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Review

Phyllanthi Fructus: A modal medicinal and food homologous item in quality evaluation

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ABSTRACT

Phyllanthi Fructus is a highly unique medicine and food homologous item, which exhibits distinctive flavor, notable nutritional value, and abundant pharmacological activity. It has enormous potential in the creation of health products and pharmaceuticals. However, due to the unique laws of quality formation and transfer of *Phyllanthi Fructus*, its appearance, shape, chemical compositions, nutrients, and sensory flavors are frequently greatly influenced by botanical resources, the processing and storage conditions. As a result, the current quality evaluation model is difficult to meet the needs of *Phyllanthi Fructus* as a medicine and food homologous item in the development of diversified products. This paper constructs the hierarchical utilization mode of *Phyllanthi Fructus* based on its unique quality formation and transmission laws, explores the quality evaluation model for food-oriented use and medicinal-oriented use, respectively, and systematically describes the quality evaluation idea under diversified application scenarios. This paper aims to serve as a reference for the construction of a quality evaluation model suitable for the medicine and food homologous item of *Phyllanthi Fructus*.

Contents

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1. Introduction

Phyllanthi Fructus (the ripe fruits of *Phyllanthus emblica* L., Yuganzi in Chinese) also known as Indian gooseberry or Amla, is a fruit that is rich in nutrients and is also used as a medicine. It has a potent sour and astringent flavor as well as an impressive sweet aftertaste. *Phyllanthi Fructus* has the efficacy of clearing heat and cooling the blood, fortifying the stomach and promoting digestion, promoting saliva, and relieving cough. In addition, it is rich in nutrition and has significant health care function. It plays an important role in lowering glucose, regulating blood lipid metabolism, and preventing gingivitis (Variya, Bakrania, & Patel, 2016). It can also be used as one of the important food sources of vitamin C and minerals. For thousands of years, the Middle East, Asia-pacific, and other regions have used it extensively as traditional food and medicine. *Phyllanthi Fructus* has so far been developed into cosmetics, food, dietary supplements, drinks, and other best-selling products in the global market. It is an item of medicine and food homology (MFH) with great development value for both food and medicine. Currently, the main standards for quality control of *Phyllanthi Fructus* are *British Pharmacopoeia, Chinese Pharmacopoeia,* and *Hong Kong Materia Medica Standards,* which primarily use the evaluation indices gallic acid (GA) and ellagic acid (EA). However, because polyphenols, the primary constituent of *Phyllanthi Fructus*, have a complex formation, transformation, and transmission law, various factors such as the origin of the plant, processing and storage conditions of the fruit often have a significant impact on appearance, chemical composition, nutrients, and sensory flavor of *Phyllanthi Fructus* (Huang et al., 2021), making it difficult to control and evaluate the quality. As a result, it is considered that the demands of the current market's rapid development and diversification have become increasingly difficult for the existing quality evaluation methods to meet. Accordingly, based on the special quality formation law of *Phyllanthi Fructus*, this paper clarifies the necessity of classified utilization of *Phyllanthi Fructus*, and systematically describes the quality evaluation idea under diversified application scenarios, which not only promotes the rational utilization of *Phyllanthi Fructus* but also provides a reference for the quality control of fruit kind MFH items under similar conditions.

2. Historical summary and functional understanding of medicinal use and food use of *Phyllanthi Fructus*

Phyllanthi Fructus is commonly consumed in subtropical areas and is native to tropical regions of Southeast Asia, particularly central and southern India, Nepal, China, Myanmar, and so on (Li, Pan, Tian, Yang, & Gong, 2022; Saini et al., 2022). It is rich in vitamin C, selenium, zinc, calcium, and other 16 trace elements, 18 amino acids, and superoxide dismutase (SOD) active nutrients. This fruit is also known as the "natural vitamin pill" in the medical community and holds a prominent position in the Indian traditional medical system due to its high medicinal value in addition to its rich nutritional value (Zhao, Sun, Marques, & Witcher, 2015). *The Caraka Samhita*, an ancient Indian medical book, describes *Phyllanthi Fructus* as a type of prolong-life medicine with extraordinary efficacy. The most popular representative prescription in Ayurvedic traditional medicine, Triphala is made up of the fruits of *Trminalia bellirica* Gaertn., *Terminalia chebula* Retz., and *Phyllanthus emblica* (Peterson, Denniston, & Chopra, 2017). *Phyllanthi Fructus* has a long medical history in the system of traditional Chinese medicine (TCM) and was brought into China with Buddhist scriptures. The Song Dynasty physician Zongshi Kou wrote in *Amplification on Materia Medica* that *Phyllanthi Fructus* can treat metal poisoning. In *Compendium of Materia Medica*, Shizhen Li noted that long-term consumption of *Phyllanthi Fructus* can help with weight loss and life extension. *Phyllanthi Fructus* is frequently used for diuretic, anemia improvement, and treatment of malaria, gastroenteritis, ocular keratitis, gonorrhea, and other diseases in the Middle East and Asia-Pacific regions, such as Iran (Farzaei, Shams-Ardekani, Abbasabadi, & Rahimi, 2013), Nepal (Chalise et al., 2010), Pakistan (Ishtiaq, Hanif, Khan, Ashraf, & Butt, 2007). The medical auxiliary effect of *Phyllanthi Fructus* cannot be compared to that of common edible fruits, according to modern medicine. It has tonic, anti-aging, anti-radiation, and anti-mutation properties. It contains a large amount of SOD and mineral nutrient selenium, which is one of the key factors in delaying aging process and enhancing immunity. Therefore, it can be widely used in the prevention and treatment of hyperlipidemia, hypertension, fatty liver, diabetes, and other diseases. It has since been developed into wildly available anti-oxidation, lipid-lowering, anti-fatigue, improving immunity and other related products.

3. Law of quality formation of *Phyllanthi Fructus*

Phyllanthi Fructus is a typical polyphenolic fruit that primarily contains ellagitannins (ETs), gallotannins (GTs), and flavonoids. Polyphenols are easily transformed and characterized by poor stability. It was discovered that there was little similarity between the chemical fingerprints of *Phyllanthi Fructus* from different batches and the plant sources, and the contents of GA, EA, corilagin, and other components varied greatly (Li et al., 2020a; Chen et al., 2022). The biological drive, microbial drive, and thermal drive are three broad categories that can be used to describe the causes and influencing factors of the quality difference of *Phyllanthi Fructus*. These driving factors force the polyphenols and other constituents in *Phyllanthi Fructus* to undergo continuous complex reactions like oxidation, hydrolysis, and polymerization (Fig. 1), which have a direct impact on its pharmacological activity, nutritional value, and flavor formation. Taking tannin components as an example, the relationship between the composition change and quality formation of *Phyllanthi Fructus* was summarized below.

The two main groups of hydrolysable tannins, GTs and ETs, both come from the metabolism of GA in plants and are important active substances in *Phyllanthi Fructus*. Whereas complex phenolic acyl groups in ETs are formed through chemical or biological transformation of galloyl groups, GTs are produced through esterification. As a result, ETs are both distinguished and linked in terms of chemical structural features from GTs, which makes them both distinct and distinctive in possessing commonalities of tannins. It has been found that in response to external environmental stress, components such as hydrolysable tannins in plants undergo a series of biochemical reactions, which affect their medicinal value (Chang, Wu, & Tian, 2021). Hydrolysable tannins are easily degraded by tannin enzymes secreted by various microorganisms such as linear fungi, yeasts, and bacteria to produce complex intermediate products and small molecule compounds (Rodríguez-Durán, Valdivia-Urdiales, Contreras-Esquivel, Rodríguez-Herrera, & Aguilar, 2011). Hydrolysable tannins are also highly susceptible to hydrolytic conversion during processing heating. Due to their unique molecular structure, ETs among them are more likely to polymerize to produce plant polyphenols with more intricate chemical structures. Studies have shown that ETs are hydrolyzed into EA and urolithins with a high bioavailability by the gut flora in the stomach and small intestine (Zhang et al., 2022).

The abundant polyphenols in *Phyllanthi Fructus* also have a significant impact on its flavor including taste, smell, visual and tactile. For instance, there was a significant correlation between the quantity and type of tannins and the intensity of the bitter and astringent notes in *Phyllanthi Fructus*. Astringency is a special sensory characteristic of foods containing polyphenols, and soluble

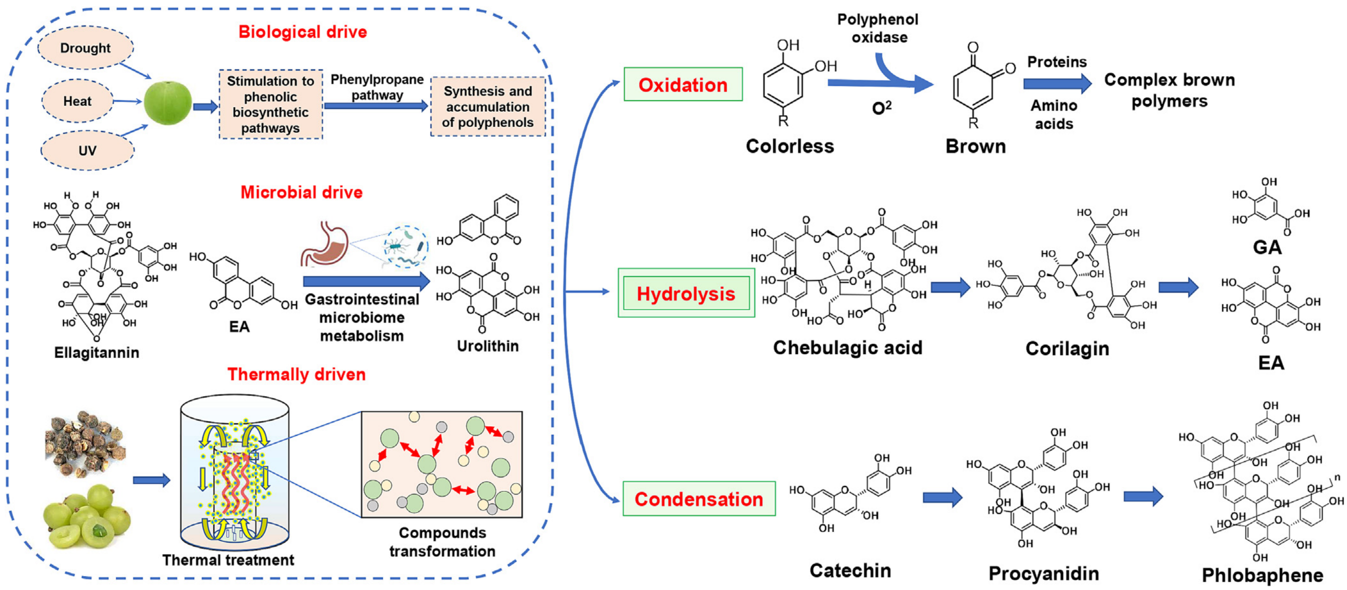

Fig. 1. Driving forces and ways of quality formation of *Phyllanthi Fructus*. The left part shows that *Phyllanthi Fructus* is affected by external environment (light, dry heat), microbial drive (gut microbiota), thermal drive (thermal extraction) and other driving forces. The right part shows that these driving forces make polyphenols and other components in *Phyllanthi Fructus* continuously undergo complex oxidation, hydrolysis, condensation and other reactions.

tannins are a major material contribution to astringency. Studies (Wu, Zhu, Wang, Grierson, & Yin, 2022) have shown that tannins in suitable concentrations contribute to the flavor enhancement of food products and the stability of related products, such as fruit juices. High concentrations of tannins are therefore thought to be extremely medicinal but may impair consumption of the food concerned. It is generally agreed upon that tannins with low molecular weight are typically more bitter and those with high molecular weight are more astringent. Soares et al. (2020) reported that bitter and astringent notes of tannins are complementary taste attributes. Tannin is easily oxidized, which has a significant effect on the color of plants and processed products in addition to its taste. Although plant tannins are typically lighter in color when present in their natural state, they are always mentioned when discussing natural pigments because tannins frequently produce reaction products that are quite dark in color after undergoing chemical reactions, leading one to believe that plant tannins are precursors to some pigments. Poor quality *Phyllanthi Fructus* is often accompanied by batches of browning, which may be due to poor storage conditions that accelerate the oxidation of tannins by polyphenol oxidases and couple to yield reddish-brown or brown toxic quinone products (Tuominen & Sundman, 2013).

The formation and transformation of polyphenols and other substances in *Phyllanthi Fructus* will have a critical impact on the medicinal value and edible quality of it. As can be seen from the above discussion, it is difficult to strike a balance between the two, because the good medicinal value is always accompanied by bitter and astringent sensory flavor. Consequently, it is crucial to combine the quality formation and transfer law of *Phyllanthi Fructus* in order to better construct an evaluation model.

4. Classified utilization of *Phyllanthi Fructus*

P. emblica is rich in resources, leading significant quality differences of its fruit. To ensure the rational utilization of *Phyllanthi Fructus*, it is urgent to construct a classified utilization method. At present, the worldwide *P. emblica* is mainly distributed in the Asia Pacific, Southeast Asia, and the Middle East, making its fruit mainly characterized by two characteristics. Firstly, even though there is a lot of *Phyllanthi Fructus* stored, there is still insufficient resource protection and development of its plant. *P. emblica* has a wealth of wild resources (Liu, Ma, Wan, Li, & Ma, 2020). Taking China as an example, *P. emblica* is widely distributed in the east and west directions south of the Yangtze River, mainly in Yunnan, Guangxi, Fujian, and Taiwan of China, where more than 90% of them are still in the wild or semi-wild state (Qu et al., 2015). Additionally, food use oriented artificial cultivation breeding for *P. emblica* continues to emerge in response to the rising demand for *Phyllanthi Fructus's* food and health products. Some of the fruits in their varieties reported to have superior yield, storage tolerance, and flavor (Kuang, Lai, Xiao, Gao, & Shao, 2020; Lai et al., 2021). Secondly, the quality of the fruit of *P. emblica* varies greatly due to the large difference in habitat and the high level of genetic diversity (Liu, Ma, Wan, Li, & Ma, 2020). *P. emblica* is widely distributed in many regions of the world. Climatic and geographical conditions such as sunshine length, rainfall amount, and altitude have significant effects on its growth. According to the study (Gantait, Mahanta, Bera, & Verma, 2021), this effect is particularly evident in the formation and accumulation of secondary metabolites in its fruits, which alter the fruit's flavor and pharmacological activity.

In addition to the above-mentioned medicinal versus edible categorical utilization, there is a need for further high-quality refined delineation. For instance, the total tannin content in *Phyllanthi Fructus* varies between 6.72% and 11.95% in different producing regions (Wu et al., 2013), while the GA and EA index components range from 2.03 to 31.83 and 4.34 to 39.39 mg/g, respectively (Zhen, Zhang, Dong, & Zhan, 2013). This represents a difference of almost 10 times. Although tannin has strong pharmacological activity, it also has unacceptable astringency. *Phyllanthi Fructus* with a high tannin content is therefore better suited for medicine than food. In addition, other significant factors that contribute to the differences of *Phyllanthi Fructus* in flavor and activity include variations in the content of polyphenols, vitamin C, amino acids, flavonoids, and organic acids (Zhao et al., 2021). The content of these compounds can also be used as a basis for classifying *Phyllanthi Fructus* as edible use or medicinal use.

5. Quality evaluation ideas based on edible purpose

5.1. Study and evaluation of edible flavor of Phyllanthi Fructus

As an edible fruit in Southeast Asia, *Phyllanthi Fructus* has the characteristics of rich taste levels and persistent flavors. Its most distinctive flavor feature is the sweet aftertaste, which can make the oral cavity maintain an impressive effect of generating saliva and sweet taste after a brief stimulation of sour and astringent taste. In the process of chewing, different tastes (sour, astringent, bitter, and sweet aftertaste) appear in the mouth in turn, making it full of taste hierarchy. This unique taste hierarchy is an important edible sensory attribute of *Phyllanthi Fructus* (Jayasundar & Ghatak, 2016). In addition, *Phyllanthi Fructus* has a fresh fruity smell. The above unique taste and smell sensory characteristics constitute the unique flavor characteristics of *Phyllanthi Fructus*, which are valued by the food and beverage industries. At present, as an important raw material for food and health products, *Phyllanthi Fructus* has not established a recognized sensory evaluation standard. Referring to the sensory evaluation methods related to Food Science, it is found that some scholars use empirical oral taste single evaluation method (Teo, Tso, Dam, & Forde, 2022), fuzzy mathematics comprehensive evaluation method (Fan, Xiao, Xian, Ding, & Wang, 2022), sensory simulation evaluation method (Li et al., 2019b) and others to achieve taste assessment and control. Even though these methods are widely used, the results that are typically presented are static and memorized, making it difficult to reflect the dynamic changes in the taste characteristics of *Phyllanthi Fructus* over time. In addition, it can be challenging to evaluate food odors because the odor compounds in fruits and vegetables frequently have low thresholds and low contents.

In order to score the taste intensity at various time points, Huang et al. conducted a sensory test on volunteers using the time advantage description analysis method, which can accurately reflect the taste hierarchy and dynamic change of *Phyllanthi Fructus* (Huang et al., 2022; Li et al., 2019a). The results demonstrated a linear relationship between taste intensity and retention time. For instance, the degree of astringency within the specified range increases linearly over time. Further, the sensory intensity and retention time were combined to obtain the comprehensive taste index of each taste. The index not only reflects the taste intensity but also emphasizes its change in time scale, which can better reflect the taste characteristics of *Phyllanthi Fructus*. In addition, it is also possible to combine the results of sensory experiments described above with the results of quantitative analysis of taste component substances, and further clarify that the taste of *Phyllanthi Fructus* forms the basis. For example, those known ingredients in *Phyllanthi Fructus* have sour taste (organic acids), bitter taste (amlaic acid, Kaempferol, rutin, quercetin, and their derivatives), and sweet aftertaste (EG, EGC, amino acids, and polysaccharides).

Due to the low content of odor characteristic compounds in *Phyllanthi Fructus*, the content distribution of volatile odor components in it could be obtained after component enrichment by headspace solid-phase microextraction. But this might disregard the impact of odor thresholds (Williams & Ringsdorf, 2020). To better analyze the odor of *Phyllanthi Fructus*, Huang et al. (2022) established an identification method for the typical flavor compounds in *Phyllanthi Fructus* based on HS-SPME/GC-QQQ-MS/MS and fully correlated the content with the threshold value to obtain the odor activity value (OAV) of each compound. On this basis, odor characteristic spectra (OCS) of *Phyllanthi Fructus* were constructed, and the significant unfavorable odorants, such as 2-isobutyl-3-methoxypyrazine, of it were screened out. This was done by taking the components whose OAV was larger than the prescribed values as the contributing components. In contrast to electronic noses and volunteer sensory assessments, OCS can both reflect the actual smell of *Phyllanthi Fructus* in a systematic and intuitive manner as well as quickly and precisely identify the smell's constituent parts.

5.2. Evaluation of nutritional value

Phyllanthi Fructus has a distinctive nutritional benefit due to its high antioxidant content and excellent antioxidant capacity. Consuming *Phyllanthi Fructus* can effectively lower the body's oxidative stress and prevent the development of many connected disorders (Nowak, Goslinski, Wojtowicz, & Przygonski, 2018). Rich vitamin C and polyphenols are essential for the *Phyllanthi Fructus*'s strong antioxidant capacity, and these compounds also have significant scavenging abilities that can enhance wound healing, fight diabetes, reduce lipid peroxidation, and other conditions that are necessary for the body's better growth and development (Sadef et al., 2022). Therefore, in the evaluation of the nutritional value of *Phyllanthi Fructus*, its antioxidant value should be reflected in addition to the identification of the fundamental nutritional components. In Japan, for instance, when consuming *Phyllanthi Fructus* for import and export, total vitamin C content and SOD viability are assessed as essential indicators of the nutritional value.

Phyllanthi Fructus has the second-highest vitamin C content of any fruit after the fruit of *Rosa roxburghii* Tratt., the king of fruit vitamin C, at roughly 200 to 1561 mg/100 g (Huang et al., 2021b). The content of antioxidant components in the fruit is susceptible to physiological factors such as maturity and technical factors such as processing and storage conditions (Cendrowski, Królak, & Kalisz, 2021). The study (Lemmens, Alós, Rymenants, De, & Keulemans, 2020) found that fruits' resistance to oxidative damage increased with the ratio of vitamin C to its oxidized form, dehydroascorbic acid (DHA). Compared with the direct determination of vitamin C content, the ratio can better reflect the dynamic change of vitamin C content in fruits. SOD plays a significant role in the biological system's system of antioxidant enzymes. It has the ability to eliminate peroxides and superoxides and plays an important role in maintaining the oxidation antioxidant balance (Li et al., 2020b). SOD is present in abundance in *Phyllanthi Fructus*, which imparts its cytoprotective, anti-inflammatory, anti-aging, and anticancer activities. In addition, fruits often have better quality and storage performance with higher SOD activity (Bakpa et al., 2022). Selvaraj et al. investigated the effect of temperature on SOD activity and stability in fruits, and the authors found that SOD is easily inactivated when exposed to heat (Selvaraj, Katare, Kumar, & Chaudhary, 2019). SOD in *Phyllanthi Fructus* is not only heat-resistant and acid resistant but also can penetrate the skin. It is hypothesized to be a small SOD-like molecule with good development and application potential. The activity of the molecule in *Phyllanthi Fructus* was ascertained by Cheng et al. (2006) using the improved Marklund method, which shows good stability.

5.3. Health care efficacy and evaluation methods

Health care efficacy is the biggest characteristic and advantage of MFH items as food. At present, there are only 28 approved health care functions in China. Among them, *Phyllanthi Fructus* is frequently used in five aspects: supplementing nutrition, enhancing immunity, alleviating fatigue, and assisting in reducing blood lipid and blood glucose. In addition, it can also be used to promote digestion, resist radiation hazards, assist in protecting against chemical liver injury, and so on. As can be seen, *Phyllanthi Fructus* has high health care value. Using the Guiding principles for the functional testing and evaluation of health foods (2022 Edition) as a guide, this paper summarizes the mechanism of *Phyllanthi Fructus*'s health care effect and lists the evaluation techniques that are appropriate for it (Table 1).

Table 1
Mechanism and evaluation method of health care efficacy of *Phyllanthi Fructus*.

Health care efficacy	Mechanisms	Evaluation methods	References
Nutritional supplement	Supplement vitamins, minerals, protein, and other nutrients	Assess the comprehensive nutrient content	Huang et al., 2021b
Immunity enhancement	Enhance cytokine secretion or directly stimulate B lymphocytes or T lymphocytes through antioxidant, anti-inflammatory, and immune regulation	Measure the cellular immune function, humoral immune function, monocyte macrophage function, and NK cell activity	Baliga & Dsouza, 2011; Yahfoufi, Alsadi, Jambi, & Matar, 2018
Physical fatigue alleviation	Protect the heart from related oxidative stress damage by increasing endogenous antioxidants; Enhance cardiac mitochondrial activity and contractile function	Mice underwent a weight-bearing swimming test, and measure blood lactate, serum urea, and liver glycogen/muscle glycogen	Bhattacharya, Bhattacharya, Sairam, & Ghosal, 2002; Kumar et al., 2017
Maintaining blood glucose homeostasis	GA mediates pAkt, PPAR- γ And Glut4 up regulation; EA acts on pancreatic β cells to stimulate insulin secretion	Mice were monitored for fasting glucose, glucose tolerance, and lipid profile; Human trials can be conducted on a clinical treatment basis	Fatima et al., 2017; Variya, Bakrania, & Patel, 2020
Maintaining blood lipid homeostasis	Downregulation of adiponectin, PPARγ, cEBPα, and FABP4 to decrease the accumulation of triglycerides; Antioxidant properties reduce cholesterol activity	Measure the serum total cholesterol, serum triglycerides, serum high-density lipoprotein cholesterol, and serum low-density lipoprotein cholesterol	Balusamy et al., 2020; Usharani, Merugu, & Nutalapati, 2019
Control the internal body fat	Improve insulin resistance, promote blood glucose homeostasis; Reduce blood lipid; Enhance caspase-3 activity to initiate adipocyte apoptosis.	Detect the changes in body fat and subcutaneous fat and the improvement of waist and hip circumference	Balusamy et al., 2020
Digestion promotion	Some ACh-like component(s) may cause gastrointestinal irritation by activating muscarinic receptors; By stimulating the secretion of saliva and stomach acid	Small intestinal motility experiments and digestive enzyme assays. Improvement in appetite, food intake, and skewing could be judged	Mehmood, Rehman, Rehman, & Gilani, 2013
Defecation promotion	Saponins in fruits have a spastic effect and may irritate the intestine	Assess stool frequency, stool characteristics, and defecation status, with care taken that overt diarrhea must not be caused	Mehmood, Rehman, Rehman, & Gilani, 2013
Resisting radiation hazards	The antioxidation and immunomodulatory activities of *Phyllanthi Fructus* can reduce the adverse reactions caused by radiation; Some of the ingredients protect against radiation	Detect the peripheral blood leukocyte counts, DNA content of bone marrow cells, or number of bone marrow nucleated cells	Hari-Kumar, Sabu, Lima, & Kuttan, 2004; Jindal, Soyal, Sharma, & Goyal, 2009
Adjuvant protection against chemical liver injury	Resistance to oxidative stress caused by hepatotoxic substances; Restore the integrity of hepatocyte membrane and change the activity of liver enzymes	It can be evaluated by carbon tetrachloride liver injury model or animal experimental model of alcohol induced liver injury model	Huang, Tung, Hsia, Wu, & Yen, 2017; Shivananjappa & Joshi, 2012; Singh, Dwivedi, Yadav, Sharma, & Khattri, 2014; Yadav, Singh, Singh, & Kumar, 2017

6. Quality evaluation ideas based on medicinal purpose

6.1. Study on commodity specification of Phyllanthi Fructus based on sensory analysis

The traditional experience identification method has long occupied the core value in the quality evaluation of Chinese Herbal Medicines (CHMs). This could be viewed as the consolidation and mapping of the efficacy of CHMs based on extensive clinical experience. Similarly, combined with the appearance, morphology, and some characteristic influencing factors closely related to the efficacy of *Phyllanthi Fructus*, it can provide an important reference for its evaluation and grade division. Commodity specification and grade are important factors affecting the price of CHMs. Establishing commodity specification grade classification standards is a simple and intuitive method to reflect the quality difference of medicinal materials (Zhao et al., 2020). At present, gradeless, uniformly priced goods are the main form of sale for *Phyllanthi Fructus* in the Chinese market. And the GA content is used as the evaluation index, and the quality standard primarily refers to Chinese Pharmacopoeia (2020 edition). The "qualification" of the medicinal materials is what this model is more interested in, but it is challenging to choose the better.

After the preliminary classification of the fresh fruits of *P. emblica*, some of them are used as food, and some of them are dried and processed as medicinal materials. The most fundamental requirement to guarantee the safety of *Phyllanthi Fructus* is the absence of mildew. Due to the low content of active components and insignificant antioxidant and antibacterial activities in the core of *Phyllanthi Fructus* (Luo et al., 2021a), those with a small proportion or without a core are preferred in the market. According to Luo et al. (2021b), *Phyllanthi Fructus*'s skin color is an indirect indicator of the content of key active ingredients like chebulagic acid, corilagin, and EA. Based on this finding, they made a colorimetric card for the commodity classification of *Phyllanthi Fructus*. Additionally, after prolonged storage, some *Phyllanthi Fructus* will develop white frost on the surface, which is regarded as the embodiment of some CHMs' superior qualities (Yu, Zha, & Peng, 2018). Tan et al. (2022) confirmed that the quality of *Phyllanthi Fructus* after frost precipitation is better, the function of generating saliva is stronger, and it is more suitable for medicinal use. Based on previous studies, this paper summarized the sensory analysis methods of *Phyllanthi Fruc-*

tus (Fig. 2) and aims to add more evaluation indexes for the classification of its commodity specifications.

6.2. Chemical evaluation

In *Chinese Pharmacopoeia* (2020 edition), it is stipulated under the content detection of *Phyllanthi Fructus* that the content of GA shall not be less than 1.2% according to the calculation of dried products. This index's content limit and selection are debatable. *Phyllanthi Fructus* contains a lot of GTs, which can form GA after hydrolysis, and it is the natural repository of GA. Studies have confirmed that the hydrolysis of GTs by heat significantly increased the content of GA in the preparation of *Phyllanthi Fructus* tested by heating reflux extraction in accordance with pharmacopoeia methods (Huang et al., 2019). It is clear that GA measured using the pharmacopoeia method contains GA released by the hydrolysis of GTs. Therefore, the hydrolysis of GTs needs to be decreased to avoid this issue.

However, only the determination of GA naturally existing in *Phyllanthi Fructus* also has some shortcomings. It was found that in addition to the extraction stage, the tannins of *Phyllanthi Fructus* were also decomposed to form GA due to the influence of environmental and microbial factors during storage. This indicates that GA is continuously released in *Phyllanthi Fructus* at any time. There is evidence that this transformation is partially pharmacodynamically favorable. According to *in vivo* research, GTs is difficult to be absorbed directly and must first undergo metabolism in the body to become GA before they can be absorbed and act effectively (Aguilar-Zarate et al., 2018; Ran et al., 2021). Related pharmacological studies also showed that the more complete the hydrolysis of GTs, the stronger the anti-pharyngitis and anti-liver injury pharmacological activities (Ran et al., 2021). Therefore, it can be concluded that GA reserves in the GTs should be considered in the quality evaluation of *Phyllanthi Fructus*.

At present, with the development of detection technology, rapid qualitative and quantitative detection methods for GA and GTs in plants are developing rapidly. Considering the comprehensive factors such as detection accuracy, effectiveness, and feasibility, the following methods are selected for reference in this paper, which can be mainly divided into the hydrolysis method and photochemical method. Gallnut, a polyphenolic medicinal material with GA as the content determination index, can be used as an example in the hydrolysis method. In the preparation of the test solution, it is worth noting that the GA content is determined after 3.5 h of full heating hydrolysis under a strongly acidic environment according to the *Galla Chinensis*'s content determination item of Chinese Pharmacopoeia. (2020 edition). The method has the ability to completely release GA and the benefits of being simple to operate, highly accurate, and having only modest requirements for operators, instruments, and equipment.

Despite the hydrolysis method's straightforward theory and strong operability, it is challenging to meet the need for rapid detection with a long time of pretreatment. The galloyl group is the common structure of GTs and GA (Fig. 3), which has the characteristic structure of pyrogallol and is the key to the identification and detection of GA. In recent years, the combination of flow injection (FL) with chemiluminescence (CL) has found wide applications in food, drug, and bioanalysis (Moazzam, Asghar, Yaqoob, Ali, & Nabi, 2021). Using suitable chromogenic agents combined with CL, the content of GTs and GA can be rapidly characterized, which is a sophisticated analytical technique with high sensitivity, and a wide linear range. Kanwal et al. established an FI-CL system for the

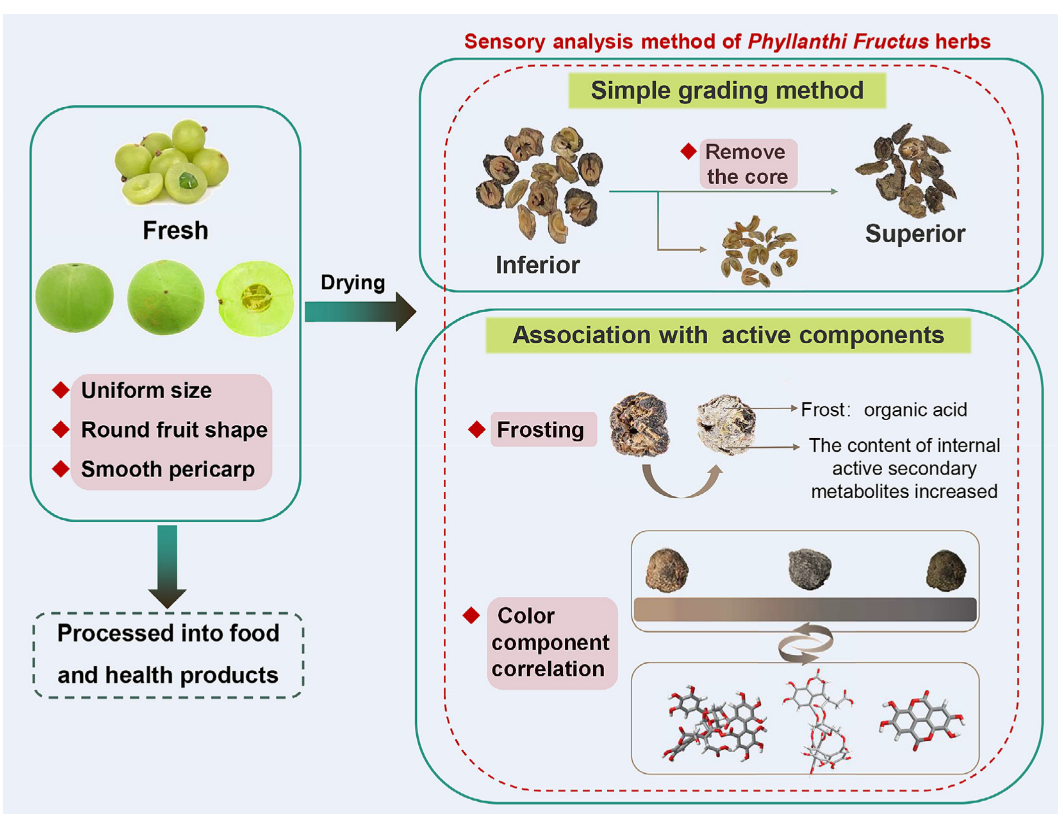

Fig. 2. Methods for sensory evaluation of *Phyllanthi Fructus*. The fresh fruit of *Phyllanthus emblica*, which is uniform in size, round in shape and smooth in skin, is partially processed into food and health products, and partially dried for medical use. The right part lists the sensory analysis methods of *Phyllanthi Fructus*. Including the basic grading method (based on whether to remove the core), to the grading method combining sensory characteristics and active ingredients (frosting, appearance color).

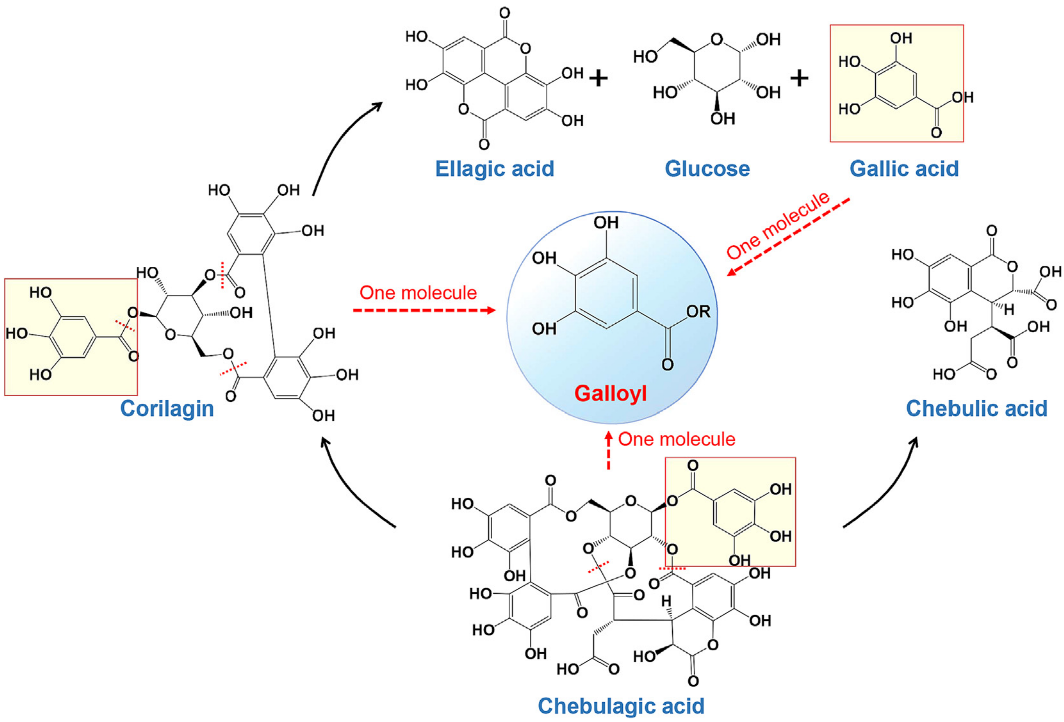

Fig. 3. Schematic representation of GTs hydrolysis and source of galloyl groups.

detection of more than two pyrogallol compounds, which relied on the enhancing effect of pyrogallol on the CL signal of the $KMnO_4$-H_2O_2 system in a weakly alkaline medium of PBS (Kanwal, Fu, & Su, 2009). This system is well suited for determining galloyl groups present in different forms combined in medicinal herbs because it can detect multiple pyrogallol compounds present at once. Nevertheless, the system may also be disturbed by other substances with pyrogallol structure in *Phyllanthi Fructus*, such as some flavanols and flavonoids. Galloyl structural compounds account for a significant portion of *Phyllanthi Fructus*'s active components, so even though their specificity is not currently dominant, it may still be a very suitable method for quick quality assessment.

6.3. Biological evaluation

Biological evaluation has the advantages of the overall evaluation, correlating the efficacy, and is suitable for *Phyllanthi Fructus*, which has weak basic research of pharmacodynamic substances. *Phyllanthi Fructus* has significant antihyperglycemic activity, and studies have also demonstrated that it has a beneficial impact on managing diabetic complications while suppressing diabetes (Huang et al., 2021a). However, there are currently no recognized evaluation methods for calculating the relevant efficacy. As a result, this paper suggested using biological evaluation to assess *Phyllanthi Fructus*'s anti-hyperglycemia activity. Polyphenols can inhibit key digestive enzymes to delay starch digestion, which can be evaluated by hypoglycemic experiments such as α-glucosidase inhibition experiments and α-amylase inhibition experiments (Sun & Miao, 2020). Our research team discovered that *Phyllanthi Fructus* still exhibits excellent anti-fatigue activity when compared to some well-known anti-fatigue CHMs, making it a potential natural anti-fatigue functional food and drug. According to the research, the anti-fatigue activity of *Phyllanthi Fructus* is a comprehensive reflection of hypoxia resistance, muscle function improvement, and anti-inflammatory properties (Ni et al., 2013; Chen et al., 2021; Zhu et al., 2021), and its most common and intuitive quantitative method is to compare and evaluate the exhaustive loaded swimming time of mice (Zhang et al., 2019). In addition, other methods for the biological evaluation of the efficacy of *Phyllanthi Fructus* are extremely promising and valuable, such as anti-inflammation, regulation of body fat metabolism, and enhancement of immunity. Future research can continue to explore approaches for the biological assessment of *Phyllanthi Fructus*, reflect its functional indications as much as possible, and make up for the dearth of biological assessment of *Phyllanthi Fructus*'s quality.

7. Discussion and perspectives

Polyphenols are the most important pharmacodynamic basic substances with high content in *Phyllanthi Fructus* and are closely related to most pharmacological activities and health care effects of *Phyllanthi Fructus*. However, polyphenols have the characteristics of low stability and ease of transformation, which makes it easy for factors like sources of the plant, processing and storage conditions, extraction, preparation technologies, etc. to have an impact on the medicinal qualities and edible qualities of *Phyllanthi Fructus*. As a result, the single index quality control model which the Pharmacopoeia is mainly based on is not only difficult to reflect the commonality of the multi-purpose of MFH items, but also to cope with the three high characteristics of "high activity, high content, and high variation" of components in *Phyllanthi Fructus*. Based on the unique quality formation mechanism and transmission law of *Phyllanthi Fructus*, this paper addresses the aforementioned issues by examining separately the evaluation concepts for its medicinal use and edible use.

When evaluating the edible quality of *Phyllanthi Fructus*, it is important to take into account its homology of food and medicine, especially to evaluate its high nutritional value and rich health care effect while guaranteeing its flavor. The flavor of *Phyllanthi Fructus* is special, and its evaluation and control are challenging. It can effectively address the issues of high levels of rich taste and low levels of odor characteristic substances in *Phyllanthi Fructus* when combined with the comprehensive taste index and OCS suggested by scholars.

Compared with the edible purpose, the evaluation of the medicinal properties of *Phyllanthi Fructus* is sufficient, especially the determination of index components such as GA and EA. To avoid the fluctuation of the content of the index components caused by the hydrolysis of GTs, we proposed the hydrolysis determination method and the direct determination method based on the structure of the pyrogallol. This paper also summarizes the traditional and modern empirical discrimination methods for the quality of *Phyllanthi Fructus*, which can achieve the purpose of rapid and low-cost identification of their superiority and inferiority in quality through sensory judgment, and combined the key efficacy of *Phyllanthi Fructus*, hypoglycemic and anti-fatigue activity were taken as examples to propose the available biological evaluation methods.

Phyllanthi Fructus is a typical polyphenolic fruit as well as a traditional MFH item. In this study, the edible types and medicinal types of *Phyllanthi Fructus* were categorized, assessed, and the distinctions between edible and medicinal properties were emphasized, which may have a certain reference significance for the quality evaluation of the fruit kind among MFH items. It also provided a reference for promoting the high-quality development of *Phyllanthi Fructus* and further enriched the quality control theories and strategies of MFH and polyphenol items.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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