Industrial production of soy sauce

B.S. Luh
Dept of Food Science & Technology, University of California, Davis, CA 95616, USA
(Received 27 June 1994; accepted 22 September 1994)

Key words: Soy sauce; Fermentation; Aspergillus oryzae; Aspergillus sojae; Pediococcus halophilus; Zygosaccharomyces rouxii; Candida species

SUMMARY

Soy sauce is a seasoning agent with a salty taste and a distinct aroma suggestive of meat extracts. The sauce is made by fermentation of a combination of soy beans and wheat in water and salt. This paper covers the method for production of fermented soy sauce, and that for acid-hydrolysis of defatted soy bean proteins. The microorganisms involved in soy sauce production, and biochemical and chemical changes in soy bean and wheat during fermentation influence greatly the sensory attributes and quality of soy sauce. Recent progress in industrialization of soy sauce manufacture is discussed.

INTRODUCTION

Of the many Oriental fermented products, soy sauce is the one most widely consumed in China, Japan, Korea and other Asiatic countries as a condiment and coloring agent in preparation of foods and for table use. It is a dark brown liquid, stable at ambient temperature, which does not require refrigeration during storage due to its low water activity and high salt content. Soy sauce and miso are flavoring agents having similar aroma and flavor. Soy sauce is a liquid whereas miso is a paste. Each is made by a two-step fermentation process from wheat flour and soy beans with a mixture of molds, yeasts and bacteria. The first step involves fermentation with mold to produce proteolytic and amylolytic enzymes in the Koji which is a culture starter. A good culture starter must give characteristic aroma and flavor to the soy sauce, have high proteolytic and amylolytic activities, and must be easy to culture. This is followed by a second fermentation with yeast and bacteria in the presence of 18–20% salt. The microorganisms used in these fermentation steps are not inoculated at the same time, but are applied sequentially.

Literature on soy sauce manufacture is largely in Chinese, Japanese, and other Oriental languages. Several references have been published by Fukushima [4,5,6], Noda [10], Numamura and Sasaki [11], Wang and Hesseltine [20], Onaga et al. [13], Reed [15], Skinner et al. [16], Sugimori [18] and Yokotsuka [19]. This paper covers the methods for production of soy sauce made by fermentation of wheat and soy beans, and by acid hydrolysis of defatted soy beans. The chemical properties of soy sauce, and recent progress in technology concerning soy sauce production are also presented.

PRODUCTION OF FERMENTED SOY SAUCE

Soy sauce is made by fermentation of a combination of soy beans, wheat grain, water and salt [8,17]. The processes for production of fermented soy sauce consist of three major steps, namely, Koji production, brine fermentation, and refining. A flow sheet for manufacture is shown in Fig. 1.

Koji production

Koji is a source of proteolytic enzymes for converting soy bean proteins into peptides and amino acids, and amylase for hydrolyzing gelatinized starch into simple sugars. The substances converted by the enzymes in Koji become the nutrients for yeasts and lactic bacteria in the subsequent brine fermentation. In Koji production, defatted soybean flakes or soy beans are soaked in water to increase the moisture content and then cooked under pressure in a retort. Formerly, the soaked soy beans containing 60% moisture were cooked with saturated steam at 0.8–1.0 kg cm$^{-2}$ gauge pressure for 40–45 min in a batch type pressure cooker. Currently, the soaked beans containing 30–45% moisture are cooked at 6–7 kg cm$^{-2}$ gauge pressure (about 170 °C) for 20–30 s in a continuous cooker which allows high pressure and short time cooking. The wheat contains 8% moisture and is heated in a continuous roaster with hot air at 150 °C for 30–45 s at atmospheric pressure. It is then cracked in a machine into 4 or 5 pieces per kernel accompanied by smaller pieces of wheat flour. In making regular soy sauce, the cooked soy beans or defatted soy flakes are mixed with an equal amount of roasted wheat and then inoculated with 0.1–0.2% of starter mold (Aspergillus oryzae or Aspergillus sojae) in wooden trays, each loaded with a 3–5 cm thickness of the fermenting Koji. The ratio of wheat to cooked soybean may vary, depending on the type of soy sauce.
A. sojae

After 3 days, large shallow perforated vats in closed chambers and forced aeration are used. The soy beans, a continuous wheat roaster, mixer, cooler, and automatic control systems heat and mix the contents. During the fermentation period, proteolytic enzymes from Koji hydrolyze the proteins in soy bean and wheat to form amino acids and low molecular weight peptides. Starch is converted to simple sugars which are fermented primarily to lactic acid, ethanol and carbon dioxide. During the brine fermentation, the pH of the mixture drops from 6.5 to 5.0. Then cultures of Z. rouxii and Candida species are added as a starter. The temperature of the moromi is allowed to rise slowly to nearly 28 °C until vigorous alcoholic fermentation starts. The temperature in the tank can be controlled by coil-type heat exchangers with mixing devices, thermocouples, and control systems.

After the alcohol fermentation is finished, the temperature is kept at 25 °C. Aeration stimulates microbial growth and mixes the contents. During the fermentation period, proteolytic enzymes from Koji hydrolyze the proteins in soy bean and wheat to form amino acids and low molecular weight peptides. Starch is converted to simple sugars which are fermented primarily to lactic acid, ethanol and carbon dioxide. During the brine fermentation, the pH of the mixture drops from 6.5 to 5.0 in the first month at 15 °C. This is followed by fermentation at 28 °C for four months. Sometimes it is necessary to add more pure cultures of P. halophilus and Z. rouxii and Candida species to the moromi mash during the fermentation.

**Brine fermentation**

The second step in making fermented soy sauce is brine fermentation. It utilizes the lactic bacterium, *Pediococcus halophilus* and the yeasts *Zygosaccharomyces rouxii* and *Candida* species both of which tolerate a salt concentration of 20 g per 100 ml. The brine effectively prevents growth of undesirable microorganisms. The harvested Koji is mixed with 20% salt brine, and transferred by means of a spiral pump into deep fermentation steel tanks coated with epoxy resins on the interior. The resultant mixture is called moromi mash. It is important to control the microorganisms in the brine fermentation. The specially selected *P. halophilus* is cultured and added to the mash. To control its growth rate it is necessary to keep the fermenting mixture at 15 °C for the first month, allowing the pH of the mash to decrease slowly from 6.5 to 5.0. Then cultures of *Z. rouxii* and *Candida* species are added as a starter. The temperature of the moromi is allowed to rise slowly to nearly 28 °C until vigorous alcoholic fermentation starts. The temperature in the tank can be controlled by coil-type heat exchangers with mixing devices, thermocouples, and control systems.

After the alcohol fermentation is finished, the temperature is kept at 25 °C. Aeration stimulates microbial growth and mixes the contents. During the fermentation period, proteolytic enzymes from Koji hydrolyze the proteins in soy bean and wheat to form amino acids and low molecular weight peptides. Starch is converted to simple sugars which are fermented primarily to lactic acid, ethanol and carbon dioxide. During the brine fermentation, the pH of the mixture drops from 6.5 to 5.0 in the first month at 15 °C. This is followed by fermentation at 28 °C for four months. Sometimes it is necessary to add more pure cultures of *P. halophilus* and *Z. rouxii* and *Candida* species to the moromi mash during the fermentation.

**Refining**

The final process in soy sauce fermentation is refining which includes pressing, filtration, pasteurization and packaging.

The aged moromi is pressed in a vertical automatic press to separate the soy sauce from the residue. After pressing, the filtered raw soy sauce is pasteurized in a heat-exchanger at 70–80 °C for a few minutes to ensure clarity, to inactivate residual enzymes, and to inactivate any undesirable microorganisms. It may be necessary to clarify the soy sauce additionally by centrifugation or sedimentation. The sauce is treated with caramel as a coloring agent, and then packaged either in clean glass bottles, enameled gallon cans or in plastic containers.

The residue from the press can be extracted with more 20% salt brine to increase the yield. Much expertise is needed to produce a soy sauce that is attractive in flavor and taste, stable on storage at room temperature, and acceptable to the consumer. The quality assurance group must check the pH, acidity, amino nitrogen, salt content, color, microbial contamination, and sensory attributes: color, aroma and flavor of the product.