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Basic research and industrial development status of suancai in Northeast China: history, microflora diversity, processing technology, nutrition and safety

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ABSTRACT

Suancai has a lengthy history and a wide range of categories, which has some influence on the pickled diet culture around the world. Suancai production is transitioning to a large-scale, standardized production due to the growth of the market. It has a unique flavor and is rich in nutrients, and its abundance of free amino acids, vitamins and phenolics has many positive effects on the human body. This review gives the types and history of suancai, as well as its impact on the world's pickled culture. The changes in nutritional composition and flavor of suancai during fermentation are summarized. It presented the production technology and influencing factors of the northeast suancai, examined the quality and safety issues in suancai, and put forth some ideas and opinions on the standardization development of the suancai industry. It also summarized the geographic distribution and flora diversity of pickles around the world. In order to provide some knowledge and guidance for the promotion of modern industrial production in the suancai industry.

1. The development history of fermented vegetables

Traditional forms of fermented vegetables have largely been produced by immersing vegetables in a brine solution and subjecting them to spontaneous fermentation, mainly by lactic acid bacteria (LAB)[1]. The raw materials used in the production of pickled cabbage are notably abundant, encompassing not only the conventional cabbage but also various other ingredients like cucumbers, radishes, and kale. Pickled cabbage is a traditional food in Northeast China, as well as Korea, Japan, and Germany. In the absence of a standard of identity, the term "sauerkraut" is considered the common or usual name for a product obtained by the lactic acid fermentation of cabbage in the presence of salt[2]. In addition, sauerkraut may also refer to German pickled cabbage, a word of German origin. Because there are some differences in the ingredients and processes used to make pickled cabbage in different countries, it can be distinguished by different names, for example, Korean pickled cabbage is known as kimchi and Chinese pickled cabbage is known as suancai.

China: Suancai has a long-documented history of consumption, and finds reference in cultural records such as *Zhou Li* and *The Book of Songs*, dating as far back as 100 AD. Different pickling techniques for the preparation of Chinese pickled cabbage are explained in depth in the *Qi Min Yao Shu*, an ancient treatise on agricultural knowledge. Over time and with continuous research and development, it has evolved into popular contemporary versions such as Northeast Chinese pickled cabbage with light brine (2%–10%)[3], Henan pickled cabbage with millet water, Shanxi pickled cabbage with water and a small bit of sugar, and Sichuan pickled cabbage. Suancai, which can be prepared in a variety of ways, is depicted in Fig. 1.

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Fig. 1 Utilization of suancai in diet.

South Korea: Kimchi is a traditional Korean fermented vegetable that is primarily created from fresh vegetables and enhanced with garlic, ginger, scallions, chili peppers, and fermented seafood (jeotgal). It is further processed through steps like salt pickling and seasoning. Kimchi was initially created as a means of preserving fresh produce for extended periods. In Korea, the flavor of kimchi varies significantly depending on provenance, and further, the addition of supplementary ingredients has a large impact on the flavor of kimchi[4].

Germany: The origins of sauerkraut can be traced back to the ancient Greek and Roman empires. When the Mongol cavalrymen invaded Europe in the 13th century, they carried Chinese pickled cabbage with them, which is also where the similarities in pickling techniques and tastes between Germany's sauerkraut and China's suancai have their historical roots. Pickled cabbage persisted throughout Europe and gained popularity first in Eastern Europe before migrating to Western Europe with the Jews. Thus, sauerkraut became a popular winter dish in countries like Germany, Holland, Poland, and other cold-weather nations in northern Europe. In Germany, the average person consumes 10 kg of sauerkraut per year. The "national dish" of Germany is sauerkraut because it is not only one of the most consumed foods at home but also a staple at state banquets.

Other countries: Similar fermented vegetable dishes have been made in Nagano Prefecture, Japan, for at least 300 years. It is prepared by subjecting red turnip leaves to lactic acid fermentation[5]. Japanese Sunki, in contrast to other kimchi, is fermented in an unsalted environment and made in the first few weeks of winter every year. It offers several advantages for human health and is highly valued because of its salt-free fermentation and abundance of LAB[6]. Like Japanese Sunki, a fermented vegetable known as Gundru can be found in the eastern Himalayas and is a widely consumed dish in parts of northeastern India and Nepal[7]. The resulting Gundru is sun-dried after fermentation after which it may be used to make pickles or soup[8].

2. Geographical distribution and flora diversity of fermented cabbage in the world

2.1 Geographical distribution of fermented cabbage

Sauerkraut is very common in China, especially in the northeast region, where winters tend to be cold and long. Autumn cabbages are inexpensive, and people stock up on them when they are harvested. The main way to stock it is to pickle it into sauerkraut at the beginning of October each year, and it is ready for consumption after a month or so of pickling, which enables the cabbage to be stored during the winter and imparts a characteristic fermented flavor[9].

Globally, the consumption of fermented sauerkraut is distributed across Asia, Burope, North America, and Oceania. Domestically, the provincial distribution of Chinese saverkraut manufacturing enterprises is illustrated in Fig. 2, with major concentrations in the thre northeastern provinces, as well as Guangxi, Yunnan, and Sichuan provinces.

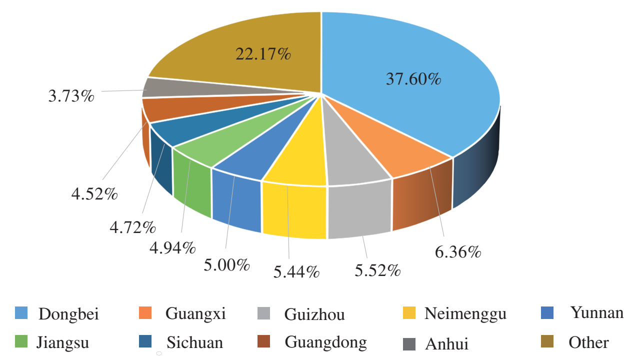

Fig. 2 Share of suancai manufacturing companies in China by province.

2.2 Production and scale situation

With the advent of modern production technology, the production of northeast sauerkraut has accelerated rapidly. The combined output of large-scale enterprises and some small enterprises and workshops currently is estimated to be in the hundreds of thousands of tons, with a value of nearly 5 billion RMB[10]. There is a large gap in the scale of production of sauerkraut manufacturers in northeastern China. Some of the larger manufacturers account for an annual production capacity of over 10 000 t, while some have a capacity of several hundred tons and some have a capacity of only a few dozen tons. Most of the sales occur in the three northeastern provinces and to a certain extent in their neighboring provinces and cities, with some companies also exporting their products to Korea, Russia, the United States and Canada. There are also many internationally renowned sauerkraut companies, such as Kühne, Develey, Chungjungone, Fermented Food Holdings, Inc..

2.3 Natural fermentation flora diversity

Fermentation is the critical processing step in the manufacture of northeast sauerkraut, and as such, determines the physicochemical properties of the product. Since fermentation tends to be spontaneous, the composition of microflora varies depending on raw materials

Table 1
Number and market share of pickled vegetables enterprises of different sizes in China.

Size of business	Number of enterprises (pcs)	Raw materials	Market share
L (Large)	6	The vast majority of products are made with cabbages, the main varieties being the kong series, while in Liaoning and a few parts of Heilongjiang the application of kale fermentation is more common	Most of the sauerkraut industry comprises small and micro enterprises, with Jixiangju occupying the leading position, accounting for 1.2% of the overall market share followed by Chuannan Brewing and Huitong Food accounting for 0.92%, and 0.37%, respectively
M (Medium)	33		
S (Small)	186		
XS (Micro)	3 745		

Note: The enterprise sizes in the table are based on a big data model, combining data on the operating conditions of enterprises in different industries and building an algorithmic model to form a system of four size categories—L (Large), M (Medium), S (Small) and XS (Micro).

and fermentation conditions. Sauerkraut fermentation involves many physicochemical changes that directly affect the quality and safety of the product, and microbial action is the origin of these changes[11]. Therefore, an understanding of microbial dynamics is essential for the preparation of a flavorful, safe and high-quality product.

LAB, yeasts and moulds are present during the fermentation of sauerkraut, with LAB playing a dominant role in the entire fermentation process. During the fermentation process, the microbial community is highly dynamic: initially, spoilage bacteria such as *Escherichia coli* proliferate, but later, species such as *Leuconostoc mesenteroides*, *Lactobacillus brevis* and *Lactobacillus plantarum* quickly establish themselves. Towards the terminal stages of fermentation, strains of *E. coli* (*Alcaligenes castellani* & *A. chalmers*) and *Vibrio* begin to grow and cause proteolysis, while species of *Pseudomonas* and *Bacillus* cause the cell walls of the plant material to soften and discolor[12]. In addition, natural fermentation of sauerkraut is an open system in which eukaryotic microorganisms are also involved. Eukaryotic microorganisms' structure gradually diversifies as the fermentation process lengthens. Guan et al.[13] found that in addition to bacteria, fungi such as Ascomycetes and Basidiomycetes are also involved in the fermentation of sauerkraut, the most important of which is yeast.

3. Introduction to Chinese fermented cabbage technology

3.1 Traditional natural fermentation

Traditionally, the preparation of fermented Chinese cabbage has relied on spontaneous natural inoculation, which was commonly practiced within family and workshop settings. During the winter season, it is customary for nearly every household to engage in the pickling of suancai. The traditional approach is highly favored as it not only prolongs the longevity of cabbage but also enhances its nutritional composition and flavor. Currently, the practice of producing suancai remains prevalent among individuals residing in Northeast China. However, with the development of fermentation technology and the increase in market demand, large-scale suancai production enterprises have begun to replace small-scale production operations. Additionally, natural spontaneous fermentation has gradually been replaced by heterogeneous inoculations containing multiple strains of bacteria, thus eliminating seasonal limitations in suancai production.

3.1.1 Traditional natural fermentation process flow

The process flow for suancai production by traditional fermented is as follows Fig. 3:

i. Air-curing: Whole Chinese cabbages that have reached a specific size (usually weighing 1.0–1.5 kg) are collected and spread in open spaces to air dry. If required, an additional cold-resistant material may be laid on top to prevent freezing. To facilitate even drying, the cabbages are turned over at least once daily. Approximately after 2 weeks, the outer layers become slightly wilted, at which time the old leaves are removed and the raw material is ready for the next stage.

ii. Blanching: The dried cabbage is blanched and cooled to reduce microbial load and to mitigate the growth of spoilage microorganisms. A secondary purpose of blanching is to facilitate further exudation of water from the cells in the cabbage tissue. Normally, the bottom is blanched for up to 2–3 min followed by the top for 1–2 min.

iii. Salting and packing: Blanched cabbages are layered uniformly in sanitized fermentation vessels and in between layers, salt (approximately 1% of the total fresh weight of the cabbage) is evenly distributed. The osmotic potential of the salt-rich matrix provides a natural bactericidal environment. Finally, enough clean drinking water or water left over from washing rice is added to submerge the vegetables under approximately 10 cm of liquid. Occasionally, a layer of blanched outer leaves, weighed down by rocks or stones, may be used to compress and expel air pockets from the matrix, maintain anaerobic conditions and prevent the growth of spoilage or pathogenic bacteria.

iv. Fermentation: The vessels are sealed and allowed to ferment for approximately 30 days. Following this, the vessels are opened, when the temperature is between 10 and 20 °C. The suancai is considered "mature" and ready for consumption if the dish's body is visibly sinking and the Chinese cabbage is somewhat darker after fermentation, the young leaves are vivid yellow, and a sour odor can be detected. Suancai fermentation typically takes place inside, where the temperature should be maintained at 10 °C. After 35–45 days of fermentation, it can be consumed or sold. Additional salt (3%–6%) is added as a preservative to enhance flavor at the end of fermentation .

3.1.2 Fermentation mechanism of traditional natural fermented suancai

Two processes occur during fermentation, which impart the characteristic flavor of suancai—the plasmolytic activity of the added salts and fermentation. The addition of salt causes an environment of low osmotic potential, resulting in the exudation of water and nutrients from the plant cell walls. This in turn yields a nutrient rich environment conducive for microbial growth and fermentation.

Further, traditional suancai natural fermentation is largely reliant on the autochthonous microflora found on the surface of the vegetable substrate, which includes LAB, intestinal bacteria, *Pseudomonas*

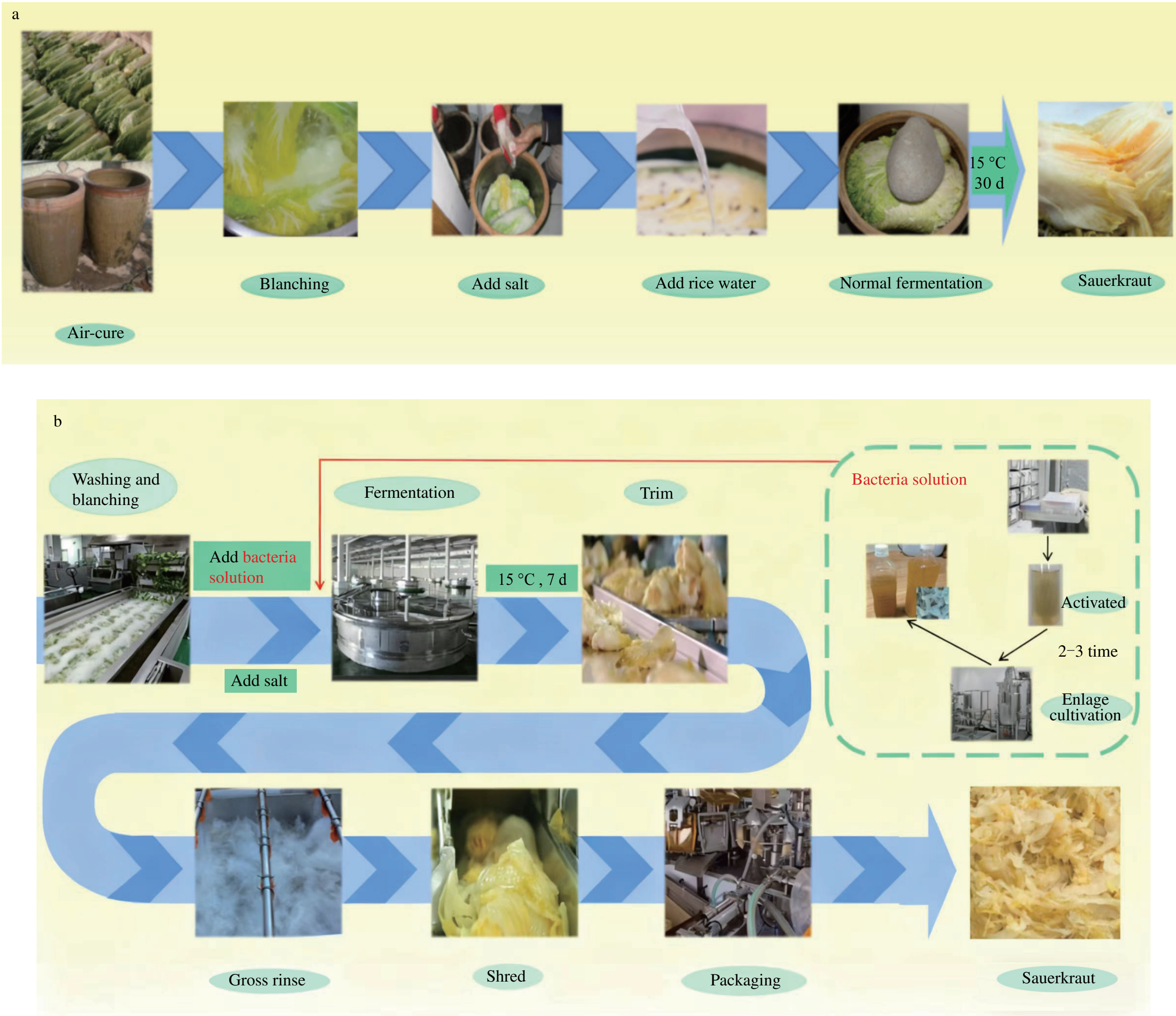

Fig. 3 Process flowchart of (a) traditional suancai fermentation and (b) fermentation by artificial inoculation.

spp. and yeast. The succession of microorganisms that take place during fermentation can alter suancai significantly. Suancai's fermentation may be separated into two stages: mixed fermentation and homologous fermentation, depending on the fermentation strain. As fermentation progresses, the relative concentrations of various LAB species are known to vary considerably. In the initial stages, *L. mesenteroides* and *Weissella koreensis* dominate a hybrid fermentation. However, the homologous fermentation stage is dominated primarily by the activities and concentrations of *L. plantarum*, *L. brevis* and *Lactobacillus sakei*. Additionally, it was observed that the suancai fermentation process also involved concurrent occurrences of homologous fermentation and heterologous fermentation, albeit to a limited extent[14]. In terms of the terminal metabolites produced, the fermentative process may be differentiated into 3 phases, i.e., alcohol fermentation, lactic acid fermentation, and acetic acid fermentation. Yeast and aerobic bacteria strains dominated the early parts of the fermentation process. Alcohol fermentation is driven by yeast adhering to the surface of the cabbage, whereby ethanol is synthesized *via* the Emden-Meyerhoff (EM) pathway.

3.2 Artificial inoculation fermentation process

Preparation of lyophilized inoculum: The fermentation process may be initiated without requiring a culture activation or proliferation step, by utilizing bacterial suspensions known as a straight vat starter. These starters may either be of the concentrated or solid fermentation varieties. The inoculum is prepared by first introducing bacterial strains (either individually or in combination) into an appropriate nutrient medium. This is followed by vigorous agitation to create a homogenous mixture and incubated at approximately 40–42 °C in an electric thermostatic incubator, until a curd-like consistency is reached. To initiate suancai fermentation, the viable bacterial cell concentration in the inoculum should ideally be in the range of 10^{10}–10^{12} CFU/g. Alternately, the cell suspensions may be centrifuged, and the resulting sediment may be collected and freeze-dried. In this case, polymers such as trehalose, albumin, gelatin and polyethylene glycol may be used as cryoprotectants to maintain cell viability. The initial viable cell counts of the freeze-dried inoculum must ideally expected to be 10^8 CFU/g or more. Spray drying, drum drying, fluidized bed drying, and air drying may be employed as alternatives to freeze drying.

Prior to inoculating the raw cabbage, older and decaying material is removed, and introduced in layers into the fermentation tank. Salt, equivalent to 1% of the total weight of the cabbage is sprinkled on each layer. Clean, potable water is added such that its level does not exceed the raw vegetable by more than 10 cm. During this step, the quality of suancai can be improved by choosing different concentrations of fermented brine or adding prebiotics to the brine. After being revived with warm water for 30 min prior to addition, the direct-vat starter culture (0.03% of the total volume of the contents of the fermentation tank) is then introduced. The mixture is compacted, nitrogen-filled, deoxygenated, and sealed to initiate fermentation. The temperature is maintained at approximately 20 °C for between 7–14 days. Following this step, the fermented matrix is passed through a cleaning machine to get rid of residual salt before entering a commercial assembly line scale. It is then wrapped and packaged by completely automatic vacuum packaging equipment after being cut into silk using a wire-cutting machine.

The northeast sauerkraut created through artificial inoculation was found to ferment faster than in the case of natural or spontaneous fermentation, and the resulting product was found to be more stable, making it suited for large-scale, industrial manufacturing. As the bacterial strains introduced as part of the inoculum can establish themselves relatively quickly, artificially inoculated suancai may be prepared using lower levels of salt, which may be beneficial for consumers looking to lower sodium levels in their diet. Wu et al.[15] reported that inoculating starters can more effectively reduce the nitrite concentration in fermented suancai. The suancai industry's next main avenue for growth is the selection of inocula with unique fermentation and processing characteristics.

4. Factors influencing suancai fermentation

With consumers'evolving lifestyles and advances in processing technology, suancai production has shifted from being done at the domestic level to being produced industrially. Considering that suancai is susceptible to contamination by spoilage microbes and pathogens, especially during the hot summer months, it is crucial to comprehend the variables influencing the quality of fermented suancai to meet the demands of the large-scale commercial development of suancai. Studies indicate that the freshness of the raw ingredients[16], temperature[17], salt concentration[18], starting[19], packaging[20], and transportation are the primary determinants of suancai quality[21].

4.1 Quality of cabbage

Various Chinese cabbage cultivars differ in their nutritional composition in addition to the nature and concentrations of naturally occurring, autochthonous microorganisms—these factors have a significant impact on the final flavor and quality of suancai. For instance, the initial concentrations of available glucose and fructose in Chinese cabbage impact the degree of lactic acid produced, while that of pectin impacts the degree of methanol production. There is, however, little information on how the composition of raw materials affects the chemical and sensory characteristics of suancai. Eight different types of late-maturing Chinese cabbage were examined by Satora et al.[22], they discovered that while the resulting suancai had various levels of "green" flavor and sulfur compounds, they had higher concentrations of alcohol, acetic acid derivatives, and volatile acid, which was greatly affected by the microbial content in the fermentation process. The flavor and aroma of suancai are significantly influenced by the composition of its ingredients. To ensure the quality of suancai, suitable vegetable kinds must be used. Selecting cabbage cultivars with a lengthy growth cycle, sugar concentration of 2% to 3%, and modest crude fiber level is therefore advised. The essential physical and chemical indicators, such as maturity, degree of decay, contaminants, and pesticide residues, must be verified before the raw materials enter production.

4.2 Processing technology

The suancai processing method has a significant impact on the sauerkraut's quality, and is outlined below from the following perspectives: blanching, fermentation temperature, sterilization, and fermentation tank material.

Blanching: Blanching increases tissue permeability, enhances the capacity of materials to be transferred across cell membranes, facilitates the production of fermentation flavor, imparts a crisp texture to suancai and inactivates any microbial cells that naturally occur on the raw materials' surface. Additionally, cabbage's oxidase and polyphenol oxidase are inactivated during blanching. Cabbage was blanched by Sarkar et al.[23] at 80, 90, and 100 °C for 128 and 2 min, respectively. The total phenol content of Chinese cabbage was found to be higher at 100 °C for 2 min than at 80 °C for 12 min, and it had a higher capacity to retain color, under the conditions of relative humidity of 60%, at 60 °C. Suancai can efficiently be prevented from browning by using salt and a boiling temperature for the blanching process. While the inhibitory effect of blanching may be improved at higher blanching temperatures, 100 °C was found to be the sufficient to deliver the desired effects. Additionally, studies have shown that blanching can greatly accelerate the fermentation of Chinese cabbage, boost acidity, shorten the product's ripening period, and significantly decrease nitrite production, most likely due to the inactivation of undesirable pathogens and spoilage microbes[24]. Additionally, the eggs and larvae of insects are also destroyed during this process, thereby enhancing food safety.

Fermentation temperature: Suancai ferments at varying rates and with varying degrees of quality depending on the raw materials used and the surrounding climate. Early autumn is thought to be the ideal time for suancai fermentation in central and northern Ohio. The suancai fermented in spring has superior taste and flavor, but the texture tends to be more brittle and the preferred, glossy appearance is not achieved, likely due to the difference in the ambient microflora found at that time. The suancai fermented in the summer is young, proceeds swiftly, and contains little nitrite. However, there are higher levels of bacteria resulting in a diminished sour flavor, and reduced crispness because of the high ambient temperature. Autumn-fermented raw materials tend to be fresh as the fermenting environment is relatively free of a variety of bacteria, the temperature is close to 20 °C, the rates of fermentation and nitrite degradation are slower, but the sensory quality of the resulting product is superior, with nitrite values being much lower than the national standard. According to the data above, the effect of autumn-fermented suancai is optimal in a space with heating capabilities and suancai fermented in the summer is of inferior quality. Thus, it is advisable for commercial operations to target production either in the fall or spring instead of summer. According to He et al.[25], suancai's volatile flavor compounds were altered significantly as fermentation temperature increased. Among these, 20 °C might encourage suancai's maturity and enhance its sensory quality, while low-temperature fermentation at 15–20 °C produced the best results.

Sterilization: Chinese pickled cabbage may be sterilized to improve its flavor and nutritional value and regulate the fermentation process. A high microbial population during the fermentation of suancai may result in the production of detectable hazardous compounds like biogenic amines. It is advisable to terminate fermentation through pasteurization when pH values are below 4. Some investigations have discovered that the histamine production tended to increase at pH values below 3.8–3.6. However, consumers appear to prefer mildly acidic suancai, and thus a product's acceptance may be affected by a lager LAB level that results in excessive acidity. Due to these factors, the majority of German suancai made in Europe is pasteurized when a pH range of 3.8–4.1 is reached[19]. Pasteurization can prevent deterioration of quality and reduce bag expansion by at least 2–3 orders of magnitude by reducing the overall number of microbial colonies in suancai. But at the same time, it may also speed up the browning rate of suancai, which has an irreversible impact on the product's color, a reduction in crispness, a decline in flavor, and a significant loss of nutrition, all of which affect the product's sensory quality. It hinders the sale of goods, severely limits the value that vegetables' deep processing adds. Therefore, a technical bottleneck in the production of suancai in Northeast China is the need to develop novel sterilization techniques that can replace thermal processing and can ensure the effective sterilization of suancai while preserving its distinctive flavor and taste.

Material for fermentation tanks: Fermentation tanks used in suancai production are required to be made of materials with high tensile strength and need to be completely sealed. A wide range of materials are frequently employed ranging from ceramics, stainless steel, and glass fiber to reinforced plastic, organic glass, and plastic. Studies have revealed that the flavor and taste of suancai are more significantly influenced by the material they come into contact with during the fermentation process. Comparing the effects of traditional pickling and fermentation (i.e., using ceramic cylinders) with fermentation in plastic tanks, it was discovered that the traditional method of fermentation typically involves low-temperature fermentation, which results in a longer fermentation period. Plastic cans contain a variety of possible safety risks, and thus must be avoided for suancai production. However, stainless steel tanks are better suited for large-scale suancai manufacturing in contemporary industry than ceramic jars are. The need for hygienic production procedures along with stainless steel's ability to withstand acids and alkalis and the benefits of easy cleaning, make it the top material of choice for commercial suancai production[26]. In the brewing and fermentation industries, glass fiber-reinforced plastic material is a viable alternative to stainless steel and carbon steel lined tanks, as it is non-toxic, odorless, lightweight, has high tensile strength, excellent corrosion resistance, flame retardancy, and aging resistance. Improvements in fermentation tank design utilizing novel materials could significantly improve production capacity, product quality and profitability.

4.3 Salt

Salt is necessary for the fermentation of vegetables and its addition changes suancai's physicochemical composition, microbial load, and sensory appeal. The role of salt is outlined as follow:

(1) A protective impact: sodium chloride, which is the predominant salt used in suancai production, has very potent osmotic activity—it can significantly alter cell permeability, and is able to diffuse into plant cells with ease and restrict cellular respiration and other vital functions. It can also stop the growth and proliferation of pathogenic microbes. According to Thakur & Kabir[27], salt dissolved in water can lower the oxygen content in the water, prevent the growth of Gram-negative bacteria, extend the shelf life of suancai, improve the sauerkraut's ability to be preserved, and reduce suancai's tendency to brown.

(2) Fermentation stimulation: the growth, reproduction, and fermentation of beneficial microbes introduced into plants can be encouraged by using appropriate salt concentrations.

(3) Enhancement of sensory properties (aroma, flavor and texture): salt can interact with free amino acids in fermented vegetables, particularly glutamic acid, and aspartic acid, to enhance the umami flavor of goods in addition to giving vegetables their natural salty flavor. Salt can also affect the fermentation of lactic acid, which can impact the flavor and quality of pickles. Salt can also prevent tissue from softening, promote brittleness, and impede pectinase activity[28].

(4) Dehydration: the increased osmotic pressure of salt leads to plasmolysis and increased tissue permeability, resulting in a denser tissue texture. Yang et al.[29] investigated how fermentation of suancai was affected by various salt concentrations. The findings demonstrated that a concentration of 0.5% (*m/V*) greatly accelerated sauerkraut maturation and enhanced the sensory quality of suancai.

4.4 Microbial density and diversity in starter cultures

The fundamental reason that gives traditionally naturally fermented suancai its rich and sour flavor is the richness of its microbial community. During suancai fermentation, the whole fermentation environment can be regarded as a special microecological environment. The ultimate quality and flavor of suancai are strongly influenced by a variety of biological processes carried out by microorganisms in the fermentation environment[30]. Thus, the composition and selection of the starter cultures will have an impact on the quality and flavor of the suancai.

Highly active LAB are directly added by the vegetable starter culture to the fermentation broth. It is appropriate for domestic and industrial production because of its straightforward and practical operation, which eliminates the need for numerous intermediate stages like strain activation. While research on the fermentation agents has been ongoing for a long time in China, the focus has been on single strains which tend to have low levels of activity and inconsistent functionality. As a result, the effect of fermentation has been found to be extremely different from that of natural fermentation. Industrial technology is still in its infancy. In order to ferment traditional northeast sauerkraut, Yang et al.[31] chose 23 strains of native LAB and identified their physical and chemical indicators, microbiological indicators, and metabolomic indicators in the product. It was discovered that the starter culture employed greatly influenced the physicochemical and sensory properties of suancai. The addition of starter cultures improved the rate of acidification and reduced the synthesis of biogenic amine in Chinese cabbage. The starter's composition also has an impact on the suancai's quality. A mixed culture containing *L. mesenteroides* and *L. plantarum* was discovered to be able to enhance pickle quality, offering a further means of satisfying consumer demand. According to Minervini et al.[32], co-cultivating *L. paraplantarum* A1 and *L. plantarum* A2 enhanced the product's antioxidant activity, color, aroma, and microbiological stability. It has been challenging for single strain starter cultures to satisfy demand for high-quality suancai production, and the creation of a mixed fermentation agent holds significant merit.

4.5 Fermentation brine

Different fermentation brines affect the microbial community and the production of volatile flavour substances during the fermentation of suancai, thus affecting the final quality and flavour of suancai. Suancai fermented in brines containing prebiotics has a softer taste and increased freshness, which affects the distribution of flavour substances by influencing the diversity of bacterial communities during the fermentation process, and the addition of prebiotics inhibits the accumulation of nitrites, which is beneficial to the safety of suancai[33]. The flavour and quality of suancai in different concentrations of brine also differ, Yang et al.[34] studied the microbiota and volatile distribution of suancai fermented in different brine concentrations of the same fermenter, and the results showed that fermentation in 0.5% (*m/m*) brine was more conducive to the growth of *Lactobacillus* and had the highest relative content of esters, aldehydes and ketones, and suancai fermented in 2.5% and 3.5% brine had a higher relative content of acids, alcohols, isothiocyanates and hydrocarbons. The study of Liang et al.[35] also illustrated the differences in the distribution of volatile flavour substances in suancai fermented with different concentrations of brine.

4.6 Packaging

Product quality is significantly impacted by packaging components. Packaging serves as a barrier against mechanical and microbiological deterioration during transportation and storage. In addition, the packing material also plays a key role in limiting the ingress of oxygen and light and loss of moisture, which are critical to protecting product integrity[36]. The nature and efficiency of packing were included in a set of criteria that define food quality by Muratore et al.[37]. Biaxially orientated polypropylene (BOPP), low density polyethylene (LDPE), polyester (PET), nylon (PA), cast polypropylene (CPP), and aluminized film are prime examples of the materials used in packaging. The properties of BOPP material include strong compressive strength, high clarity, and wear resistance, yet it performs poorly when it comes to heat sealing and printing. On the other hand, LDPE demonstrates reasonable acid and alkali resistance, flexibility and ductility, light weight, but inadequate mechanical strength, moisture and air insulation, and solvent resistance. While PET materials are transparent, non-toxic, odorless, and safe as well as acid, alkali, and high temperature resistant, they are not biodegradable, and therefore environmentally unsustainable. Aluminized film can block light and shield against ultraviolet (UV) rays; it increases the brightness of the film while also extending the shelf life of the material. It replaces the utilization of aluminum foil to an extent. Additionally, it is inexpensive, attractive, and performs well as a barrier, although it is not corrosion-resistant against acids and alkalis. Low-density polyethylene (PE-LD) metalized polyethylene terephthalate (PET met/PE) and PET bags were investigated by Kapusta-Duch et al.[38] for their influence on the chosen quality characteristics of refrigerated white pickles. It was discovered that the kind of packaging significantly affected the antioxidant activity of chilled sauerkraut. Packaging made of composite materials combines the benefits of many materials, which may help balance the drawbacks of a single material, with beneficial properties such as low density and weight, good barrier qualities, molding processability, decorating, and high chemical stability.

4.7 Transport

In the transportation process of suancai, quality defects are often caused by factors such as variations in ambient temperature and light. Common defects include suancai browning, swelling bags and malodorous product, limiting the sales of suancai in large quantities to the southern regions and export markets. Therefore, transportation has been identified as a key factor restricting the development of suancai.

Due to vibration during transit, suancai, a type of food that contains both liquid and solid, causes the agitation and mixing of its components, thus accelerating oxygenation and oxidation reactions. According to studies, there was no significant difference between suancai preserved by intermittent vibration and static storage in terms of color change or total phenol content ($P > 0.05$), but there was a significant difference in terms of sensory indices. It is clear that the duration of vibration time impacted the extent of browning of suancai during preservation. Dampening measures must ideally be implemented in the actual production process as a result. The light should be avoided during preservation since it can hasten the development of browning in suancai. The quality of suancai is also significantly influenced by temperature, with the extent of browning being encouraged at higher temperatures, and low temperatures, being conducive for preserving suancai. The ideal temperature for the majority of vegetables is between 0–10 °C, which is the range utilized for refrigeration. Low temperatures also aid in suppressing the growth of pathogens, lowering enzyme activity, and regulating vegetable metabolism[39]. According to one investigation, suancai may lose more polyphenols and vitamin C due to long-term storage, high temperatures, or physical and chemical damage[40]. As a result, after packaging, attention should be given to the products' inspection, and special care should be taken to prevent suancai damage during transit.

5. Fermented cabbage nutrition analysis

5.1 Separation of probiotics in traditional production of suancai

5.1.1 Probiotic function

The suancai, a traditional fermented vegetable product in the northeastern region of China, has gained popularity among the general population due to its abundant nutritional content, refreshing acidity, and appetite-stimulating properties. The presence of numerous LAB in suancai juice has been demonstrated, with a specific group of these bacteria assuming a prominent role during fermentation. Combined with the activity of salt, the organic compounds synthesized during LAB fermentation impart the unique flavors and textures characteristic of suancai. These metabolites also inhibit the growth of pathogens and spoilage microbes in the fermentation matrix. Numerous animal and human clinical investigations have demonstrated that LAB derived from natural suancai exhibit a multitude of discernible probiotic properties. Suancai contains a lot of fiber and vitamins that can prevent constipation and is low in calories, which helps to control body weight[41], and some components of pickled cabbage have antioxidant effects, with thioglucosides inducing antioxidant enzyme activity in the body and flavonoids protecting blood vessels from oxidative damage[42]. In addition, certain LAB in pickled cabbage produce conjugated linoleic acid[43], which has anticancer and anti-atherosclerotic effects[44], and clinical trials have demonstrated that consumption of pickled cabbage reduces the severity of irritable bowel syndrome[45]. It has been demonstrated more recently that eating fermented vegetables can help prevent new coronavirus pneumonia (COVID-19). Depending on the region of origin, method of fermentation, and stage of fermentation, there are various kinds and quantities of probiotics in suancai. As shown in Table 2, there are regional variations in the types of microorganisms found in fermented vegetables. Some of the probiotic bacteria isolated from fermented vegetables were isolated from local suancai with region-specific probiotics.

5.1.2 Flavor

Consumer preferences are strongly influenced by flavor, and fermentation can both heighten flavor and improve hunger. By creating diacetyl-like taste metabolites during the metabolism of lactic and citric acid, LAB help to add to the distinctive physical qualities of meals. These metabolites offer a favorable environment for enzymatic or non-enzymatic processes. The flavor components of suancai are shown in Fig. 4. Through the study of volatile compounds in suancai, Cao et al.[52] fermented suancai using *L. plantarum*, *Lactobacillus intestinalis*, and *L. brevis* as fermenters, and discovered an increase in alcohols. It was eventually shown that the volatile substances in suancai were connected to the fermentor type used for inoculation. LAB create diacetyl, ethanol, hydrogen peroxide, acetaldehyde, carbon dioxide, and bacteriocins, in addition to organic acids (lactic and acetic acids). These organic substances function as biological preservatives by preventing the development of harmful, non-harmful, and spoilage microorganisms. They lengthen the food's shelf life by enhancing the safety of fermented foods. During the fermenting process, suancai releases volatile chemicals that may affect the flavor of the suancai.

5.1.3 Regulation of intestinal flora

Numerous publications have documented the beneficial effects of LAB on the gut microbiota. Some LAB colonize the intestinal tract of humans and animals and promote digestion, among other beneficial functions. Additionally, suancai's fermentation produces a significant amount of lactic acid, which can regulate the gastrointestinal environment. First studies on the impact of fermented vegetable consumption on the human gut microbiome by Thriene et al.[53] revealed an increase in microbial diversity in the human gut. Kimchi demonstrated appreciable anti-mutagenic activity in both the Ames test and the SOS colorimetric test, according to the Park et al's study[54]. In several studies, Majumder et al.[55] demonstrated that the *L. plantarum* YLM015 they isolated from the well-known Korean fermented vegetable "kimchi" has effective antiviral activity against the influenza A (H1N1) virus. Using an *in vitro* co-culture model of the intestinal epithelial barrier (Caco-2 monolayer) and circulating immune cells (PBMCs), Gaudioso et al.[56] demonstrated that sauerkraut fermentation water has a positive effect on regulating intestinal permeability and intestinal immune function.

5.2 Transformation of nutrients in suancai

The LAB used in the traditional suancai fermentation process originates from the raw materials that have been fermented as well as the surrounding environment. They convert the nutrients present in the raw materials, like sugars, into acid metabolites, which

Table 2
Composition of probiotic bacteria in fermented vegetables.

Country (region)	Source	Probiotics	References
China	Suancai	*Lactobacillus breve*, *Pediococcus ethanolidurans*, *Pichia membranifaciens*, *Pichia fermentans*, *Kazachstania bulderi*, *Lactobacillus casei*, *Clostridium*, *Pediococcus pentosaceus* MP12	[46]
	Taiwan fermanted mustard	*Lactobacillus suantsaiihabitans*, *Lactobacillus suantsaicola*	[47]
	Guangxi suancai	*Lactobacillus*, *Serratia*, *Lactococcus*, *Stenotrophomonas*	[13]
	Yunnan Fuyuan suancai	*L. plantarum*, *Lactobacillus pentosus*, *Lactobacillus delbrueckii*, *Lactobacillus fermentum*, *Lactobacillus buchneri*	[48]
Korea	Spicy cabbage	*Leuconostoc citreum*, *Leuconostoc holzapfelii*, *Leuconostoc lactis*, *Weisceella soli*, *L. sake*, *Leuconostoc gasicomitatum*, *Weisceella koreensis*	[49]
India	Suancai	*Lactobacillus paracasei*	[50]
United States	Vegetarian pickles	*Lactobacillus*, *Leuconostoc*, *Tetragenococcus*, *Weissella*	[51]
Japan	Fermented red beet leaves	*Lactobacillus des deuteri*, *L. fermentation*, *L. plantarum*	[5]

Fig. 4 Flavor substance map of suancai.

impart the sour flavor of suancai. Some carbohydrates undergo the transformation into alcohol metabolites. Esters are created when acid metabolites and alcohol metabolites interact, giving the product a mild and estery flavor profile. Through the protein hydrolysis mechanism, LAB breaks down soluble proteins in the fermentation matrix to create small molecule metabolites such as short peptides and amino acids, which give the finished product its distinct fresh flavor qualities. Suancai has specific health benefits because during the fermentation process, the proteins in cabbage can be hydrolyzed by microorganisms and their proteases to produce small molecules of amino acids. Suancai also have a salty and sour flavor. It improves appetite and aids in digestion. It also wakes up the wine and gets rid of any greasiness. In the Northeast, it has long been one of the staple foods served at meals.

5.2.1 Protein

Proteins can be hydrolyzed into short chain peptides and free amino acids during the fermentation of suancai. Amino acids are the building blocks for the production of aromatic compounds, which are crucial for the development of a distinctive flavor. Arginine, which has a harsh taste, threonine, proline, glutamic acid, glutamine, cysteine, and proline are the primary amino acids found in cabbage. Therefore, it is believed that the primary flavor-presenting components generated by microbial metabolism during suancai fermentation are free amino acids. According to Zhang et al.[57], the amounts of glutamic acid and aspartic acid in fermented kimchi brine were higher than their limits, which may be responsible for the vegetables' fresh flavor. Some amino acids can be transformed to heteroalcohols during the fermentation of suancai, which can then be oxidized to aldehydes, which can then be converted to acids and go through esterification processes to generate esters. Alcohols and aldehydes with alcoholic and fruity tastes are the principal products. The generation of aromatic compounds can also be aided by the enzymes found in LAB. Additionally, thioglucose made from amino acids has the ability to break down into isothiocyanate, which contributes to the distinct flavor and scent of suancai and the taste and aroma of Brassica crops after fermentation.

5.2.2 Fat

Most vegetables are low in fat, and suancai, which is made by fermenting cabbage as the primary raw material, is no exception. However, the breakdown products of the cabbage help to create the distinctive flavor of suancai. Free fatty acids can create esters that have aromatic qualities. Most LAB cells synthesize esterases, which can create esters from alcohol. Suancai which has spontaneously fermented has significant levels of ethyl caprylate, which has a brandy wine aroma. Additionally, suancai's esters include those that taste fruity. *Enterococcus lucidus* and *L. plantarum* are 2 strains that may facilitate the biosynthesis of fatty acids, which in turn affects the flavor of suancai. After fermentation, certain vegetables, particularly broccoli, cucumbers, and peppers, have a higher fat content.

5.2.3 Carbohydrates

Carbohydrates can be converted to lactic acid during suancai fermentation through the intermediate product pyruvate, which is then transformed into many aromatic compounds. In the fermentation process of suancai, this is the main metabolic pathway for carbohydrates. According to prior research, choosing specific fermentation strains might increase the amount of ethyl acetate, which can be converted into flavors[31]. It has been established that *Lactobacillus* is the primary consumer of glucose, with the concentrations of glucose demonstrating an inverse relationship with that of *Lactobacillus*. Therefore, suancai fermentation, *Lactobacillus* is thought to be the predominant genus of LAB that converts glucose to organic acids. Additionally, according to Zhang et al.[57], during the fermentation of dry salt made from squeezed vegetables, lactic acid and acetic acid accumulated for 30 to 90 days and other organic acids were consumed. This suggests that as the degree of organic acid (especially lactic acid) synthesis increased during the pre-pickling stage of suancai, the duration of this stage was also prolonged. Additionally, as longer pickling durations corresponded to higher acidity, lower fresh amino acid content and lower aminobutyric acid activity in suancai, all of which would impact the flavor of suancai.

5.2.4 Vitamins

Vegetable fermentation also affects the vitamin content in the food. Fermented vegetables were shown to possess lower amounts of phenols and vitamin C[58]. Due to its potent antioxidant capabilities, vitamin C is a very effective preservative for vegetables that have undergone fermentation. However, vitamin C is known to be sensitive to acidity and is heat labile, and therefore a reduction in its concentration during fermentation is a common occurrence. Strains such as *L. casei* demonstrate beneficial probiotic activity, and could potentially improve the vitamin content of suancai while simultaneously increasing its acidity and lowering its nitrite concentration[59]. Suancai was fermented by Yang et al.[31] using a mixed culture of *L. plantarum* and *Enterococcus luminescens*. Thiamin, folic acid, and riboflavin were discovered to be significant vitamins produced by *E. lucidus* and *L. plantarum* during the fermentation of suancai. Ultimately, the vitamin profile of finished suancai varies according to the duration of and predominant microbial strains employed during fermentation.

6. Quality and safety status of fermented cabbage

6.1 Browning

Reducing the occurrence of browning in the preservation of suancai in northeast China is a key aspect of product quality control. Browning is a common phenomenon that occurs during food processing and storage, that contributes to product discoloration. In terms of the underlying mechanisms, browning can either be enzymatic or non-enzymatic[60]. When stored under ambient conditions, pickled cabbage is prone to browning. Although vacuum packaging may help mitigate this issue to an extent, browning of Chinese pickled cabbage remains a challenge especially during the late storage period, as it is of a short duration, and has a significant negative impact on the industry's ability to grow sustainably. Numerous studies have demonstrated that the Maillard reaction, oxidative degradation of ascorbic acid and polyphenol oxidase-mediated polymerization may all contribute to the browning of suancai. There are, however, limited studies on the technologies used to control the browning of sauerkraut.

A processing technique that is frequently used in manufacturing to prevent browning is the addition of browning inhibitors. To obtain the desired result, either a single browning inhibitor or a combination of multiple inhibitors might be added. An additive for food that serves as a stabilizer, antioxidant, and preservative is EDTA-2Na, a common integrator. Its use in suancai, however, has not been documented. Notably, according to the *Hygienic Standard for the Use of Food Additives* GB 2760–2014, the use of additives in suancai and other pickled foods is strictly forbidden. Therefore, selecting appropriate packaging materials and techniques offers the most effective means of controlling the browning of suancai.

6.2 Nitrites

The manufacture of fermented pickled dishes, especially those made from vegetables and fruits like suancai, paocai, and pickles, frequently results in the synthesis of nitrites. While nitrate is generally safe for human health, certain bacterial strains convert nitrates to nitrites in anaerobic conditions, such as during intestinal passage, or the pickling processes, resulting in a human health hazard. Additionally, nitrites can combine with the byproducts of protein hydrolysis in meals, such as amine compounds, to form carcinogenic N-nitroso compounds, which are known risk factors for gastric, esophageal, prostate, and nasopharyngeal cancers. Further, nitrites can cause symptoms including tachycardia and lower blood lipid levels by interfering with the body's ability to absorb vitamin A. Therefore, the presence of nitrites in food products is a key food safety concern and has become the focus of academic research and government regulatory bodies.

The issue of nitrite levels in pickled cabbage has recently come to light both domestically and internationally. The production cycle of pickled cabbage should be controlled for more than 30 days when using natural fermentation, even though the content of nitrite in products obtained by industrial and natural fermentation is less than the national limit standard of 20 mg/kg. Instead, pickled cabbage fermentation by inoculation with LAB can be completed in about 15 days, and nitrite concentrations in both fermentation processes were observed to first increase, followed by a decline[61].

6.3 Bioamines

The maturing of pickled cabbage frequently results in the production of biogenic amines. Biogenic amines are low molecular weight, nitrogen-containing compounds biosynthesized by microorganisms, by the action of decarboxylases on amino acids[62]. Frequent consumption of foods containing excessive levels of bioamines can result in the expression of various symptoms of allergies, including nausea, vomiting, abdominal cramps, and other unfavorable physiological responses[63]. Additionally, the sensory qualities of food may be diminished by the presence of biogenic amines. In addition to being produced during fermentation, biogenic amines also tend to accumulate when fermented vegetables during storage. Peñas et al.[19] chose *L. plantarum* and *L. mesenteroides* for fermentation at 0.5% and 1.5% salinity, respectively, and stored at 4 °C for 3 months. They discovered that the experimental group using *Enterocentrum* as a starter culture produced low levels of biogenic amines. The concentration of biogenic amines in sauerkraut, particularly putsutrine and spermidine, is significantly affected by the storage duration and total amine level when the salinity is regulated at 0.5%, lower than 1.5%. In their work, Cvetković et al.[64] discovered that low salt and low temperature fermentation can ensure low biogenic amine content and that salt concentration has a greater impact on spermidine content, and that adjusting salinity to 2% increases the creation of putrescine and calamine. Contrary to popular perception, high salinity promotes low amine fermentation by inhibiting microbial metabolism. High salinity cannot entirely lower the overall amine levels, however, it can only prevent Lactobacillus from generating these harmful metabolites.

6.4 Toxins

Raw cabbage may be contaminated directly in the field with foodborne pathogens due to contact with irrigation water, organic fertilizers, manual handling, post-harvest transport and washing. Enteroviruses, including norovirus (NoV), hepatitis A virus (HAV), rotavirus, astrovirus and enteric adenovirus are considered major causes of foodborne illness and outbreaks[65-66]. Enteroviruses that appear in fresh produce or in the water used to make sauerkraut may survive lactic acid fermentation, especially if the sodium barrier is compromised. Limited data is available regarding the presence and survival of enteroviruses during sauerkraut processing and storage. Gagné et al.[39] measured the survival of murine (NoV) during the production of fermented sauerkraut and storage under standard and reduced sodium conditions. The results suggest that lactic acid fermentation by itself cannot mitigate or neutralize the contamination of vegetables by enteric viruses, regardless of the fermenting agent or sodium chloride concentration used in the fermentation process, so the potential for toxin contamination must be strictly controlled during the production, procurement, and transportation of the raw material.

6.5 Fermentation broth treatment

Sauerkraut fermentation liquid is the residual liquid produced during the fermentation of sauerkraut by LAB, which contains nutrients such as polysaccharides and proteins in addition to LAB cells and inorganic salts[67]. However, it is classified as a type of high-salt wastewater and is characterized by the presence of potential pollutants and bad odor, which is very harmful to the environment. According to preliminary estimates, the kimchi industry in Sichuan province produces about 76 million tons of wastewater each year. In addition, as the production of sauerkraut is seasonal, a large amount of sauerkraut wastewater is produced in a short period, which brings a huge burden to the wastewater treatment infrastructure. Ciska et al.[68] found that sauerkraut fermentation broth is a good source of biologically active ascorbic acid and isothiocyanate and can be considered as a functional food with beneficial effects on human health. Kang et al.[69] conducted composting trials with sauerkraut fermentation wastewater and *L. paracasei* HD1.7 and found that the use of sauerkraut fermentation wastewater for aerobic composting increased colony linkage and enhanced colony robustness, as well as enhancing the effects of colony robustness and colony cohesion on the assembly process, providing new insights into the biological treatment of sauerkraut wastewater.

6.6 Rising bag

Vacuum-packed sauerkraut can produce a rise in the bag or a decrease in vacuum, which is a normal phenomenon caused by the production of CO_2 by heterolactic fermenting bacteria of the genus *L. mesenteroides* and *Streptococcus*. As fermentation progresses, lactic acid accumulates to create an acidic environment, leading to the inhibition of the activity of heterolactic fermenters such as *L. mesenteroides* and *Streptococcus* and the cessation of gas production. In addition, gas production can also result from the metabolism of non-oxidizing yeasts, even in an anaerobic state, whereby the yeast converts available sugars to gaseous compounds, causing a vacuum reduction but not deterioration of other properties. Bag rise is caused by spoilage bacteria, which utilize sugars and acids, causing an increase in acidity, imparting a sticky texture and putrid odors in the kimchi. Therefore, the inactivation of fermenting microorganisms can prolong the shelf life of sauerkraut. The heat was the first method of sterilization to be mastered by man and is widely used in food processing[70]. The use of pasteurization on sauerkraut can effectively prevent spoilage, but can have varying degrees of impact on product quality, thus reducing the nutritional value of the sauerkraut. Microwave treatment of sauerkraut can destroy the cellular structure of microorganisms and effectively inhibit spoilage[71]. Ozone is a strong oxidizing agent that kills bacteria through the oxidation of cell membrane constituents. Ozone decomposes into oxygen after use and is non-toxic, non-hazardous, residue-free and a broad-spectrum anti-bacterial treatment, and is widely used in the food processing industry. The effect of bacterial reduction increases as the concentration of ozone increases, but the retention time after reduction is short.

6.7 Food additives

Food additives have a vital relationship with human health, involving the abuse of food additives, the overuse of food additives and the use of toxic additives, which has traditionally been a hotspot for food safety issues. As natural fermentation involves the use of microbial flora on the surface of the cabbage and in the air to naturally ferment northeast sauerkraut, the diversity of strains involved in fermentation makes it difficult to avoid undesirable bacteria during the fermentation process, which could lead to product deterioration, thereby limiting the profitability and expansion of the fermented vegetable industry. Additives are a relatively economical and viable solution. In addition, preservatives and antioxidants are added to sauerkraut to extend its shelf life, and excessive additives are generally the result of irregular production. In 2022, the CCTV 3·15 Gala revealed that many sauerkraut producers in Yueyang, Hunan Province, were buying “earth pit sauerkraut”, produced in a poor environment and using a variety of food additives more than the permissible levels, which severely compromises food safety. As an important raw material for sauerkraut processing, manufacturers need to pay attention to the quality and safety of the food additives themselves and incorporate them only at safe levels.

7. Status of Chinese fermented cabbage standards

Traditionally fermented cabbage uses LAB in the cabbage for spontaneous fermentation, its fermentation process is uncontrollable and product quality is difficult to guarantee. Due to technological advances and market demand suancai production must be industrialized to guarantee product quality under various regulatory controls, and consistent quality and safety products are more likely to satisfy consumers' requirements for food health. During the production of suancai a number of safety issues may arise such as spoilage of bags, contamination with pathogenic bacteria, high biogenic amine content etc. There are many scientific studies and methodological strategies to prevent these issues from occurring. Commercial production of suancai usually uses starters, which can accurately control the fermentation process to ensure the quality of the product[72], and there are also a variety of functional starters that can be used to meet the needs of different production conditions[73] and to improve the flavor of the product[74]. The acid produced by suancai in LAB will inhibit the growth of many other microorganisms, and the appropriate concentration of fermentation salts can also play a certain antibacterial effect and reduce the content of biogenic amines[3]. To ensure that the production process is not contaminated by spoilage microorganisms pathogenic microorganisms, most pickled cabbage is pasteurized when the pH reaches 3.8–4.1[75], and there is also a high hydrostatic pressure technique, which ensures a better quality of the food compared to the traditional heat treatment[76]. In addition to the various methods and techniques, some standards and regulations govern the production operations to ensure the quality of the product. Sauerkraut production must follow Good Agricultural Practices (GAP) and Good Hygienic Practices (GHP)[77], which standardize the requirements from raw materials to the processing environment to minimize the probability of undesirable microbial contamination occurring. In addition to the basic standard requirements, different countries have different regulatory requirements for the production of pickled cabbage and product quality, in accordance with a series of standard requirements, each production link is monitored to avoid the contamination of spoilage microorganisms and pathogenic bacteria, to ensure that the final quality and safety of pickled cabbage products.

GB 2760–2014, *Food Safety National Standard–Food Additive Use Standard* and GB 2714–2015, *Food Safety National Standard Pickled Vegetables* are both based on the use of fresh vegetables as raw materials for pickling and fermentation treatment. The sensory requirements, physical and chemical indicators, microbial limits, salt detection methods, and amino acid nitrogen limit values and detection methods have all been revised for the upcoming implementation of the Chinese agricultural industry standard NY/T 437–2023 *Green Food Pickled Vegetables* in the main provisions of the pre-packaged pickled vegetables. Additionally, some regions of China have developed their local standards in accordance with their unique regional characteristics. Foreign nations have also put forth pertinent requirements for kimchi and fermented agricultural produce. The definitions and breadth of the standard content of fermented vegetables as proposed by various nations and institutions are compared in Table 3. It has been discovered that, when compared to China, foreign standards for fermented vegetables include not only physical, chemical, and microbiological testing but also requirements for appropriate labeling, storage, and transportation.

Table 3
Comparison of domestic and foreign standards for fermented vegetables.

Country	Standards	Definition of fermented vegetables	Content scope	References
China	GB 2714–2015 *National Food Safety Standard Pickled Vegetables*	With fresh vegetables as the main raw material, various vegetable products processed by pickling or sauce, such as pickled vegetables, salted vegetables, soy sauce vegetables, sugar vegetables, vinegar vegetables, sweet and sour vegetables, shrimp oil vegetables, fermented sauerkraut and bad vegetables	Sensory requirements, raw material requirements, contaminant limits, microbial limits, food additives	[78]
United Kingdom	ISO 24220:2020	Salted fermented vegetable products made from vegetables such as cabbage, mustard stalks, long beans, peppers, white radish, carrots, etc., sterilized or not sterilized after soaking and fermenting and adding salt or salt solution, with or without seasoning	Sensory, physical and chemical, safety, labeling, transportation and storage of fermented vegetables	[79]
U.S. Food and Drug Administration	CPG Sec585.750 Sauerfraut-Definition; Adulteration by Thrips	A product with characteristic sourness, obtained by full fermentation (mainly lactic acid) at a salt content of not less than 2% or more than 3%. After fermentation is complete, it contains not less than 1.5% acid, expressed as lactic acid. Sauerkraut re-pickled during canning or repackaging contains not less than 1% acid, expressed as lactic acid. Products which are not fermented but whose acidity is attributable to the addition of vinegar, acetic acid or other acidifying agents are not entitled to use the name sauerkraut	Labeling, adulteration	[80]
Code of Law	CODEX STANDARD FOR KIMCHI CODEX STAN 223-2001	Kimchi is made from the cabbage as the main ingredient, as well as other vegetables that have been trimmed, cut, pickled and seasoned before fermentation	Classification and processing of fermented vegetables, quality factors, food additives, contaminant residues, packaging labels, quality testing	[81]
Food and Agriculture Organization of the United Nations	STANDARD FOR PICKLED FRUITS AND VEGETABLES CODEX STAN 260-2007	Processing or handling to produce an acid or acidified product preserved by natural fermentation or acidulants	Basic components of fermented vegetables, quality factors, food additives, contaminant residues, microbiological standards, testing practices, and labeling	[2]
United States Department of Agriculture	United States Standards for Grades of Bulk Sauerkraut	Bulk or barrel sauerkraut, hereinafter referred to as sauerkraut or bulk sauerkraut is a product with a characteristic sour taste, obtained by the adequate fermentation (mainly lactic acid) of properly prepared and chopped cabbage in the presence of salt. Upon completion of fermentation, it contains not less than 2.3% acid, expressed as lactic acid	Color, shredding thickness, texture and flavor of first and second grade sauerkraut	[82]

8. Conclusion and outlook

Suancai has a distinctive flavor and is rich in nutrients. In addition to the nutrients naturally found in fresh vegetables, it also creates acids, alcohols, esters, and other compounds during the fermentation process, giving suancai its sour, salty, and fragrant flavor in addition to various prebiotic properties. Currently, several LABs with various functional traits have been isolated from suancai, including strains with high yields and acid resistance, salt tolerance, and low temperature tolerance. The development and usage of the microbial resources present in conventionally fermented food will benefit from the screening of these high-quality strains, which will also help clarify how fermented vegetable quality is formed. Suancai production is becoming increasingly standardized because of the ongoing advancements in fermentation technology and growing consumer demand. Industrial production is more suited to artificial inoculation and fermentation than to conventional fermentation. There have been numerous studies in recent times focused on developing single and compound starters that operate well. The environment, norms, and laws governing suancai production and processing also have a significant impact on the uniform production of these products. Future laws and regulations should be improved, and comprehensive standards for the suancai industry should be developed. In a standardized market environment, ongoing enterprise optimization can help pickled cabbage businesses raise their production value, their income, and their level of development, leading to a flourishing state for the entire sector.

Declarations 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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