

# Present Situation and Prospective of Camellia Nut Shells Utilization

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## Abstract

With the rapid development of *Camellia oleifera* industry, more and more Camellia nut shells have been produced, leading to serious environmental pollution problem. This paper reviews the works on the characterization of the physical and chemical properties of Camellia nut shells, active ingredient extraction, its application in chemical production, growing media and animal feed and its properties as a biomass. Based on the review, we proposed a novel all-component high value application strategy to covert camellia nut shells into high value biomasses, which could realize waste recycling and environmental protection.

## Keywords

Camellia Nut Shell, Physical and Chemical Property Analysis, All-Component High Value Utilization, Utilization Status, Prospective Analysis

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## 1. Introduction

*Camellia oleifera* is an important oleiferous tree species in southern China. It is one of the most valuable oleiferous species of Camellia and is considered, along with oil palm, olive and coconut, the four major oleifera tree species in the world (Zhuang, 2008). *Camellia oleifera* has been extensively cultivated in Yangtze River and the Pearl River basins of southern China, mostly in the provinces of Hunan, Jiangxi, Guangxi, Guangdong, Zhejiang, Fujian, Anhui, Guizhou, Yunnan, Henan, Hubei and so on. It can also be found in the provinces of Hainan, Sichuan, Shanxi, Jiangsu, Gansu and Taiwan (Hu, Tang, & Liu, 2006). With the development of tea oil processing industry, the cultivation area of *Camellia oleifera* in China has reached ~5.5 million-hm<sup>2</sup> (Jiang, Chen, Zhuang, Pan, & Zhang, 2011), which leads to an annual production of nearly 10 million tons of Camellia fruit 518,000 tons tea oil and nearly 8 million tons of camellia nut shells (Qiu, Chen, & Hu, 2009; Shen, Kang, & Chen, 2010;

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Jiang, Ying, & Chen, 2010). In recent years, the research on the extraction techniques and technology of tea oil extraction has made a significant progress. The processing and recycling of camellia nut shells have also been improved.

## 2. Studies on the Utilization of Camellia Nut Shells

### 2.1. Physical and Chemical Property Analysis

Camellia nut shell (*Oiltea camellia* or tea bags) is the shell of *camellia oleifera* fruit, which accounts for more than 60% weight of the whole fruit (Qiu, Chen, & Hu, 2009). Generally, Camellia nut shells are burned as fuels, causing a great waste of resources. Zhang et al. characterized the camellia nut shells of six most popular *Camellia* species including *Camellia oleifera* Abel, *Camellia reticulata* Lindl., *Camellia semiserrata* Chi, *Camellia mairei* (Levl.) Mehler, *Camellia meiocarpa* Hu and *Camellia polyodonta* How (Zhang, Du, Yao, & Hu, 2015). The results showed that cellulose, hemicellulose, lignin, ash and content of the organic extracts of the six *Camellia* nut shells were 13.87% - 20.95%, 34.21% - 49.34%, 30.07% - 36.23%, 2.00% - 4.75% and 2.36% - 7.76%, respectively. The contents of K, Na, N and organic carbon content were 7.6 - 13.80 mg·g<sup>-1</sup>, 0.02 - 0.26 mg·g<sup>-1</sup>, 2.91 - 4.42 mg·g<sup>-1</sup>, 44.4 - 48.6 mg·g<sup>-1</sup>, respectively, and their cellulose crystallinity was 37.4% - 62.3% (Zhang, Du, Yao, & Hu, 2015). The thermal degradation of the six *Camellia* nut shells subjected to three stages including water loss in the temperature range of 30°C - 150°C with a weight loss rate of 10%, fast weight loss in the temperature range of 200°C - 430°C with a weight loss rate of 60% and finally slow weight loss (Zhang, Du, Yao, & Hu, 2015). Using Šatava-Šesták method, Ozawa integral method and Kissinger differential method, Gu et al. indicated that the pyrolysis process of camellia nut shell can be divided into three stages: drying, fast degradation and slow degradation, after analyzing *Camellia* nut shell from Hunan based on the thermogravimetric experiment data. Thirty kinds of reaction mechanism functions were adopted to analyze the kinetics of pyrolysis process of *Camellia* nut shell. The Avrami-Erofeev equation was the most reasonable model for camellia nut shell pyrolysis at different rates. The integral form was  $[-\ln(1 - a)]^3$  and the average activation energy was 79.59 kJ·mol<sup>-1</sup> (Gu, Liu, Wang, Zhang, & Zhou, 2015). *Camellia* nut shell extracts contain large amounts of saponins and polyphenols and low amount of flavonoids (Luo, Shen, Xiao, & Chen, 2011). Xu et al. reported that the average tannin content in the *Camellia* nut shells from Guangxi province was 11.06% (Xu, Chen, Wang, Wu, & Wu, 2009). Zhang et al. identified 46 compounds in the *Camellia* nut shells He gas pyrolyzed at 590°C by Py-GC/MS method, including large amounts of rare bioactive medicine, spices and other ingredients (Zhang, Peng, Liu, Ma, Tan, Chen, & Tian, 2008). Li et al. reported that the saponin content in the *Camellia* nut shells from Zhejiang province of China was 9.66% (Li, Fang, Zhong, Fei, & Luo, 2013). Li et al. analyzed six *Camellia* nut shells and regular *Camellia* from three different cultivation regions, including *Camellia chekiangoleosa* Hu, *Camellia meiocarpa* Hu, *Camellia yuhsienensis* Hu, *Camellia semiserrata* Chi, *Camellia gigantocarpa* Hu et Huang, *Camellia oleifera* Abel from Xianju, Sanjiang and Changshan, by spectrophotometry method. The results indicated that the extracts contain relatively high amounts of active compounds. The highest active ingredients were found in the *Camellia oleifera* Abel nut shells, with >317 mg/g polysaccharide, >35 mg/g flavonoids, >292 mg/g saponin, >252 mg/g polyphenol, 272.99 ± 5.54 mg/g condensed tannin and 135.36 ± 2.54 mg/g hydrolysis tannin content in its extract (Li, Fang, Zhong, Fei, & Luo, 2013).

### 2.2. Extraction and Application of Active Ingredients

#### 2.2.1. Extraction and Application of Pigments

The pigment in *Camellia* nut shells is an abundant, low cost and safe natural food coloring. However, the extraction and stability of the pigments in *Camellia* nut shells are rarely studied. Ling et al. tested the toxicity of the brown pigment from *Camellia* nut shells and the results indicated that it had a chocolate brown color and was a safe food coloring (Ling, 1985). Qiu et al. extracted the brown pigment from *Camellia* nut shells by a microwave-assisted extraction method. The resulting brown pigment is a relatively stable natural pigment and can be widely used in the industries of food, medical and cosmetics and so on.

#### 2.2.2. Extraction and Application of Phenols

##### 1) Extraction and application of tannin

Tannin is a class of water-soluble compounds containing polyphenol hydroxyl groups. It can be classified hy-

dolyzed tannins and condensed tannins and can be found in most plants. Camellia nut shells are an abundant natural tannin source due to its high tannin content. Solvents with a good solubility for tannin and ability to break the hydrogen bonds are required for the tannin extraction. Compared with water and alcohols, acetone is a better tannin extraction solvent (Li, Shen, & Wu, 2013). Xu et al. extracted tannin from Camellia nut shells with the conventional and ultrasonic-assisted water extractions (Xu, Chen, Wang, Wu, & Wu, 2009). The preliminary study showed that the average tannin content in Camellia nut shells was 11.06% and the main ingredients were partially gallated proanthocyanidins. Yang et al extracted tannin from Camellia nut shells by a response surface optimized ultrasonic assisted distilled water extraction method and obtained 4.25% tannin (Yang, Liu, Li, & Hu, 2012). Shen et al. purified tannin extracted from Camellia nut shells with macroporous resins and the purified 3-O-methylellagic acid 4'-O- $\beta$ -D-glucopyranoside (MEAG) and ellagic acid (EA) contents were improved to 11.0974 mg/g and 2.0338 mg/g, respectively, with a 85% recovery (Shen, Li, & Wu, 2013).

Tannin has excellent physiological activities such as anti-bacterial, anti-viral, anti-allergic, anti-oxidation and so on. It has been widely used in leather production, food, household chemicals and mining industries. For example, ellagic acid can be used to reduce serum resisting levels and degrade the adipocytes resisting protein. It can also be used as an ingredient in cosmetics for skin whitening and scar repairing. In all, tannin is a promising new additives for food, nutrient supplements and cosmetics.

### 2) Extraction and application of tea polyphenols

Tea polyphenols is one of the most important and most widely distributed secondary metabolites. Tea polyphenols usually form complexes with biological molecules through hydrogen bonding. Solvents including acetone, methanol, ethanol and water can be used for polyphenol extraction. Chen et al obtained 20.17% polyphenol from Camellia nut shells with 60% acetone-water (Chen, Tang, & Li, 2008). The yields increased to 45% with elution with 30% ethanol. Lin et al obtained 71.13 mg/g polyphenols from Camellia nut shells by refluxing extraction with ethanol under optimized conditions (Lin, Zhu, & Wang, 2014). It has been tested that, among the Camellia nut shells from Guangxi, Jiangxi, Hunan, Zhejiang and Anhui provinces, the extract of *Camellia oleifera* Abel nut shells contains highest total phenol content (gallic acid equivalents = 234.90 mg/g) and has the strongest antioxidant capacity (DPPH Clearance IC<sub>50</sub> = 899.25  $\mu$ g/mL and antioxidant capacity and anti-ascorbic acid equivalent = 12.91 mg/g) (Zhang, Wang, & Wu, 2010). The main active ingredients in Camellia polyphenols are gallic acid, ellagic acid and 3-O-methyl ellagic acid -4'-O- $\beta$ -D-glucopyranose (MEAG) and so on. The content of gallic acid is the lowest with an extraction rate of 3.67 mg/g by alcohol extraction and an extraction rate of 8.94 mg/g by acid extraction (Chen, 2011; Chen, Shen, & Zhao, 2014). The antioxidant capacity of polyphenol is affected by the extraction solvents and the amounts of the solvents and follows the order of ethyl acetate phase, butanol phase, the crude extract and water phase. The extracts have better abilities to remove H<sub>2</sub>O<sub>2</sub>, O<sub>2</sub> and  $\cdot$ OH than its anti-ascorbic acid ability (Chen, Kang, Chen, & Shen, 2011). Polyphenols from Camellia nut shells have effects of antioxidant, inhibition of cancer cell proliferation, hypoglycemic, lipid-lowering diet, prevention of prostate disease and so on. Gallic acid has effects of anti-tumor, anti-oxidation, anti-inflammatory, antibacterial, antiviral, hypoglycemic and so on and can be widely applied to the industries of medicine and nutrient supplement and so on.

### 3) Extraction and application of flavonoid

Flavonoid is a class of natural polyphenol. It is a series compounds consisting of two benzene rings with a phenolic hydroxyl group linked with each other through three carbon atoms (C<sub>6</sub>-C<sub>3</sub>-C<sub>6</sub>). Shen et al. soaked Camellia nut shells in 30 times weight of 60% ethanol and extracted with the assistance of ultrasonic at 40°C for 45 min, and repeated the extraction one more time. The recovery of total flavonoid extraction reached 97.34% and extracted amount was 1.709% of the shell weight (Shen, Jiang, & Wang, 2008). Experimental studies show that the crude flavonoid extract from Camellia nut shells has a certain inhibition to the oxidation of cooking oils (Peng, 2012). Flavonoids have a variety of physiological functions and pharmacological effects, such as anti-oxidation, anti-cancer, anti-cardiovascular disease, anti-inflammatory, anti-viral, immune regulation and so on. Its extract has been applied to the products of food, medicine, cosmetics and so on (Shen, Jiang, & Wang, 2008).

#### 2.2.3. Extraction and Application of Other Active Ingredients

Saponins from Camellia nut shells can be used as a food preservative. Li et al. reported that the decoction of Camellia nut shells mixed with various amounts of bleach powder could be used for the storage of oranges harvested under desired conditions with controlled moisture (Li & Wu, 1991). In addition, the decoction of Camellia nut shells can also be mixed with other reagents for the preparation of preservatives, pesticides, etc.

The Camellia nut shell extracts contain a large amount of insoluble dietary fiber (IDF). Xie et al extracted the IDF from Camellia nut shells by base method under the optimum conditions (1:14 solid-liquid ratio in 0.35 mol/L NaOH at 80°C for 3 h) and obtained 40.4% IDF with a purity of 91.52% (Xie, Chen, Chi, & Liang, 2013). The water-holding capacity and swelling rate of the IDF at room temperature are 2.04 g/g and 1.2 mL/g, respectively, suitable for conventional food applications (Xie, Chen, Chi, & Liang, 2013). Therefore, the IDF in Camellia nut shells can be applied to nutrient supplement for weight loss, digestion, laxation, blood sugar control, and so on.

### 2.3. Preparation and Application of Chemical from Camellia Nut Shells

The abundant cellulose, hemicellulose and lignin in Camellia nut shells have been used for the preparation of ethanol, xylose and vanillin, respectively, under optimum conditions (Zhu, Zhu, Jiang, Xu, Ouyang, & Yu, 2013). Zhu et al. pretreated Camellia nut shells in 12% NaOH, at 120°C for 150 min with a liquid-solid ratio of 10.0 and obtained liquid and solid phases. The solid residue was enzymatically hydrolyzed and feminized, resulting in 17.35 g/L ethanol with an 80.90% conversion rate. The partial hydrolysis and oxidation of the liquid phase produced 1758.63 mg/L xylooligosaccharides and 322.07 mg/L vanillin (Zhu, Zhu, Jiang, Xu, Ouyang, & Yu, 2013). The hemicellulose was hydrolyzed to xylose (ketopentose) that was further hydrogenated to xylitol. Guo et al. sequentially pretreated Camellia nut shells with hot water, NaOH solution and dilute sulfuric acid, followed by the hydrolysis in 1% - 2% sulfuric acid for the preparation of xylose (Guo, 1992). The xylose solution was then neutralized with lime emulsion, decolorized on active carbon, concentrated, cleaned by ion exchange, concentrated, crystallized, centrifuged and dried to obtain a xylose crystalline with a purity over 97.5%. Xu from Lishui city, Zhejiang province hydrolyzed the pentosan from Camellia nut shells to xylose and hydrogenated xylose to xylitol with acceptable quality. Camellia nut shells can be mixed with pig manure as a raw material to produce biogas by the fermentation under anaerobic condition in batches or semi-continuous batches. A maximum yield of 2025 mL/dL was obtained with 1:1 manure/shell ratio (Yu, 2013). Xylose prepared from Camellia nut shells can be used in the food, chemical, and leather industries, such as the production of xylitol, animal feed yeast, furfural and sweeteners. Xylitol is a polyol with five hydroxyl groups. It is a white fine crystal and can be used as the raw materials for the production of plasticizers, paint, chemical fiber additives and so on. It has also been applied to the light industrial products, such as toothpaste, cigarettes, paper and so on. Xylitol is a best-selling medicine for the treatment of diabetes. Camellia nut shells can be processed by various methods, such as fermentation, hydrolysis, enzymatic hydrolysis and so on, to prepare biomasses. For example, the ethanol prepared from Camellia nut shells is an important organic solvent and raw material for the synthesis of other solvents. It has also been used as fuel, disinfectants, preservatives, beverages, food additives, and so on. Vanillin is an important spice and can be used as a fixative agent and flavoring agents. It has also been applied to pharmaceuticals.

Furfural (furaldehyde) is a heterocyclic organic compound. It is a colorless or transparent amber oily liquid and generally produced by the hydrolysis of pentosan followed by dehydration and cyclization (Liu, Li, Wang, & Hu, 2013). One-step and two-step methods have been used for the production of furfural. One-step method includes sulfuric acid method, modified sulfuric acid method, hydrochloric acid method, acetic acid method and inorganic method. Among all crops, Camellia nut shells contain the highest amount of furfural (~19%). Therefore and can be used as the raw material for the production of furfural. Ye et al. obtained 0.137 mol/L furfural from Camellia nut shells by sulfuric acid catalyzed hydrolysis with 230 mL 2 mol/L sulfuric acid at 155°C (Ye, Hu, & He, 2015). Yang et al. extracted furfural with a modified sulfuric acid method (sulfuric acid with bisulfite, phosphate, calcium phosphate, etc.) with a solid-liquid ratio of 5.96 mL/g at 140°C for 3.33 h and obtained 1.93% furfural (Yang, Liu, Li, Xu, & Hu, 2011). Furfural in foods can be directly used as a preservative. It can be oxidized and reduced to synthesize advanced preservatives added in chewing gum, candy, cereal to prevent dental caries. It can also be used in the production of pesticides, such as the production of maleic acid or maleic anhydride by oxidation and Marathon by esterification for killing rice leafhopper, aphid, scale insects and mites. Furfural with a variety of reagents can be used to synthesize multiple pharmaceutical products, such as antibacterial agents, anticancer drugs, anesthetic and anti-inflammatory agents and so on. Its double bond, ether bond and aldehyde group can be oxidized to generate various chemical products, such as the furan resin with good corrosion resistance and thermal stability. In all, furan ring and the aldehyde group of furfural provide extensive potential for its application in the preparation of various chemicals and their derivatives (Jiang, 2009). Hy-

drochloric acid is a common pickling reagent. Small amount of corrosion inhibitor in the pickling solution can slow corrosion process. Corrosion inhibitors of inorganic reagent or synthetic chemicals have a variety of disadvantages, such as toxicity, high cost and so on. Furfural has been used as a high efficient, low cost, multiple controlling and environment-friendly corrosion inhibitor (Liu, Li, Wang, & Hu, 2013).

Potassium carbonate is an important raw material for the industries of chemical, pharmaceutical and light industry. It has been widely used in the industries of light bulbs, electroplating, pharmaceutical industries and so on. Feng et al. extracted potassium carbonate and potassium pyrophosphate crystalline with high purities from Camellia nut shells (Feng & Xu, 2002). Potassium pyrophosphate can be used to substitute potassium cyanide for non-toxic electroplating. In Sanjiang county of Guangxi province, Camellia nut shells have been used to produce composite fertilizer-monopotassium phosphate with a process of Camellia nut shells ashing → dehydrating → boiling dry → high temperature calcination → water dissolving (7 - 10 days) → neutralizing with phosphoric acid solution → water removing by centrifuge. The resulting water-soluble and high efficient composite fertilizer contains 30% potassium chloride and 50% phosphorus pentoxide.

#### 2.4. Utilization in Bio-Energy and Bio-Material

Cellulose, hemicellulose and lignin rich in hydroxyl group are the major components of Camellia nut shells. Theoretically, these compounds can be used to substitute petroleum-based polyether polyols in the nucleophilic addition reactions with isocyanate to prepare polyurethane materials. Zhang et al. liquefied Camellia nut shells at 130°C - 170°C for 120 min with PEG400 and glycerol as the liquefying agent and 3% sulfuric acid as a catalyst. The liquefaction rate reached 98.12% and the resulting liquefied product contains ethers and large amount of esters that can substitute petroleum-based polyether or polyester for the preparation of polyurethane polyols (Zhang, Du, Hu, Fei, & Fang, 2012).

The briquettes fuel has been made which has certain specifications and dimensions, by crushing and compressing Camellia nut shell using biomass compression molding equipment (Wei, 2013). Wei discussed the mechanism of Camellia nut shell molding, and designed a set of processing equipment with can with an theoretical annual output of 40,000 tons Camellia nut shell pellet fuel. The work can provide a theoretical basis for the technical improvement of biomass compression molding and the design optimization of the molding equipments. Zhu et al. has prepared machine-made carbon with the shells of camellia (*Camellia oleifera*), chestnut tea (*Castanea mollissima*) and walnut (*Caryacathayensis*) as raw materials, which will provide a basis for high efficient energetic utilization of epicarps resources and the development of deep processing products of carbon derivatives (Zhu, Zhuang, Pan, Chen, & Zhang, 2013).

#### 2.5. Extraction and Application of Absorbent

Camellia nut shells are carbon-rich and a good raw material for the preparation of activated carbon. It can be produced from Camellia nut shells by steam/flue gas activation method, phosphoric acid activation method, zinc chloride activation method, potassium hydroxide activation method and so on. Sun et al prepared the microporous and mesoporous activated carbon with excellent adsorption performance by steam activation and phosphoric acid re-activation method, which can be used for the purification of the water containing complex contaminations (Sun, Jiang, He, Lin, Cui, & Lu, 2010). Jiang et al. prepared activated carbon powder from Camellia nut shells by microwave heating method with phosphoric acid as the activator. The activated carbon showed 226 mg/g absorption of methylene blue and 100% caramel decolorization ratio (Jiang, Chen, Zhuang, Pan, & Zhang, 2011). Zhou et al. prepared activated carbon under reduced pressure by zinc chloride method, which showed an 1120 mg/g absorption rate for iodine and 373.16 mg/g absorption rate for methylene blue (Zhou, Qiu, Shen, & Huang, 2015). Song et al. studied the absorption properties of the ground Camellia nut shells for the crystal violet in wastewater and found that it showed 95% removal of crystal violet after recycled for 7 times (Song, Guo, & Yan, 2014).

The activated carbon prepared from Camellia nut shells is a good adsorbent material with a large surface area, good mechanic strength, homogenous size, high porosity, high absorption, and other good properties. It can be used for the effective absorption of free chlorine, phenol, sulfur, oil, gum, pesticide residues and other organic pollutants, organic solvent recycling and so on. The activated carbon can also be applied to the industries of pharmaceutical, petrochemical, production of sugar and beverages, alcohol purification and environmental protection, as well as bleaching, refining and purification of organic solvents and sewage treatment. It can also be

used for air purification and odor absorption, such as the deodorants for refrigerators, toilet and so on. In addition, the untreated Camellia nut shells can be used as a bio-absorbent for the dyes in wastewater.

## 2.6. Application in Cultivation Substrate

Camellia nut shells contain a variety of nutrients and chemical components and is a promising cultivation substrate with very good market prospects. For example, sawdust with 30% - 40% Camellia nut shells were used for the shiitake cultivation and no significance was observed on the production and quality (Lv, Ying, Li, Xue, Chen, & Fan, 2014; Ying, Lv, Xue, & Li, 2015). The cultivation of *Hericium erinaceus* in the sawdust with 20% and 40% Camellia nut shells can improve its growth. Its production was significantly increased 29.2% in the cultivation substrate containing 63% Camellia nut shells (Lv, Li, Ying, Xue, Ye, Wang, & Zhu, 2011). Partially Camellia nut shell powder substituted cotton seed hull cultivation substrate can be used for the cultivation of *Enokitake*. However, the growth rate, production and biotransformation rate of *Enokitake* is decreased with the increase of substitution rate when the substitute rate is over 40% (Chen & Mao, 2015). Chen et al mixed the dried Camellia nut shell powder and sawdust at different ratios for the cultivation of black fungus and found that the production of black fungus was significantly improved and the highest production was obtained with 2:8 ratio of Camellia nut shell powder to sawdust (Chen, 2013). Luo et al. prepared a soilless cultivation substrate by the fermentation of Camellia nut shells with nitrogen and microbes (Luo, Tan, & Peng, 2011). Zhang et al developed a cultivation substrate for *Dendrobium nobile* with a composition of 30 - 70 Camellia nut shells, 10 - 40 Camellia meal, 10 - 30 organic filler and 10 - 20 biomass polyurethane release fertilizer (Zhang, Wang, Du, Yao, & Hu, 2015). The cultivation substrate was able to retain and absorb water and provide active ingredient for the growth of *Dendrobium nobile*. The polysaccharide content of the 1 - 2-year-old *Dendrobium nobile* grew in the substrate reached as high as 40% - 50%. Qu et al. investigated the effects of Camellia nut shell substrate on the growth of spring *Dendrobium* and the results indicated that pure Camellia nut shell can potentially replace sphagnum as the cultivation substrate for *Dendrobium nobile* in central China (Qu, Qiu, Wu, Liu, & Wang, 2012). In addition, Camellia nut shells can also be used as the cultivation substrates for other edible fungi, medicinal plants and so on.

## 3. Application Study Tendency of Camellia Nut Shells

At present, the study of the utilization of Camellia nut shells has made some significant progresses. The extraction techniques for pigments, tannin and polyphenols and the preparation of activated carbon and chemicals from Camellia nut shells have been well developed. However, the most utilization of Camellia nut shells is limited in the laboratory and lacks of variety. Therefore, all-component high-value utilization has not been realized, which limits its application in industrial scale. Particularly, 1) the physical and chemical properties of Camellia nut shells have not been well studied. Only the physical and chemical properties of some Camellia nut shells have been reported. 2) Studies have been focused on utilizing Camellia nut shells as a raw material, active ingredient extraction, and chemical conversion. It is based on single product extraction and preparation of chemicals from some components in Camellia nut shells. The large amounts of residues produced from these ingredient extraction and chemical production have not been studied. 3) The function mechanism of the active ingredients from Camellia nut shells has been focused on its extract as lipid-lowering diet, antioxidant and anti-cancer and so on. The applications of saponins, flavonoids, volatile oils, polyphenols, polysaccharides and other ingredients of Camellia nut shells have been rarely studied. These active ingredients can be potentially used for the development of new medicines and nutrient supplements. 4) The application of Camellia nut shells in bio-feed and cultivation substrates have been only focused on their effects on the growth rates of animals, plants and edible fungi mycelial. The effects of the active ingredients such as tannins, pigments, proteins, polysaccharides, phenols and so on, on the growth and metabolism of animals, plants and edible fungus have been rarely investigated.

Based on the review of the current studies on Camellia nut shells, we proposed the study strategies for the utilization of the Camellia nut shells in the future.

First, due to the lack of the knowledge of the physical and chemical properties of Camellia nut shells, further work should be focused on determining the physical and chemical properties of all Camellia nut shells to establish a physical and chemical property database of Camellia nut shells. The database will provide a foundation for the characterization and utilization of Camellia nut shells.

Second, future work should be focused on the systematic and comprehensive study all-component high-value utilization. Based on the physical and chemical properties of various kinds of *Camellia* nut shells, the extraction sequence of active ingredient shall be established. The extracts and residues shall be subjected continuous tracking and analysis to determine their physical and chemical properties that can be used for further exploration of their applications. For example, the extraction solvents can affect the physical and chemical properties, extraction process kinetics and applications of the extracts or the chemical products. High-temperature and high-pressure method or solvent can be used for complete liquefaction of the residue. The liquefied substance can be used to produce chemicals. In all, an all-component high-value conversion and application system would ultimately assist to realize the all-component utilization of *Camellia* nut shells.

Third, from the perspective of nutritional, metabolic and toxicological analysis, the future study should be focused on the effect of the pretreatment and chemical ingredients of the *Camellia* nut shells as cultivation substrates and bio-feed on the metabolisms and nutrient contents of animals, plants, edible mushrooms and so on.

#### 4. Conclusion

All in all, further exploration of the all-component high value utilization of *Camellia* nut shells is highly desired. Based on the physical and chemical properties of *Camellia* nut shell, a regulation mechanism of sequential active ingredient extraction, separation, structural characterization, and extraction techniques can provide a fundamental evidence for its high efficiency active ingredient extraction. All components in the extraction residues can be further converted to chemicals, which complete the theory of the utilization system of *Camellia* nut shells. The conversion mechanism and process micro-controlled production mechanism can be established. Based on the effects of the chemical components of *Camellia* nut shells on the growth, nutrient and metabolism of edible fungus, animals and plants, the pre-treatment methods and preparation technology system can be established to provide experimental evidence for the production of cultivation substrates and bio-feed. These proposed research strategies will completely solve the bottlenecks in the all-component high-value utilization of *Camellia* nut shells in industrial scale.

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