# 5

## Soy Sauce: Typical Aspects of Japanese Shoyu and Indonesian Kecap

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### CONTENTS

## 5.1  Introduction

Soy sauce is a typical condiment and seasoning made from soybeans in a two-step fermentation procedure. The first step is a solid fermentation by fungi, followed by liquid fermentation in a high-concentration brine solution of osmophilic lactic acid bacteria and yeasts. These two fermentation steps involve three microbial groups that give the product a desirable taste, flavor, and color, serving as a basic condiment and seasoning for the cuisines of several Asian countries. The soybeans used for its production can be from yellow or black soybean varieties.

Soy sauce originated from China and has, over the centuries, spread to Japan and Southeast Asia including Indonesia. In Japan, it is called *shoyu*, whereas in Indonesia, it is called *kecap*. Shoyu is made mostly from yellow soybeans; on the other hand, kecap is traditionally made from black soybeans. Both soy sauce products have different chemical and sensorial characteristics, primarily because of the different molds, bacteria, and yeasts as well as the different raw material compositions used in their production. In addition, kecap typically has a deeper brown color and a thicker viscosity than that of common soy sauce because of the sugar added in the final process of production.

There are several types of shoyu and kecap, which will be described subsequently. Generally, in todays' market, soy sauce is sold in three different categories, that is, fermented soy sauce, chemical or artificial soy sauce, and half-fermented soy sauce with a combination of the fermentation process and the addition of chemical soy sauce. The chemical soy sauce is made by rapid acid hydrolysis of soybean proteins at temperatures of 80°C or higher for a couple of hours, whereas the fermented variety needs several months of fermentation at room temperature between 25°C and 35°C to have complete protein

hydrolysis (Hesseltine and Wang 1980; Fukushima 1981). The two categories have wide differences in flavor and aroma characteristics. This chapter only deals with the fermented category.

## 5.2 Japanese Shoyu

### 5.2.1 History of Shoyu

Soy sauce originated from China approximately 2000 years ago and was formerly known as *chiang* and *shih*. Then, in the 16th century, it was produced as *chiang-yu*. Chiang and shih were introduced into Japan before AD 700, and since the 16th century, it has been produced as *shoyu* (which has the same Chinese characters as chiang-yu; Yokotsuka 1986). Chiang was produced using soybeans and wheat as raw materials at a ratio of 3:2. This ratio is close to a type of shoyu called *koikuchi shoyu*. On the other hand, shih uses a high proportion of soybeans with or without a small proportion of wheat, and is known as the origin of *tamari shoyu* (Fukushima 1985, 1989).

The basic procedure for the mass production of shoyu in Japan was formulated in the 17th century. It has been exported to India, Southeast Asia, and even to Europe according to a record of the Dutch East India Company stored in the archives in the Hague, Holland (Fukushima 1989). According to those records, the soy sauce products were thermally sterilized and transported in iron or ceramic containers with stoppers.

### 5.2.2 Types of Shoyu

There are five types of shoyu based on the different characteristics of color, viscosity, taste, and aroma. These are koikuchi shoyu, usukuchi shoyu, tamari shoyu, saishikomi shoyu, and shiro shoyu (Fukushima 1981, 1985, 1989; Yokotsuka 1981, 1986; Flegel 1988). The regular type for daily use in Japan is koikuchi shoyu. The different characteristics are yielded primarily due to the different raw material composition of soybeans and wheat, and the fermentation process used.

Koikuchi, usukuchi, and saishikomi shoyu use the same composition of raw materials in their production, that is, an equal amount of soybeans and wheat; however, they undergo different fermentation processes. Koikuchi shoyu has a strong aroma and a deep reddish-brown color because a relatively long brine fermentation process is applied. It is known that koikuchi production reaches 80% or more of the total shoyu production in Japan. Usukuchi shoyu has a lighter color and milder aroma as compared with koikuchi shoyu. These properties are achieved because of a shorter brine fermentation process in which the color and aroma development is reduced. Saishikomi shoyu has a specific full aroma and taste due to the use of raw soy sauce (without pasteurization) instead of the salt solution for the brine fermentation (Yokotsuka 1960, 1981, 1983, 1986; Whitaker 1978; Fukushima 1981, 1985, 1989).

Tamari shoyu uses a high proportion of soybeans with 10% or less of wheat in its production. This type of shoyu has a milder aroma, but has a greater viscosity and a darker color than that of koikuchi shoyu. With the contrast in composition of raw materials compared with tamari shoyu, that is, a very high proportion of wheat to soybeans, shiro shoyu has a bright yellowish color due to the fermentation conditions, which prevent color development (Yokotsuka 1960, 1981, 1986; Fukushima 1981, 1985, 1989).

### 5.2.3 Shoyu Manufacturing Process

In general, shoyu is produced in two main steps of fermentation: the first step is to make koji, and the second step is fermentation to yield moromi. The two steps belong to solid and liquid fermentation, respectively. After the fermentation process, there is a refining process to filter or extract the last fermentation product and pasteurize it.

Some aspects of shoyu production, which are different from those of oriental soy sauce or kecap, are described as follows: (1) the use of wheat at relatively greater amounts as a raw material in addition to soybeans; (2) protein in the raw materials is almost completely degraded by enzymes from koji; (3) in the moromi process, extensive lactic and alcoholic fermentations occur; and (4) it is subjected to

pasteurization to give a strong aroma, flavor, and color to the final product (Whitaker 1978; Hesseltine and Wang 1980; Yokotsuka 1981, 1986; Fukushima 1985, 1989). The production scheme of Japanese soy sauce or shoyu is shown in Figure 5.1.

### 5.2.3.1 Koji Preparation

The traditional koji preparation in Japan has now been replaced by a fully equipped process. This achievement allows the automatic koji preparation using a continuous soybean cooker, a continuous wheat roaster, automatic inoculators, an automatic mixer, large perforated shallow vats equipped with forced air devices, a temperature control device, and a mechanical device for turning the koji during incubation (Fukushima 1985).

Koji is prepared from cooked soybeans or defatted soybean flakes or grits mixed with roasted wheat. The soybeans are cooked in a continuous cooker at a high temperature and pressure but only for a short time, whereas wheat is roasted on a continuous roaster at 170°C to 180°C for a few minutes and then crushed slightly. In koikuchi, usukuchi, and saishikomi shoyu production, the same proportion of cooked soybeans and roasted wheat is mixed and then inoculated with a pure koji starter of *Aspergillus oryzae* or *Aspergillus sojae*. The raw material proportion for tamari shoyu production is 90% cooked soybeans and 10% roasted wheat, in contrast with shiro shoyu production, in which the roasted wheat may reach 90% of the total mix. Certain species of Aspergilli are also used in the production of usukuchi and shiro shoyu to prevent a deep color development in the next step of fermentation.

In contrast to the three soy sauces, tamari shoyu uses *Aspergillus tamarii* in addition to the two aspergillus species previously mentioned to obtain a full-bodied taste (Yokotsuka 1986; Flegel 1988). Koji preparation lasts for 3 days at temperatures of 25°C to 35°C to yield koji, which has a green-yellow color; the color comes from the spores on the material surface and is produced by molds (Yokotsuka 1960,
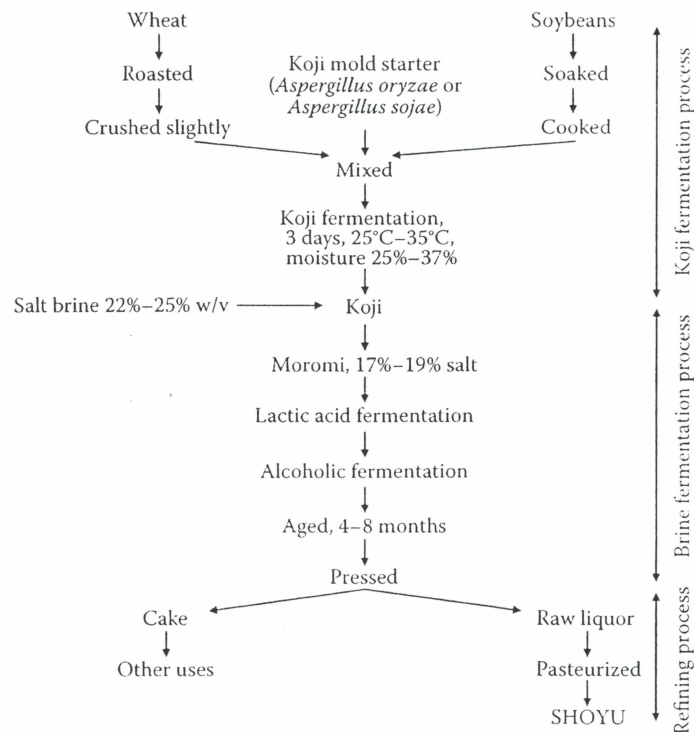


**FIGURE 5.1** Scheme of *shoyu* manufacturing process. (From Hesseltine, C.W., and H.L. Wang, in *Soybeans: Chemistry and Technology*, Vol. 1, Proteins, 2nd ed., edited by Smith A.K., S.J. Circle, 389–419, AVI Publishing, Westport, CT, 1980. With permission. Fukushima, D., *Food Reviews International*, 1, 149–209, 1985. With permission.)

1981, 1983, 1986; Yong and Wood 1977; Whitaker 1978; Hesseltine and Wang 1980; Fukushima 1981
1985, 1989; Flegel 1988; Chou and Ling 1998).

### 5.2.3.2 Moromi Process

This process is initially prepared by mixing koji with a brine solution at a sodium salt concentratior
range of 22% to 25% w/v in deep fermentation tanks (Fukushima 1985). The mix is called moromi o
moromi mash. The mixing ratio is determined based on the final sodium salt concentration desired ii
the mix. A ratio of 1.2 to 1.3 parts of brine solution to 1 part of koji is commonly applied. The final sal
concentration desired ranges from 17% to 19% to effectively prevent the growth of undesirable micro
organisms (Hesseltine and Wang 1980; Fukushima 1985). An exception is found in saishikomi shoyt
production, which uses raw soy sauce liquor instead of a fresh brine solution.

In the moromi process, osmophilic lactic acid bacteria and yeasts produce a characteristic taste
aroma, and color. High amounts of proteins and carbohydrates from the raw materials are degradec
extensively by enzymes from koji (Yong and Wood 1977; Whitaker 1978) and by the microbial actior
(Noda et al. 1980). The pure cultures of osmophilic lactic acid bacterium *Pediococcus halophilu.*
and osmophilic yeast *Saccharomyces rouxii* are added to obtain a degree of desirable flavor and colo
(Fukushima 1985, 1989; Yokotsuka 1986). The length of the moromi process ranges from 4 to {
months, depending on its temperature, agitation, and air supply by an air compressor (Yokotsuk;
1986). The moromi mash is occasionally stirred and aerated to provide homogeneous conditions anc
to stimulate microbial growth.

The first stage of the moromi process is dominated by lactic acid fermentation, which results in ;
decrease in moromi pH, followed by alcoholic fermentation with osmophilic yeasts which provide ;
lower moromi pH and a substantial release of alcohol. In koikuchi and usukuchi shoyu production, *S*
*rouxii* gives a vigorous alcoholic fermentation due to the availability of starch from wheat. On the othe
hand, in tamari shoyu production, the alcoholic fermentation is much reduced due to the shortage o
carbohydrates from its raw materials.

### 5.2.3.3 Refining Process

The refining process consists of filtration of the moromi mash, pasteurization, and sedimentation. Th
filtration is usually done by using cloth under an increasing hydraulic pressure until the residue has 25%
or less of water. The resulting filtrate is called raw soy sauce. This raw liquor is pasteurized at 70°C
to 80°C by a plate heater. This last process is very important for the development of strong flavor anc
reddish-brown color. It is also necessary to inactivate the enzymes and to reduce undesirable microorgan
isms such as film-forming yeasts (Hesseltine and Wang 1980; Fukushima 1985, 1989; Yokotsuka 1986).

After sedimentation of the pasteurized liquor, the supernatant is bottled, packed, and marketed. Tc
minimize the strong flavor of usukuchi shoyu, a saccharification autolysis procedure is applied by add
ing a digested rice koji to the moromi mash before filtration to lower the number of reducing carbohy
drates which could cause a reduction of flavor development during heating in the pasteurization proces:
(Fukushima 1989).

## 5.2.4 Microbiology, Chemistry, Biochemistry, and Sensory Characteristics of Shoyu

In koji preparation, the release of extracellular enzymes from molds was observed in an experimen
performed by Yong and Wood (1977). The enzymes consist of protease and carbohydrase complexes
These enzymes play an important role in the subsequent brine fermentation. Protease complexes, includ
ing glutaminase, hydrolyze proteins into small molecular weight peptides and amino acids, wherea:
carbohydrase complexes hydrolyze carbohydrates into sugars (Kuroshima et al. 1969; Yong and Wooc
1977; Whitaker 1978; Hesseltine and Wang 1980; Fukushima 1981, 1985, 1989; Yokotsuka 1983, 1986
Flegel 1988). The main free amino acids released by the enzymes' action are glutamine and glutamic
acid (Flegel 1988), which are known as the major amino acid residues in soybean and wheat protein:

(Fujiwara et al. 1962a; Kuroshima et al. 1969; Fukushima 1991). The release of glutamic acid is related to the umami taste of shoyu (Nishimura and Kato 1988; Lioe et al. 2010).

In the second step of shoyu fermentation, the sodium salt concentration of moromi mash, averaged at 18%, limits the growth of microorganisms. The microbes in this fermentation belong to halophilic bacteria and osmophilic yeasts. At the earlier stages, lactic acid fermentation occurring because of *P. halophilus* resulted in a pH decrease of 6.5 to 7.0, to lower than 5. The next stage is alcoholic fermentation by *Zygosaccharomyces rouxii* or *S. rouxii*. Then, at the last stage, *Torulopsis* sp. or *Candida* sp. grow to produce phenolic and aromatic compounds (Yokotsuka 1960, 1983, 1986; Fujiwara et al. 1962a; Kuroshima et al. 1969; Whitaker 1978; Hesseltine and Wang 1980; Noda et al. 1980; Fukushima 1981, 1985, 1989; Inamori et al. 1984; Chou and Ling 1998; Kinoshita et al. 1998).

The chemical compositions of five types of shoyu are presented in Table 5.1. The ratio of inorganic to organic constituents is nearly 1:1. The inorganic components are primarily sodium and chlorine, which comprise 46% of the total soluble solid, whereas the organic components consist of approximately 25% free amino acids and small peptides, 13% sugars, 3% organic acids, and 5% alcohols (Yokotsuka 1986). The ratio of free amino acids to small peptides is approximately 1:1 (Yokotsuka 1960, 1983, 1986; Whitaker 1978; Fukushima 1985, 1989). Glutamic acid and aspartic acid are the major amino acids found in shoyu (Fujiwara et al. 1962b, 1962c; Kaneko et al. 1994; Chou and Ling 1998). Lactic acid and glucose are the main organic acid and sugar, respectively. It has been proved that the presence of lactic acid can be used to distinguish the fermented soy sauce from the chemical one (Fukushima 1981, 1985, 1989; Kaneko et al. 1994).

The delicious taste of shoyu primarily comes from its nitrogenous compounds, that is, free amino acids and small peptides that are found in their low molecular weight fractions of less than 500 Da, which have the highest intensity of umami taste compared with the fractions higher than 500 Da (Lioe et al. 2007). It is already known that free amino acids and some peptides contain some flavor (Solms 1969; Yamasaki and Maekawa 1978; Nishimura and Kato 1988; Nakata et al. 1995). The small nitrogenous compounds as well as the sugars and organic acids formed during brine fermentation together make up soy sauce taste and quality (Yokotsuka 1960; Noda et al. 1980; Lioe et al. 2007, 2010).

Glutamic acid has a pure umami taste in the presence of sodium salt (Ikeda 1908; Fuke and Shimidzu 1993; Lioe et al. 2005). In shoyu, it has been revealed that free amino acids consist of umami amino acids such as glutamic acid together with sweet amino acids such as alanine, serine, and glycine giving a strong delicious taste to koikuchi shoyu, whereas the taste of tamari shoyu is mainly contributed by glutamic acid and aspartic acid (Lioe et al. 2006).

The small peptides contained in koikuchi shoyu and tamari shoyu were found in half of the total free amino acid content in their umami fractions, most of which have glutamyl residues. After further elucidation, the peptides contributing directly to the intense umami taste were considered to be negligible; however, an interaction between these peptides and free amino acids may have occurred (Lioe et al. 2006). Takeuchi et al. (1962) have reported that small peptides present in tamari shoyu comprise 19% of the total nitrogenous compounds, about twice of that in koikuchi shoyu. The length of the peptides in

## TABLE 5.1
Chemical Composition of Shoyu Recognized by the Japanese Government

| Type of Shoyu | NaCl (% w/v) | Total N (% w/v) | Sugars (% w/v) | Alcohol (% v/v) | pH |
|---|---|---|---|---|---|
| Koikuchi shoyu | 17.6 | 1.6 | 3.8 | 2.2 | 4.7 |
| Usukuchi shoyu | 19.2 | 1.8 | 5.5 | 0.6 | 4.8 |
| Tamari shoyu | 19.0 | 2.6 | 5.3 | 0.1 | 4.8 |
| Saishikomi shoyu | 18.6 | 2.4 | 7.5 | Trace | 4.8 |
| Shiro shoyu | 19.0 | 0.5 | 20.2 | Trace | 4.6 |

*Source:* Fukushima, D., *Journal of the American Oil Chemists' Society*, 58, 346–354, 1981. With permission.

tamari shoyu are approximately 3 to 4, whereas in koikuchi shoyu, it is 2 to 3. Other researchers found three glucodipeptides and eight dipeptides in a neutral fraction of the Japanese soy sauce which had no flavor (Oka and Nagata 1974a), whereas four peptides, ten glycodipeptides, and two tripeptides found in an acidic fraction had a slight umami taste, considered less than 12% of the monosodium glutamate taste (Oka and Nagata 1974b). Moreover, the other peptides isolated by Kirimura et al. (1969) had bitter and astringent tastes.

Approximately 150 flavor volatiles or aroma compounds were identified in shoyu, including organic acids, alcohols, esters, carbonyls and related compounds, phenolic compounds, lactones, pyrazines, sulfur-containing compounds, and terpenes (Yokotsuka 1986). These are formed during wheat roasting, koji and moromi fermentation, and pasteurization. None of the known compounds affect the character of shoyu aroma. Among the flavor volatiles, 4-hydroxy-2(or 5)-ethyl-5(or 2)-methyl-3-(2*H*)-furanone (HEMF) is the most abundant in shoyu, and is formed through Maillard browning reaction during shoyu processing (Yokotsuka 1986). HEMF can be present at concentrations of 100 to 300 ppm (Yokotsuka 1986; Fukushima 1989; van der Sluis et al. 2001). Interestingly, HEMF, which is actually less volatile, may give a full-bodied taste, recognized as a sweet and caramel-like taste, especially to koikuchi shoyu. However, the compound is rarely found in tamari shoyu, which uses very little or no wheat in its production.

Half of the color development of shoyu occurs during the roasting of wheat, shoyu fermentation, and moromi aging, whereas the rest of the color development occurs during pasteurization as observed from the color intensity scores observed during the shoyu processing procedure (Whitaker 1978; Yokotsuka 1986). This color development is most likely due to Maillard browning reaction between amino compounds and reducing sugars (Whitaker 1978; Yokotsuka 1986; Fukushima 1989; Villamiel et al. 2006).

### 5.2.5 Shoyu Manufacturers in Japan

According to a literature review by Fukushima (1989), there are five large shoyu manufacturers in Japan. These are Kikkoman, Yamasa, Higashimaru, Higeta, and Marukin companies, whose market shares total more than 50%. The total shoyu production of these companies was reported to be as high as 1.2 million kiloliters per year.

## 5.3 Indonesian Kecap

### 5.3.1 A Brief History of Kecap

Until two decades ago, kecap was widely produced in Indonesia by small-scale operators (Röling et al. 1996; Apriyantono et al. 1999) using only black soybeans as a raw material (Judoamidjojo 1987; Röling et al. 1996; Apriyantono et al. 1999). This traditional product was introduced several centuries ago. However, in the last two decades, the kecap available in the markets has been dominantly produced by several soy sauce manufacturers using yellow soybeans and wheat as raw materials and applying modern Japanese technology for its fermentation processes (Röling et al. 1996; Apriyantono et al. 2004).

The kecap produced by either small-scale producers or manufacturers has the same types, these are *kecap asin* (salty soy sauce) and *kecap manis* (sweet thick soy sauce). Kecap asin has similar physical and taste characteristics as well as similar production steps as tamari shoyu and common soy sauce. In contrast, kecap manis has a sweet and darker color with a typical aroma due to further heat processing for 1 hour with the addition of brown sugar to approximately 50% w/v, along with spices such as fennel and star anise (Apriyantono et al. 1999). The difference between kecap asin and kecap manis is the heating process after fermentation. Therefore, the flavor formed during the heating process in kecap manis is much more important than that formed by fermentation. Kecap manis is actually much more popular than kecap asin because of its sweet and *gurih* (tasty, umami) taste; thus, the term kecap in Indonesia can be directly attributed to kecap manis.

### 5.3.2 Basic Kecap Production

The same principle of shoyu fermentation is applied in kecap, that is, the process consists of two steps of fermentation, koji making or mold fermentation called *bungkil* fermentation in Indonesia, and brine fermentation to yield moromi called *baceman* fermentation (Judoamidjojo 1987; Röling et al. 1994; Apriyantono et al. 1999, 2004). The molds used in bungkil fermentation are a mix of *Aspergillus* sp. and *Rhizopus* sp. The length of fermentation is several days to 1 to 2 weeks at room temperature. The bungkil is then dried under the sun, and blown to remove any spores on its surface. Baceman fermentation is started by mixing dried bungkil with three to four times the amount of brine solution at a salt concentration range of 17.5% to 20% w/v (Röling et al. 1994; Apriyantono et al. 1999, 2004). In traditional baceman fermentation, spontaneous fermentation is allowed for 4 months or less and is done under the sun. The evaporation of some water on the surface of the baceman mix under the sun may avoid the formation of a microbial layer which can spoil the mix.

During traditional baceman fermentation, total nitrogenous compounds consisting of amino acids and small peptides substantially increased within 2 weeks of fermentation (Röling et al. 1994; Apriyantono et al. 2004) primarily due to the enzymes of bungkil. The growth of lactic acid bacterium *P. halophilus* (or *Tetragenococcus halophila*) was observed during the baceman process; however, the growth of yeasts was almost not detected because of the fewer carbohydrate sources (Röling et al. 1996; Apriyantono et al. 1999; Lioe et al. 2010). After the baceman process, the result of filtration is boiled with the addition of palm sugar (brown sugar) and spices for at least 1 hour to yield kecap (kecap manis) which has a relatively higher viscosity. Unlike traditional kecap, in industrial kecap fermentation, yeast fermentation is obviously present due to the use of wheat as one of the raw materials (Röling et al. 1996). Recently, some pure microbial starters have been used in kecap production as found in the shoyu fermentation process.

### 5.3.3 Flavor and Sensory Characteristics of Kecap

The flavor volatiles composition of kecap has been observed in kecap manis, extracted by a Likens–Nickerson apparatus with diethyl ether as the extraction solvent. The 98 volatiles found consisted of 16 acids, 4 aliphatic aldehydes, 4 aliphatic alcohols, 1 phenol, 6 aliphatic ketones and lactone, 21 furans, 10 pyrazines, 5 esters, 1 pyran, 1 pyridine, 3 pyrroles, 1 thiazole, 4 alicyclic hydrocarbons, 11 benzene derivatives, and 11 unknowns (Apriyantono et al. 1999). These compounds are mainly associated with the Maillard reaction that occurred during the heating process and in the presence of sugars. Some acids such as malic and citric acids derived from palm sugar were observed in the investigation. These acids may contribute to the typical taste of kecap.

The delicious taste of kecap is dominantly from nitrogenous compounds with molecular weights of less than 500 Da (Apriyantono et al. 2004; Lioe et al. 2004a,b). In this case, free acidic amino acids such as glutamic acid and aspartic acid, with sweet amino acid alanine and bitter amino acid phenylalanine in the presence of sodium salt could give the intense umami taste of kecap (Lioe et al. 2004b). Kecap or kecap manis is commonly marked by a sweet and umami taste (Apriyantono et al. 1999).

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