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Review article

Baijiu (白酒), Chinese liquor: History, classification and manufactureXiao-Wei Zheng^a, Bei-Zhong Han^{b,*}^a Biotechnology Center, Nutrition & Health Research Institute, COFCO Corporation, Beijing, China^b College of Food Science and Nutritional Engineering, China Agricultural University, Beijing, China

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ABSTRACT

Baijiu (白酒) is a traditional fermented alcoholic drink originating in China, which is typically obtained by natural fermentation. It has a high reputation and constitutes an important part of Chinese dietary profile. The production of *baijiu* involves five major steps, materials preparation, *daqu* (大曲) making, alcoholic fermentation, distillation, and aging. There is a range of *baijiu* with different flavors and corresponding names. *Baijiu* can be categorized according to the production techniques (solid state and semi-solid state), types of starter [*daqu*, *xiaoqu* (小曲), and *fuqu* (麸曲)] and product flavor (strong, light, sauce, etc.). different types of *baijiu* have their *home microbiota* and flavor because of their distinct production techniques. In this review, we discuss the critical steps and the microorganisms involved in the production of different types of *baijiu*. Although *baijiu* contains alcohol, it has been proven that it plays a significant role in the health and quality of peoples' lives.

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1. Introduction

Chinese traditional fermentation techniques have benefited Chinese people for centuries. Traditional fermented products have improved the daily diet habit of Chinese people and have also enriched the catering culture in the world. Chinese fermented products primarily include staples, alcoholic drinks, condiments, and adjuncts to staples. They constitute a major part of the Chinese national food industry, valued at approximately 278 billion RMB annually [1]. *Baijiu* (白酒), Chinese liquor, has been regarded as the backbone of fermented products by Chinese people, because its production increased quickly and currently exceeds 12 million metric tons annually [2]. On average, each Chinese individual consumed *baijiu* at 9.43 L/y in 2013, which is almost equal to the maximum drinking volume of alcoholic drink by an American individual (8.2 L/year) [3].

Baijiu, written in hieroglyphics as a Chinese word, was derived from the words *bai* (白, transparent) and *jiu* [dju] (酒, alcoholic drink). *baijiu* is also known as *samshu*, *baigan* (白干), or *shaojiu* (烧酒, fired liquor), which is obtained by complex fermentation processes using natural mixed culture starters followed by distillation. *Baijiu* is a type of Chinese traditional distilled liquor and regarded as

one of the most famous distilled liquors in the world, together with brandy, gin, rum, vodka, and whiskey. As a product, it is not only an important commodity but also has a very close connection with social and economic activities. *Baijiu* has enriched living standard connotations of Chinese people and it was often given as a present or during important events.

The manufacture of *baijiu* began at least before the 2nd century BCE [4]. The *Ben-Cao-Gang-Mu* (本草纲目, Chinese Materia Medica), compiled by Li Shi-Zhen (李时珍) in 1597, indicates that solid-state fermentation (SSF) combined with distillation was invented during the era of the Yuan dynasty [5]. However, it is difficult for researchers to describe exactly when *baijiu* was invented. It is known that some of the early distillation appliances were closely linked to *baijiu* manufacture. An historical record mentions that the earliest distillation tools (distillation pan) appeared during the era of the Song dynasty [4]. The *Song-Shi* (宋史), authored by TuoTuo (脱脱) in 982 CE, described a method using wheat, barley, sticky rice, etc. to produce a distilled liquor, which is the exact approach for *baijiu* production used today.

Based on the development perspective of the historical and cultural heritage, *baijiu* can be used for a long time because of its good taste and healthy aspects. *Baijiu*, a special series of distilled liquors, was normally made from sorghum or a mixture of barley, corn, rice, wheat, and sorghum, containing abundant volatile components such as esters and organic acids [6]. These nonalcoholic components might participate in the prevention of cardiovascular diseases [7]. It has been reported that moderate

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consumption of *baijiu* could reduce uric acid concentration in serum and the risk of Alzheimer's disease [3]. It could improve serum lipid profiles in young people and decrease platelet aggregation and endothelial adhesion molecules to protect against the risk of cardiovascular diseases [5]. Therefore, Chinese people have regarded *baijiu* as a healthy product for a very long time and have recommended its consumption in small volumes every day.

2. Classification of *baijiu*

Hundreds of different types of *baijiu* are produced by various processes in different regions of China. They can be distinguished based on the manufacturing techniques, fermentation starters, and product flavors, as outlined below.

2.1. Manufacturing techniques

2.1.1. SSF *baijiu* (固态发酵白酒)

SSF is a process in which microbial cultures are grown on a solid matrix in the absence of a liquid (aqueous) phase [8]. This method has been commonly used for most of the well-known *baijiu* production techniques, and it has a long history and has been passed on through several generations. This type of *baijiu* is typically produced from grains such as sorghum, wheat, rice, glutinous rice, and maize by a complex SSF process, which consists of: (1) material preparation; (2) *daqu* making; (3) SSF; (4) solid-state distillation; and (5) aging [8]. This technique results in fermented materials containing approximately 60% water [8]. It can produce components with different flavors, depending on the different fermentation processes and operation conditions. Therefore, SSF is regarded as a method that could produce the maximal types of *baijiu*, with each product having different flavor and characteristics.

2.1.2. Semi-SSF *baijiu* (半固态发酵白酒)

Semi-SSF *baijiu* is represented by *guilinsanhua-jiu* (桂林三花酒) and *quanzhouxiangshan-jiu* (全州湘山酒). The fermentation process is operated under semi-solid state [9].

2.1.3. Liquid-state fermented *baijiu* (液态发酵白酒)

Liquid-state fermented *baijiu* is represented by *hongxing erguotou-jiu* (红星二锅头酒). All the production processes include saccharification, fermentation, and distillation performed under liquid state [10].

2.2. Fermentation starters

According to the starters used, three different types of *baijiu* can be distinguished [5], which are as follows:

- (a) *Baijiu* produced using *daqu* as the starter is represented by four most famous *baijiu*: (*moutai-jiu* 茅台酒, *wuliangye-jiu* 五粮液酒, *fen-jiu* 汾酒 and *luzhoulaojiao-jiu* 泸州老窖酒). *Daqu* is a type of grain, *qu* (曲), which is made from raw wheat, barley, and/or peas [11]. The wetted materials are transferred to a molding press and shaped as a brick, each weighing approximately 1.5 kg to 4.5 kg [12], with either a flat surface or one side in a convex shape. Because of its big size, it is therefore named as *daqu* (big starter). In general, four categories of microorganisms (bacteria, yeast, filamentous fungi, and actinomycetes) are found in *daqu*. They provide different enzymes and flavor precursors for the production of *baijiu*. *Baijiu* produced using *daqu* is enriched in flavors, with a long fermentation time and low alcohol production.
- (b) *Baijiu* produced using *xiaoqu* (小曲) as the starter is represented by *guilinsanhua-jiu* (桂林三花酒) and *liuyanghe-jiu* (浏

阳河酒) [13]. Compared to *daqu*, *xiaoqu* is a small starter, which is made from rice or rice bran [13]. Unlike *daqu*, only very a few types of microorganism are present in *xiaoqu*, including *Rhizopus*, *Mucor*, lactic acid bacteria, and yeasts. These microorganisms are primarily good fermentation performers; therefore, a small quantity of the starter and short fermentation period are used in the production of this type of *baijiu*. However, due to a few types of microorganism involved, *baijiu* produced using *xiaoqu* contains less flavor than that produced using *daqu*.

- (c) *Baijiu* produced using *fuqu* (麸曲) as the starter is represented by *erguotou-jiu* (二锅头酒) [14]. *Fuqu* is different from the other two starters and is made from bran and contains only pure culture of *Aspergillus* [14,15]. *Aspergillus* is a well-known starch degrader and can convert starch into fermentable sugars. Using *fuqu* as the starter, the produced *baijiu* has characteristics of light flavor and high liquor production.

2.3. Flavor of *baijiu*

Based on their flavor, *baijiu* can be divided into three major and nine minor categories (Fig. 1).

- (a) Sauce-flavor *baijiu* (酱香型白酒), such as *moutai-jiu* (茅台酒) and *lang-jiu* (郎酒), which provides a flavor resembling soy sauce, full-body and a long-lasting aroma. The major representative aroma compounds are phenolic compounds, primarily tetramethyl pyrazine (3,000–5,000 mg/L) and syringic acid, along with small quantities of amino acids, acids, and esters [16].
- (b) Strong-flavor *baijiu* such as *luzhoulaojiao-jiu* and *wuliangye-jiu*, which have the characteristics of fragrant flavor, soft mouthfeel, and endless aftertaste. The representative aroma compounds are predominantly ethyl hexanoate in harmonious balance with ethyl lactate, ethyl acetate, and ethyl butanoate [17].
- (c) Light-flavor *baijiu* (清香型白酒) such as *fen-jiu* (汾酒) and *erguotou-jiu*, which gives a pure and mild flavor, mellow sweetness and refreshing aftertaste. The major aroma compounds are ethyl acetate in balance with considerable levels of ethyl lactate [18].

The characteristics of these three flavor types are very typical and representative, and they comprise approximately 60% to 70% of *baijiu* in China. The production techniques for these three types of *baijiu* are standardized and stereotyped. In addition to these three types, some *baijiu* such as *baiyunbian-jiu* (白云边酒), *dong-jiu* (董酒) and *site-jiu* (四特酒), with a specific flavor and aroma characteristics are also produced using different techniques. They do not belong to the first three categories, and therefore nine additional flavors were established, which are described as follows (Fig. 1).

- (d) Miscellaneous-flavor *baijiu* (兼香型白酒) such as *baiyunbian-jiu* (白云边酒) has sensory characteristics ranging between those of sauce-flavor and strong-flavor *baijiu*. The representative aroma compounds in miscellaneous-flavor *baijiu* are heptanoic acid, ethyl heptanoate, isoamyl acetate, 2-octanone, isobutyric acid, and butyric acid.
- (e) *Feng*-flavor *baijiu* (凤香型白酒) such as *xifeng-jiu* (西凤酒) is characterized by sweet entrance and elegant aftertaste. The representative aroma compounds in *Feng*-flavor *baijiu* (凤香型白酒) are primarily ethyl acetate in balance with ethyl caproate [19].



Fig. 1. Examples of different flavor types of baijiu. Representative brand for each baijiu type. (A) Sauce-flavor baijiu, represented by moutai-jiu; (B) strong-flavor baijiu, represented by luzhoulaojiao-jiu; (C) Light-flavor baijiu, represented by fen-jiu; (D) Miscellaneous-flavor baijiu, represented by baiyunbian-jiu; (E) feng-flavor baijiu, represented by xifeng-jiu; (F) Rice-flavor baijiu, represented by guilinsanhua-jiu; (G) Dong-flavor baijiu, represented by dong-jiu; (H) Sesame-flavor baijiu, represented by jingzhi-jiu; (I) Te-flavor baijiu, represented by dite-jiu; (J) Chi-flavor baijiu, represented by yubingshao-jiu; (K) Laobaigan-flavor baijiu, represented by hengshuilaobaigan-jiu; (L) Fuyu-flavor baijiu, represented by jiugui-jiu.

(f) Rice-flavor baijiu (米香型白酒) such as guilinsanhua-jiu (桂林三花酒) is a type of xiaoqu baijiu (小曲白酒) made from rice. It has the characteristics of soft sweet flavor and clean aftertaste. This type of baijiu contains primarily β -phenethyl alcohol in balance with ethyl acetate and ethyl lactate.

(g) Medicine-flavor baijiu (药香型白酒) such as dong-jiu (董酒) provides a flavor resembling medicine, with moderate sweet and sour aroma and long aftertaste. The characterized aroma compounds in medicine-flavor baijiu can be summarized as “high in total acids, alcohols and ethyl butanoate; low in ethyl lactate.” In addition, the total quantity of acids and alcohols in this type of baijiu are higher than that of esters. This is significantly different from the aroma composition of other types of baijiu [19].

(h) Sesame-flavor baijiu (芝麻香型白酒) such as jingzhibai-jiu (景芝白干酒) and bandaojing-jiu (扳倒井酒) provide a flavor resembling sesame or burnt.

(i) Te-flavor baijiu (特香型白酒) such as site-jiu (四特酒) has high concentrations of ethyl acetate and ethyl caproate as the primary aroma compounds in balance with heptylate. This type of baijiu has a harmonious, strong and light flavor. The concentrations of ethyl propionate, ethyl valerate, ethyl heptanoate, and ethyl nonanoate are higher than those in any other types of baijiu.

(j) Chi-flavor baijiu (豉香型白酒) such as yubingshao-jiu (玉冰烧酒) provides fermented soybean flavor and very clean aftertaste. The primary aroma compounds in this type of baijiu are β -phenethyl alcohol and ethyl ester.

(k) Laobaigan-flavor baijiu (老白干型白酒) such as hengshuilaobaigan-jiu (衡水老白干酒) is characterized by soft, mellow and rich mouthfeel. The representative ester compounds in laobaigan-flavor baijiu are ethyl acetate, ethyl

lactate, and small quantities of ethyl hexyl acetate, ethyl butyrate, palmitic ester, and linoleic acid. Among these, the concentration of ethyl hexyl acetate is higher than those of light-flavor baijiu and feng-flavor baijiu. The content of fusel oil, particularly isoamyl alcohol content, in this type of baijiu (7.17 mg/100 mL) is higher than that in light-flavor baijiu (清香型白酒, 28.89 mg/mL), which enhances its sweet and soft taste.

(l) Fuyu-flavor baijiu (馥郁香型白酒) such as jiugui-jiu (酒鬼酒) has sensory characteristics of light-flavor, strong-flavor, and rice-flavor baijiu. The primary aroma compounds are ethyl caproate, with an equal amount of ethyl lactate and ethyl acetate.

As described above, characterization of the different types of baijiu is still vague. With the development of science and technology and using various starting materials, baijiu types with different and various flavors can be produced. More strict and accurate standards are required in the future to distinguish baijiu based on their flavor-enriching compounds.

2.4. Other classifications

Baijiu can also be divided into high alcohol content (above 50% v/v), medium alcohol content (41–50% v/v), and low alcohol content (< 40% v/v); and according to the raw materials used for fermentation, there are sorghum-based baijiu, corn-based baijiu, and rice-based baijiu.

3. Manufacture of baijiu

Baijiu production technique is a precious national heritage of China, and the appearance of present-day baijiu types is the result

of gradual technological progress [21]. Although there are more than 10,000 factories producing *baijiu* using their own techniques, the principle of *baijiu* production remains the same [20]. However, the raw materials, techniques of *daqu* manufacture and conditions of alcoholic fermentation are varied in *baijiu* production. Herein, the production techniques of three major flavor types of *baijiu* are described in order to understand the key production line in the context of the different types of *baijiu* production.

3.1. The production process of light-flavor *baijiu*

Light-flavor *baijiu* is represented by *fen-jiu*. The production of *fen-jiu* is simple compared to other types of *baijiu*. We took *fen-jiu* as an example to describe the production process of *baijiu* since it involves several important steps in relation to *baijiu* production (Fig. 2). *Fen-jiu* is primarily produced in northern China using sorghum as the raw material in combination with low-temperature *daqu* (maximum temperature reaching 40–50°C) to carry out alcoholic fermentation. In total, there are eight major steps: (1) ingredient formulation; (2) grinding and cooking; (3) mixing and cooling; (4) mixing with *daqu*; (5) loading to the fermentation vessel; (6) alcoholic fermentation; (7) distillation; and (8) aging.

Ingredient formulation: *Fen-jiu* uses sorghum as the primary material.

Grinding and cooking: Sorghum is ground in order to release starch with the purpose of increasing the cooking and microbial correlation area and obtaining a desirable cohesion of mass. This step plays an important role in the quality of *baijiu*, since soft grinding leads to ineffective saccharification and harsh grinding influences the flavor of *baijiu*. The aim of cooking is to introduce starch for gelatinization.

Mixing and cooling: Water hotter than 85°C and other additives are mixed in order to obtain a homogenous texture and desirable flavor. Cooling is used to reduce the temperature to be ready for mixing with active microbiota (*daqu*).

Mixing with *daqu*: Low-temperature *daqu* is used for production of *fen-jiu*, which is made from barley and peas. It is normally made into a block shape [11] and ground before mixing with sorghum.

Loading fermented materials into an earthen jar: When the temperature of the fermented materials (grains with *daqu*) reduces to between 18°C and 20°C, the mixture is loaded into an earthen jar.

Alcoholic fermentation: This step is typically carried out in an earthen jar (Fig. 3). The jar is circulated to use from one batch to another batch. The fermentation time is dependent on various factors such as climate and moisture content. Alcoholic fermentation takes about 1 month.

Distillation: This is the key step in the development of flavor of *baijiu*. The efficiency of distillation depends on the steam flow rate, water content, distillation speed and porosity of materials [22]. It has been shown that a lower steam flow rate may not provide the thermal condition for the complete evaporation of ethanol, while a higher steam flow rate may cause the fermented grains to stick together and increase the diffusion resistance [23].

Aging: Aging plays an essential role in the flavor of liquors, since a variety of aromatic compounds (mainly acids and esters) are balanced during this process through physical changes mainly van der Waals interaction combined with chemical reactions such as reduction–oxidation, esterification, hydrolysis, condensation, decomposition, and the Maillard reaction [24]. In general, the aging time for sauce-flavor liquor is more than 3 years, while at least 1 year is required for strong- and light-flavor liquors [25].

A specific feature in the techniques used in the production of light-flavor *baijiu* is the making of low-temperature *daqu*. It follows distinct and specific temperature regimes, which are named as *woqu* (卧曲, laying and covering, 20°C), *shangmei* (上霉, molding, 38–40°C), *liangmei* (晾霉, cooling and hardening, 24–36°C), *chao-huo* (潮火, succession of dominant groups of microorganisms, 43–47°C), *dahuo* (大火, enhancing microbial metabolism), *houhuo* (后火, evaporative dehydration and equilibration, 34–38°C), and *yangqu* (养曲, prematuration, 30°C) periods [26]. These seven steps are associated with initiation of microbial growth, succession of dominant groups of microorganisms, enhancing proteolysis, and maturation. *daqu* provides enzymes and chemical components for microbial growth and precursors for the development of *baijiu* flavor. Previous studies have shown that *Bacillus licheniformis*, *Lactobacillus plantarum*, *Pediococcus pentosaceus*, *Saccharomyces*

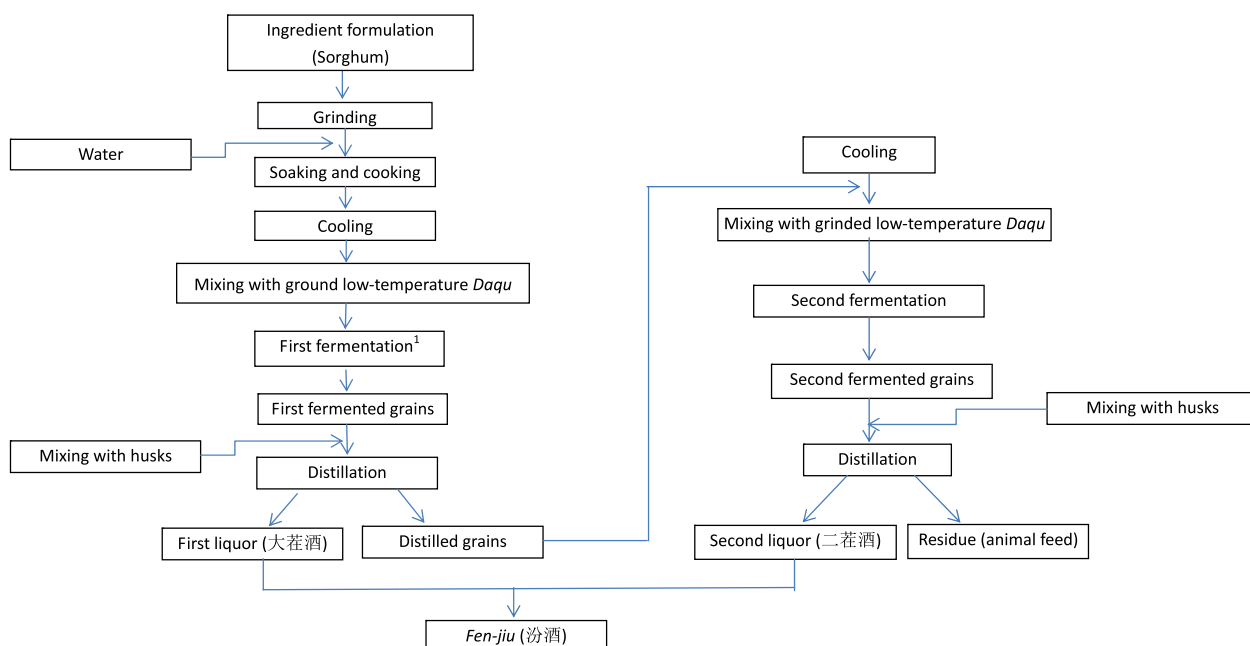


Fig. 2. Process diagram for the production of *fen-jiu*. Alcoholic fermentation was carried out for about 1 month.

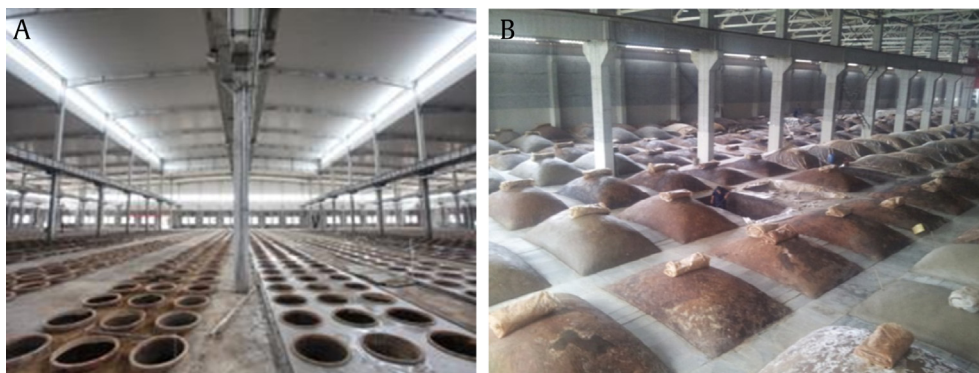


Fig. 3. Alcoholic fermentation. (A) In earthen jars: alcoholic fermentation is typically carried out under anaerobic conditions in earthen jars dug in the ground. (B) In mud pits: alcoholic fermentation is typically carried out under anaerobic conditions in cellars dug in the ground.

cerevisiae, *Saccharomycopsis fibuligera*, *Pichia kudriavzevii*, *Wickerhamomyces anomalus*, and filamentous fungi, including *Mucor circinelloides*, *Absidia corymbifera*, and *Rhizopus stolonifer*, are present in light-flavor *daqu* [27]. Of these, *P. pentosaceus*, *L. plantarum*, *S. cerevisiae*, *P. kudriavzevii*, and *W. anomalus* are active throughout the alcoholic fermentation process [28].

3.2. Manufacture of sauce-flavor baijiu

Sauce-flavor *baijiu* is represented by *moutai-jiu*. Herein, we describe only the techniques that are different or specific from other types of *baijiu* and not each step. Sauce-flavor *baijiu* has characteristics resembling soy sauce. Therefore, it is necessary to increase the accumulation of flavor during the production of sauce-flavor *baijiu*. The production processes are highly complicated and need to be carefully controlled. The specific techniques applied in the production of sauce-flavor *baijiu* are described below.

Use of high-temperature *daqu*: High-temperature *daqu* is produced with a maximum temperature reaching more than 60°C. Due to the high temperature used in *daqu*-making process, thermophilic microorganisms can survive and grow well. Therefore, the dominant microorganisms in *daqu* are primarily bacteria, particularly *Bacillus* spp., because fungi are more sensitive to heat than bacteria. High-temperature *daqu* is made from wheat and sorghum at a combination ratio of between 0.85 and 0.9 (w/w). This ratio is higher than that used for other types of *daqu*. *Daqu* with too high and too low temperatures can influence liquorification and *baijiu* flavor. Thus, this needs to be strictly controlled.

Use of high-temperature stacking fermentation (堆积发酵): This is the key process in the production of sauce-flavor *baijiu*. During the *daqu*-making process, high temperature is used to obtain *daqu* dominated by thermophilic bacteria. However, yeasts and molds play significant roles in alcohol fermentation, since they convert fermentable sugar into alcohol and aroma compounds. Due to this, high-temperature stacking fermentation is introduced directly after adding *daqu* to sorghum. The principle of this technique is rather simple, that is, to stack the fermented material for a few days (2–4 days) before alcoholic fermentation with the purpose of increasing the number of microorganisms, particularly yeasts, and balancing the chemical components [29]. Xiao et al [4] showed that 53.76% of bacteria and 46.24% of yeasts were present before high-temperature stacking fermentation, while 5.61% of bacteria and 94.39% of yeasts developed after high-temperature stacking fermentation [4]. The microorganisms involved in this process are *S. cerevisiae*, *Candida intermedia*, *Saccharomyces italicus*, and *Saccharomyces talluri* [30]. The authors also showed that the composition of amino acids changed as well.

Use of multiple turns of alcoholic fermentation: The fermentation process is circulated eight times. Each time, fermentation takes approximately 1 month. Upon the completion of the first fermentation, new *daqu* is added to carry out the next turn of fermentation. The purpose of multiple times of fermentation is to obtain an optimal microbial composition dominated by functional microorganisms, which are known as soy sauce flavor microbes [31]. This technique is primary used because: (1) it could increase the enrichment of functional microorganisms; (2) it could increase saccharification and fermentation of materials; and (3) it could increase the flavor of soy sauce.

Adding sorghum two times. Before the second alcoholic fermentation, about 50% sorghum is added in order to generate more starch and protein for the fermentation.

3.3. Manufacture of strong-flavor baijiu

Strong-flavor *baijiu* is represented by *luzhoulaojiao-jiu* (Fig. 1). This type of *baijiu* production normally uses sorghum as the raw material in combination with medium-temperature *daqu* (maximum temperature reaching 50–60°C) to conduct alcoholic fermentation. The specific techniques used in strong-flavor *baijiu* production are described below.

Use of mud pit (窖池): The mud pit is a cellar made from mud (Fig. 3). The average volume of the mud pit is from 6 m³ to 8 m³. When the temperature of the fermented materials (grains with *daqu*) reduces to between 20°C to 21°C, the mixture is loaded into the mud pit. Experience has shown that the pit not only provides the place for fermentation but also contributes to the flavor of *baijiu*.

Ingredient formulation: Most strong-flavor *baijiu* use sorghum as the primary material in combination with other grains. The *baijiu* produced from southern China, such as *wuliangye-jiu* and *jian-nanchun-jiu* (剑南春酒), primarily use sorghum, rice, glutinous rice, wheat, and corn as the raw materials, while the *baijiu* produced from northern China use sorghum as the only material.

Opton of *daqu*: Strong-flavor *baijiu* produced from southern China use wheat as the raw material to make *daqu*, while those from northern China use barley, wheat, and peas as the raw materials to make *daqu*. *Daqu* is normally made into a block shape [11] and ground before mixing with sorghum and other grains.

Alcoholic fermentation: Alcoholic fermentation is typically carried out under anaerobic conditions in the mud pit. The pit is circulated to use from one batch to another batch. As a result, the microorganisms in the pit may play important roles in alcoholic fermentation. The fermentation time is dependent on various factors such as climate and moisture. Due to the subtropical monsoon climate, alcoholic fermentation takes from 60 to 90 days for the *baijiu* produced from

southern China. Compared to southern China, northern China has the characteristics of low moisture and long daylight. Therefore, alcoholic fermentation takes approximately 45 to 60 days. *Daqu* provides enzymes and chemical components for microbial growth and precursors for the development of the *baijiu* flavor. The primary microorganisms involved in the fermentation are those from *daqu* and those from the mud pit. Previous studies have shown that *Bacillus*, *Lactobacillus*, *Saccharomyces*, *Candida*, and filamentous fungi, including *Mucor*, *Absidia*, *Penicillium*, and *Aspergillus*, are present in strong-flavor *daqu* [32,33]. The dominant microorganisms in the mud pit are primarily bacteria, including *Clostridium diolis*, *Lactobacillus acetotolerans*, and *Bacillus subtilis* [34].

Use of back-slopping (续糟) technique: *baijiu* is obtained by alcoholic fermentation followed by distillation, and the products are normally unstable and inconsistent. *Back-slopping* technique is introduced by adding the fermentation residue during the beginning of alcoholic fermentation for a better regulation of the fermentation process. This technique allows for an optimal composition of the microbial communities, which in turn increases the success of natural fermentation. This technique is regarded as an important step compared to other types of *baijiu* production.

In summary, each type of *baijiu* has its own specific and critical techniques that result in the different flavors of *baijiu*. As described earlier, in addition to the three main types of *baijiu*, the other nine types of *baijiu* have different characteristics. They are all associated with the specific *daqu*-making process and alcoholic fermentation process. Changes in each step will alter the microbial profiles, which consequently alters the microbial metabolites as well. As a result, *baijiu* with different flavors could be produced.

4. *Baijiu* and health

Baijiu is a great invention of the ancient Chinese. From ancient times to the present day, *baijiu* has been closely connected with the life of the Chinese people. However, the relationship between liquor and health is very complicated. Consumers regard liquor as the primary product, as *baijiu* contains mostly ethanol and water. However, people neglect that *baijiu* also contains various micro-nutrients. The *Huang-Di-Nei-Jing* (黄帝内经) recorded that “*Jiu* has long been used as a base for medicine (酒乃百药之长)”; this emphasizes the importance of *Jiu* in the healthcare and disease treatment [35]. The *Ben-Cao-Gang-Mu* (本草纲目, *Chinese Materia Medica*) indicates that moderate consumption of *baijiu* may eliminate the feeling of cold, fatigue, and phlegm dampness. Moreover, some clinical data show that moderate consumption of *baijiu* may speed up blood circulation and improve the functioning of cardiovascular and circulatory systems [7]. Yang et al studied health factors in relation to *baijiu* by using an *in vitro* model and found that pyrazine compounds (primarily tetramethyl pyrazine) are related to antioxidant activities, immunity enhancement, and reduction of triglycerides [36]. It also has been proven through clinical studies that moderate consumption of *baijiu* every day may play a significant role in the digestion of food by dissolving nutrients and stimulating the digestive system; moreover, it decreases the formation of blood clots and in turn may prevent arteriosclerosis [37]. Therefore, moderate intake of *baijiu* is healthy and safe, although it is critical to control high intake. Some studies have focused on the relationship between the level of *baijiu* consumption and consumers' health needs in order to guide people for a rational consumption of *baijiu*.

5. Conclusion

The *baijiu* industry is a traditional and unique industry that plays a very important role in the construction and development of

the Chinese economy. For the Chinese people, *baijiu* is not only a food product but also a culture heritage. This review has focused on the history, classification, manufacture, and health aspects of *baijiu*. Recently, European and other western countries have shown great interest in *baijiu*. It has been already exported to the USA, France, and Canada. In order to allow for an increasing recognition and appreciation by the international market, *baijiu* production processes, including *daqu* making, have been modernized and developed. However, due to the diverse types of *baijiu*, their production techniques have to be updated on the basis of retaining the original flavor. Therefore, knowledge regarding the ecology and function of the relevant microorganisms for each type of *baijiu* is a prerequisite to standardize *baijiu* production.

Conflicts of interest

All authors have no conflicts of interest to declare.

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