewing practices in the short term, the optimization of processing techniques holds significant value in terms of minimizing the harm of refined betel nut products. However, there is little research and review articles focusing on their processing technology.

This review aims to present the primary processing methods employed for refined betel nuts along with their major factors related to quality control while providing an overview of the technology used to improve the quality of refined betel nuts.

2. Betel Nut Fruit and Its Products in China

The betel nut is composed of a fibrous outer shell and a rigid inner kernel (Figure 1). The primary chemical constituents of dried betel nut comprise 42.7% cellulose; 15% phenols; 11.1% moisture; 10.7% lignin; 5.3% reducing sugars; 4.6% fatty acids; 3.2% proteins; 2.6% amino acids; 3.0% ash; 0.8% alkaloids; and 1.0% other substances, such as vitamins [17].

Betel nut is rich in bioactive components such as alkaloids, tannins, flavonoids and terpenes, exhibiting various effects including digestion promotion, antioxidant and anti-inflammatory properties, parasite resistance and antimicrobial activity [1,18,19]. Recent research has suggested that the main active components of betel nut are alkaloids [19]. Among the 54 known species in the palm family, betel nut palm, which belongs to the genus *Areca*, is the only plant containing alkaloids such as arecoline, which are mainly in complex with tannic acid. Arecoline is involved in various pharmacological activities including effects on nervous, cardiovascular, digestive and endocrine systems and antiparasitic effects [19].

In betel-nut-planting areas in China such as Hainan, people prefer the consumption of fresh betel nuts (Figure 2). Betel nuts in Hainan are conventionally harvested from August to January. Typically, the fresh fruit is combined with betel leaves and slaked lime and chewed directly. The betel nuts contain betel red pigment, which triggers the production of red juice in the chewer's mouth. Moreover, the alkaloids in the betel nut result in facial flushing and a raised heart rate [19]. In traditional Chinese medicine, the betel nut kernels are bathed in water for 3 to 5 days until they are thoroughly soaked. Then, the kernels are cut into thin slices and dried and collected as raw arecae semen. Raw arecae semen is fried over gentle heat until it is light yellow and is referred to as fried arecae semen. Alternatively, raw arecae semen can be fried over medium heat until it turns brown and is known as coked arecae semen [6]. The proportion of betel nuts eaten fresh or used as a medicine is limited. Over 95% of the harvested fruits are processed into dried betel nuts and transported to Hunan Province. They are further processed into refined betel nuts there (Figure 2). Hunan Province is also the traditional consuming area for refined betel nuts (Figure 2).

There are significant differences among refined and fresh betel fruits. During the production of refined betel nuts, the kernel of the nut is removed and only the outer shell or pericarp is consumed. The processing procedure for refined betel nuts involves high temperature and high pressure. The decomposition and reactions of the ingredients can occur. For example, compared with fresh betel fruits, 35.5% of arecaidine, 42.0% of guvacine, 66.5% of arecoline, 67.9% of guvacoline and 27.6% of polyphenols are reduced in refined betel nuts [20]. Also, there are notable distinctions between medicinal betel nuts and refined betel nuts in China. Firstly, medicinal betel nuts are derived from the kernels of the fruit, whereas refined betel nuts utilize the pericarps of the fruit [6]. Secondly, the two types undergo distinct production processes as medicinal betel nuts are simply stir-fried while complex traditional processing including boiling, flavor addition and brine addition is employed for the production of refined betel nuts [6,21–23]. Additionally, they are used differently, with medicinal betel nuts in China typically being utilized as aqueous extracts, presenting no substantial hazards to oral health. In contrast, refined betel nuts are commonly chewed directly in the mouth for leisure and refreshment and pose potential risks to oral health [6].

Figure 2. Different kinds of betel nut products in China.

3. Process of Refined Betel Nut Production

According to the differences in raw materials and processing methods, refined betel nuts can be divided into three types: smoked betel nut, smoked green betel nut and green betel nut [21]. Among them, smoked betel nut and smoked green betel nut are made from smoked and green fruit with traditional processing techniques, respectively. They are characterized by intricate processing involving multiple steps and higher requirements for the color, aroma, shape and taste of the final product (Figure 3).

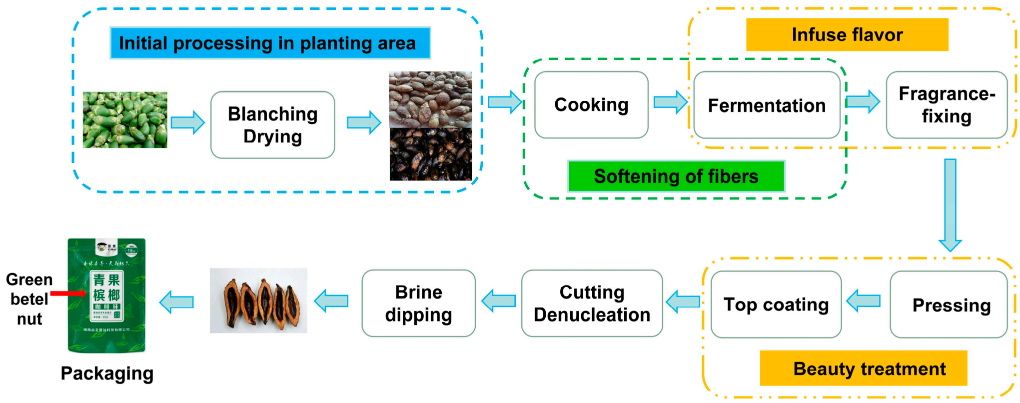

Figure 3. Production process of refined betel nut.

The primary aim of the processing procedures is to improve the taste, smell, coolness and shape of the betel nuts, ensuring a harmonious combination of flavors. The main procedures generally include the following steps: blanching, drying, cooking, fermentation, drying, fragrance fixing, compressing, top coating, cutting, denucleating, brine dipping, drying and packaging (Figure 3 and Table 1). The most crucial steps are blanching, cooking, fermentation, fragrance fixing, top coating and brine dipping [22,23]. Depending on the manufacturer, there may be variations in the processing techniques and ingredient formulations.

Table 1. The processing procedures for refined betel nuts.

Procedures	Operation Methods	Major Objective
Initial processing	Cooking in boiling water for 30–50 min followed by drying and roasting with electric or steam ovens.	Conservation of betel nut fruit.
Cooking	Cooking in boiling water for 20 min or exposure to steam (110 °C and 0.05 MPa) for 15 min.	Cleaning, rehydration, softening and sterilization.
Fermentation	Soaking in solution containing plant extract, sweeteners, flavors and fragrances at 40–50 °C for one day and at room temperature for the next couple of days.	Enhancing the flavor and aroma.
Roasting	Drying with hot-air baking machines.	Reducing the water content.
Fragrance fixing	Soaking in a solution containing various flavors and fragrances.	Stabilizing and enhancing the aroma.
Compressing	Flattening using hydraulic equipment.	Loosening the fibers and creating specific patterns on the surface.
Top coating	Spraying gelatin film onto the surface of the betel nuts.	Increasing brightness.
Cutting and denucleation	Cutting betel nuts into two pieces manually or mechanically and picking out the kernel.	Denucleation.
Brine dipping	Adding the brine to the middle point of the betel nut shell.	Flavoring and beautifying.

3.1. Initial Processing in Planting Area

The suitable original fruits for refined betel nuts are primarily oblong and an elongated oval in shape. It is difficult to preserve fresh betel nuts, so they need to be dried within a few days after harvesting. Blanching is the first step in the traditional processing of fresh betel nuts, which involves cooking in boiling water for 30–50 min followed by the drying and roasting of the nuts by using smoke generated by burning moist rubber wood. Betel nuts are porous materials with numerous capillaries, and the drying and roasting steps help to quickly remove the bound moisture from the capillary walls. Generally, after these processes, the moisture content of the betel nut is below 20% [24]. These processes can also inhibit microbial growth and facilitate the long-distance transportation from Hainan to Hunan Province.

The smoked betel nut fruits gradually develop a dark skin due to the accumulation of smoke particles on the fruit surfaces (Figure 3). Therefore, they are commonly named smoked or black fruit and exhibit a distinctive smoky flavor. However, certain by-products, such as benzo[a]pyrene, are generated by smoking [24]. In modern production methods, betel nut fruits are typically processed via cold smoking technology by using electric or steam ovens. The resulting betel nut fruits exhibit green or brown coloring and are known as green or white fruit (Figure 3) [25,26], which significantly reduces both the environmental impact and health risks [27].

During the drying process, the moisture of the betel nut kernels gradually permeates into the shell and eventually dissipates into the air. Alkaloids and polyphenols exist in the shell and kernel of the betel nut, but their content in the kernel is much higher. Since polyphenols and alkaloids are soluble in water, they would migrate from the kernel to the shell along with the moisture. Consequently, after drying processing, the content of arecaidine, guvacine, arecoline, guvacoline and polyphenols in the shell of the dried betel fruits increased by 1.23, 1.56, 2.44, 11.04 and 9.84 times, respectively [20].

3.2. Cooking of the Dried Betel Nuts

The dried betel nuts have a relatively low moisture content. Prior to further processing, they must undergo the cooking or steaming processes for cleaning, rehydration and sterilization. Typically, the nuts are boiled under atmospheric pressure for approximately 20 min. Alkaline substances, such as food-grade sodium hydroxide, sodium bicarbonate, sodium carbonate or calcium hydroxide, are added during the rehydration process, which facilitates the complete penetration of the subsequent fermentation liquid into the betel nuts and the release of alkaloids [28]. The cooking process is the only high-temperature step in the traditional process, serving to eliminate microorganisms and soften fibers. Raising the cooking temperature proves advantageous for sterilization; however, it may also cause discoloration of the incisions of the betel nut seed.

Optimizing the cooking process is crucial for the quality of the final product. Li Zhi et al. employed high-temperature steaming technology to rehydrate betel nuts and demonstrated that treating the seeds at 110 °C and 0.05 MPa for 15 min not only eliminated the endogenous bacteria but also softened the fibrous texture [29]. The incisions on the seeds did not exhibit any noticeable discoloration. During the cooking step, the dried betel nuts are soaked in alkaline water for some time. Alkaloids are dissolved in the cooking solution. Their contents in the nuts are reduced [20]. Simultaneously, soluble tannic acids are converted into insoluble form; thus, the astringency of the nuts is effectively reduced [30].

3.3. Fermentation of the Betel Nuts

Fermentation, referred to as "Fa zi" by the local betel-nut-processing enterprise in Hunan Province, is a crucial step for refined betel nut production. This fermentation process can enhance the flavor, aroma and overall quality of the betel nuts, making them more desirable for consumption. The betel nuts are usually treated with a softening enzyme and tannin enzyme which can soften the fibers and eliminate astringency before fermentation. Then, betel nuts are immersed in a solution containing protein sugar, sodium cyclamate, licorice extract, vanillin and edible flavors during the fermentation step. The water-soluble components such as organic acid, tannins and alkaloids are dissolved in the fermentation solution. Consequently, this process effectively diminishes the bitter, sour and astringency tastes associated with the fruit. The betel nut shells will absorb flavor compounds, such as ethyl maltol, menthone, isomenthone and vanillin, from the solution. This contributes to the development of basic flavors in betel nuts, such as cooling, aromatic, sweet, salty and umami characteristics [31].

The effects of the fermentation process depend on the formulation of the soaking liquid as well as the control of processing conditions. By precisely regulating the temperature, duration and rotation frequency of the fermentation tank, optimal flavor infusion can be achieved. The conventional fermentation process primarily involves soaking at 40–50 °C for one day and at room temperature for the next couple of days. This process is usually constrained by a long process cycle, low liquid penetration and uneven flavor distribution. A rapid fermentation process was developed, in which compressed air is employed to enhance the course of fermentation [32]. Nonetheless, the implementation of high-pressure equipment requires stricter safety protocols. For example, the pipeline of the pressure gauge can be blocked by betel nuts, resulting in incorrect readings.

3.4. Roasting and Fragrance Fixing

The moisture content of betel nuts after fermentation is approximately 45%. Therefore, the nuts are roasted to reduce the water content before fragrance fixing. Typically, seed roasting is conducted by using hot-air baking techniques. The sweet substances that have penetrated into the betel nuts are fixed in situ through roasting. This step has a minimal effect on the alkaloid content of betel nuts [20,28,33].

Fragrance fixing serves to stabilize and enhance the rich aroma of the fruit with a confidential solution containing various flavors and fragrances. The duration of the fragrance-fixing process typically ranges from several hours to three days. However, excessively long periods of fermentation and fragrance fixing in the traditional process can decrease the utilization rate of equipment and induce the growth of microbes. To reduce the time, current research is focused on vacuum infiltration technology, continuous fermentation and fragrance-fixing technology, as well as improvements in the equipment [34,35].

3.5. Compressing and Top Coating

To improve the visual quality, the ovoid betel nuts are flattened by using hydraulic equipment, which alters their shape to become flat, loosens the fibers and creates specific patterns. The patterns present on the surface of betel nuts serve as indicators of their moisture content and tenderness. Typically, a deeper and finer pattern signifies a higher moisture content and a more succulent flesh. Additionally, the symmetrical appearance of betel nuts suggests that the original fruit is completely filled. Gelatin film is sprayed onto the surface of the betel nuts to increase their brightness during top coating. Coating agents primarily comprise natural gums such as gelatin, gum arabic, carrageenan and modified starch, in addition to sweeteners, preservatives, fragrances and flavors. However, coating agents formed by gelatin get sticky and dark easily, severely affecting the overall appearance of the products. The composition and preparation process of the gels could be improved [36]. The film made from salad oil (35%), an emulsifier (10%), a stabilizer (0.3%) and water (54.7%) at an emulsification temperature of 45 °C, shear speed of 8000 r/min and shear time of 10 min can improve the gloss of the surface gum and reduce pilling and stickiness [36].

3.6. Cutting, Denucleation and Brine Dipping

After being coated, the betel nuts are transported to the high-clean area for further processing. First, the betel nut is cut into two pieces and then the kernel is picked out. In general, some of the kernels are utilized for extracting bioactive compounds such as arecoline while the majority are treated as waste or burned and cannot be massively utilized after processing [6]. A suitable amount of special brine is added to the middle point of the betel nut shell. The brine is the "soul" of the refined betel nut as it has a special effect on its flavor and texture. Before brine dipping, the moisture content of the betel nut slices is controlled at 22–24%. The brine solution is kept at 50–60 °C in a water bath to ensure moderate flowability.

The brine formula and preparation process developed by different manufacturers are highly confidential. Typically, the brine solution consists of maltose (30~80%), food-grade calcium hydroxide (10~40%), white sugar, additives (0.5~5.0%), water and natural flavorings. After brine dipping, the betel nuts are dried naturally to remove the moisture from the brine and the betel nuts. The interior cavity of the nut develops a glossy dark brown or black surface [37]. After the drying process, the refined betel nuts are packaged for sale.

At present, both manual and automatic operations are employed for cutting and brine dipping. Due to the probable pollution of workers and rising labor costs, automatic cutting and brine dipping equipment have gained significant attention in recent years [38,39].

4. Processing Technology of Refined Betel Nut

4.1. Fiber-Softening Technology

Betel nut fibers are chain polymers consisting of β-D-glucose molecules linked by 1,4-glycosidic bonds. These cellulose molecules are enveloped and interconnected by substances such as hemicellulose and lignin, forming a compact tissue structure. Therefore, betel nut fibers possess a firm texture and are challenging to chew directly. The prolonged consumption of betel nuts can lead to tooth wear as well as vertical root fractures [40,41]. In severe cases, it can also cause damage to the soft tissues of the oral cavity, leading to the development of oral submucous fibrosis (OSF) [42–44]. The hard fibers not only impact the chewing experience but also reduce the absorption of additives such as flavors.

Consumers prefer betel nuts with flexible and thin fibers and a high content of soluble solids. Consequently, the effective softening of betel nut fibers is crucial for the development of better betel nut products [45]. Currently, a range of softening methods is employed, including chemical, physical, biological and composite techniques [46]. However, it is challenging to evaluate the advantages and disadvantages of different softening methods (Table 2). As a result, a large number of repetitive experiments are required for screening.

4.1.1. Chemical Softening Technology

Chemical softening methods, such as acid and alkali treatments, have shown significant potential in improving the degradation efficiency. Acid treatments facilitate the hydrolysis of hemicellulose into monosaccharides, consequently reducing the polymerization degree of fibers. Alkali treatments effectively decrease the content of hemicellulose and lignin in plant tissues, as well as certain components of cellulose. In addition, appropriate alkali treatments have been proven effective in eliminating the astringency of betel nuts [30]. Therefore, alkali treatments have been widely utilized in traditional betel nut processing [28].

4.1.2. Biological Softening Technology

Biological softening methods employ enzymes or enzyme-producing microorganisms. For enzymatic softening, enzyme cocktails containing pectinase II, cellulase and xylanase were chosen in one report, and the optimal condition was 55 °C, pH 5.5, a solid–liquid ratio of 1:4 (g/mL) and 0.5 h [47]. These enzymes hydrolyze substances such as lignin and pectin, thereby disrupting and loosening the structure of betel nuts. Li Wei et al. utilized high-pressure cellulase hydrolysis techniques to soften the betel nut fiber, and the most effective condition was 50 °C, 30 FPU/g enzyme and pH 4.8 for 5 h [48]. Wu Shuo et al. performed an orthogonal experiment on the enzymolysis of fresh betel nuts after a 25 min blanching treatment. When an enzyme dosage of 0.08% (w/v), enzymolysis time of 30 min and enzymolysis temperature of 50 °C were employed, a maximum hardness reduction of 20.5 Rockwell hardness (HRC) was achieved [49]. Compared to previous studies, the enzymolysis time and dosage were significantly reduced, likely due to the looser fiber structure of the fresh betel nuts. However, further investigation is required to assess the industrial potential of this method.

4.1.3. Physical Softening Technology

Physical softening methods, such as microwaves, ultrasounds and steam explosions, are also commonly employed. Microwaves are utilized to vaporize the moisture present within the plant fiber cell walls, which leads to the formation of high pressure in conjunction with the air contained within the cell walls. Consequently, the fine pores on the cell walls are incapable of promptly releasing all of the high-pressure gas, resulting in the rupture of the cell walls. As a result, the connections between the cellulose, hemicellulose and lignin become loose, ultimately reducing the crystallinity of cellulose. Microwave-puffing technology can uniformly expand the inner and outer fibers as well as the coarse and fine fibers of betel nuts [50], significantly enhancing the chewiness quality of the betel nut. Chao Yuzhou et al. successfully decreased the hardness of the betel nut through the use of ultrasound-aided enzymatic softening technology. The optimal condition was 560 W, 45 °C, 32 h, 0.4% enzyme, pH 4.8 and a 1:2.5 (g/mL) bath ratio [51].

A steam explosion is a physicochemical pretreatment method that utilizes thermal reactions and physical tearing resulting from instantaneous pressure release and expansion in a high-temperature and high-pressure environment, and it can effectively damage the cell wall. It offers advantages such as low energy consumption and environmental friendliness [52]. The morphology, texture and chemical composition of betel nuts are influenced by operational parameters including the holding time, explosion pressure and initial moisture content. Specifically, the fiber hardness decreased by 56.17–89.28% and the shore hardness decreased by 7.03–34.29% after the steam explosion [53]. Huang et al. applied a steam pressure of 0.25 MPa and a holding time of 180 s, significantly enhancing the chewing character of the betel nuts [54]. Experimental findings demonstrated that the most significant expansion of betel nuts occurs at a holding time of 180 s and a temperature of 130 °C, resulting in a 3.3 cm increase in the height of the packed betel nuts when the steam pressure is 2.3 bar [55]. Steam explosions also increase the release of phenols, alkaloids and soluble solids. The content of arecoline in betel nuts is increased after a steam explosion, possibly due to the transformation of the bound arecoline into its free form by mechanical energy [53].

Table 2. Softening methods employed for betel nuts.

Methods	Conditions	Advantages	Disadvantages	Reference
Chemical	Alkali treatment: 1.25% sodium hydroxide, 90 °C, 7 min.	Low investment cost and simple operation, reduced astringency.	Color change in products, low efficiency, formation of unpleasant flavors.	[28]
Biological	Pectinase II, cellulase and xylanase: 55 °C, pH 5.5, 1:4 (g/mL) bath ratio, 0.5 h.	Enhanced efficiency and specificity, milder operation condition, environmental friendliness.	High cost of enzymes, formation of unpleasant flavors, uneven texture of products.	[47]
	High-pressure pretreatment: 0.1 MPa, 121 °C, 30 min; enzyme treatment: 50 °C, 5 h, 30 FPU/g enzyme, pH 4.8.			[48]
	Blanching treatment: boiling water, 25 min; enzyme treatment: 50 °C, 0.5 h, 0.08% enzyme, pH 4.8.			[49]
Physical	Microwave puffing: 915 or 2450 MHz, 2 min, 60 mm height of raw materials.	Better chewiness quality, reduced processing time and solvent use, environmental friendliness.	Increased pressure, high capital and operating cost, additional safety management.	[50]
	Ultrasonic treatment: 560 W, 45 °C, 32 h, 0.4% enzyme, pH 4.8, 1:2.5 (g/mL) bath ratio.			[51]
	Steam explosion: 80 s, 0.75 MPa, 8.51–17.65% moisture content of betel nuts.			[53]
	Steam explosion: 0.25 MPa, 180 s.			[54]
	Steam explosion: 180 s, 130 °C, 0.23 MPa.			[55]

4.1.4. Composite Softening Technology

There are certain limitations associated with the use of a single softening method. For instance, alkali boiling can easily darken the color of the betel nuts, thereby affecting the overall aesthetics of the product. Microwave softening methods can cause dryness in the inside of the betel nut. Chemical and biological softening methods may result in unpleasant flavors. Limitations in mass transfer could occur in enzymatic treatment. The betel nut cannot be effectively softened at a low enzyme dosage while a high enzyme dosage can lead to overhydrolysis on the surface, increasing the sludge content and consequently reducing the chewiness properties [45].

It is recommended to combine multiple softening methods for superior outcomes. Our investigations and interviews have revealed that a composite softening technique including enzymes, steam explosions and microwaves is currently being employed by large companies, but its process parameters are confidential. Moreover, betel nut companies prefer a moderate level of softening in consideration of better chewiness properties, while complete softening can effectively reduce oral cavity damage. Thus, the requirements for the degree of softening should be issued by the supervision department.

4.2. Microbial Control Technology

4.2.1. Microbial Contamination of Refined Betel Nut

Microbial contamination, especially fungal contamination, continues to pose the primary concern for the quality and safety of refined betel nut [56]. The microbial contamination of betel nuts primarily arises from their endophytes and microorganism invasions during the production processes. The ripe betel nut fruit is susceptible to the invasion of plant pathogens. Mold and bacterial spores become endophytes after their invasion and persist in the nut, even after the blanching process. The refined betel nuts contain significant amounts of sugars and proteins as well as a high content of moisture (>20%), so they are highly susceptible to microbial contamination. Additionally, the traditional production processes of refined betel nut are often conducted in an open environment and involve numerous manual operations. Consequently, betel nuts are susceptible to contamination by both environmental and human-derived microorganisms [57,58].

Yinbo et al. conducted a microbial community structure analysis on dried betel nuts and found that mold was the main biological contaminant [59]. *Anthracis*, *Penicillium* and *Fusarium* were identified as the main pathogens of stored betel fruit [60]. Ruan Zhiqiang et al. analyzed the bacterial diversity and community structure in stored betel fruits by using Illumina-Miseq high-throughput sequencing technology and found that endophytic bacteria were the main source of microbial contamination in the refined betel nuts [61]. Zhang Qiling et al. studied the fungal community during the processing of refined betel nuts and found that the predominant contaminant fungus was the endophytic fungus *Aspergillus*, and its survival rate remained high during the processing [62].

4.2.2. Principle of Microbial Control Technology for Betel Nut

Thermal sterilization is a widely employed method in the food industry. However, prolonged heat treatment tends to toughen the fibers of betel nuts, resulting in a decrease in their chewiness quality. Additionally, excessive heating leads to the darkening of the betel nut surface. Consequently, thermal sterilization is considered unsuitable for betel nut processing. Nonthermal sterilization techniques are more desirable.

4.2.3. Physical and Chemical Technologies for Microbial Control

Wan Xin et al. found that 30 s in the 800 W microwave can effectively extend the shelf life and inhibit the microbial contamination of the betel nut [63]. Du Daolin et al. treated the refined betel nuts with 2450 MHz in a 650 W microwave for 50 s [64]. The total bacterial count of the treated refined betel nuts was less than 10 CFU/g, and the microwave treatment did not have a significant impact on the taste and chewiness of the refined betel nuts. Xu Yuanfang et al. examined the sterilization effects of irradiation on refined betel nuts and determined that at a dose of 8.45 kGy, no bacterial colonies, mold or *Escherichia coli* were detected [65]. Wu Shuo et al. [49] discovered that an irradiation dose of 8–10 kGy could effectively eliminate microorganisms in dried betel nuts and extend their storage time by 60 days.

Jin Haiyan and colleagues employed a combination of preservatives to inhibit the growth of mold on betel nuts [66]. Li Zhi et al. utilized a combination of arabic gum, glycerin and sodium chloride to control the water activity of betel nuts and prevent mold growth [67]. Modified atmosphere packaging is another method that effectively hinders microbial reproduction during the storage of refined betel nuts [68].

4.2.4. Automated Production Technologies for Microbial Control

With the rapid development of the refined betel nut industry, there has been an increasing application of automation technologies and equipment, effectively reducing the microbial contamination caused by human factors. Li Wenxiang et al. have suggested several measures, including improving the storage conditions of the dried betel nuts, as well as disinfecting production workshops and workers [69]. These measures can effectively control microbial contamination during the production process and ensure the safety of the products. Due to the improvement in production technology and the implementation of standardized management practices, the qualification rate of microbiological indicators for refined betel nuts is increasing [70].

4.3. Brine Quality Control Technology

Another significant constraint on the refined betel nut industry is the unstable brine quality. Betel nut brine is a colloidal solution created by the reaction between calcium hydroxide and maltose [37]. The whitening and returning of brine commonly occur in betel nut products on store shelves (Figure 4). The phenomenon of brine whitening and brine returning in betel nut production has prompted industry professionals to implement changes, primarily those involving controlling the moisture content of brine, adjusting the raw material, enhancing the reaction and incorporating inhibitors.

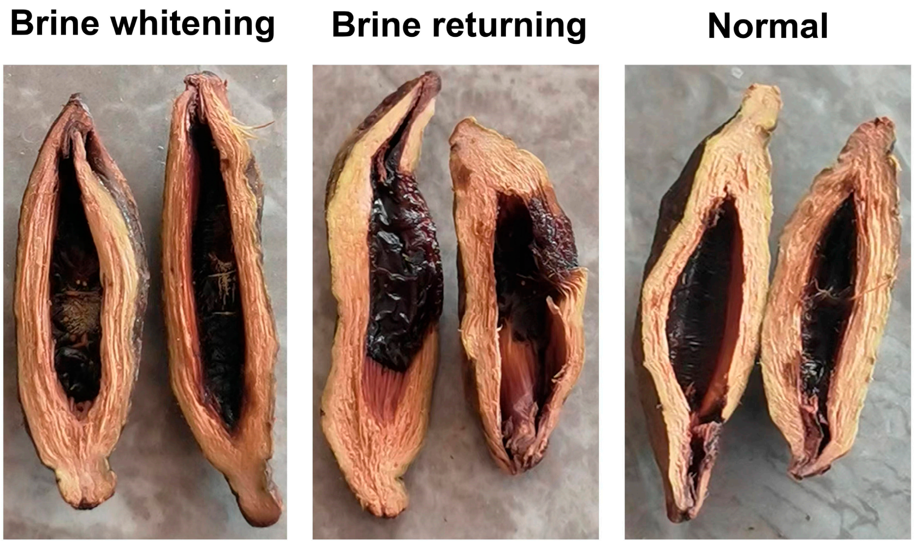

Figure 4. The whitening and returning of brine.

4.3.1. Brine Whitening and Brine Returning

Brine whitening is characterized by scattered white or pale-yellow spots in the brine of the internal cavity of betel nut slices. Brine whitening is more likely to occur during the dry and cold seasons of autumn and winter, possibly due to low environmental temperatures and humidity. Consumers may mistakenly believe that the brine has become moldy, thus affecting the shelf life of refined betel nuts. Chen Qiheng et al. conducted tests on the whitening substance and discovered that the primary component is calcium carbonate, which accounts for 85% of the substance. This can be attributed to the reaction between calcium ions dissociated from incompletely reacted calcium hydroxide or sugar calcium and carbon dioxide in the air, leading to the formation of carbonate [71]. Ma Jinshuang et al. detected the presence of calcium carbonate, ethyl maltol, sucrose, menthol and other substances in whitening brine by using nuclear magnetic resonance [72]. Fu Chengrong et al. also suggested that the incomplete reaction of calcium hydroxide or the formation of sugar calcium could be responsible for the brine whitening [73].

Specifically, brine returning refers to the melting of brine within the internal cavity of betel nut slices, resulting in a liquid state. Brine returning is prone to occur within 30 to 45 days, particularly at high temperatures. The returned brine is stuck to the tooth. Guo Zhiguang et al. proposed that the occurrence of brine returning is more likely in refined betel nuts exposed to high-temperature and high-humidity environments [74]. The underlying cause of brine whitening and returning is the variation in the moisture content and the form in which water exists resulting from temperature change and external forces during transportation [75]. For instance, the moisture content of betel nut slices before brine dipping ranges from 26% to 28% while the moisture content of the brine is between 35% and 38%. After brining and cooling, the moisture content of the finished betel nut decreases to 21% and 23%. Throughout the processes of brining, cooling, storage and transportation, it is possible for free water to migrate from the brine to the betel nut slices. Simultaneously, weakly bound water undergoes a transformation into deep-bound water, resulting in the precipitation of calcium carbonate and other substances. Consequently, this phenomenon induces the whitening of the brine. Alternatively, the original colloidal structure of the brine is disrupted and the weakly bound water is converted into free water with higher mobility, thus resulting in the returning of the brine [37].

4.3.2. Improvement in Brine Reaction

Tang Mingxiang developed an automated brine reactor for betel nut, which can enhance the reaction between the brine components and improve brine stability [76]. Wang Wei et al. designed an automated brine-dipping machine that adapted to the size of the betel nut cavity, resulting in a more-effective adhesion of brine to the betel nut [77]. Researchers have discovered that brine whitening can be effectively reduced by controlling the reaction conditions of the brine, particularly the particle size of the calcium hydroxide [37]. Kang Xiaoning et al. determined the solidification point, softening point and viscosity of the brine, establishing corresponding numerical regulations that could replace the traditional empirical judgments, thus providing a unified standard for evaluating brine performance [78].

4.3.3. Incorporating Compound Additives

It is preferable to make the water in the brine exist in bound and semibound states while reducing the content of free water [41]. Desiccants were employed by some manufacturers, but the actual impact was insignificant. This ineffectiveness can be attributed to the absorption of moisture from both the betel nut slices and brine by desiccants, resulting in a more significant disparity in the moisture content between them. Additionally, the frictional contact between the packaging bag of the desiccant and the betel nut slices can easily damage the surface film formed by the coating reagents [37]. Chen Qiheng et al. successfully addressed the issue of brine whitening by incorporating adsorbents into the packaging bag while emulsifiers and thickeners were added into the brine at the same time [71]. Li Liangyi et al. proposed that the control of the moisture content and additives dose can effectively suppress brine whitening [79]. Xiao Dong et al. mitigated whitening and extended the built-up time of brine whitening to 65 days by introducing complex thickeners and moisture retainers into the brine [80]. Therefore, the use of compound additives, such as emulsifiers, thickeners and moisture retainers, can effectively inhibit brine whitening and returning. These compound additives offer the advantages of a synergistic enhancement, low dosage, low cost, minimal side effects and ease of transportation and use.

4.3.4. Processing Environment Control

Since the occurrence of brine whitening and brine returning is closely associated with temperature and humidity, numerous betel nut companies have taken measures to maintain a consistent temperature and humidity within the brine-adding workshop. When it comes to the step of packaging, either individual vacuum packaging or the addition of carbon dioxide adsorbents can be utilized. Maintaining a constant low-temperature environment can also help [37]. Nevertheless, further research is necessary to determine how to preserve the stability of brine during the two-month shelf life of betel nuts [37]. Additionally, an alternative approach could be the development of a new type of refined betel nut without brine through process improvement [25].

4.4. Fresh Fruit Storage Technology

Ensuring the quality of fresh betel nut fruit is of significant importance. It is crucial that the betel nuts do not show any signs of mold and maintain their original appearance and color during storage. However, fresh betel nuts are particularly susceptible to mechanical damage, metabolic effects and microbial infections after harvest. To tackle the problem of fresh betel nut storage, chemical reagents, low-temperature preservation, modified atmosphere preservation and coating preservation are employed [81] (Table 3).

4.4.1. The Problems of Fresh Betel Nut Storage

After the fresh fruits are harvested, kernel browning and internal rotting can occur within 2 to 3 days under normal storage conditions. The skin turns yellow, the flesh becomes fibrous, the taste deteriorates and mold and decay occur within 5 to 7 days [81].

The browning of the betel nut during storage primarily occurs in the flesh and kernel of the fruit, and the mechanism of betel nut browning has not been disclosed yet. The peel of the fruit is primarily composed of cellulose, lignin and hemicellulose while the kernel is rich in phenols and water, making the kernel susceptible to browning. Jiang Yueming et al. discovered that the browning of the betel nut flesh is primarily caused by enzymatic browning, with chlorogenic acid and dopamine serving as the main substrates [82]. Guo Yuting observed that the browning of the betel nut is caused by damage to the peel, flesh and kernel tissues since increased membrane permeability and aggravated tissue damage were observed [83]. Moreover, the degradation of the fruit wax on the surface of the fruit, damage to the outer cuticle layer and lignification of the flesh were observed. Those would lead to the loosening of the structure, allowing for the permeation of oxygen (O_2) to the kernel. Subsequently, the oxidation of chlorogenic acid, dopamine and epicatechin, catalyzed by polyphenol oxidase (PPO), results in the browning of the betel nut.

4.4.2. Chemical Preservation Technology

Zhang Jiaojiao et al. used 2-(4-thiazolyl) benzimidazole (TBZ), a low-toxicity systemic bactericide, in combination with heat and ultraviolet treatment to preserve fresh nuts [84]. The TBZ treatment can reduce nutrient consumption and lignin formation as well as prevent the invasion of pathogenic microorganisms and reduce rotting during the storage process [84]. Xia Bing discovered that sulfur dioxide released preservatives and can effectively prevent mold growth on the peduncle of betel nut fruits under storage conditions of 8 °C and humidity of 70% to 80%, thereby extending the storage period by more than 40 days [85].

4.4.3. Cold Storage and Chilling-Injury-Prevention Technology

Cold storage is a commonly employed technique to slow down metabolic processes and extend the postharvest lifespan of fruits. However, as a tropical fruit, the betel nut can experience a chilling injury when stored below 14 °C [83]. Storage at 25 or 5 °C increased polyphenol oxidase (PPO) activity and reduced the total phenolic content in the kernel [86]. Another study has shown that a storage temperature of 10 °C was better than 4 °C [87]. When the temperature drops further to −18 °C, betel nuts maintain a better appearance and color compared to 4 °C and 10 °C. At this temperature, betel nuts do not undergo respiration [87]. However, during the thawing process after cold storage, some betel alkaloids may be lost due to dehydration [50]. The recommended storage condition for fresh betel nuts is 13 °C with a relative humidity of 90% [88,89].

Methyl jasmonate (MeJA) was tested to prevent a chilling injury in fresh betel nuts [90]. The results indicated that 100 μmol/L of the MeJA treatment significantly alleviated the chilling injury at 11 °C, especially by inhibiting lignin formation and retaining phenolic substances. Hot water treatments have been found to induce a chilling tolerance and delay the lignification of betel nuts during cold storage. Betel nuts treated with hot water at 45 °C exhibited the lowest levels of chilling injury, MDA content and relative electrolyte leakage (EL) while maintaining the highest total phenolic content. Additionally, both the 45 °C and 50 °C hot water treatments effectively hindered the accumulation of lignin by inhibiting the activities of phenylalanine ammonia-lyase (PAL), cinnamyl alcohol dehydrogenase (CAD) and peroxidase (POD) [91].

4.4.4. Modified Atmosphere Packaging (MAP) Technology

Modified atmosphere packaging (MAP) technology is commonly used for preserving fruits and vegetables. The gases typically employed in MAP include ethylene, nitrogen (N_2), sulfur dioxide (SO_2), oxygen (O_2), ozone (O_3) and carbon dioxide (CO_2) [92]. Li Yaoyao et al. stored fresh betel nuts in MAP bottles containing 3% oxygen and 20% carbon dioxide and effectively maintained the original color of the betel nuts for a period of 30 days [68]. Another study conducted by Xia Bing demonstrated that storing betel nuts in an environment with 2% oxygen, 5% carbon dioxide and 93% nitrogen at a temperature of 6 °C and a relative humidity of 75% extended the storage period of the nuts to over 40 days [85]. These findings align with the research conducted by Huang Shuisheng et al. [93], who also concluded that MAP can effectively delay the browning of betel nut kernels and preserve their appearance and texture.

4.4.5. Coating Preservation Technology

Coating preservation refers to the application of an edible film layer to the surface of fruits, typically composed of polysaccharides, lipids, polyvinyl alcohol and protein-based composite films. This process enhances the fruit's appearance by increasing its brightness; reducing the infection of external pathogens; and regulating quality indicators such as the respiration intensity, hardness and substance composition [94]. Pan Liao et al. discovered that the yellowing of betel nut skin can be delayed for up to 30 days by soaking in a solution containing chitosan (0.5%) and sodium dehydroacetate (50 mg/L) [95]. Li Shangbin et al. achieved a further delay in the yellowing and deterioration of betel nuts by treating them with a coating film containing 100 mg/L 6-benzylaminopurine (6-BA), 100 mg/L gibberellin (GA3) and a 50% fruit wax, followed by low-temperature storage [96]. Zhang Jiaojiao et al. found that treating betel nuts with a combination of fruit wax and sulfur dioxide effectively controlled betel nut aging from both physiological and pathological aspects, protecting the color, preventing browning and reducing the rotting rate [97]. Chemical coating preservation yielded better results by effectively delaying the decrease in the peel color and brightness and exhibited a more pronounced initial antibacterial effect. However, traditional water-soaking treatments may lead to secondary pollution as drug molecules or ions can easily penetrate the fruits.

4.4.6. Plant-Based Preservatives

Plant-based preservatives are derived from plant extracts. These preservatives offer several advantages, including nontoxicity, harmlessness, safety, reliability and low cost. As a result, they hold promising potential for applications in the field of food preservation [98]. Cheng Hongbin et al. conducted a study in which they investigated the effects of plant-based preservatives such as *Magnolia* ethanol extract, *Perilla* and *Centella asiatica* water extracts and pine needle essential oil, in combination with a low-temperature vacuum environment. The findings revealed that this method effectively increased the moisture and titratable acid content of betel nuts while significantly reducing the levels of polyphenols and the cell membrane permeability. Moreover, it demonstrated a significant inhibition of POD and PAL, thus prolonging the storage period of betel nuts [99]. Additionally, thymol, an essential oil extract that is derived from plants, demonstrated a strong inhibitory effect on major pathogenic microorganisms such as mold. Composite films containing tea polyphenols, thymol and chitosan, combined with radiation-treatment technology, exhibited excellent preservation capabilities for betel nuts [100].

Table 3. Storage technologies employed for fresh betel nuts.

Methods	Conditions	Advantages	Disadvantages	Reference
Chemical-processing technology	Treatment condition: 0.27 mg/L TBZ, 16 °C, 24 min; preservation condition: 14 °C, RH 80–90%, 40 days.	Eliminating microorganisms, stable treatment effect, simple process.	Secondary pollution.	[84]
	Preservation condition: solid sulfur-dioxide-release preservatives, 0.03 mm PVC bag, 3.0 kg fruit per bag, 8 °C, RH 70–80%, 40 days.			[85]

Table 3. *Cont.*

Methods	Conditions	Advantages	Disadvantages	Reference
Cold storage and chilling-injury-prevention technology	Treatment condition: 100 µmol/L MeJA, 15 °C, 24 min; preservation condition: 11 °C, RH 90–95%, 30 days.	Reduced metabolism, inhibited microorganism growth, no chemical residues, high safety, simplicity.	Specific operations needed for chilling-injury prevention.	[90]
	Treatment condition: 45 or 50 °C hot water, 5 min; preservation condition: 13 °C, RH 90%, 60 days.			[91]
Modified atmosphere packaging technology	3% oxygen, 20% carbon dioxide, 11 °C, 30 days.	Reduced metabolism, retained flavor, decreased organic matter consumption, inhibited microorganism growth.	Increased capital and material cost, complicated operation.	[68]
	2% oxygen, 5% carbon dioxide, 93% nitrogen, 6 °C, RH 75%, 40 days.			[85]
Coating preservation technology	Treatment condition: 0.5% chitosan, 50 mg/L sodium dehydroacetate. Preservation condition: 4% oxygen, 4% carbon dioxide, 92% nitrogen, 13 °C, RH 90%, 30 days.	Reduced metabolism, decreased organic matter consumption, inhibited microorganism growth.	Reagent residue.	[95]
	Treatment condition: 100 mg/L 6-BA, 100 mg/L GA3, 50% fruit wax. Preservation condition: 7 °C, RH 90%, 21 days.			[96]
	Treatment condition: fruit wax for 30 s, fumigated with 2500 µL/L SO_2, 0.5 h for every 15 days.			[97]
Plant-based preservatives	1% Magnolia ethanol-extracting solution, 2% Perilla water-extracting solution, 1% *Centella asiatica* water-extracting solution, 0.3% pine needle essential oil.	Nontoxic, harmless, low residue, environmentally friendly.	Higher cost, average performance.	[99]
	3.56 g/L tea polyphenols, 1.75 g/L thymol, 11.83 g/L chitosan.			[100]

4.5. Chemical Pollution of Betel Nut and Its Control Technology

In addition to microbial contamination, potential chemical pollutants in betel nuts should not also be ignored. According to a study conducted by Kang Xiaoning et al., the residual content of benzo[a]pyrene in dried betel nuts, processed by traditional smoking methods, can reach up to 26.52 µg/kg [101]. When betel nuts are dried by using improved modern ovens, the benzo[a]pyrene content falls within the control standards [101]. Lin Lin et al. suggest that the high concentration of copper ions in betel nuts is also a factor contributing to oral submucous fibrosis (OSF). They discovered that soaking betel nuts in dilute hydrochloric acid can significantly reduce the copper content [102]. Furthermore, betel nuts may also contain excessive fluoride ions. This may be attributed to the high fluoride ion content in the original betel fruits as well as the unqualified processing ingredients, such as fluoridated lime [58].

During the processing of betel nut, different kinds of food additives such as preservatives are added. Furthermore, it is noted that the standards outlined in GB 2760-2014 stipulate that only three preservatives can be used in refined betel nuts [103]. For example, the maximum allowable addition of sorbic acid and benzoic acid is 0.5 g/kg. Therefore, it is crucial to prevent the excessive and inappropriate use of preservatives. In the initial development of the betel nut industry, excessive amounts of preservatives such as dehydroacetic acid and its sodium salt were utilized to prolong the shelf life of betel nuts by some unethical companies [104]. In a subsequent sampling conducted by local media in 2022, it was discovered that the content of dehydroacetic acid in all betel nuts fell within the specified range [70]. This suggests that advancements in betel-nut-processing technology over the past decade have reduced the reliance on preservatives to prolong the shelf life of the betel nuts.

In order to enhance the flavor of the betel nut and reduce the costs, some unethical companies may have excessively used sweeteners such as saccharin. A survey conducted in 2012 revealed that some refined betel nut products contained sweeteners such as sodium saccharin and acesulfame in amounts that exceeded the permissible limit by up to 12 times [58]. A survey conducted in 2022 found that the sweetener content in all refined betel nut products did not surpass the limit [70]. However, over the past decade, the variety of sweeteners added to refined betel nut has increased. Limited quantities of sweeteners can be metabolized by the human body, but prolonged excessive buccal intake can harm the liver and kidneys [105].

In conclusion, the chemical contamination of refined betel nut primarily stems from substandard and illegal manufacturing processes. By optimizing the processing methods and strengthening regulatory measures, the chemical pollution of betel nut products can be effectively controlled.

5. Conclusions

Refined betel nut is a traditional local addictive substance in Hunan. The development of its processing technology has gone through a long historical process. Significant progress has been made in the areas of betel nut storage, the softening of betel nut fibers, the comprehensive control of microorganisms and the prevention of brine whitening and brine returning. The extensive implementation of emerging technologies can improve both the production efficiency and product quality in the betel nut industry. However, it also introduces new challenges concerning quality control and risk prevention. Nowadays, the betel-nut-processing industry faces numerous unresolved policy and scientific issues.

The betel-nut-processing industry currently faces a primary issue concerning the absence of production and evaluation standards. Currently, there are only local standards pertaining to the refined betel nut industry, including local standard DB43/132-2004 in Hunan Province and DB46/T75-2007 in Hainan Province [106,107]. These outdated standards are ineffective at guiding the current production process of refined betel nuts. This lack of supervision inadvertently paves the way for illegal activities. Policymakers may consider establishing and issuing new local standards and processing regulations with sufficient binding force to facilitate the strict and orderly management of the betel-nut-processing industry, considering the unchanging nature of refined-betel-nut-chewing customs in the short term.

The health impact of chewing betel nuts has been the focus of public concern. However, research on the pathogenicity mechanism of betel nut chewing has been progressing slowly, which is detrimental to both the physical health of betel nut consumers and the improvement in betel-nut-processing technology. Therefore, there is a need for increased efforts to investigate the effects of refined betel nuts on human health, focusing on its chemical composition, pharmacological activity and underlying mechanisms, especially the risks of oral cancer associated with betel nuts' coarse fibers and alkaloids like arecoline. Urgently required research encompasses the development of animal disease models for chewing betel nuts as well as investigating the mechanisms of synergistic carcinogenesis by risk factors. It is hoped that future fundamental studies can make significant progress in these areas and provide guidance for the production of safer betel nut products.

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References

1. Chao, Y.Z.; Liu, Y.; Chen, J.; Zhao, Z.Y.; Xia, Y.B.; Li, Y.X. Study on the Present situation of edible areca industry and development strategy in Xiangtan. *Farm Prod. Process.* **2019**, *2*, 74–77.
2. Williams, S.; Malik, A.; Chowdhury, S.; Chauhan, S. Sociocultural aspects of betel nut use. *Addict. Biol.* **2002**, *7*, 147–154. [CrossRef] [PubMed]
3. Jain, V.; Garg, A.; Parascandola, M.; Chaturvedi, P.; Khariwala, S.S.; Stepanov, I. Analysis of alkaloids in betel nut-containing products by Liquid Chromatography–Tandem Mass Spectrometry. *J. Agric. Food Chem.* **2017**, *65*, 1977–1983. [CrossRef] [PubMed]
4. Li, M.; Pang, X.; Gu, Z.; Guo, Z.; Xin, Y.; Zhang, L. Rapidly analyzing of ingredients during chewing and processing of betel nut using feature-based molecular networking. *Food Chem.* **2023**, *410*, 135205. [CrossRef] [PubMed]
5. Dalisay, F.; Buente, W.; Benitez, C.; Herzog, T.A.; Pokhrel, P. Adolescent betel nut use in Guam: Beliefs, attitudes and social norms. *Addict. Res. Theory* **2019**, *27*, 394–404. [CrossRef]
6. He, X.Y. *Study on the Changes in Material Basis and Biological Effects during the Roasting Process of Betel Nut*; Chengdu University of TCM: Chengdu, China, 2015.
7. Hu, J.; Chen, M.; Li, L.J.; Feng, C.; Zhang, D.L. Research report on the overview of betel nut cultivation and processing in Hainan. In Proceedings of the 5th National Local Mechanical Engineering Society Academic Annual Conference 2015 and Made in China 2025 Development Forum, Tengchong, China, 1 November 2015.
8. Wang, D.; Pang, Y.X.; Hu, X.; Zhang, X.D.; Lin, M.X.; Yu, F.L.; Xie, X.L. Development and motivation analysis of areca planting industry in Hainan province. *Guangdong Agric. Sci.* **2013**, *40*, 207–209.
9. Chen, W.L.; Wang, C. Promoting the healthy and sustainable development of the betel nut industry in Hainan. *Hainan Daily*, 13 October 2019; p. 1.
10. Yuan, J.; Zhang, H.; Zhao, H.; Ren, H.; Zhai, H. Study on dissociation and chemical structural characteristics of betel nut husk. *Molecules* **2023**, *28*, 1513. [CrossRef]
11. Huang, H.D. 2015 betel nut industry development report and forecast. *World Trop. Agric. Inf.* **2017**, *1*, 31–39.
12. Xie, H. Accelerating the rule of law: A fundamental measure to solve the dilemma of the betel nut industry in our province. *People's Friend* **2022**, *9*, 49–50.
13. Betel nut market monitoring analysis in June. *World Trop. Agric. Inf.* **2019**, *7*, 40–42.
14. International Agency for Research on Cancer. Personal habits and indoor combustions. A review of human carcinogens. *IARC Monogr. Eval. Carcinog. Risks Hum.* **2012**, *100*, 1–538.
15. Marques, M.M.; Beland, F.A.; Lachenmeier, D.W.; Phillips, D.H.; Chung, F.L.; Dorman, D.C.; Guyton, K.Z. Carcinogenicity of acrolein, crotonaldehyde, and arecoline. *Lancet Oncol.* **2021**, *22*, 19–20. [CrossRef] [PubMed]
16. Jing, Y.S.; Ma, Y.F.; Pan, F.B.; Kuang, F.J.; Zhang, D.S.; Guo, X.D.; Wu, L.F. Research Progress on Herbal Textual Research, Chemical Constituents and Pharmacological Effects of Areca Catechu. *Asia-Pac. Tradit. Med.* **2022**, *18*, 232–239.
17. Chen, X.X.; He, Y.Z.; Deng, Y. Chemical composition, pharmacological, and toxicological effects of betel nut. *Evid. Based Complement. Altern. Med.* **2021**, *2021*, 1808081. [CrossRef] [PubMed]
18. Yi, S.; Zou, L.; Li, Z.; Sakao, K.; Wang, Y.; Hou, D.X. In vitro antioxidant activity of betel nut polyphenol extracts on RAW264.7 Cells. *Foods* **2022**, *11*, 3607. [CrossRef]
19. Peng, W.; Liu, Y.J.; Wu, N.; Sun, T.; He, X.Y.; Gao, Y.X.; Wu, C.J. *Areca catechu* L. (Arecaceae): A review of its traditional uses, botany, phytochemistry, pharmacology and toxicology. *J. Ethnopharmacol.* **2015**, *164*, 340–356. [CrossRef]
20. Peng, Y.M.; Gong, N.C.; Li, P.H.; Tan, D.B. Compositional changes and multivariate statistical analysis of edible betel nut during processing. *Food Ind.* **2021**, *3*, 96–101.
21. Zhu, L.; Zhang, H.D. Current situation and prospect of betel nut processing. *Farm Prod. Process.* **2011**, *8*, 68–69+73.
22. Chen, W.X.; Dou, H.G.; Li, C.F.; Wang, Z.N.; Fu, X. Study on the processing technique of edible areca. *Food Sci. Technol.* **2007**, *32*, 57–59.
23. Yan, D.; Li, Y. Study on the processing technique of edible areca. *Food Mach.* **2003**, *19*, 34–35.
24. Rasheed, S.; Dasti, A.A. Quality and mechanical properties of plant commercial fibers. *Pak. J. Biol. Sci.* **2003**, *6*, 840–843. [CrossRef]
25. Chen, G.; Liu, Z.Y. Study on the processing technique of edible areca with green areca fruit. *Food Sci. Technol.* **2009**, *34*, 80–83.
26. Zhon, Q.D. Hainan Qionghai will ban some traditional betel nut processing sites. *World Trop. Agric. Inf.* **2013**, *12*, 9–10.
27. Li, D.X. Techniques of smoking meat product. *Meat Ind.* **2006**, *7*, 18–20.
28. Xiao, X.Y. *Optimization of Alkali Boiling Process for Edible Betel Nut Soften and Analysis Changing during Chewing*; Agricultural University of Hunan: Changsha, China, 2020.
29. Li, Z.; Xu, H.H.; Deng, J.Y.; Jiang, X.W.; Li, H. Study on inteneration and sterilization of areca by high-temperature dry steam treatment. *Food Mach.* **2015**, *31*, 194–197.
30. Dai, J.H.; Kang, X.N.; Ji, J.B.; Dai, W.T.; Wang, S.P.; Ma, J.S. Research and optimization of alkali deastringency technology for dried Areca nut. *Storage Process.* **2021**, *21*, 88–95.

31. Song, X.H.; Zhu, J.D.; Li, Z.; Ma, C.Y.; Wang, H.X. Study on the influence of processing steps and storage conditions on the physicochemical properties of betel nut. *Food Ferment. Ind.* **2023**, *1*, 1–8.
32. Hunan Huangye Food Co., Ltd. A High-Pressure Rapid Fermentation Method for Betel Nut. China Patent CN201510349525.0, 21 October 2015.
33. Huang, Q.; Liu, K.K.; Chen, K.; Jian, X.P. Effect of processing technology on the content of arecoline in areca product. *Food Ind.* **2021**, *42*, 57–60.
34. Xie, L.L.; Zhang, H.J.; Fang, J. Research progress of betel nut processing in China. *Guangdong Agric. Sci.* **2011**, *38*, 96–98.
35. Duan, W.F. Vacuum Fermentation and Immersion Processing Method for Betel Nut: China. China Patent 1554248A, 29 December 2003.
36. Jian, X.P.; He, J.W.; Chen, K. Preparation of emulsified coating agent and its application in Areca nut coating. *Food Ind.* **2021**, *42*, 22–25.
37. Li, L.Y. *Study on the Quality Changes and Characteristics of Edible Betel Nut Pickled Water during Shelf Life*; Central South University of Forestry and Technology: Changsha, China, 2022.
38. Shi, Y. *Structure Design of Edible Betel Nut Cutting Machine*; Xidian University: Xi'an, China, 2014; pp. 20–23.
39. Zhou, C.L. *Research and Design of Areca-Nut Cutting Machine*; Guangdong University of Technology: Guangzhou, China, 2015; pp. 27–29.
40. Yin, X.M.; Peng, J.Y.; Gao, Y.J. Clinical study on the relationship between tooth abrasion and the habits of chewing betel nut. *Hunan Yi Ke Da Xue Xue Bao* **2003**, *28*, 171–173.
41. Shirzaiy, M.; Neshat, F. Effect of areca nut on oral health. A review. *J. Res. Dent. Maxillofac. Sci.* **2020**, *5*, 1–6. [CrossRef]
42. Li, W.C.; Lee, P.L.; Chou, I.C.; Chang, W.J.; Lin, S.C.; Chang, K.W. Molecular and cellular cues of diet-associated oral carcinogenesis-with an emphasis on areca-nut-induced oral cancer development. *J. Oral Pathol. Med.* **2014**, *44*, 167–177. [CrossRef] [PubMed]
43. Nguyen, X.H.; Reichart, P.A. Betel quid chewing, oral cancer and other oral mucosal diseases in Vietnam. A review. *J. Oral Pathol. Med.* **2010**, *37*, 511–514.
44. Song, P.D. A review of the habit of chewing betel nut and oral health research in China. *J. Diet. Suppl.* **2021**, *23*, 295–296.
45. Zhao, Z.Y.; Chao, Y.Z.; Yuan, S.S.; Liu, Y.Y.; Xiao, D.; Xia, Y.B. Effects of different softening methods on quality of edible areca. *Food Mach.* **2017**, *33*, 189–193.
46. Rajan, R.; Ajith, S.; Joshy, A.; Anita, R. Bleaching and softening of coir fiber using *Averrhoa Bilimbi* extract. *J. Nat. Fibers.* **2022**, *19*, 4477–4484. [CrossRef]
47. Cheng, L.F.; Li, Q.; Ji, J.B.; Duan, S.W.; Feng, X.Y.; Zeng, J.; Yang, Q.; Liu, Z.Y.; Zheng, K.; Peng, Y.D. Enzymatic softening technology of Areca nut shell. *J. Biobased Mater. Bioenergy* **2017**, *11*, 644–648. [CrossRef]
48. Li, W.; Zheng, C. Study on inteneration Areca hull by enzymatic hydrolysis coupled with high pressure treatment. *Guangdong Chem. Ind.* **2007**, *5*, 23–25.
49. Wu, S.; Li, Z.J.; Tan, Y.; Du, S.; Huang, R.T.; Wu, J. Boiling softening effects and irradiation preservation research of dried betel nut. *J. Nucl. Agric. Sci.* **2017**, *31*, 711–718.
50. Wang, X.D. *Study on Key Technology of Microwave Puffing Areca*; Zhengzhou University: Zhengzhou, China, 2018.
51. Chao, Y.Z.; Xia, Y.B.; Zhao, Z.Y.; Ou, Y.H.; Wu, Y.X.; Li, Q. Optimization of ultrasonic enzyme softening technology for edible Areca. *Farm Prod. Proces.* **2016**, *21*, 14–17.
52. Li, G.; Ma, L.; Yan, Z.; Zhu, Q.; Cai, J.T.; Wang, S.; Yuan, Y.; Chen, Y.Z.; Deng, S.W. Extraction of oils and phytochemicals from *Camellia oleifera* seeds: Trends, challenges, and innovations. *Processes* **2022**, *10*, 1489. [CrossRef]
53. Yang, B.; Xu, Y.P.; Chen, W.J.; Chen, W.X.; Zhong, Q.P.; Zhang, M.; Pei, J.F.; Chen, H.M. Effect of steam explosion on the morphological, textural and chemical composition characteristics of betel nut. *Res. Sq.* **2023**. [CrossRef]
54. Huang, Q.; Xiao, W.D.; Zhang, X.J.; Li, Z.; Yang, S.L.; Gao, X.T. Research and application of steam explosion on the quality of Areca Product. *Food Ind.* **2019**, *40*, 73–77.
55. Sun, Z.Q.; Tan, H.H.; Song, J.Q.; Hou, Y.B.; Huang, J.X. Orthogonal experimental study on steam explosion treatment technology of Areca nut. *Adv. Eng. Technol. Res.* **2022**, *1*, 70. [CrossRef]
56. Deng, J.Y.; Li, H.; Jiang, X.W.; Yao, L.; Xu, Y.T.; Lu, K.Q. Research progress on processing technology, chemical, and microbial contamination of edible betel nut. *Food Mach.* **2018**, *34*, 173–176.
57. Bhat, S.K.; Ashwin, D.; Sarpangala, M. Contamination and adulteration in arecanut (*Areca catechu* L.) and its chewing foms: The less focused subject by health researchers. *IOSR J. Environ. Sci. Toxicol. Food Tech.* **2017**, *11*, 7–12. [CrossRef]
58. Xu, D. *Safety Risk Analysis of Edible Betel Nut*; Central South University of Forestry and Technology: Changsha, China, 2012.
59. Yin, B.; Yu, J.; Sheng, C.M.; Cheng, Y.H. Betel nut mold of the advantages of raw materials and the development of fungicide. *Food Mach.* **2008**, *24*, 24–28.
60. Kang, X.N.; Ji, J.B.; Xia, B.; Wang, H.C. Preliminary identification of storage period diseases in betel nut fruits. *China Trop. Agric.* **2011**, *6*, 61–63.
61. Ruan, Z.Q.; Deng, J.Y.; Jiang, X.W.; Yao, L.; Li, H.; Luo, X.M.; Lu, K.Q. Variations of bacterial community structure during storage and processing of the betel nut. *Food Mach.* **2021**, *8*, 146–152.
62. Zhang, Q.L.; Peng, L.; Cheng, X.M.; Xu, Y.F.; Zhou, Y.J.; Feng, Y.Y.; Li, W.G. The composition and changes of fungi community during processing of edible betel nut. *J. Nucl. Agric. Sci.* **2020**, *34*, 2541–2550.
63. Wan, X.; Wan, J.Z.; Ai, C.X. Research and development of the fresh-keeping *Areca catechu*. *Food Sci. Technol.* **2003**, *6*, 19–22.

64. Du, D.L.; Gan, B.C.; Wang, Y.S.; Feng, J.D.; Chen, W.P. Study on sterilization by microwaves on edible *Areca catechu*. *Food Sci. Technol.* **2005**, *7*, 86–88.
65. Xu, Y.F.; Deng, G.Q.; Peng, L.; Li, W.G.; Zou, C.H.; Mao, Q.X.; Hu, J.S.; Cheng, W. Effect of irradiation on sterilization and quality of edible Areca nut. *J. Nucl. Agric. Sci.* **2014**, *28*, 240–244.
66. Jin, H.Y.; Fu, C.R. Effect of complex preservative on betel nut. *China Food Addit.* **2014**, *23*, 128–133.
67. Li, Z.; Xu, H.H.; Hu, H.; Chen, J. Study on technology of reducing water activity of Areca production. *Farm Prod. Process.* **2015**, *5*, 11–13.
68. Li, Y.Y.; Yang, X.Z.; Li, S.H. Effects of different storage conditions on quality of *Areca catechu* L. *China Fruit Veg.* **2015**, *36*, 11–13.
69. Li, W.X.; Li, F.; Zhou, S.H.; Yuan, X.; Huang, X.W.; Xu, B.C.; Luo, J. Monitoring and analysis on microbes in edible areca processing. *Food Mach.* **2020**, *36*, 58–62.
70. China Consumer Reports Home Page. Available online: https://www.ccreports.com.cn/food/41534.html (accessed on 24 October 2023).
71. Chen, Q.H.; Jian, X.P.; Chen, S.; Kang, M.X.; Liu, K.K. Study on edible areca nut brine whitening and its inhibition. *China Food Addit.* **2020**, *31*, 83–88.
72. Ma, J.S.; Kang, X.N.; Wang, S.P.; Dai, W.T.; Dai, J.H.; Ji, J.B. Composition analysis of white substances on the surface of edible Areca brine. *Food Ind.* **2021**, *42*, 261–264.
73. Fu, C.R.; Chen, Y.H.; Li, Y.S. A Brine of Edible Betel Nut and an Inhibitor of Brine Whitening: China. China Patent 104304846A, 28 January 2015.
74. Guo, Z.G.; Kuang, F.J.; Kuang, F.J.; Zhang, Q.L. An Edible Betel Nut Brine and Its Production Method: China. China Patent 101843305A, 29 September 2010.
75. Li, L.Y. *Study on the Quality Changes of Edible Betel Nut in Brine Solution during Shelf Life*; Central South University of Forestry and Technology: Changsha, China, 2022.
76. Tang, M.X. An Automated Betel Nut Brine Reactor: China. China Patent 213881673U, 6 August 2021.
77. Wang, W.; Chen, X.P.; Wang, J.W. Automatic Betel Nut Brining Machine: China. China Patent 304600498S, 27 April 2018.
78. Kang, X.N.; Ji, J.B.; Dai, W.T.; Wang, S.P.; Ma, J.S.; Dai, J.H. A Method for Evaluating the Brine of Edible Betel Nut: China. China Patent 112179938, 5 January 2012.
79. Li, L.Y.; Pan, F.B.; Zhou, W.H.; Qian, X.; Wang, Y.R.; Mo, H. Study on quality control of edible areca during shelf life. *Food Mach.* **2021**, *37*, 188–193, 218.
80. Xiao, D.; Zhao, Z.Y.; Wu, Y.X. Edible Betel Nut Brine with the Ability to Inhibit Returning of Betel Nut and Its Preparation Method: China. China Patent 106551365B, 17 November 2020.
81. Huang, Q.; Gao, X.; Jian, X. Research progress on preservation and deep processing technology of areca nut. *Food Ind.* **2021**, *42*, 251–254.
82. Jiang, Y.M.; Chen, F.; Zhang, D.L.; Liu, S.X.; Li, Y.B. Browning substrates of betelnut. *Chin. J. Trop. Crops* **1992**, *2*, 93–96.
83. Guo, Y.; Pan, Y.; Zhang, Z.; Zhang, W. Study on the browning mechanism of betel nut (*Betel catechu* L.) kernel. *Food Sci. Nutr.* **2020**, *8*, 1818–1827. [CrossRef]
84. Zhang, J.J.; Hao, X.L.; Li, H.X.; Liu, J.; Li, M.; Zhang, W.T.; Du, Y.R. Effects of different preservation treatments on storage quality of betel nut. *Stor. Process.* **2016**, *16*, 16–20.
85. Xia, B. *Study on the Respiratory Mechanism and Key Technologies of Storage and Preservation for Betel Nuts*; Hainan University: Haikou, China, 2010.
86. Pan, Y.; Guo, Y.; Huang, Q.; Zhang, W.; Zhang, Z. Enzymatic browning in relation to permeation of oxygen into the kernel of postharvest areca nut under different storage temperatures. *J. Food Sci. Technol.* **2021**, *9*, 3768–3776. [CrossRef]
87. Gu, W.L. *Effects of Fresh Keeping and Processing of Areca catechu on Its Active Components*; South China University of Technology: Guangzhou, China, 2017.
88. Yao, X.L. *Postharvest Storage and Packaging Preserving Process of Betel Nut*; Jiangnan University: Wuxi, China, 2018.
89. Li, W.; Shao, Y.Z.; Gan, X.L.; Wu, S.F. The preliminary study on storage and fresh-keeping methods of arecatechu fruit. *Guizhou Sci.* **2005**, *23*, 69–72.
90. Li, X.H.; Zhang, J.J.; Hao, X.L.; Liu, J.; Li, M.; Zhang, W.T.; Du, Y.R. Effect of Methyl Jasmonate on chilling injury regulation in fresh betel nut. *Mod. Food Sci. Technol.* **2016**, *32*, 260–265.
91. Pan, Y.F.; Xu, M.J.; Guo, Y.L.; Zhang, J.J.; Li, X.H. Effect of hot water treatment on chilling injury and lignification of cold-stored fresh areca nut (*Areca catechu* L.). *J. Food Sci. Technol.* **2020**, *57*, 4337–4344. [CrossRef]
92. Wilson, M.D.; Stanley, R.A.; Eyles, A.; Ross, T. Innovative processes and technologies for modified atmosphere packaging of fresh and fresh-cut fruits and vegetables. *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 411–422. [CrossRef]
93. Huang, S.S.; Qiu, Z.N.; Zhang, Z.Q.; Huang, X.M. Study on postharvest managements of *Areca catechu* fruits. *Guangdong Agric. Sci.* **2012**, *39*, 114–116.
94. Elsa, D.M.; Roberto, C.M. Edible films and coatings as food-quality preservers: An overview. *Foods* **2021**, *10*, 249.
95. Pan, L.; Yao, X.L.; Lu, L.X.; Zhang, D.H. Effect of chitosan and sodium dehydroacetate coating on the quality of betel nuts. *Packag. Eng.* **2019**, *40*, 1–5.
96. Li, S.B.; Zhang, W.W.; Pan, Y.G. Effects of compound with 6-BA, GA-3 and fruit wax coating on the water loss and skin color of betel nuts and its mechanism. *Sci. Technol. Food Ind.* **2017**, *38*, 319–323, 348.

97. Zhang, J.J.; Li, X.H.; Hao, X.L.; Liu, J.; Li, M.; Zhang, W.T.; Du, Y.R. Application of fruit wax coating and SO_2 fumigation in preservation of fresh betel nut. *Food Sci. Technol.* **2015**, *40*, 356–359.
98. Michel, M.B.; Michael, E.N.; Yasmina, S.; Heather, S.; Louwrens, C.H. Plant-based phenolic molecules as natural preservatives in comminuted meats: A review. *Antioxidants* **2021**, *10*, 263.
99. Cheng, H.B.; Pan, X.C.; Wang, F.L.; Jia, X.Y.; Li, J.H.; Wang, D.J. Effect of compound natural antistaling agent on cold storage of betel nut. *Food Ind.* **2022**, *43*, 1–5.
100. Liu, C. *Effects of Electron Beam Irradiation on the Quality of Fresh Betel Nut in Coated and Packaged*; Huazhong Agricultural University: Wuhan, China, 2022.
101. Kang, X.N.; Ji, J.B.; Li, L. Analysis of unsafe factors in baked craft of betel nuts. *Food Mach.* **2015**, *31*, 68–70.
102. Lin, L.; Cheng, L.H.; Zhang, P. Determination of copper content in betel nut and study on methods to reduce its content causing submucous fibrosis of oral mucosa. *Exp. Lab. Med.* **2015**, *33*, 264–265.
103. *GB 2760-2014*; National Food Safety Standard for Uses of Food Additives. National Health and Family Planning: Beijing, China, 2014.
104. 59 Batches of Food Products Fail Quality Inspection. *Guangxi Qual. Superv. Guide Period.* **2013**, *2*, 37.
105. Witkowski, M.; Nemet, I.; Alamri, H.; Wilcox, J.; Gupta, N.; Nimer, N.; Haghikia, A.; Li, X.S.; Wu, Y.; Saha, P.P.; et al. The artificial sweetener erythritol and cardiovascular event risk. *Nat. Med.* **2023**, *29*, 710–718. [CrossRef] [PubMed]
106. *DB43/132-2004*; Local standard for edible betel nut in Hunan. Hunan Provincial Bureau of Quality and Technical Supervision: Changsha, China, 2004.
107. *DB46/T75-2007*; Local Standard for Edible Betel Nut in Hainan. Hainan Provincial Bureau of Quality and Technical Supervision: Haikou, China, 2007.