Designing an Improved Strategy for Chinese Warehouses to Store Bamboo and its Semi-finished Products

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Bamboo plants are fast-growing, quickly produce usable material, and are an abundant resource. Bamboo is an excellent, natural, and renewable material. It has a long history of application in human life, industrial manufacturing, cultural industries, and other fields. The warehousing of bamboo and its finished products is an emerging industry with much potential. A reasonable, stable, and orderly warehouse could be an effective solution for the sustainable management, seasonal harvesting, and raw material stability issues. In addition, the warehouse plays an important role in the processing of raw materials, reserve logistics, keeping a robust and real-time supply for downstream products. This is of great significance for alleviating problems associated with Chinese timber safety and for improving the quality of life. This paper focuses on warehousing experience in grain and coal fields, reviews the common material processing and preservation measures of bamboo, analyzes advantages and developmental prospects of bamboo warehousing, and explores and suggests appropriate storage methods, technical systems, and application models. It is expected to provide technical guidance for construction in the bamboo storage industry, and to supply ideas and suggestions for the modern development of the bamboo industry.

DOI: 10.15376/biores.17.4.Jia

Keywords: Bamboo; Warehouse; Preservation measures; Green storage; Carbon sink

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INTRODUCTION

The total current global area of bamboo plantations is about 30.5 million hm^2 (Du *et al.* 2018). It is mainly distributed throughout Asia, accounting for 65% of the world's total forested bamboo area (Dlamini *et al.* 2022). China is one of the richest countries in bamboo resources, with the largest forested bamboo area and the highest global stock volume and bamboo output (Li *et al.* 2015). Bamboo has a short timber cycle and is an abundant resource. Warehousing of suitably aged bamboo that is not used fast enough to ensure subsequent processing and utilization is an important mode for advantageously using bamboo resources for creating an economic advantage. It is also an important hub connecting bamboo forest cultivation and downstream processing. It is necessary for adjusting the time and space “distance” from harvest to processing and is important to extend the bamboo industry chain to ensure the quality of bamboo during a stable supply period (Fei 2019). Bamboo warehousing refers to: entering and preserving bamboo materials, management and control of their quantity and quality, and storing and exporting bamboo resources through the establishment of storage facilities. It plays an important role in warehousing, storage, distribution, processing, ensuring the orderly circulation of materials, adjusting material transportation capacity, and real-time information sharing, along with other aspects. In the past, the warehousing of bamboo materials was mostly done by natural stacking, which was not systematic, had no standards, and lacked scale. Presently, the grain, coal, and other industries have an established and effective reserve system. They have gradually implemented intelligent and digital management and operation within their systems. This has played a pivotal role in regulating the supply and demand of grain and coal in the country, stabilizing the market, responding to sudden natural disasters, and creating a new pattern of domestic and international multi-party cycles. Compared with the warehousing status in the grain and coal industries, the bamboo warehousing industry has only just begun, and its technical level is relatively primitive. The current bamboo warehousing method lacks systematic research, lacks a scientific and standardized theoretical basis, has difficult logistics and transportation, and the industrial scale is not yet formed. Therefore, it was necessary to study the developmental experience of the leading industries in grain and coal, and combine it with bamboo's own characteristics to develop a standardized, large-scale, and smart warehousing development. This development prospect is significant for the healthy growth of bamboo forests, pooling carbon sinks, boosting rural revitalization, and improving people's quality of life (Fadrique *et al.* 2021).

THE CURRENT SITUATION OF THE DEVELOPMENT OF WAREHOUSE

Warehousing plays an essential role in ensuring the orderly circulation of materials, adjusting the transportation capacity of materials, and implementing accurate information transmission (Balaji *et al.* 2021). However, the key difference between the past traditional warehousing model, and the current warehousing model lies in the innovation of its application technology (Kamali 2019). During the first and second Industrial Revolutions, with the rapid development of the manufacturing industry, the warehousing model created a demand for the development of large volumes and wide distribution. This can be clearly seen by localities usually being close to major transportation hubs, such as canals and railways. Early in the 21st century, warehousing companies expanded their warehousing space and storage capacity by integrating old facilities, and by building larger warehousing equipment to adapt to the increasing freight demand (Hesse and Rodrigue 2004). However, the cost of warehousing became an urgent problem requiring a solution. Maras (2015) stated that "the trick to reducing storage costs was to eliminate human contact factors", and so the concept of automated operation was born. Currently, with the development of logistics and transportation infrastructure, and the gradual decrease in transportation costs, the spatial distribution of warehousing facilities has changed drastically from its layout ten years ago, leading to the phenomenon of global "logistics spread" (Dablanc *et al.* 2014). In contrast, the advent of smart warehousing has improved overall service quality, automation, productivity, and efficiency. Simultaneously, economic costs and operational errors were minimized, which manifested into the wide application of new information technology (IT), such as voice picking, radio frequency identification device (RFID), internet of things (IoT), cloud computing, warehouse management system (WMS), data mining analyses, and so on, creating new challenges and opportunities for warehousing operations in various fields. China's warehousing technology has gradually moved towards mechanized and automated operations. At present, the developmental speed varies due to the differing requirements of various industries. For example, the grain and coal warehousing industries started early, which allowed the gradual formation of a systematic warehousing technology, achieving industrialization. It is worth mentioning that bamboo warehousing technology has relatively lagged, and the industry level needs to be further improved (Fig. 1).

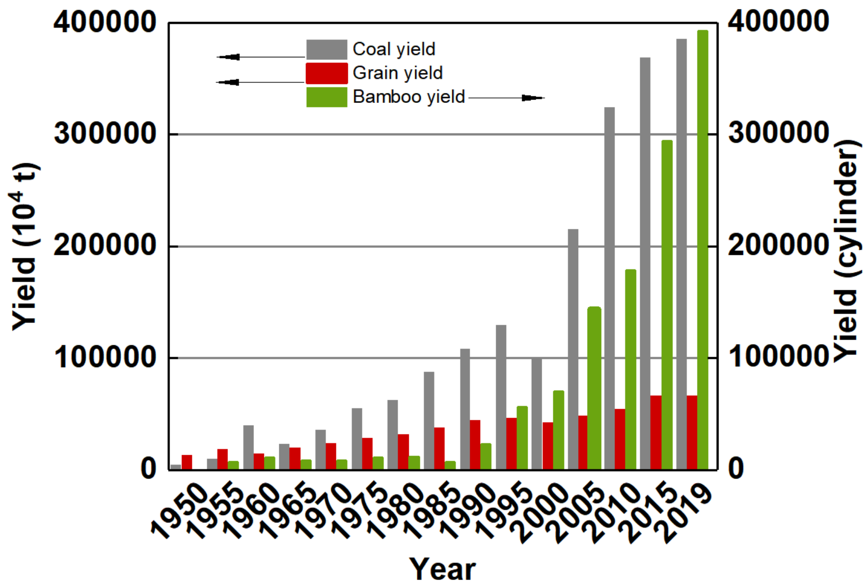

Fig. 1. Chinese total yield of coal, grain, and bamboo over the years (1950 to 2019)

Development Status of Grain Warehouse

In terms of grain warehouses, the warehousing process route has been greatly improved and perfected (Fig. 2). The wide application of technological solutions, such as temperature controlled-technology, electron beam processing technology, ozone fumigation, and other technologies, has greatly contributed to food security. Temperature control storage technology works by controlling the warehouse environment temperature, and it creates conditions that are not conducive to the growth of pests, mildew, and bacteria. This technology began in the 1950s, and people have implemented research based on temperature-controlled storage using natural low temperatures, auxiliary mechanical ventilation, and other technologies (Zhou *et al.* 1990; Dunkel 1995).

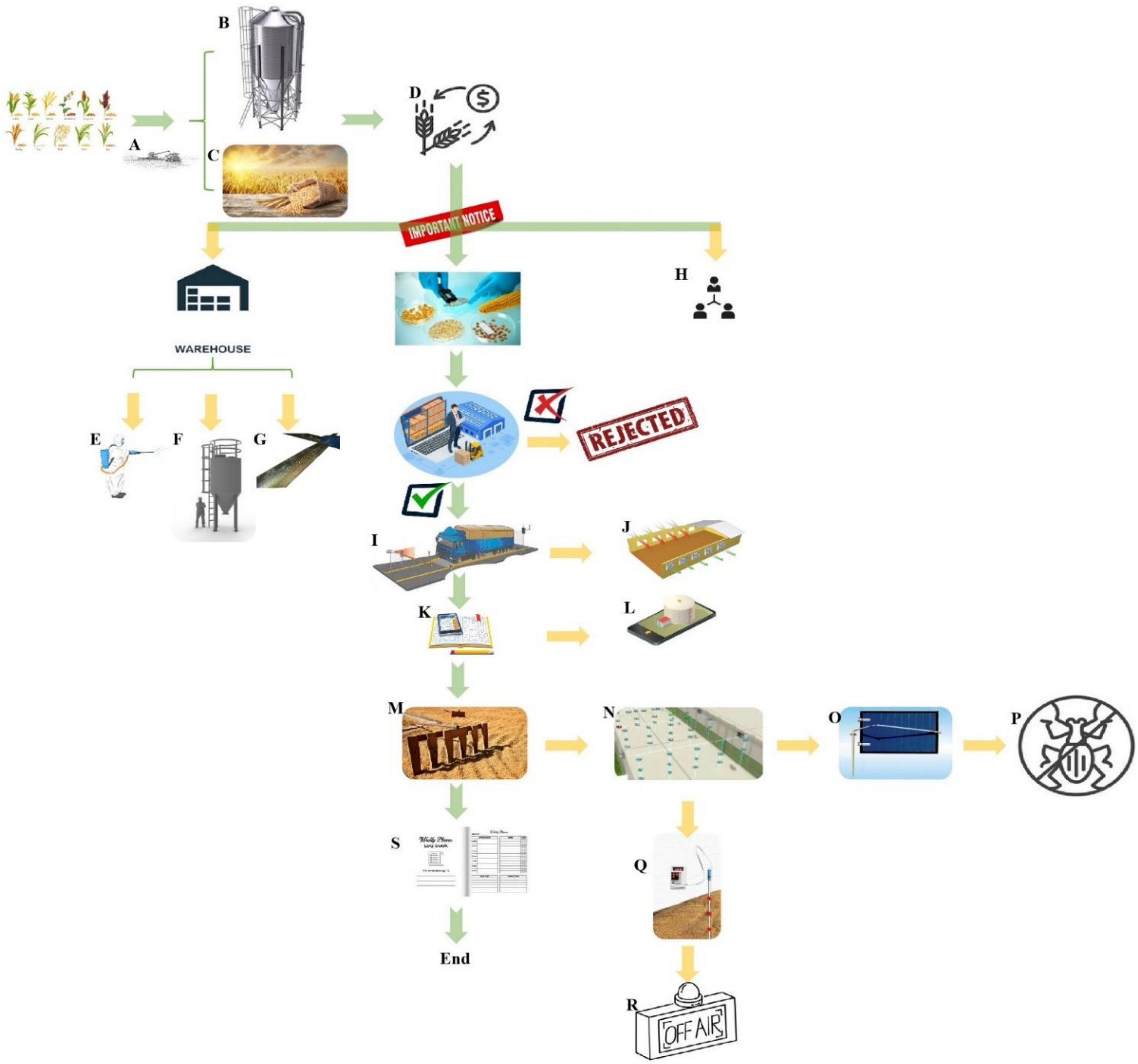

Fig. 2. Traditional grain warehousing process: A: Fully harvested; B: Mechanical drying; C: Natural drying; D: Grain purchase; E: Warehouse disinfection; F: Equipment maintenance; G: Laying ventilation cage; H: Management and personnel; I: Weigh into the grain; J: Ventilation and cooling; K: Statistical posting; L: Data sharing; M: Level the grain surface; N: Sensor laying; O: Laying grain board; P: Insect wire; Q: Monitoring grain temperature; R: End ventilation; S: Enable grain inspection record register

After the 1980s, the application and implementation of refrigerants, or air conditioning, for mechanical temperature control and storage technology, appeared one after another, but due to restrictions on operating costs and storage facilities, conditions were not yet widely promoted and applied (Lu 1999). Other temperature control methods that subsequently emerged mainly included airtight heat insulation, internal circulation temperature control, five-sided airtight glands on the grain surface, and heat preservation of thermal insulation materials, *et al.* (Demito *et al.* 2019; Singano *et al.* 2020; Ziegler *et al.* 2021). Electron beam processing technology can effectively control and kill pests, prevent mold, and inhibit bacterial growth during grain storage. Moreover, it has the characteristics of low energy consumption, high efficiency, and no pollution, so its application broadens prospects for use in other storage fields (Sun *et al.* 2020). Because ozone is green, safe, efficient, and low-consumption, it has a great utilization potential in the warehousing field. Degradation of mycotoxins by ozone treatment was first reported in food (Young 1986). Its green, residue-free features have been highly valued in the development of warehousing technology, and it is important to note that ozone was considered safe (GRAS/ Generally Recognized as Safe) by the FDA (Food and Drug Administration) and was approved for use in organic foods as a sanitizer (Zhu 2018).

Developmental Status of Coal Warehousing

The traditional coal storage method is shown in Fig. 3. The operational speed and site turnover rate in the coal warehousing field has higher requirements compared with other material reserves. It manifests as the gradual transition and developmental process of technical methods from warehousing direct sales, environmentally-friendly closed warehousing, information-based intelligent warehousing, and more. In the 1990s, the rise of the warehousing direct sales model had important practical significance in solving the problems of coal market saturation and oversupply (Zhang 1998; Sauer and Seuring 2017).

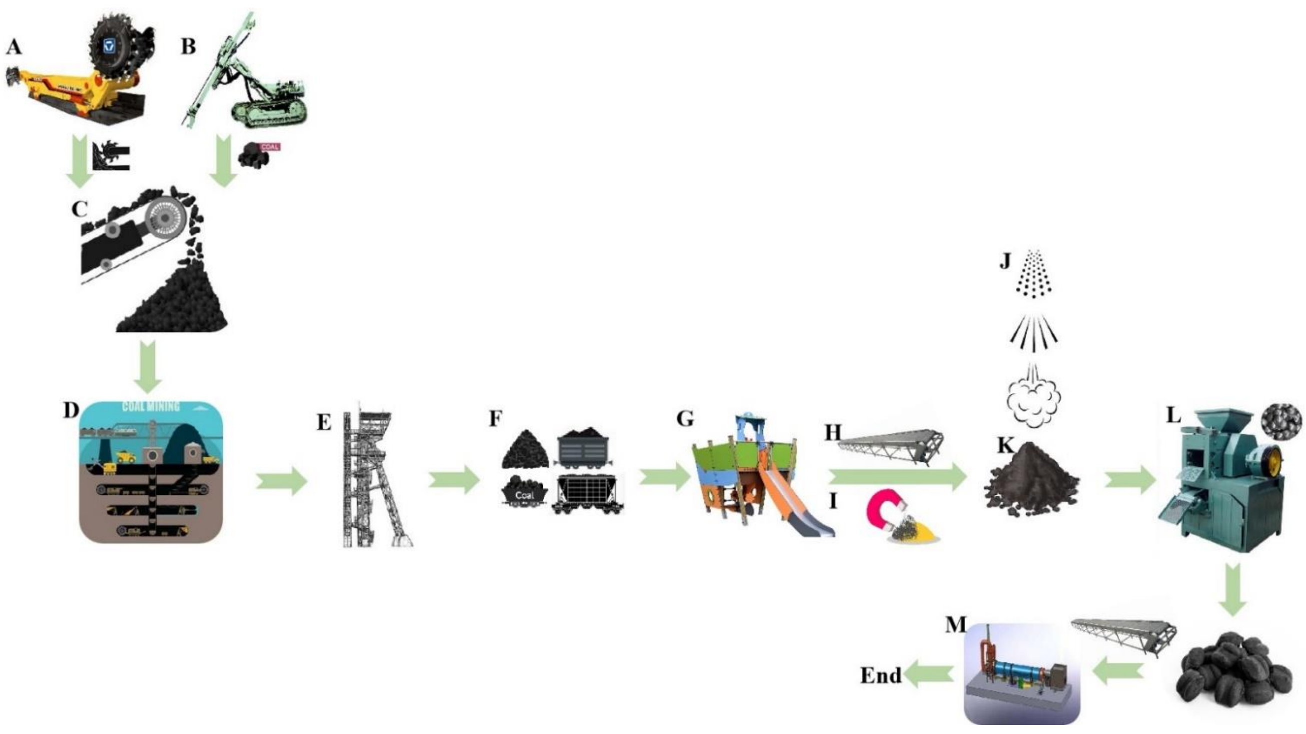

Fig. 3. Traditional coal warehousing process: A: Fully-mechanized mining workbench; B: Cannon mining workbench; C: Workbench belt conveyor; D: Vibrating screen; E: Main shaft bucket elevator; F: Ground coal warehouse; G: Material sorting; H: Conveyor belt; I: Magnetic separation; J: Configure binder; K: Mix; L: Roll forming; M: Drying

At the beginning of the 21st century, the simple and messy coal warehousing model could not meet the requirements of the green industry. The emergence of steel silo, container, and other storage facilities created a closed storage and transportation environment, which greatly improved environmental conditions and created a green economy (Aguirre-Villegas and Benson 2017). With the continuous application of modern technology in the warehousing field, the coal industry was gradually transformed and upgraded from a small to medium, chaotic system, to a large-scale, intelligent, and intensive production model. The empowerment of information technology, such as EAM (Enterprise Asset Management) (Zhang *et al.* 2018), WMS (Lototsky *et al.* 2019), ERP (Enterprise Resources Planning) systems (Ng and Ip 2003), IoT, and Remote Radio Frequency (RRF) (Tosun and Zaim 2018), has effectively improved warehouse capacity, utilization, and access efficiency.

Development Ideas for Bamboo Warehousing Technology

Lessons can be learned from the storage technology development experience of grain and coal mines. From bamboo forests to standard structure bamboo, the design process route of preparation and warehousing is shown in Fig. 4. Its application of temperature control, ozone treatment, electron beam processing technology, as well as information technology, in grain storage technology, IoT, and RFID technology in coal storage methods provides important ideas and reference values for the development of warehouse technology in other fields. This is critical for promoting standardization, automation, and intelligence in modern storage technology.

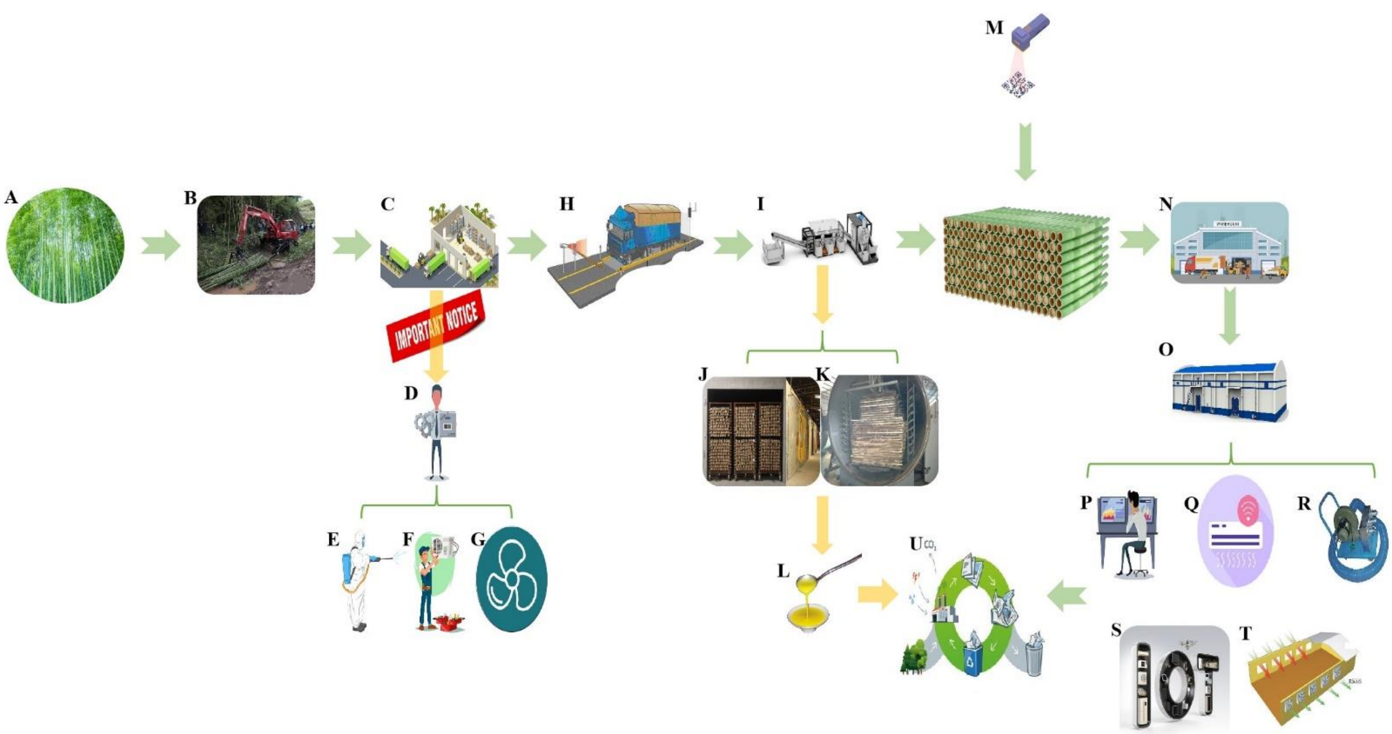

Fig. 4. Imagination of modern bamboo warehousing process: A: Bamboo forests; B: Thinning; C: Transportation; D: Library staff; E: Warehouse disinfection; F: Equipment maintenance; G: Laying ventilation cage; H: Weigh into the factory; I: Pretreatment; J: Dry baking; K: Wet carbonization; L: Bamboo by-products; M: Radio frequency identification; N: Receipt; O: Warehouse; P: Warehouse monitoring; Q: Mechanical refrigeration; R: Internal circulation sterilization; S: IOT quality inspection; T: Smart ventilation; U: Recycling

BAMBOO STORAGE AND TECHNICAL FEASIBILITY

Bamboo warehousing technology can be expected to solve problems of integration and optimization of bamboo resources. It has brought a new wave of development to the bamboo industry. At the same time, proper bamboo storage technology was a prerequisite for the continuous supply to downstream enterprises. With the application and promotion of bamboo drying, storage, fixed arc, and processing equipment, the bamboo industry has achieved a certain degree of mechanized operation. At present, progress has been made in the use of bamboo warehousing technology, including the development of the entire industrial chain of bamboo forest cultivation, logging, storage, semi-finished product processing, and sales, the promotion of the bamboo industry in terms of market risk, competitive advantage, and main technologies. Important aspects include adaptation to the harvest time, protective processing, and intelligent storage.

Adaptation to Harvest Time

Generally, spring is the season in which various pests breed, and this coincides with a higher content of nutrients, such as starch, soluble sugars and fats, and water found in bamboo. Harvesting bamboo not only affects the growth of spring bamboo shoots, but it also loosens internal tissues due to lost bamboo soluble material, leading to moth erosion, and the laying of their eggs; insect survival rates are as high as 40% to 50% (Okahisa *et al.* 2006). Because of the scorching summer heat, the internal organization of bamboo becomes relatively dense, the texture becomes hard, and the energy consumption of mechanical processing is high; thus logging during that season is not recommended. Bamboo grows best in autumn, during which it becomes rich in nutrients, and it can easily be devoured by pests when harvested. An old farmer proverb states "cut in winter but not spring". After the start of winter, and before the beginning of spring the following year, the bamboo is harvested, not only to make room for the growth of new bamboo shoots, but also to prevent degradation by pests.

Protective Treatment

Firstly, bamboo is similar to other plants because its material is both hydrophilic and has a strong moisture absorption capacity; indeed, the moisture content is one of the important factors that causes the bamboo to shrink, swell, and to become moldy. Common treatment methods include heat treatment (Table 1), microwave vacuum drying, micro-carbonization, and hornification.

Table 1. Bamboo Heat Treatment with Different Heat Transfer Media, Processing Temperature, and Duration (Li *et al*. 2022)

Heat Transfer Media			Temperature (°C)	Duration (min)
Steam	Superheated steam		160-220	60-360
	Saturated steam		100-180	4-50
Oil	Vegetable oil		100-220	30-240
	Mineral oil		140-200	120-360
Gas	Air		100-220	60-240
	Inert gases		130-220	60-360
Hot water			100	240-2880
Fire			~300-800	~0.1-5

Heat treatment (≤ 200 °C) is characterized by high efficiency and does not change the aggregate structure of bamboo fibers (Fig. 5a), but it causes changes in hydrogen bonds within or between molecules, as well as breakage of glycosidic bonds in the amorphous and crystalline regions of cellulose (Lin *et al.* 2020). Microwave vacuum-drying technology improves the drying rate of bamboo and reduces the cracking rate during drying (Fig. 5b) (Lv *et al.* 2019). Micro-carbonization is regarded as a stable storage technology; the surface of the round bamboo treated with high temperature and high pressure forms a hard carbonized particle layer, which achieves an antibacterial effect (Fig. 5c) (Ishihara 1996; Lin *et al.* 2014). Carbonized forming and carbonized coating polymer pretreatment technology for treating bamboo has obvious advantages in durability, weather resistance, dimensional stability, overall bearing capacity, and low cost; therefore it has a wide range of applications. Hornification treatment wets and dries the bamboo for several cycles to reduce its water holding capacity, achieving high-quality storage, and improving its mechanical properties (Cid *et al.* 2020). Microwave vacuum-drying restricts the promotion of this technology due to high energy consumption and high cost, and hornification is cumbersome and difficult to achieve in large-scale application. Hot air-drying uses air and micro-carbonization as a medium to achieve a large surface area of heat and mass transfer of gas- gas-liquid two-phase, which is environmentally friendly and safe. Micro-carbonization treatment not only improves the quality of bamboo, but also it uses bamboo by-products extracted by carbonization in the field of food and medicine, which also has broad application prospects in the pre-treatment methods of bamboo warehousing.

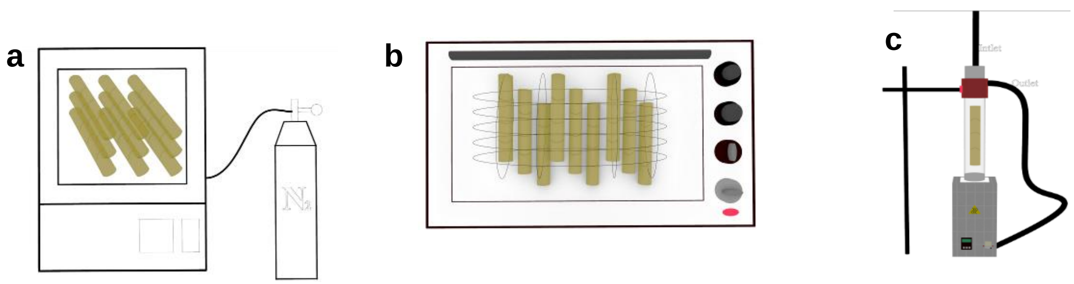

Fig. 5. Different drying pretreatment methods. a. Heat treatment; b. Microwave vacuum dry; c. Micro-Carbonization

Secondly, taking into account the different processing uses of bamboo, it is also possible to extend the bamboo warehousing cycle by adding anti- degradation and anti-fungal agents, amongst others. However, chemical methods are limited by their application fields. Such methods are mainly used in outdoor bamboo products and rely on anti-degradation wood treatment methods. For example, natrium pentachlorophenol (PCP-Na) (Yaping 2008), rosin (Su *et al.* 2021), tannin-boron preservatives (Gauss *et al.* 2021), neem seed oil (NSO) (Erakhrumen 2011), and leaf extracts from *Ocotea lancifolia* (da Silva *et al.* 2017), are profitable. However, bamboo is an anisotropic material, which forces the preservatives to penetrate longitudinally through the vascular bundle, while other tissues are penetrated unevenly, so it cannot achieve the ideal treatment effect and is easy to lose. The pressure infusion method promotes the lateral penetration of the preservative in the bamboo, but the penetration effect decreases with the extension of the penetration distance (Akhter *et al.* 2001). The addition of phosphate prevents the loss of preservatives rich in ammonia-soluble quaternary ammonium copper (ACQ-B) (Wang *et al.* 2008).

Simultaneously, exploring alcohol preservatives is also helpful to improve permeability (Krisdianto *et al.* 2019). Additionally, research has shown that the treatment effect of industrial alkali is not satisfactory (Zhao *et al.* 2010). Heat treatment could improve the anti-loss resistance of preservatives. Yang *et al.* (2016) suggests that heat treatment in linseed oil is the most effective method in improving the durability of the bamboo. Palanti *et al.* (2011) impregnated a mixture of mineral and vegetable oils heated to 80 °C, into stone pine and Scots pine wood, followed by natural durability tests in the field. The dissolution and soaking method of a 60 °C water bath significantly improves the permeability of food-grade chitosan in bamboo and has a good antiseptic and antifungal effect (Li *et al.* 2021).

Additionally, starch, sugar, crude fat, crude protein, amino acids, and other nutrients contained in bamboo are one of the main reasons that pests devour it, which affects the industrial value of bamboo (Wang *et al.* 2020). Wang *et al.* (2018) found that ultrasound is a green technology for the extraction of bamboo components. It can be carried out without solvent, with high efficiency, and with low energy consumption (Fig. 6a). Zhan *et al.* (2021) studied the chemical composition and mechanical properties of bamboo poles during the storage period (120 days) of water storage (*i.e.*, lake storage) (Fig. 6b). Although this traditional storage method was good for the papermaking and construction industries and made bamboo processing and utilization easy, it was difficult to promote on a large scale in the market due to the limitations of the application conditions. Therefore, as an environmental protection method for extracting nutrients from bamboo, ultrasound processing has broad prospects for industrial application.

In summary, physical and chemical treatment methods produce good results, the high energy consumption and serious chemical wastewater pollution both pose a threat to humans and the environment, and the current physical and chemical treatments applied to bamboo storage must be further optimized. Industrial enterprises could reduce the feeding impact of erosive pests at the source by reducing the nutrients of bamboo. However, it is challenging and complicated to improve the natural resistance of bamboo to pests by reducing the nutrient content of bamboo during storage.

Fig. 6. Different extraction methods a. Ultrasonic treatment; b. Freshwater environmental warehousing

BAMBOO WAREHOUSING GUARANTEE MEASURES

Compared with the current state of storage in industries, such as grain and coal, there are still some problems in the warehousing of bamboo. First, the concept of bamboo warehousing has not been widely popularized, a unified understanding has not been formed, and the utilization of bamboo resources is not sufficient. The cultural level of bamboo farmers is relatively primitive, the awareness of bamboo forest management and bamboo warehousing is weak and coupled with the lack of sufficient subsidy funds and labor, no one manages post afforestation, and mature bamboo is not harvested (Deng *et al.*

2020). The second is that the bamboo warehousing system and standards are not established in time, and they are still imperfect and immature. For example, downstream processing companies have simple and extensive storage of bamboo materials, are fragmented and small-scale, and their methods are prone to shrinkage, swelling, deformation, mildew, and other problems during warehousing. Simultaneously, most of the managers of bamboo forest lands have placed emphasis on cutting and have neglected structural nurturing of bamboo forests, even without developed a system of storage, and this has resulted in a waste of resources (Fu *et al.* 2020). Third, bamboo warehousing lacks supporting storage facilities. Based on the above-mentioned acute problems, corresponding safeguard measures are urgently needed, which are now discussed.

Practicing the Concept of Bamboo Warehousing

Improving enterprises' awareness of the importance of bamboo storage is crucial. With the development of eco-friendly protection, the conservation strategies and industrial applications of sustainable materials attract much attention. The warehousing awareness of grain and other agricultural products is highly valued by the people, together with the warehousing of bamboo to satisfy the old proverb, which says that "Clear waters and green mountains are as good as mountains of gold and silver". Bamboo resource reserve guaranteed an adequate supply of bamboo resources, not only to stabilize market prices and reduce production costs, but also to promote the healthy growth of bamboo forests.

Establishing a Bamboo Warehousing System

Establishing a more scientific and complete warehousing management standard system is needed. The harvesting capacity of mature bamboo materials should be increased and preserved in time. This should be done, using the platform of the internet to enable data sharing between downstream processing enterprises and the warehousing system, and according to the characteristics of different semi-finished products, different warehousing conditions, and graded and divided quality reserves. This would be helpful to meet the needs of diversified bamboo materials. For example, there would be value in expanding bamboo reserves and forming a certain scale of distribution in various provinces and cities. Responding to the urgently needed building materials in refuge areas by way of an emergency building reserve, this model not only has a low economic cost and strong assembly ability, but also avoids idle resources that are wasted to a large extent (Chen 2008).

Develop Bamboo Storage Facilities

Bamboo warehousing facilities refer to the various equipment used for bamboo storage, from cleaning, drying, and storage after harvest, to before entering the circulation or deep processing, including warehousing cages, cleaning machinery, conveying devices, weighing equipment, drying equipment, and quality inspection equipment, amongst others. Over the years, the volume of storage facilities in China's coal and grain industries have been dynamically changing in combination with its own development needs (Fig. 7). Due to the continuous increase in the concentration of the coal industry, the industrial structure has gradually merged and reorganized, and the volume of the warehouse has decreased annually since 1980. The difference was that the stock of grain warehouses has increased annually (1950 to 2020). The degree of modernization has increased significantly and has played a decisive role in ensuring the safe storage of grain. However, advanced warehousing facilities were also key to achieving high bamboo standards and an adequate supply, as well as ensuring precise material specifications and safety. At present, wood warehousing equipment has developed greatly, from manual forklift warehousing, to roller-type automatic storage, to automatic warehousing of wood-based panels (Bartolini *et al.* 2019). China's grain warehousing facilities include various silos, such as shallow round silos, flat silos, building silos, ball silos, cave silos, metal plate silos, metal mesh silos, color steel plate combination silos, hot-dip galvanized steel silos, steel net type round warehouses, and steel frame rectangular warehouses with a storage capacity of less than 10 tons (Luo *et al.* 2020). However, the construction of bamboo warehousing facilities is still in its infancy, so the development of a variety of warehousing facilities on demand is of great significance to guarantee the quality of bamboo, bamboo units, and semi-finished products. In the past, the bamboo storage concept was not widely appreciated, and the concept of cutting as you go was deeply rooted. With the prevalence of bamboo instead of plastic, the storage concept is becoming more and more profitable, and the number of storage depots is expected to show a spurt surge in the future as the bamboo industry flourishes. Bamboo warehousing is an important link between bamboo forest cultivation and bamboo processing (Fig. 8), and will be of great significance to slow down the rate of carbon emissions, reduce carbon emissions, and help carbon peaks.

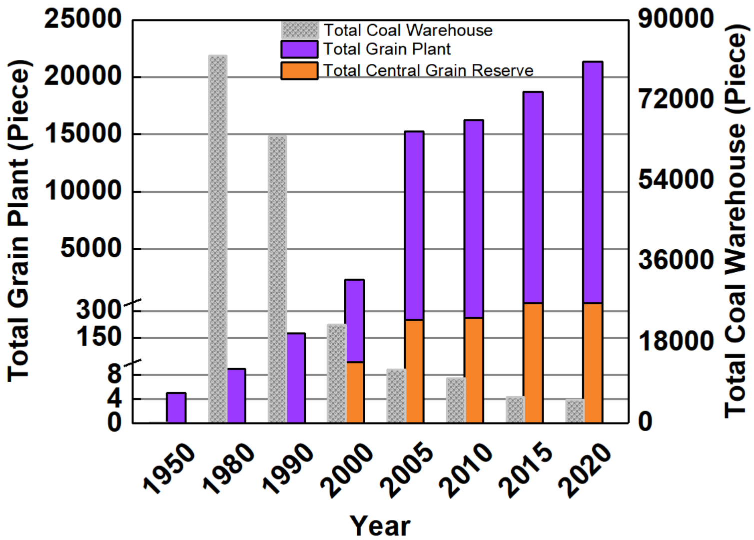

Fig. 7. Chinese total grain plant and coal warehouse over the years (1950 to 2020)

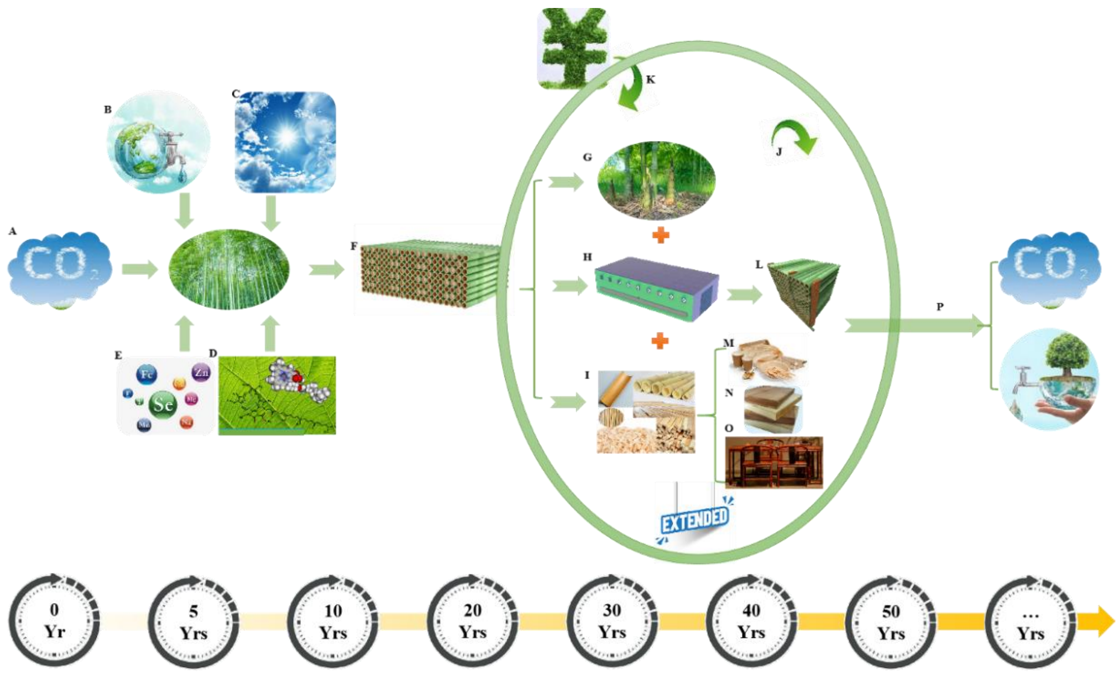

Fig. 8. The regulation mechanism of bamboo warehousing on the whole industry chain: A: Carbon dioxide (CO_2); B: Water; C: Sunlight; D: Chlorophyll; E: Trace elements; F: 100% harvested mature timber; G: Ecological benefits; H: Warehousing; I: Bamboo product; J: Recycling; K: Carbon subsidy; L: Strategic reserve; M: Bamboo daily necessities; N: Bamboo board; O: Bamboo furniture; P: Slow down microbial degradation

DEVELOPMENTAL PROSPECTS OF THE BAMBOO WAREHOUSING INDUSTRY

The recent outbreak of the corona virus disease in 2019 was unexpected, and the warehousing industry has withstood a large test. Green, environmentally friendly, and intelligent warehousing systems have become the mainstream direction of future development. As an important strategic material, the establishment of its storage system should be highly valued.

In terms of conditional control, wireless sensors will be used to sense factors, such as temperature and humidity, atmospheric pressure, and light intensity, during the bamboo warehousing period. Intelligent ventilation will control the moisture content of bamboo, mechanical drying technology will guarantee the safe moisture content of bamboo, circulation fumigation systems will prevent degradation by pests, and automatic storage systems will provide new construction ideas for bamboo source.

In terms of smart systems, smart warehousing technology will enable managers to move from manual recording to automatic identification of two-dimensional codes and will be conducive to tracing the source of problematic bamboo materials, as well as real-time tracking and positioning. IoT technology will match the real-time needs of customers, will improve the efficiency of the management of bamboo material in and out of warehouses, as well as the traceability management of inventory problems, and will help realize smart and information-based bamboo material storage and operation. The system will not only satisfy the cross-regional trade of bamboo, but it will also improve the utilization rate of bamboo resources. It is believed that with the development of the IoT, big data, and artificial intelligence, intelligent information warehousing will reasonably be applied, which will promote the construction of a bamboo warehousing system.

In terms of technical methods, green pre-treatment and scientific warehousing methods will be necessary conditions to ensure a sufficient amount of bamboo raw materials. The green and environmentally friendly antidegradative treatment method will be a prerequisite for assuring the safe warehousing of bamboo materials. Keeping the moisture content of bamboo materials low will be an important measure to reduce deformation, shrinkage, swelling, warming, and mildew during warehousing, and nutrient reduction methods to decrease pest damage and stabilize bamboo materials' quality before storage will be necessary.

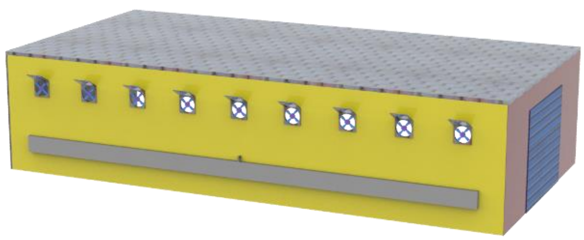

Fig. 9. Bamboo warehouse

Fig. 10. Bamboo strips storage facility

In terms of equipment and facilities, storage facilities should be constructed according to their grades and qualities. Bamboo units, such as chips, strips, bundles, shavings, and semi-finished materials, such as bamboo carbon and fibers, have different characteristics, and the environmental conditions required for storage are therefore also different. Bamboo materials are gradually becoming more and more popular as they are stored in separate storage facilities that should be constructed according to their grades and qualities. Examples include bamboo strips cages (Fig. 10), round bamboo cages (Fig. 11), indoor bamboo cages (Fig. 12), and bamboo chip cages (Fig. 13), *etc*. The classification and control of bamboo warehousing (Fig. 9) and the construction of storage facilities are important ways to promote the high-quality development of the bamboo industry.

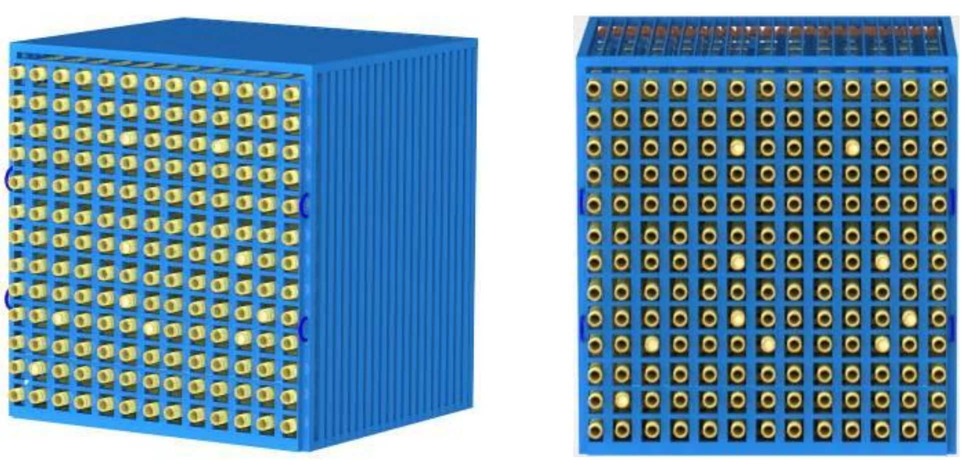

Fig. 11. Storage facility for engineering round bamboo

Fig. 12. Storage facility for indoor bamboo

Fig. 13. Bamboo chip storage facility for papermaking

In terms of developmental concept, bamboo industry will adhere to the original and low-cost warehousing technology of bamboo. Making full use of the characteristics of raw materials, low-decomposition, and low-cost warehousing will be the ideas of future development. The regulation and standardization of bamboo warehousing will be an essential approach to promote the extension and upgrade of its application in the industry chain. Bamboo warehousing can be processed based on grades, stored in group zones, and used in different types, which can be conducive to promoting the transformation and upgrading of the Chinese bamboo industry, leading to a continuous and steady increase in economic value.

CONCLUDING REMARKS

With the promotion of global sustainable development and the green materials concept, renewable biomass materials are gaining popularity. Establishing a bamboo warehousing mechanism to continuously warehouse mature bamboo is as important as grain and coal reserves, and it has the same national strategic significance. China's bamboo warehousing system requires relevant political support, drive from leading enterprises, investment in science and technology, and information intelligence empowerment to achieve its goals of high starting point development, mechanized operation, and standardization. It will be tremendously beneficial to promoting carbon neutrality if mature bamboo warehousing and the ecological value of bamboo forests can be investigated, and their relationships, as well as explore the coordination and regulation mechanism within the bamboo industry, such as the growth of fresh bamboo, the utilization of mature bamboo, and carbon sinks.

ACKNOWLEDGMENTS

The authors gratefully acknowledge financial support from the Fundamental Research Funds of International Center for Bamboo and Rattan (1632021007).

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Article submitted: May 2, 2022; Peer review completed: July 30, 2022; Revised version received and accepted: August 7, 2022; Published: August 12, 2022.
DOI: 10.15376/biores.17.4.Jia