Introduction of data-driven approach into food industry

– a case study on fish sauce –

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Contents

1. Introduction

The most essential need for all living organisms is energy, which is usually obtained by consuming food. But for human being, it is also a source of pleasure and comfort, and reflects and conveys information relating to personal and cultural characteristics, social status and relationships. In other words, the food affects all aspects of human life. Humans are faced with several food choices each day and make decisions on what food to eat based on several criteria. It can be considered as common knowledge that people have different food preferences.

In the food industry filed, consumer research surveys and interviews are performed to acquire the information regarding consumer preferences and acceptances (Honkanen & Frewer 2009; Kearney *et al.* 2000; Milošević *et al.* 2012), to construct concepts for new products. On the other hand, the consumer acceptance to the foods may be assessed by the sensory evaluations using trained panels. In this “traditional” approach for the product development, many human cooperators are needed for the questionnaire, interview and sensory evaluation. For the questionnaire and interview analyses, the quality of the analyses highly depends on the prepared questions and capacity of interviewer (Krosnick and Presser, 2010; Bastian et al., 2015). Furthermore, to gather good results from the sensory evaluations, the panels should be trained with great time and efforts (Murray et al., 2001).

Information is needed for making decision in every situation containing business. Data is a set of values of quantitative or quantitative variables. Pieces of data are individual pieces of information. Making decision using data is not new concept. For example, in Major League Baseball, data is presented for managers each season in the Bill James Handbook. Bill James is the innovator of advances statistics and SABR-metrics for baseball and an annual volume of informative statistics are still printed each year after conclusion of season before the next season begins from 1977 (Paul et al., 2016).

Big data and its analysis are the center of modern science and business. These data are generated from online transaction, emails, videos, audios, images, click streams, logs, posts, search queries, health records, social networking, interactions, science data, sensors and mobile phones and their applications (Fig. 1). Until 2003, 5 exabytes (10^{18}

bytes) of data were created by human. In 2012, digital world of data was expanded to 2.72 zettabytes (10^{21} bytes).

Due to the development of information technology, various data related to dairy life and business, containing online search records or measurement data using sensors, are accumulated in some available databases. Judgment and decision making utilizing these data are carried out, in many fields such as medical care, education and sports. In the field of business, a "data-driven approach" is gathering the attention to solve problems in product development and marketing by analyzing the complex diversifying consumer demands, based on a wide variety of data. However, at the site of the sixth sector industrialization aiming at regional activation, it would be “product-driven performance” depending only on the products that can be manufactured by the business operator, because the company size and products that can be produced are limited. These problems make mismatch with customers’ demands and prevent product differentiation. In this study, the author discussed an industry of fish sauce as an example of such cases.

Fish sauce is usually obtained by mixing fish materials with salt, which are subsequently fermented in a natural environment. Recent investigation indicates that interest in fish sauce produced in Japan has gradually declined among the Japanese people. Despite the waning consumer demand, however, the production of fish sauce has gained attention, and many local fish sauce products are being produced to revitalise local communities that have the advantage of an abundant supply of inedible fish material at low market value that can be used for the production. This situation indicates a large gap between consumer demand and supply.

In this study, the author introduced the “data-driven approach” to the fish sauce market analysis, and discussed market potential of the fish sauce in Japan. First, the data related to consuming fish sauce was collected from the web site including Google search and Cookpad to analyze consumer behavior. Next, the author analyzed "smell" "taste" and "color" of 46 types of commercial fish sauce manufactured in Asian countries by electronic panel (e-panel) analyses containing electronic tongue (e-tongue), nose (e-nose) and eye (e-eye) sensory assessments. Along with the e-panel analysis, the chemical properties of these fish sauces were also analyzed to characterize the fish sauce in each country. On the other hand, from the results of the mining online activity data, it became clear that the demand for Japanese fish sauce as a seasoning of *nabe* cuisine is increasing only in winter. Furthermore, it suggests that the popularity of *shirako* seafood is rising as an ingredient of *nabe* cuisine. Based on the results, the author made a prototype fish sauce containing *shirako* and analyzed its smell, taste and color by e-panel analysis.

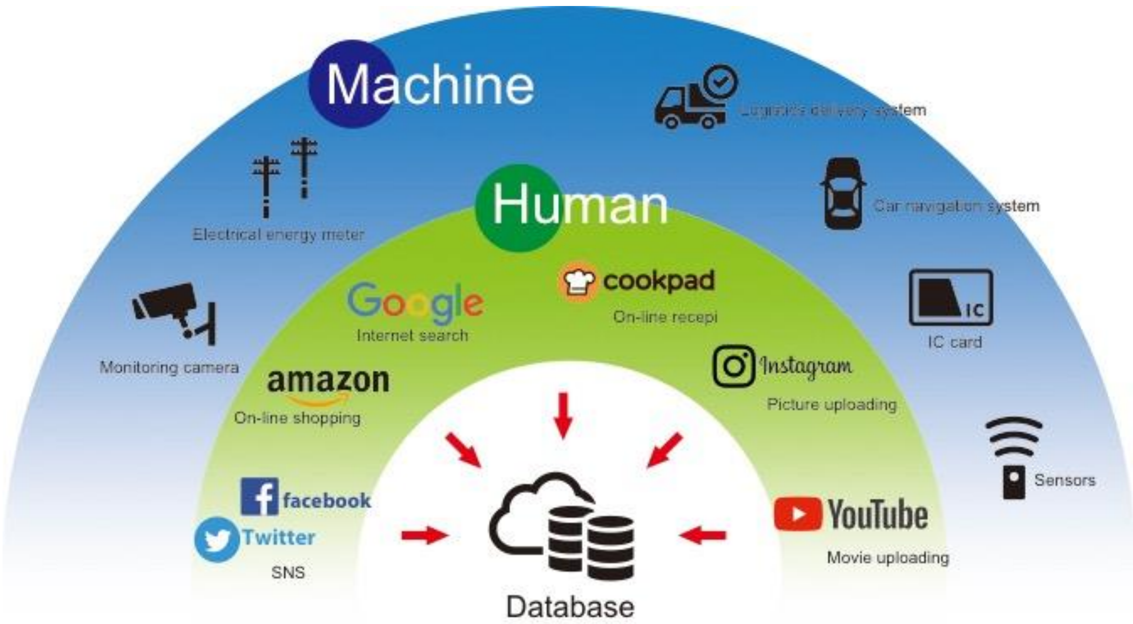

Fig. 1 Data surrounding modern society

2. Mining online activity data to understand food consumption behaviour: the case of Asian fish sauce among Japanese consumers

2.1. Introduction

Consumers choose food based on many factors, such as flavour, appearance, nutritional value, function, and package label (Borgmeier & Wstenhoefer 2009). Further, familiarity with the food is an important factor in consumer acceptance (Verneau *et al.* 2013). To understand consumer preference and acceptance, food researchers and developers conduct consumer research surveys and interviews (Honkanen & Frewer 2009; Kearney *et al.* 2000; Milošević *et al.* 2012), and based on their consumer research, they construct concepts for new products and produce pilot-scale products. This traditional approach to product development requires many human respondents for the questionnaires, interviews, and sensory evaluations. The quality of the questionnaire and interview analyses highly depends on the prepared questions and the interviewers' capabilities (Bastian *et al.* 2015).

Today, information technology has enabled the accumulation of large amounts of data from social websites and the simple extraction of such data using search engines. Economists (Carrière-Swallow & Labbé 2013; Choi & Varian 2012; Vosen & Schmidt 2011), policy makers (Ripberger 2011), epidemiologists (Carneiro & Mylonakis 2009; Seifter *et al.* 2010), and biologists (Mccallum & Bury 2013; Proulx *et al.* 2013) increasingly use accumulated online data to understand markets, public opinion trends, the spread of human infectious diseases, and conservation of creatures' behaviours. Recently, in addition to websites that provide general information, online recipe sites such as Cookpad (https://cookpad.com) and Allrecipes (http://allrecipes.com) have become popular among households for finding user-generated recipes and for planning meals.

Meanwhile, fish sauce is a brown liquid seasoning widely consumed in most Southeast Asian countries. The name for fish sauce varies across countries: *nampla* in Thailand, *nuoc mam* in Vietnam, and *shottsuru* in Japan (Akita Prefecture). In general, fish sauce is produced by fermenting a mixture of fish material and salt (Fukami *et al.* 2004), and microorganisms are often used as a starter to hasten the fermentation. During the fermentation process, the proteins in the fish material are hydrolysed into amino acids and peptides both by endogenous and microorganism proteases, which results in the distinctive taste of the fish sauce (Lopetcharat *et al.* 2001; Taira *et al.* 2007). The fermentation process also produces volatile compounds responsible for the characteristic odor of the fish sauce (Yongsawatdigul *et al.* 2007; Zheng *et al.* 2017).

In Japan, fish sauce had been widely consumed as a substitute for soy sauce and miso, especially in coastal areas. However, its consumption declined after the emergence of industrial production and commercial availability of soy sauce brought by the drastic change in Japanese society after the Meiji era (Ishige, 1986). Thereafter, the production of fish sauce was seen only in limited areas (i.e. *shottsuru* in Akita Prefecture and *ishiru* in Ishikawa Prefecture). Our recent investigation indicates that interest in fish sauce produced in Japan has gradually declined among the Japanese people (Nakano *et al.*, in submission). Despite the waning consumer demand, however, the production of fish sauce has gained attention, and many local fish sauce products are being produced to revitalise local communities that have the advantage of an abundant supply of inedible fish material at low market value that can be used for the production. This situation indicates a large gap between consumer demand and supply.

In this study, we employed Google Trends, which enables the plotting of Google search queries related to a topic, to analyse consumption behaviours for fish sauce in Japan. In addition, we employed Tabemiru, a tool provided by online recipe repository Cookpad, which enables the analysis of the frequency of recipe use to analyse household consumption of fish sauce. The combined data from Google Trends and Tabemiru represent the household consumption behaviour for fish sauce in Japan.

2.2. Materials and methods

Collection of data from Google Trends

Temporal or regional trends in web searches for the terms of concern to this study were downloaded from Google Trends (https://trends.google.com/trends/). Google Trends is a public web facility of Alphabet Inc. (Mountain View, CA, USA) that shows how often people search for a term relative to the total number of searches, in various countries and languages. In this study, the data were collected by setting the location parameter to

‘Japan’ and the time parameter to ‘2004-present’.

Collection of data through Tabemiru on Cookpad

Cookpad, Japan’s largest recipe site (http://www.cookpad.com), allows visitors to upload and search for original recipes. Tabemiru is an analysis tool provided by Cookpad Inc. (Tokyo, Japan) that allows visitors to analyse how often recipes, including relevant search terms, are used by Cookpad visitors. The frequency is expressed as the cook index (CI), in which Tabemiru counts a recipe that has been viewed continuously for more than 10 minutes as ‘made or cooked by the visitor of the site’. The CI is calculated using the following formula: number of times for which a recipe, including relevant search terms, was used for cooking / total number of recipes that were made × 1,000.

Statistical analysis

The correlation between Google Trends-based search volumes and household consumption behaviour, represented by the CI in Tabemiru, was assessed with scatter plots and regression statistics using the coefficient of determination and Pearson's correlation coefficient. Additionally, the correlations between the search volumes for the terms for fish sauce and for the names of dishes were assessed in the same manner. All statistical analyses were performed using Microsoft Excel for Mac (version 15.31; Redmond, WA, USA).

2.3. Results

Google search trends for fish sauce among Japanese consumers

We entered the set of terms 'ナンプラー' (*nampla*; Thai fish sauce), 'ニョクマム' (*nuoc man*; Vietnamese fish sauce), and 'しょっつる' (*shottsuru*; Japanese fish sauce) on the Google Trends homepage on August 2017 to access search trends for these three keywords. Fig. 1 (a) shows the Google Trends graph depicting the search frequency for the three terms from January 2004 to August 2017. Among the three terms, the *nampla* searches had the most traffic, nine times more than that for the *nuoc mam* searches and three times more than that for the *shottsuru* searches on average. Interestingly, the search trend for *nampla* reaches a peak in the summer and reaches a valley in the winter. This trend is remarkable after 2011. Conversely, the search trend for *shottsuru* demonstrates a sharp peak in December. Such seasonal search trends were not observed for *nuoc mam*. The search trends for the three terms for fish sauce on the Google Shopping site were also analysed, as shown in Fig. 1 (b). *Nampla* searches occurred every year after 2012, whereas *shottsuru* searches occurred only in the winter of 2011 and 2014. *Nuoc mam* searches were not observed for any year.

Google Trends also lists the prefectures with the highest search traffic for a given term. As shown in Figure 2, for the *shottsuru* searches, 17 of 47 prefectures were listed, with Akita Prefecture showing a remarkably high search traffic. On the other hand, the term *nampla* was widely searched by all prefectures in Japan. The *nuoc mam* searches occurred only in metropolitan areas with large populations, such as the Kanagawa, Tokyo, Saitama, and Osaka prefectures'.

Household consumption behaviour for fish sauces in Japan

To clarify the household consumption behaviour for the three fish sauce types in Japan, we analysed the frequency in the use of recipes that include *nampla*, *nuoc mam*, and *shottsuru* as an ingredient on Japan's largest online recipe repository, Cookpad, through the analysis tool Tabemiru provided by Cookpad Inc., from 2014 to 2017. The frequency was expressed as the cooking index (CI) in Tabemiru. As shown in Fig. 3 (a), the frequency of the use of recipes that include *nampla* was ten times higher than that for *shottsuru* and eighty times higher than that for *nuoc mam* in 2014. The frequency of the use of recipes that include *nampla* increased every year after 2015, whereas that for *shottsuru* decreased every year since 2014.

The monthly trends for the frequency of use of recipes that include the three types of fish sauce were compared as shown in Fig. 3 (b). Similar to the Google search trends, the frequency of use of recipes that include *nampla* demonstrated peaks in the summer, while that include *shottsuru* exhibited sharp peaks in December. Since the monthly Google search trends and the frequency of use of recipes show similar behaviours, the correlation between these two sets of data was analysed using Pearson's correlation coefficient (Fig. 3 (c)). The results show high positive correlations for *nampla* and *shottsuru* in the Google search frequency and frequency of use of recipes as represented by the CI. For *nampla*, the Pearson's correlation coefficient was 0.87. Consequently, for *nampla* and *shottsuru*, there is a high correlation between people's interest and household consumption.

Next, we analysed foods that used *nampla*, *nuoc mam*, and *shottsuru* in the recipes on Cookpad using Tabemiru. As shown in Table S1 (Appendix), *shottsuru* was almost always used as a condiment in *nabe*, a Japanese stew, with *konbu* (kelp), and *hata-hata* (Japanese sandfish). The stew, called *shottsuru nabe*, is a traditional dish in Akita Prefecture (Ishige, 1986). The data also indicate that *nuoc mam* was used as a dipping sauce for various foods or a condiment for fried chicken or other meat. On the other hand, the data also indicate a drastic change in the use of *nampla* in households since 2016. Fig. 4 indicates the CI of each food that used *nampla*. The CIs for meat, fries, and soup showed constant values throughout 2014 to 2017, which means *nampla* was used as a condiment for fried meat, fries, and soup. Further, the data demonstrated a rapidly increasing interest in *gapao* and rice, referring to a new Thai dish called *gapao rice*, which became trendy in Japan around 2015 to 2016. The upper panel of Fig. 6 indicates the Google Trends graph of the search frequencies for ナンプラー (*nampla*) and ガパオ (*gapao*) from January 2004 to August 2017. This panel implies that the trends in the popularity of *nampla* are tightly linked to those of *gapao*, and the popularity of these terms has been increasing since 2012. Additionally, the search frequency for the term タイ料理 (Thai foods) increased from 2012. These results indicate that Thai cuisine gradually became popular in Japanese society, especially with the increasing popularity of *gapao rice,* which was also eaten in households in addition to restaurants that specialise in Thai cuisine.

Increasing popularity of nampla as a condiment in Southeast Asian cuisine

As shown in Fig. 6, the search frequency for *nampla* is significantly related to those for *gapao*, *pattai*, *tom yum goong*, and *nama-harumaki*, which suggests that the people's interest in *nampla* is related to these dishes. Indeed, some of the recipes for these dishes on Cookpad list *nampla* as a condiment. Interestingly, *nama-harumaki* originated from Vietnam, and it uses *nampla* in place of *nuoc mam*. The search frequency trends for *nuoc mam* did not show relationships to any of the dish names analysed in this study, including the Vietnamese dishes *nama-harumaki* and *pho*. The search trends for *shottsuru* is related to *shottsuru nabe* and *hata-hata*.

A reason for the rapidly increasing popularity of Thai cuisine in Japan is the increasing number of visitors from Thailand. Fig. 7 indicates that the number of visitors from Thailand to Japan has been significantly increasing since 2013. On July 2013, the Japanese government permitted people from Thailand to enter the country without a visa. This increase in visitors from Thailand may have promoted cultural exchanges, including with the cuisines.

2.4. Discussion

Fish sauce used to be popular among Japanese households as a substitute for soy sauce, which is a condiment for traditional dishes or a dipping sauce (*tare*) for *sashimi* or raw fish (Ishige 1986). However, owing to drastic changes in Japanese society, fish sauce consumption has declined. Nevertheless, production of a wide variety of fish sauce continued throughout Japan, as some local communities have an abundant supply of fish and inedible fish material at low market value that can be used to make the product. However, for the industry to succeed, strategies for sales and product development are necessary. In this study, we performed data mining of internet activities (searches) related to fish sauce consumption among the Japanese.

The data mined from Google Trends indicate that fish sauce produced in

Japan, represented by *shottsuru*, has a very limited purpose as a condiment for traditional *nabe* (Ishige, 1986; Nakano *et al.*, in submission). This finding means that currently, there is an excess supply of fish sauce relative to consumer demand. On the other hand, Thai fish sauce, *nampla*, has become widely popular in Japan owing to the rapidly increasing popularity of Thai cuisine in recent years, as represented by *gapao rice*. The data mined from Cookpad indicate that Thai cuisine has now spread to households, not only to restaurants that serve such cuisine. These findings may have significant implications for the Japanese fish sauce industry. The increasing popularity of *gapao rice* in Japanese society has led to the increasing consumption of *nampla*. On the other hand, no dish has led to an increased consumption of Japanese fish sauce, and therefore, the development of dishes that use this fish sauce is necessary. Additionally, to sell unfamiliar food to people, suppliers must explain the food's benefits to them or their households. For instance, fish sauce can be very nutritious owing to its essential amino acid content (Gildberg, 2004). Additionally, fish sauce promotes various biological activities, including the angiotensin I-converting enzyme inhibitory activity and insulin secretion-stimulating activity (Ichimura *et al.*, 2003). Distribution of such useful information to consumers would be a part of a good sales strategy for Japanese fish sauce.

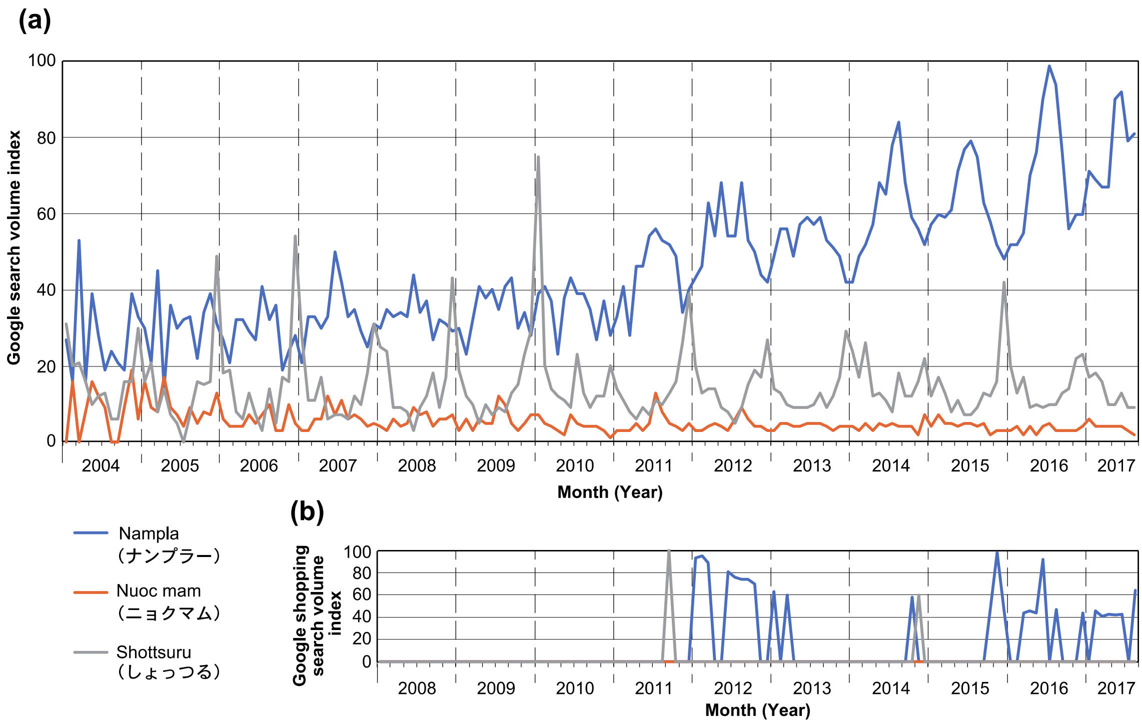

Fig. 1. (a) Interest in *nampla*, *nuoc mam*, and *shottsuru* and (b) in buying those fish sauce types. This information is represented by the Google search volumes on the query terms ナンプラー (*nampla*), ニョクマム (*nuoc mam*), and しょっつる (*shottsuru*),

from 2004 to 2017.

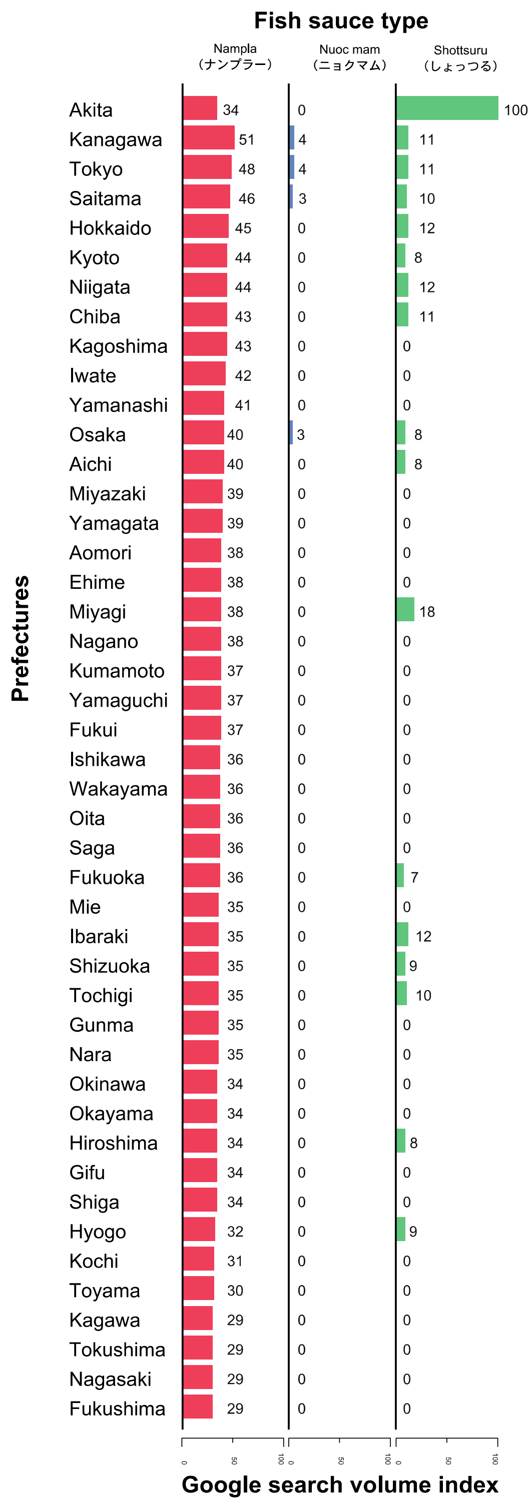

Fig. 2. Interest in *nampla*, *nuoc mam*, and *shottsuru* by prefecture. Each bar indicates

the Google search volume index.

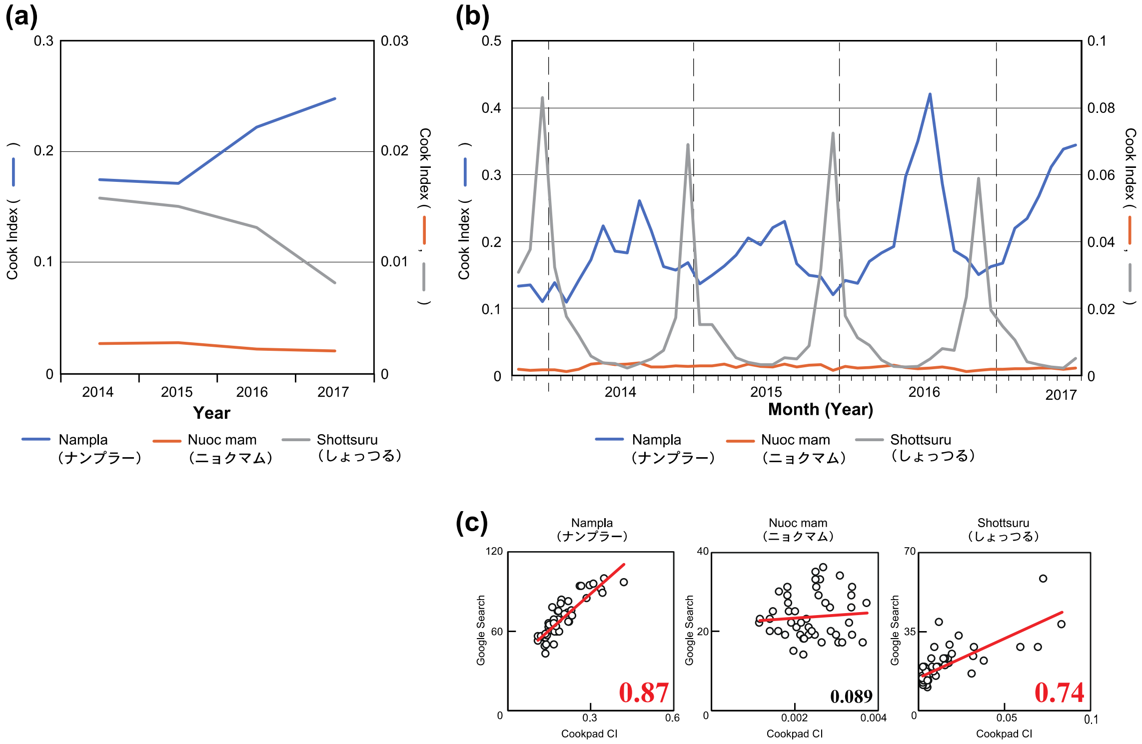

Fig. 3. (a) Annual and (b) monthly trends in use of Cookpad recipes including each fish sauce type. This information is represented by the cook index (CI). The scatter plots and regression statistics indicate a strong positive linear relationship between the Google search trends and CIs for *nampla* and *shottsuru* (c) but not for *nuoc mam*.

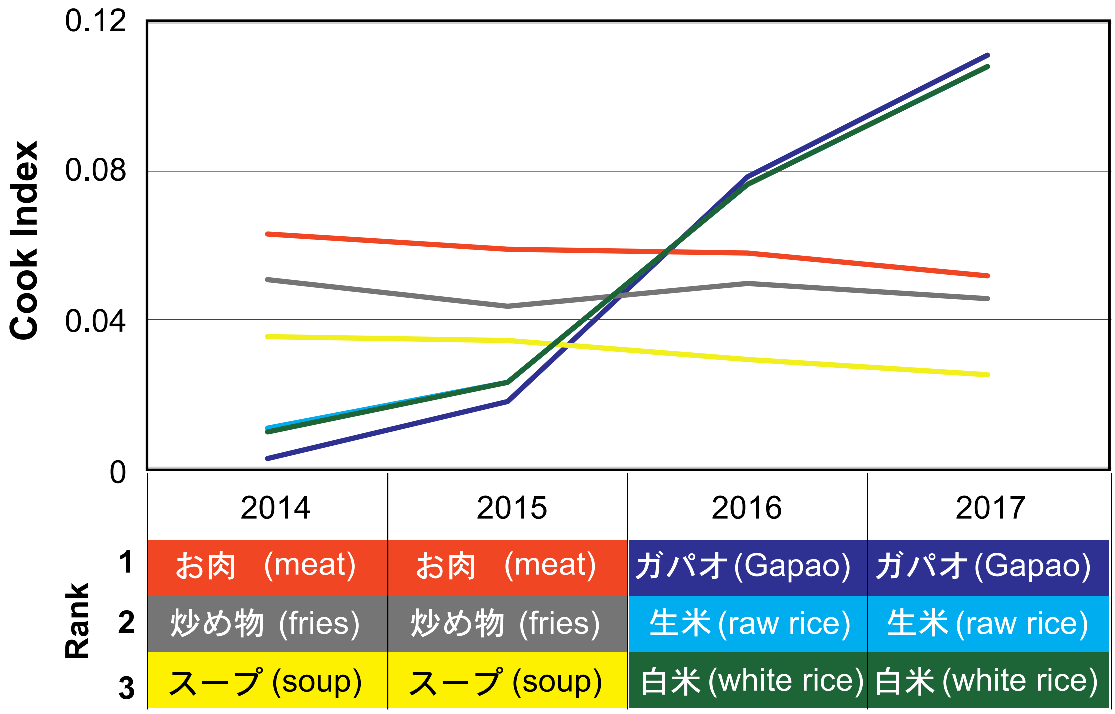

Fig. 4. Annual data on foods that use *nampla* from a combination search on Tabemiru on Cookpad. The bottom panel indicates top 3 retrieved terms for dishes that use *nampla* fish sauce

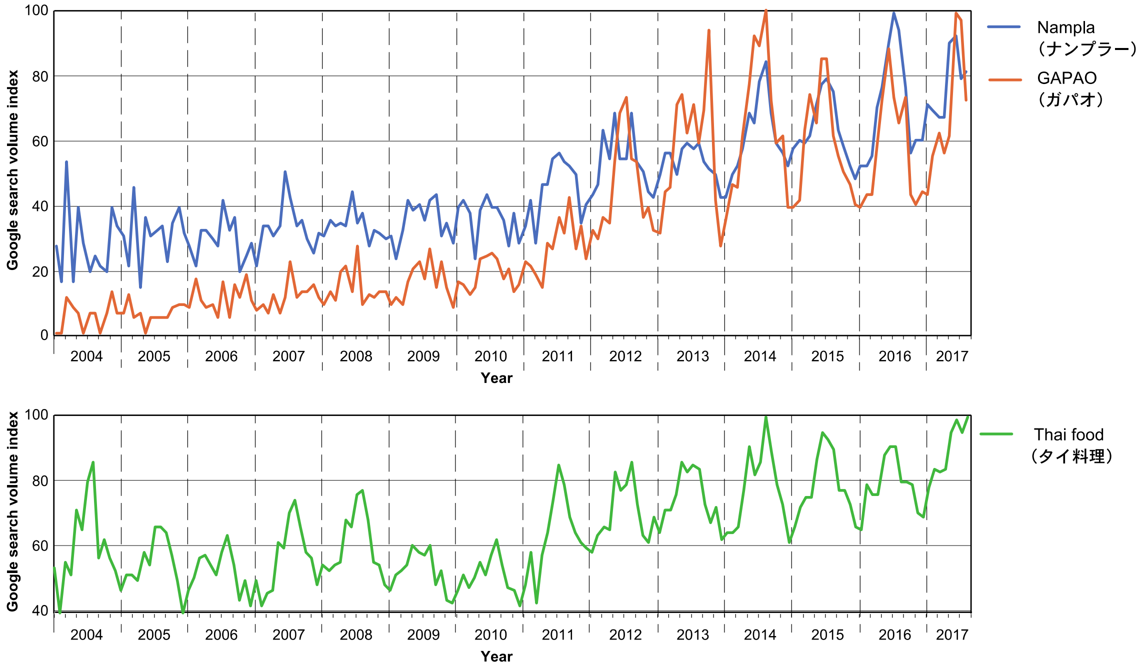

Fig. 5. Interest in (a) *nampla* and *gapao* and (b) Thai food. This information is represented by the Google search volumes on the query terms ナンプラー (*nampla*), ガパオ(*gapao*), and タイ料理 (Thai food), from 2004 to 2017.

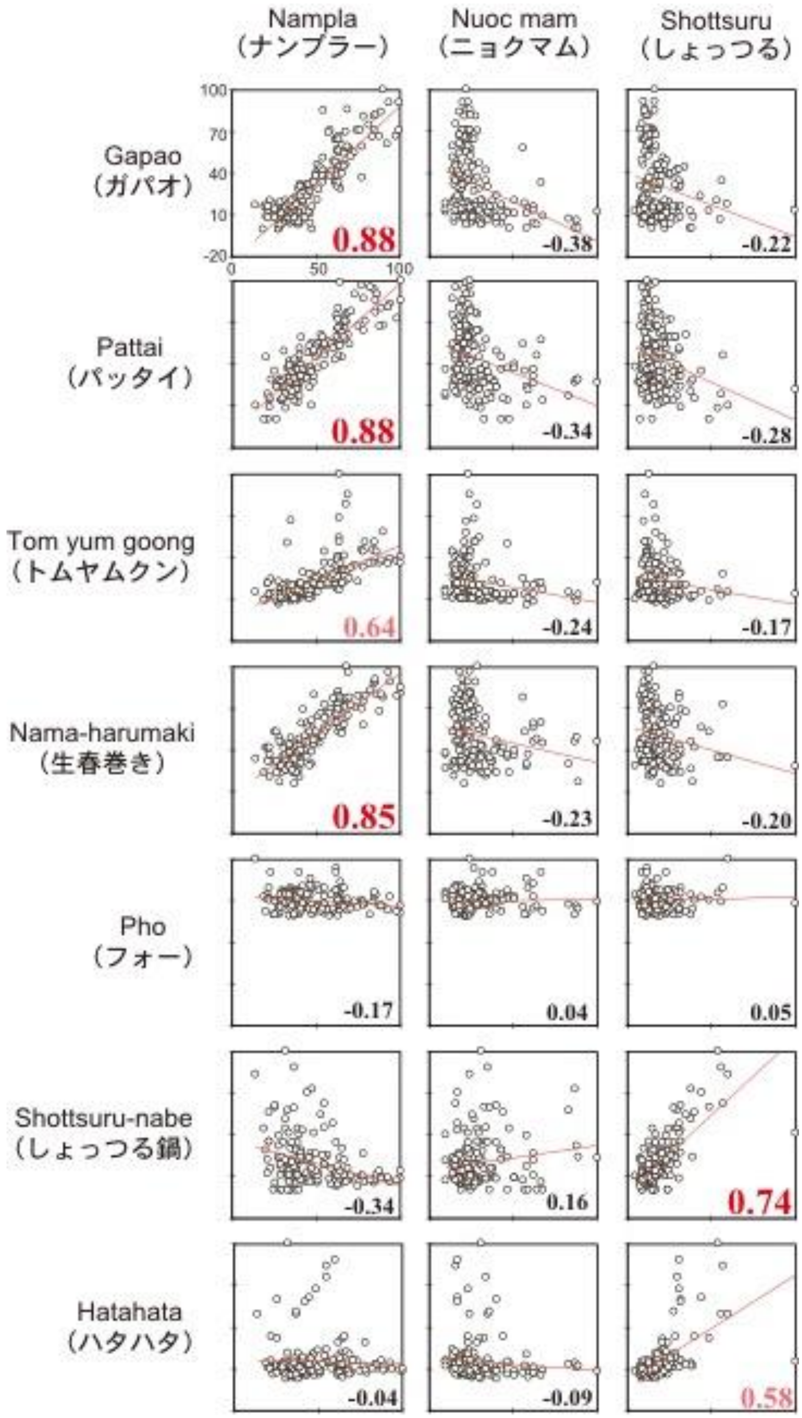

Fig. 6. Monthly Google search volume scatter plots per fish sauce type (x axis) and dish (y axis). The correlations were assessed with regression lines and Pearson's correlation cohesion.

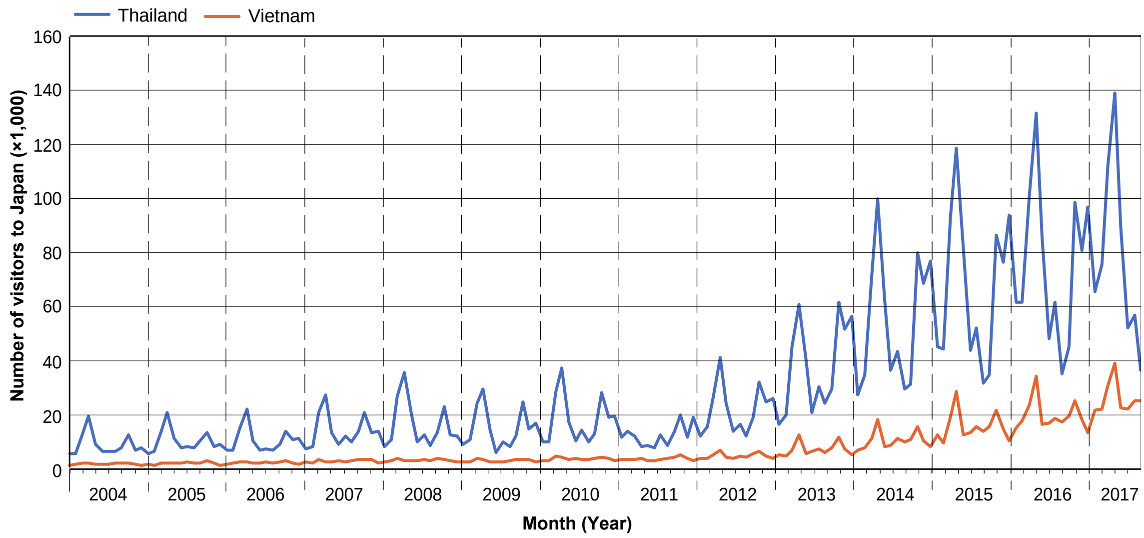

Fig. 7. Monthly data on visitors from Thailand and Vietnam to Japan. The line graph was prepared based on data from the Japan National Tourism Organization (https://www.jnto.go.jp).

3. Electronic nose and chemical analyses of commercial fish sauce products show country-specific preferences

3.1. Introduction

Fish sauce, a clear fermented brownish liquid condiment, is popular in Southeast Asia. In general, fish sauce is predominantly salty with umami taste, and has distinctive flavors (Wichaphon et al., 2013). Traditional fish sauce is usually obtained by mixing fish materials with salt, which are subsequently fermented in a natural environment (Lopetcharat et al., 2001). During an extended fermentation, the protein of the raw material is hydrolyzed into peptides and amino acids by endogenous fish proteases and the enzyme produced by microorganism in the fish sauce materials (Taira et al., 2007; Yongsawatdigul et al., 2007). The amino acids derived from the raw material provide the umami taste of fish sauce, with the microorganisms in the fermentation process, also contributing to its aroma and flavor (Zheng et al., 2017; Udomsil et al., 2017).

Fish sauce used to be produced in some seaside areas in Japan, such as in the Akita and Ishikawa prefectures as *Shottsuru* and *Ishiru*, respectively, but their production declined owing to the appearance and wide distribution of commercially available soy sauces, in a drastic change of Japanese society after the Meiji era (Ishige, 1986). Additionally, owing to its characteristic odor and flavor, fish sauce may be unacceptable for Japanese consumption in the household (Utagawa, 2012). Recently, however, fish sauce is becoming popular among consumers in Europe, North America, and other continents, as well as in Japan, due to the widely accepted ethnic cuisine (Zhao et al., 2017). Fish sauce production is also attracting attention as an effective utilization of unused valuable fishery resources (Utagawa, 2012).

The unique flavor of fish sauce is composed of three predominant distinctive notes, ammoniacal, cheesy, and meaty. It has been shown that the aroma of fish sauce comprises several volatile compounds that are associated to the distinctive flavor of the products (Shimoda et al., 1996). The ammoniacal note of fish sauce is attributed to ammonia and several amines. Low-molecular-weight volatile fatty acids are associated with the cheesy note, and volatile nitrogen-containing and aldehyde compounds are responsible for the meaty note. Food preference and acceptance are influenced by biological, physiological, psychological, and sociocultural factors (Mela, 2006; Köster, 2009; Sobal et al., 2014; Monteleone et al., 2017). Because people living in a given country tend to have similar eating patterns, it is presumed that they share similar food preferences and acceptance. For example, sensory evaluations in Japanese and Filipino populations indicate that Japanese subjects favored fish sauces with low concentrations of volatile acids, whereas Filipino subjects preferred sauce with high concentrations of volatile acids (Sanceda et al., 2003). Further, individual diversity exists in flavor responses to foods owing to different lifetime flavor experiences (Mennella and Trabulsi, 2012). However, flavor preferences have been rarely determined in market research for identification of consumer clusters (Törnwall et al., 2014).

The electronic nose (e-nose) technique is designed to crudely mimic the mammalian nose, in which electronic sensors non-selectively interact with volatile odor molecules (Baldwin et al., 2011). This technique allows the classification of food and agricultural products based on differences in the contents of volatile aroma compounds. In the current study, we determined the flavor and chemical properties of fish sauces produced in Japan, Thailand, Vietnam, China, the Philippines and Italy using e-nose analysis to estimate the preferences in fish sauce products of each country's consumers.

3.2. Materials and methods

Commercial fish sauce products

Forty-six fish sauces were purchased for this study (Appendix, Table S2). Thirty sauces were produced in Japan (labeled J1 to J30), 11 in Thailand (T1 to T11), and two in Vietnam (V1 and V2). The remaining three were produced in the Philippines (P1), China (C1), and Italy (T1). Japanese soy sauce was used as internal standard. Products were categorized into five groups: A, Japanese products made only from fish and salt; B, non-Japanese products made only from fish and salt; C, non-Japanese products made from fish, salt, and sugars; D, Japanese products made from fish, salt, and rice molt (*koji*); and E, Japanese products seasoned with additional condiments.

Determination of dried solid contents

Total dried solid measurements were performed by evaporating approximately 2 g of fish sauce at 130 °C for 20 minute with a moisture analyzer (MX-50, A&D, Japan).

Determination of salinity and pH

Salinity and pH were determined using a salt meter (B-721, HORIBA, Japan) or a pH meter (D-52, HORIBA, Japan).

Determination of total acidity and amino nitrogen

Total acidity and amino nitrogen content were measured by titration methods. For total acidity determination, 0.1 mol/L NaOH was used for the titration of organic acids, whereas amino nitrogen content was assayed using the formol titration method (Northrop, 1926). The peptide nitrogen (%) was stated as total nitrogen (%) – amino nitrogen (%).

Determination of total nitrogen

Total nitrogen was measured according to an improved Dumas method (Nozawa et al., 2007) with a combustion total nitrogen analyzer (Sumigraph NC-220F, Sumika Chemical Analysis Services, Japan).

Determination of amino/total nitrogen ratio

Amino/total nitrogen ratio was calculated using the amino nitrogen and total nitrogen content scores as follows.

$$Amino/total\ nitrogen\ ratio\ (\%) = \frac{Amino\ nitrogen\ (\%)}{Total\ nitrogen\ (\%)} \times 100$$

E-nose analysis

E-nose analysis was performed using a smell analysis system (αFOX 4000, Alpha

M.O.S., French). The E-nose consists of a headspace autosampler HS100 with numerous options, 18 metal oxide sensors each of which has different selectivity patterns, a signal collecting unit and pattern recognition software applied via a computer. Sensors in the e-nose system do not give information on sample composition, but rather give a digital fingerprint through pattern recognition (Baldwin et al., 2011).

Aliquots of fish sauce (0.5 g) were added to 10 mL vails and placed on an auto-sampler. Analyzing conditions were syringe at 50 °C, oven at 40 °C, and injection speed at 2 mL/sec.

Statistical analysis

Statistical analysis was performed using a spreadsheet software (Microsoft Excel, Japan) with the Tukey-Kramer method. Principal component analysis (PCA) was performed using a software AlphaSoft (Alpha M.O.S.) that attached to the e-nose system.

3.3. Results

Chemical characterization of commercial fish sauce products

To compare the respective chemical characteristics of fish sauce from different sources and with different ingredients, 46 products were assayed for dried solid content, salinity, pH, total nitrogen, amino nitrogen, peptide nitrogen, and total acidity.

1) Dried solid contents

Figure 1 shows the dried solid contents of fish sauce products. The highest value was 37.90 % for T2 (group C), whereas the lowest value was 16.12 % for J9 (group E). Fish sauce products in group E have relatively low dried solid values, probably owing to dilution resulting from the addition of condiments.

2) Salinity

Figure 2 shows the salinity of different fish sauce products. The degree of salinity varied from 11 to 25 %. The degree of salinity of group E products, corresponding to Japanese seasoned fish sauce products after the fermentation process, was significantly lower than that of other products.

3) pH

The pH of the fish sauce products ranged from 4.5 to 6.0 (Fig. 3). Significant differences between groups A and E probably result from the additives to the seasoned fish sauce products.

4) Nitrogen

Total nitrogen content corresponds predominantly to protein, peptides, and amino acids in raw fish (Fig. 4). Total nitrogen values varied, with the highest and lowest values being 2.95 % for V2 (group B) and 0.28 % for J8 (group E), respectively. Japanese seasoned fish sauce exhibited significantly lower values compared to other products. This difference probably results from dilution of the fish sauce components with the addition of condiments for seasoning.

Amino nitrogen content corresponds to amino acids in raw fish (Fig. 5). Similar to total nitrogen content, fish sauce in group E showed significantly lower amino nitrogen content than other products. Although the difference was not significant, the values for group C were also lower than those of other products. This difference probably results from reduction of the enzymatic activity due to decreasing of water activity with addition of sugars, in addition to the dilution of the raw fish protein with the addition of condiments or sugars.

Figure 6 displays the percentage of peptide nitrogen in the fish sauce products.

Group E products showed significantly lower values than other products, which probably results from dilution of peptides in the products with additives. On the other hand, products in group A also showed lower values than other products, although the difference was not significant. This may be reflected in the ratio of amino/total nitrogen that represents the conversion rate from peptides to amino acids (Fig. 7).

5) Acidity

Figure 8 shows the acidity values for the fish sauce products. Among the five groups, group D products had higher acidity value than other products probably due to the acids from additional condiments.

E-nose analysis of fish sauce products

To characterize the flavor of fish sauce products, e-nose analyses were performed. For variable reduction and separation into classes, principal component analysis (PCA) was employed (Fig. 9), and the fish sauce products were classified into seven classes. The three upper-right classes in the PCA plot predominantly correspond to groups A to C, which contain sauce produced in a traditional manner. Most sauces from group D were divided into two classes, located at the bottom of the PCA plot. Group E and a few products from group D form two groups at the left side of the PCA plot. Only one of Thailand products (T11) belongs to this group.

3.4. Discussion

Fish sauce, a condiment with a characteristic taste and flavor, is predominantly produced in Southeast Asia, including Japan and China, and Italy. In this study, we characterized the chemical and flavor properties of 46 commercially available fish sauce products. Based on source and ingredients, the products were categorized into five groups. Japanese products were divided into three groups: fish sauce made only from fish and salt (group A), made with rice malt *koji* as additional fermentation starter (group D), and seasoned with additional condiments such as soy sauce and rice wine (group E). Thailand products were divided into two groups: fermented with (group C) or without sugars (group B). Chinese product was categorized into group C. Fish sauce products from other countries were categorized into group B.

Based on chemical characterization, the fish sauce products in group E were clearly distinct from other groups, and were characterized as having low nitrogen and salt contents. These low contents probably result from dilution of the original ingredients by the addition of condiments. Additionally, the low salinity in group E products may result from efforts of the Japanese Government to improve public health. Before the salt reduction campaign that the Japanese Government initiated in the 1960s, most Japanese consumed a much higher level of sodium than recommended by the WHO (Asakura et al., 2016). After the campaign, the mean salt intake decreased from 14.5 g/day in 1972 to 10.6 g/day in 2010 (Hyseni et al., 2017). The low salinity in Japanese seasoned fish sauce may therefore represent the preferences of Japanese consumers to low-salt foods resulting from such campaigns.

Although the difference is not significant, traditional fish sauce products from Japan (group A) showed a higher amino/total nitrogen rate than non-Japanese traditional products (group B). This difference might be associated to differences in fermentation processes between Japanese and non-Japanese products. For example, the fermentation period ranges from 6 to 12 months for non-Japanese products and from 1 to 3 years for Japanese products (Utagawa, 2012). Therefore, in group A fish sauce, a larger amount of peptides may be degraded into amino acids during fermentation.

The e-nose characterization indicates that group E fish sauce products have a distinctive flavor compared to group A and B products, which are produced by a traditional procedure. This is not surprising, because products in this group contain additional condiments. However, the PCA plot (Fig. 9) shows that the fish sauce flavor in group E was similar to that of Japanese soy sauce used as control. These results indicate that Japanese consumers tend to choose fish sauce with soy sauce-like flavor rather than that with traditional flavor. One of Thailand fish sauce products, T11, was classified into same flavor group to group E. This product is also seasoned with additional condiments probably so that the taste and flavor of the product meet Japanese consumer needs. This tendency is also supported by the presence of group D products in which *koji* is employed as a fermentation starter. The fish sauce in group D showed a higher acidity than other products, as shown by chemical characterization. The *koji* is known to produce the flavor of soy sauce by catalyzing the transformation of glutamine into glutamate (Zhao et al., 2017; Liang et al., 2009). Anchovies (J29, I1, T2, T3, T5, and C1) and sardines (T7, V2, T4, T9, and T10) are employed in several fish sauce products from different counties. All products using these fish are included in upper-right classes in PCA map of the e-nose analysis. Thus, this result indicates that, although there are slight differences in the odor of the products, same fish materials produce similar odor of the fish sauce products.

As results in this study, we characterized the fish sauce products from several countries, based on the chemical and e-nose analyses. The characters determined would reflect the food preference and acceptance selected by consumers in each country. However, the current study does not include the data such as sales of the products in the real market and sensory test using human panelists. More precise investigations including such data would be worthwhile to reveal the country-specific preferences and acceptance for the fish sauce products.

The current study revealed slight producing country-specific preferences and acceptance of fish sauce products owing to the different flavors. Recently, for a more effective utilization of unused valuable resources in fisheries, some companies are producing fish sauce using fish and shellfish dregs such as internal organs, bone, head, and skin. However, preferences for flavors of fermented fish and shellfish may be sharply divided, including the food neophobia. To create a new market for novel fish sauce products, further investigations of the flavor preferences typical to country, region, and individual are necessary.

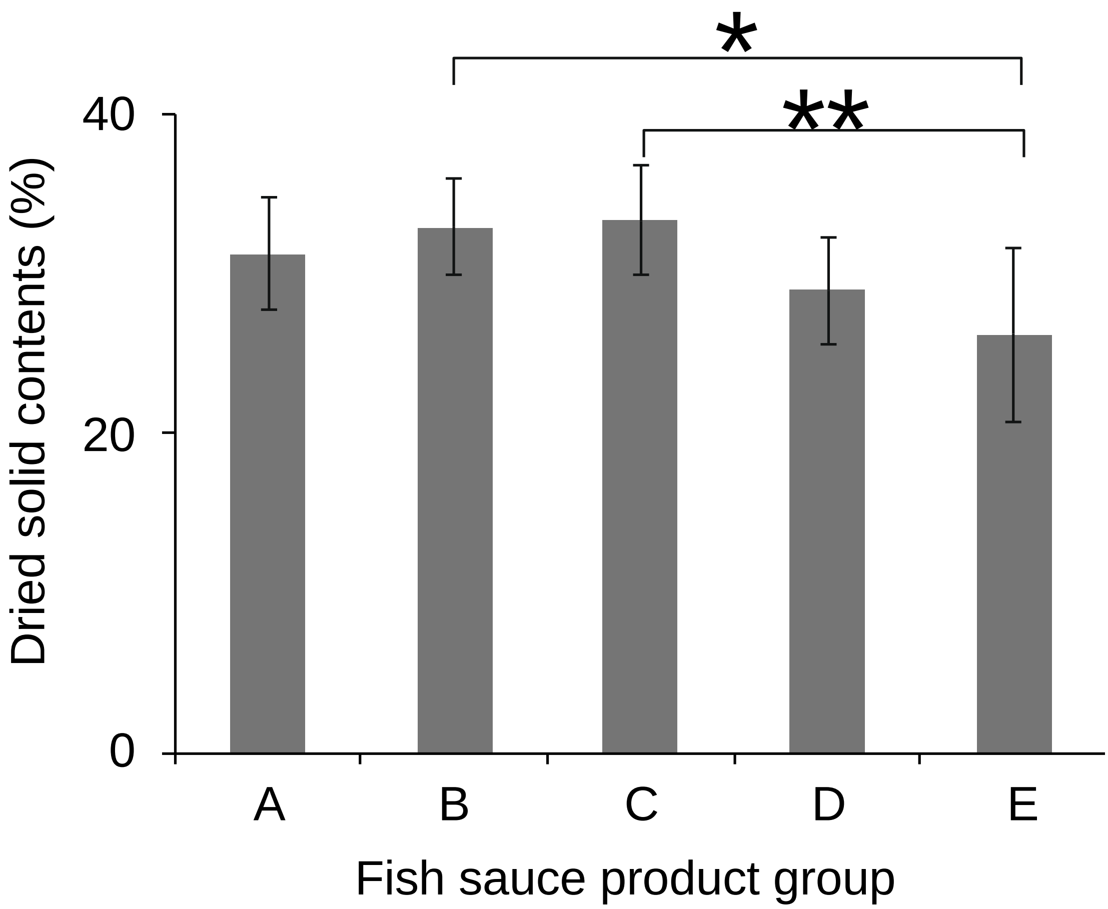

Fig. 1 Dried solid content of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, p<0.05; **, p < 0.01.

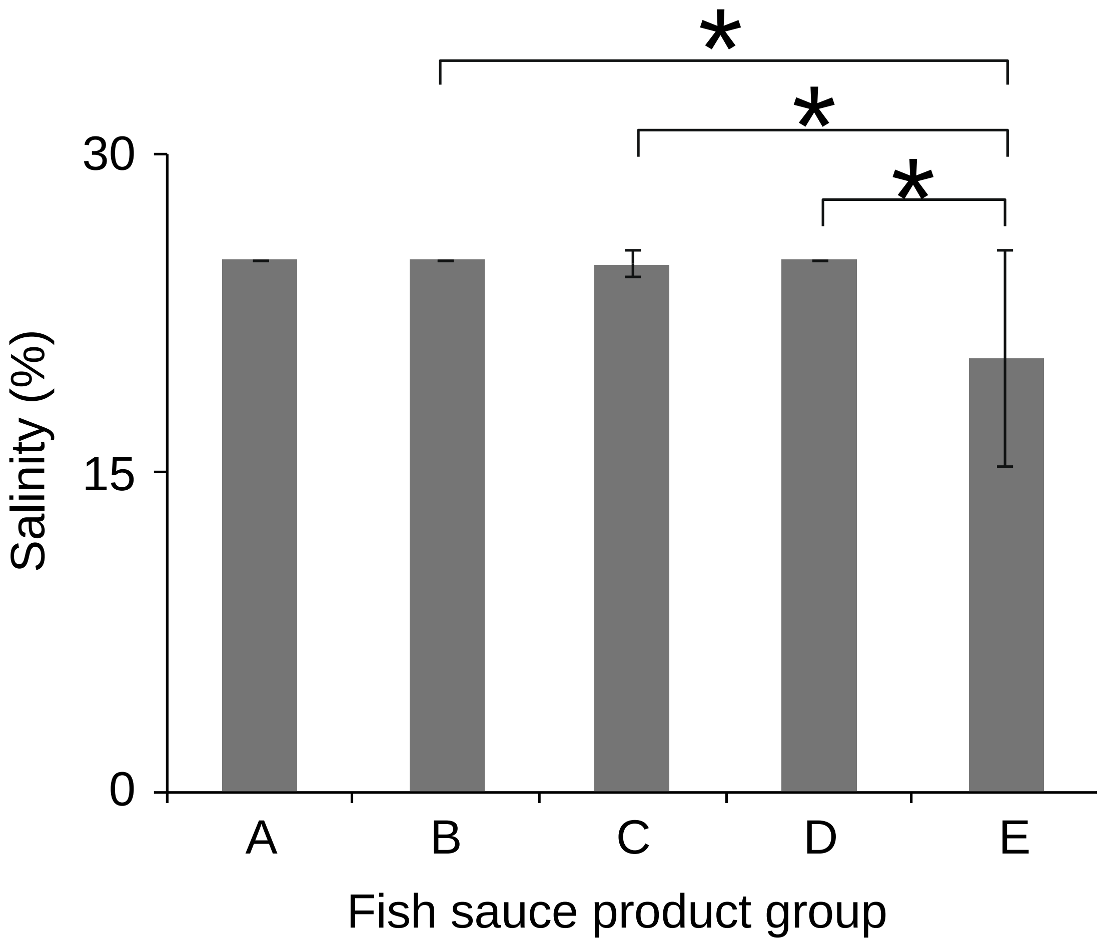

Fig. 2. Salinity in commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, $p<0.05$; **, $p < 0.01$.

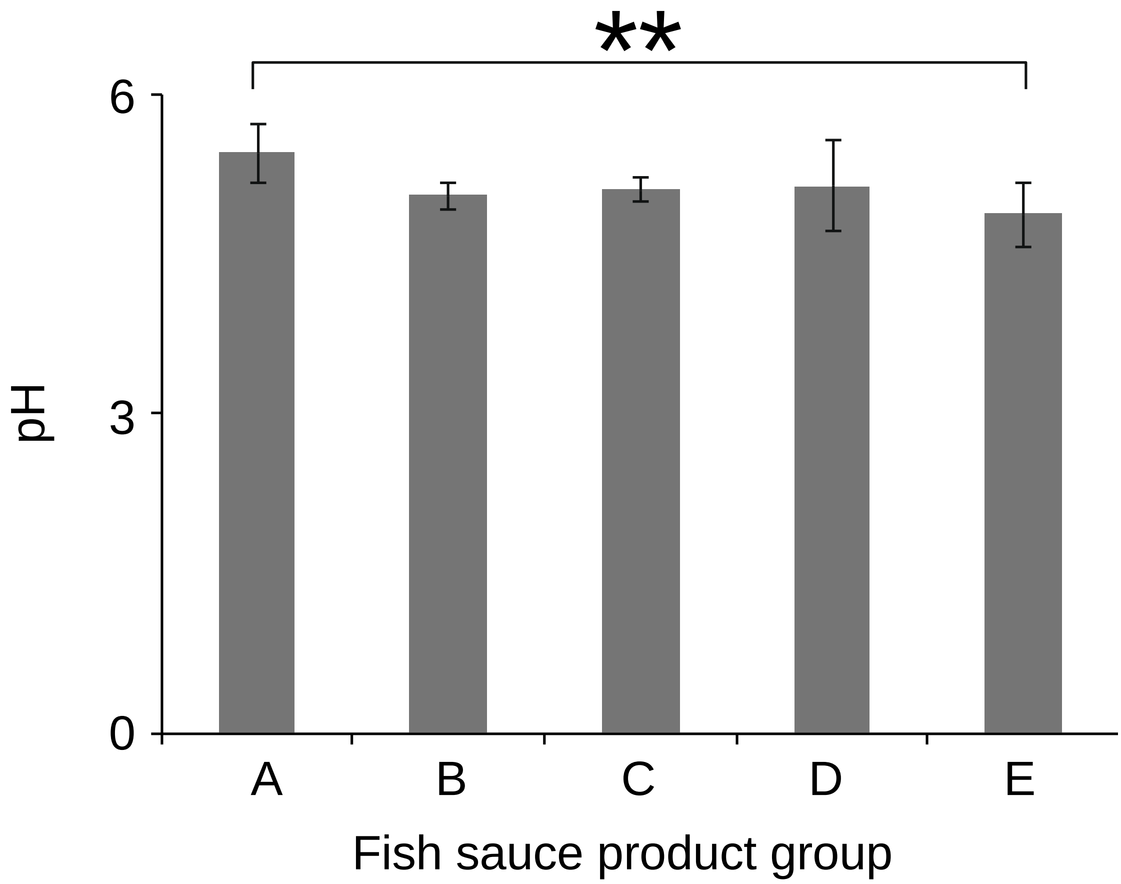

Fig. 3. pH of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. **, $p < 0.01$.

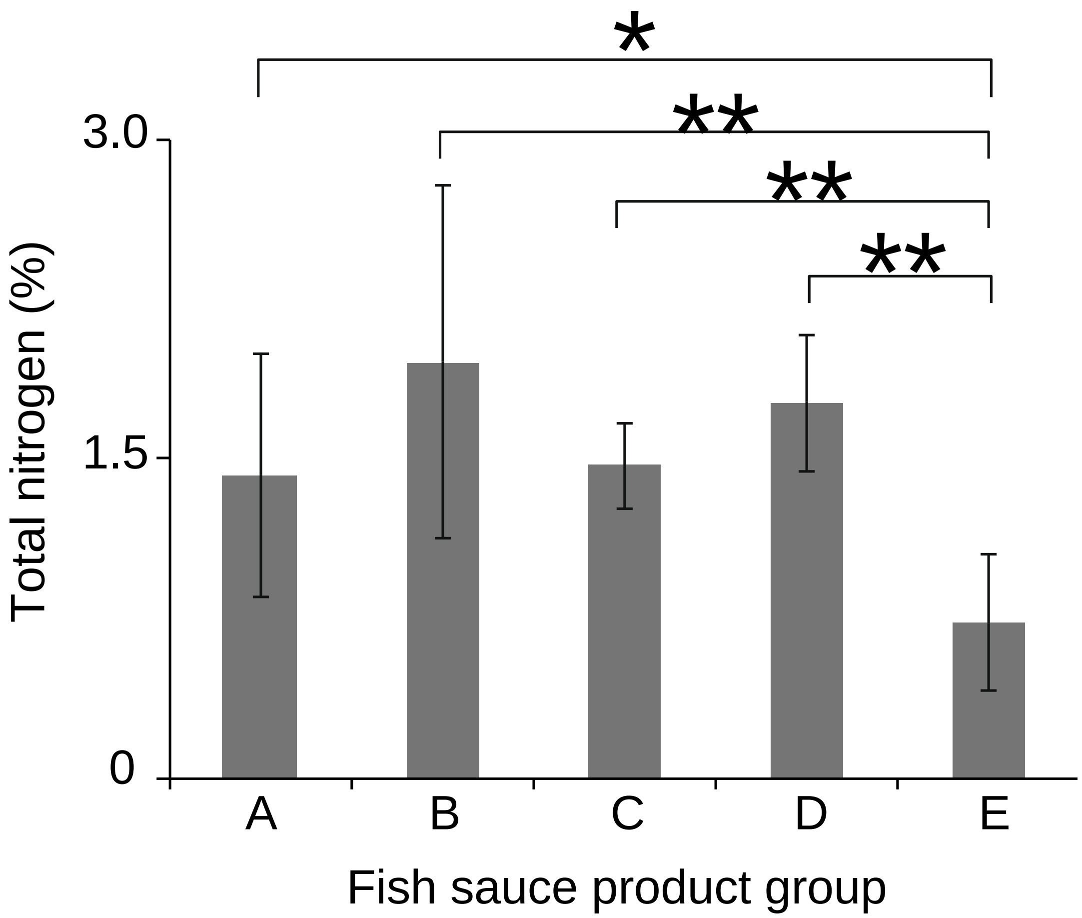

Fig. 4. Total nitrogen content of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, $p<0.05$; **, $p < 0.01$.

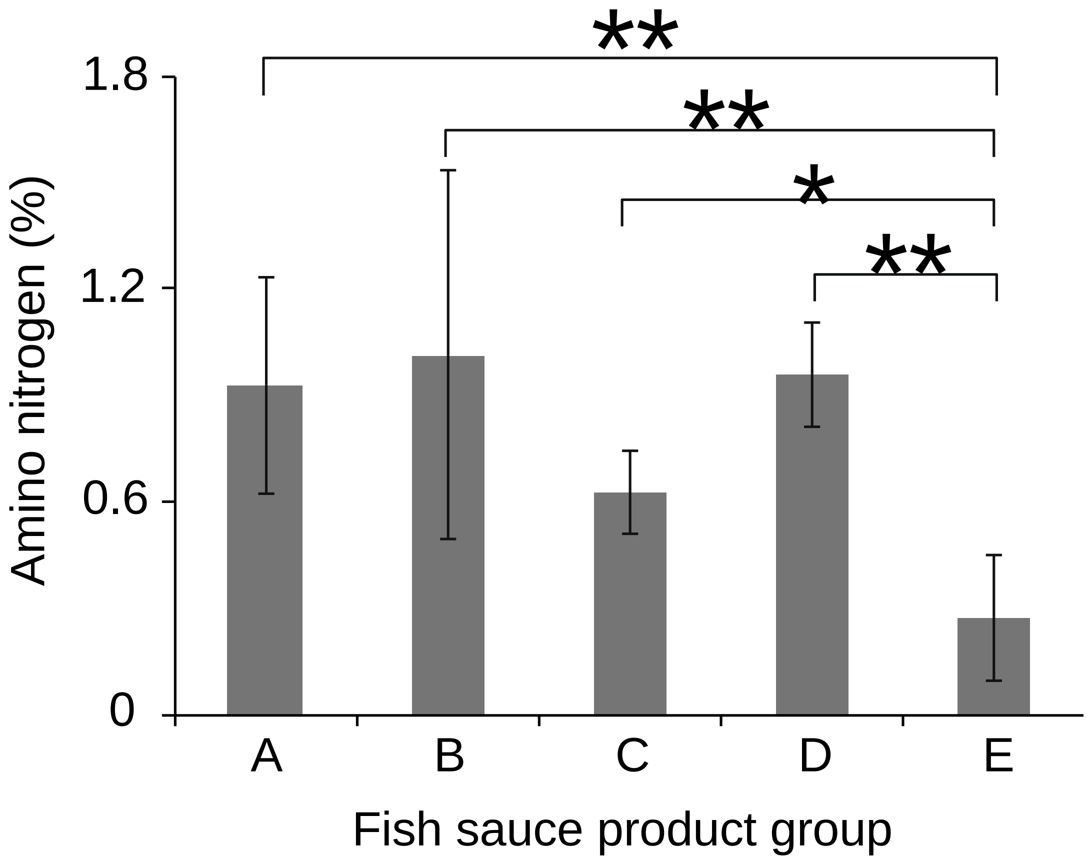

Fig. 5. Amino nitrogen content of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, $p<0.05$; **, $p < 0.01$.

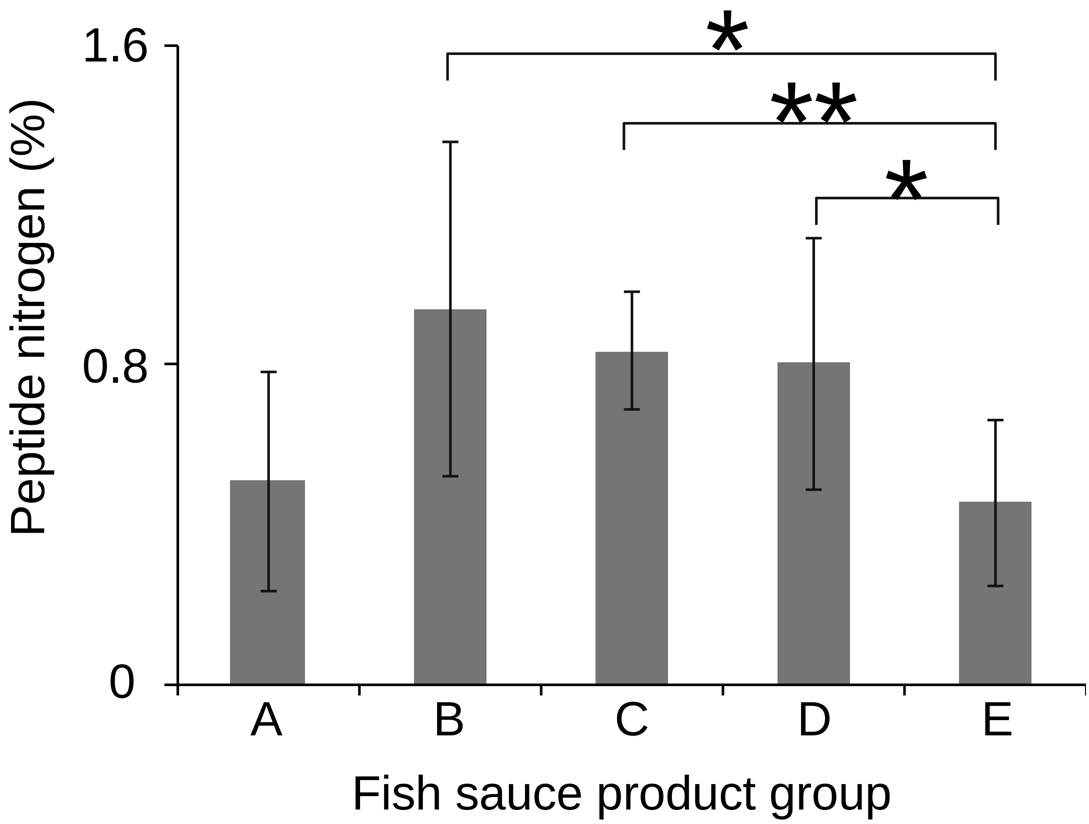

Fig. 6. Peptide nitrogen content of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, $p<0.05$; **, $p < 0.01$.

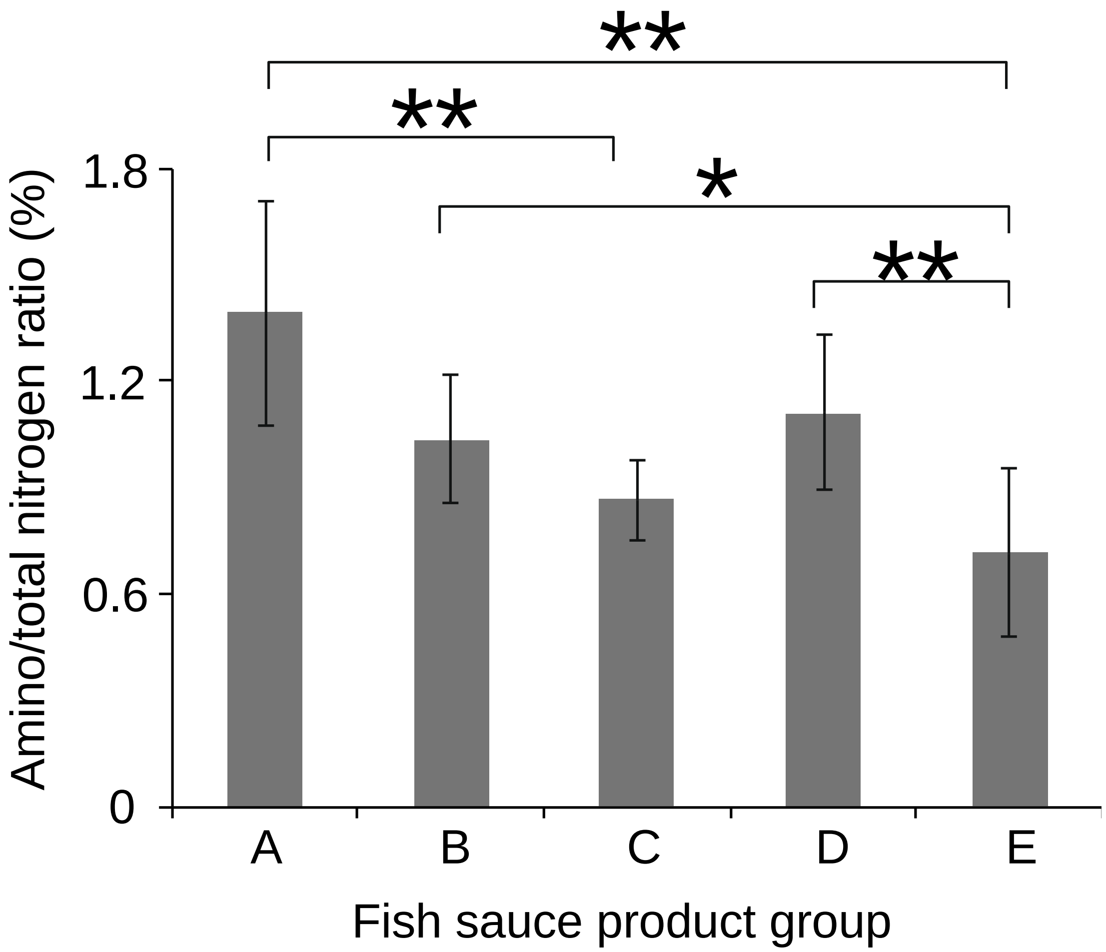

Fig. 7. Amino/total nitrogen ratio of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, p<0.05; **, p < 0.01.

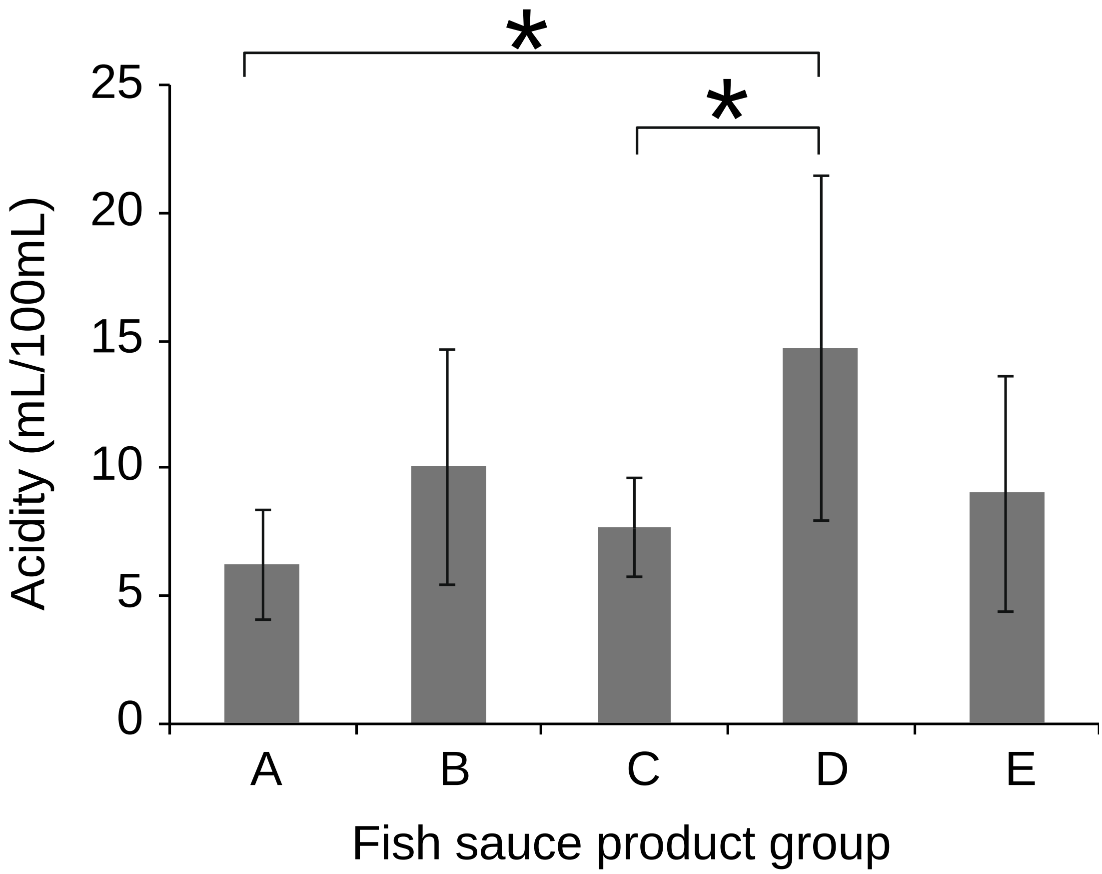

Fig. 8. Acidity of commercial fish sauce products. Data represents the mean of all products in each group, and the error bars indicate the standard deviation. *, p<0.05; **, p < 0.01.

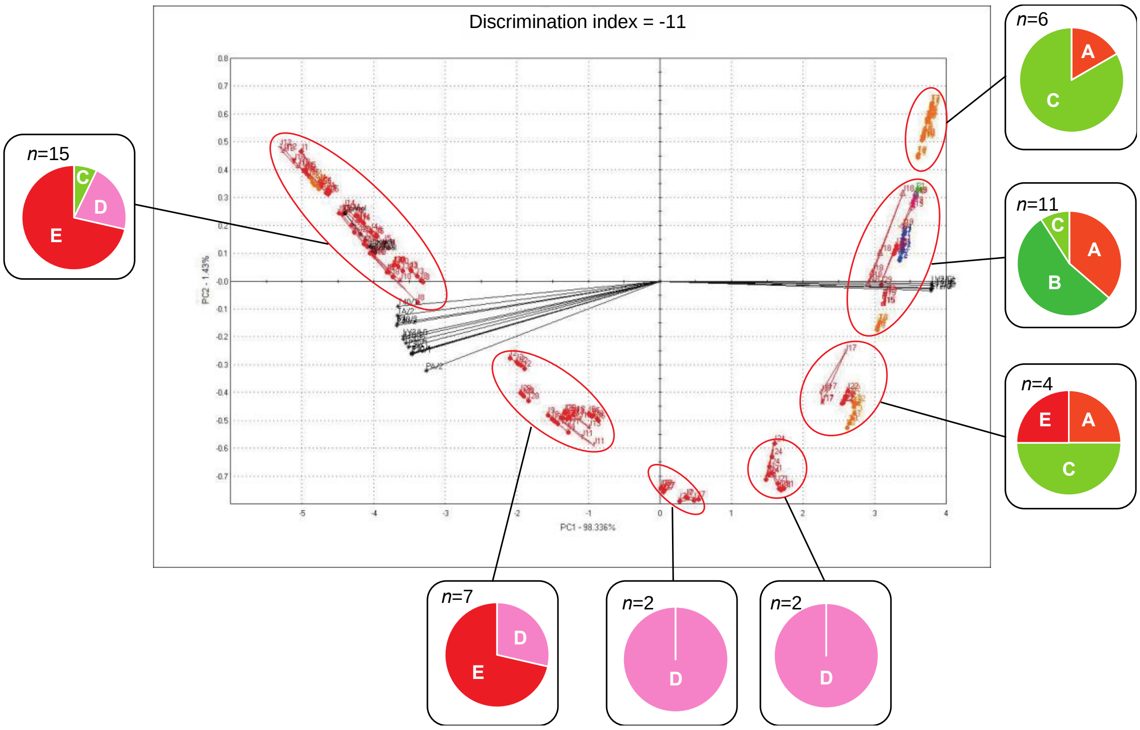

Fig. 9. Principal component analysis score plot of e-nose analysis results. Data were classified into seven groups. Numbers of the samples classified into same group indicated by red circle are indicated as "*n*=x". PC1 and PC2 are corresponding to distinct sensors, which are the most and secondary most contributed to discriminate the fish sauce products. The ratio of the fish sauce products group in each flavor classes are indicated by the pie graphs. Uppercase letters correspond to product groups as shown in Table 1.

4. Clustering of commercial fish sauce products based on an e-panel technique and chemical analysis

4.1. Introduction

The human olfactory system is by far the more complex and contains thousands of receptors that bind odor molecules and can detect some odors at parts per trillion levels and include between 10 and 100 million receptors. Apparently, some of the receptors in the olfactory mucus can bind more than one odor molecule and in some cases one odor molecule can bind more than one receptor. This results in a mind-boggling amount of combinations that send unique signal patterns to the human brain. The brain then interprets these signals and makes a judgment and/or classification to identify the substance consumed, based in part, on previous experiences or neural network pattern recognition (Baldwin et al., 2011).

Electronic noses (e-noses) and electronic tongue (e-tongues) crudely mimic the human smell and taste sensors and their communication with the human brain. The e-noses and e-tongues consist in arrays of non-selective gas or liquid sensors with a broad and partially overlapping selectivity towards compounds present in a sample. The array of sensors is combined with computerized multivariate statistical data processing tools. A number of works have been published that have used electronic noses for the characterization and for the quality control of olive oils (Apetrei et al., 2010). In the case of e-tongues, their capability to analyze and discriminate a variety of beverages such as mineral waters, milks, wines or beers has already been established (Apetrei et al., 2010). In addition, an e-eye was used to distinguish color components using camera-equipped apparatus and computer-assisted analysis.

Fish sauce is produced from seafood of various types. Anchovy and sardine appear to be widely used in fish sauce production in Thailand and featured in fish sauce products from Vietnam, China, and Italy. A fish sauce product from the Philippines contained mackerel. Flying fish, which is often used as *dashi*, a broth employed in various dishes in Japan (especially in the *Kyushu* area), was found in several Japanese fish sauce products. Bonito is also employed for *dashi* preparation throughout Japan, and was also present in many of the fish sauce products tested from this country. In addition, Japanese sandfish, tuna, cod, sea bream, cutlassfish, deep-sea smelt, sea urchin, oyster, shrimp, and squid were found to be used in the manufacture of fish sauce products in Japan. As well as the fish materials, the climates and production procedures effect on the taste, smell and colors. The factors would be also reflected by the cultures, history and society of the country. In this study, the author analyzed "smell" "taste" and "color" of 46 types of commercial fish sauce manufactured in Asian countries by electronic panel (e-panel) analyses containing e-tongue, e-nose and electronic eye (e-eye) sensory assessments. Along with the e-panel analysis, the chemical properties of these fish sauces were also analyzed to characterize the fish sauce in each country.

4.2. Materials and Methods

Materials

All of the 46 fish sauce products were purchased at local markets in Tokyo, Fukuoka, and Abashiri (Japan). The ingredients of each product as listed on their labels are summarized in Table 1. For analysis, the products were assigned product IDs as follows: J1–J30 for the Japanese products; T1–T11 for the Thai products; V1 and V2 for the Vietnamese products; and P1, C1, and I1 for the Filipino, Chinese, and Italian products, respectively.

Evaluation of smell with e-nose analysis

E-nose analysis was performed with the αFOX 4000 smell analysis system (Alpha M.O.S., Toulouse, France), which has 18 metal oxide gas sensors for different selectivity patterns. Fish sauce product samples (0.5 g) were collected in 10-ml vials, placed in an autosampler, and analyzed under the following conditions: syringe temperature, 50°C; oven temperature, 40°C; injection speed, 2 ml/s.

Evaluation of taste with e-tongue analysis

E-tongue analysis was performed with the αASTREE taste analysis system (Alpha M.O.S.), which has seven liquid potentiometric sensors (SRS, GPS, STS, UMS, SPS, SWS, and BRS) and a reference electrode (Ag/AgCl). Fish sauce products diluted 21-fold were collected in a beaker and placed in an autosampler. Each sensor was immersed in the samples for 120 s at 20 -25 ˚C with agitation to elicit a sensor response. A stable response value was then recorded at 120 s.

Evaluation of color with e-eye analysis

E-eye analysis of fish sauce products was carried out using an IRIS VA300 visual analyzer (Alpha M.O.S.) with a charge-coupled device camera. Five milliliters of fish sauce product was collected in a transparent plastic dish and placed in the measurement chamber. The color of the surface of each sample was measured three times. The collected color data were represented by IRIS color codes, which encompass 4096 colors.

Statistical analysis

The datasets, comprising a series of sensor values from the e-nose, e-tongue, and e-eye tests, were subjected to cluster analysis by Ward's method using the program R-3.4.2 (http://www.R-project.org) (Ihaka and Gentleman, 1996).

Solid contents assay

To determine the dried solid content of the fish sauce products, ca. 2 g of fish sauce sample was applied to a moisture analyzer (MX-50; A&D, Japan). The measurements were conducted at 130 °C for 20 min, as described in reference of (Harnández-Herrero and Frutos, 2014).

Salinity and pH measurements

The salinity and pH of the fish sauce products were determined using a salt meter (B-721; HORIBA, Japan) and a pH meter (D-52; HORIBA), respectively.

Total acidity assay

Total acidity was determined by a titration assay. Briefly, 10 g of fish sauce samples were diluted up to 100 mL with distilled water. Acid content in 10 mL of the diluted sample was determined by titration with 0.1 M NaOH, with 1% (w/v) phenolphthalein solution as a pH indicator.

Amino acid content determination

The total nitrogen content was determined using SUMIGRAPH NC-220F analyzer

(Sumika Chemical Analysis Service, Japan) (Nozawa et al., 2007). Amino nitrogen content was determined using the formol titration method (Northrop, 1926). Briefly, 5 mL of the fish sauce sample was diluted up to 250 mL with distilled water. For the first titration, all of the diluted sample was titrated to pH 8.5 with 0.01 M NaOH. For the second titration, 20 mL of formaldehyde solution (pH 8.5) was added to the diluted sample, and then titrated to pH 8.5 with 0.1 M NaOH. The volume of base consumed in the first and second titration was used for calculating the amino nitrogen content (Northrop, 1926). The amino nitrogen to total nitrogen ratio, i.e., a value of amino nitrogen divided by total nitrogen, was used as an index of protein-to-amino acid conversion rate.

4.3. Results and discussion

Characterization of taste of Asian fish sauces by e-tongue

Forty-six types of fish sauces from various Asian countries were applied to e-tongue analysis using αASTREE taste analysis system. Signal intensities from seven sensors are summarized in Fig. 1. CPS and CTS sensors, corresponding to pungent and salty taste respectively, showed similar intensities to all fish sauces excepting for four products from China, Italy, Philippines and Vietnam. it was shown that Japanese fish sauce tended to have strong sour (AHS) and metallic (PKS) taste and weak *umami* (NMS) and sweetness (ANS) compared with fish sauce of other countries. Meanwhile, it was revealed that even Japanese fish sauces manufactured by traditional manufacturing methods showed similar tendencies to those produced by overseas fish sauces. All of sensor data were brought to cluster analysis as shown in Fig. 2. The clustering indicates the clear difference in the taste of Japanese and non-Japanese fish sauces. Comparing to soy sauce, most of the fish sauces exhibited the stronger bitterness. This may be a factor that makes fish sauce difficult to use.

Characterization of smell of Asian fish sauces by e-nose

The Asian fish sauces were applied to e-nose analysis using αFOX 4000 smell analysis system (Fig. 3). Of 18 sensors, thirteen sensors showed the stronger signal intensities against Japanese fish sauces, otherwise five sensors exhibited the stronger intensities against the non-Japanese products. All of sensor data were brought to cluster analysis as shown in Fig. 4. The cluster clearly distinguishes the Japanese and non-Japanese products, although the Japanese ones with traditional manufacturing method belonged to same cluster with non-Japanese products. Broadly, the cluster indicates that the Japanese fish sauce have similar smelling characters with soy sauce. Therefore, Japanese fish sauce products tended to have suppressed smell unique to fish sauce, since many of them show smelling characteristics close to soy sauce.

Characterization of colors of Asian fish sauces by e-eye

The Asian fish sauces were applied to e-nose analysis using IRIS VA300 visual analyzer. The colors of the fish sauces were characterized as yellowish to brownish colors as shown in Fig. 5. All of Thai fish sauces showed yellowish colors, otherwise fish sauces from other countries including Japan showed wide variety of colors, yellowish to brownish. All of sensor data were brought to cluster analysis as shown in Fig. 6. The cluster indicates that color of the product was not influenced by the country, but it was shown that the difference by the raw material is affected.

Characterization of chemical properties of Asian fish sauces

To characterize the chemical properties of commercial fish sauce products associated with the fish sauce taste and flavor. All products were analyzed in triplicate. Dried solid content was analyzed by moisture analyzer. Fish sauce salinity was determined by a salt meter. pH was measured using a pH meter. The acidity was determined using a titration assay. Amino nitrogen and total nitrogen were evaluated using a titration assay and Combustion-type nitrogen analyzer, respectively. As a result (Fig, 7), the fish sauce from Thailand tended to have a higher solid component content, indicating the possibility that a relatively large amount of taste components is contained in the products. On the other hand, there are many low-salt-concentration products in Japanese fish sauces, and it would be related to the tendency to prefer the products with reduced salt. In Vietnamese fish sauce, the total protein amount tended to be large, which would be due to the difference in production method.

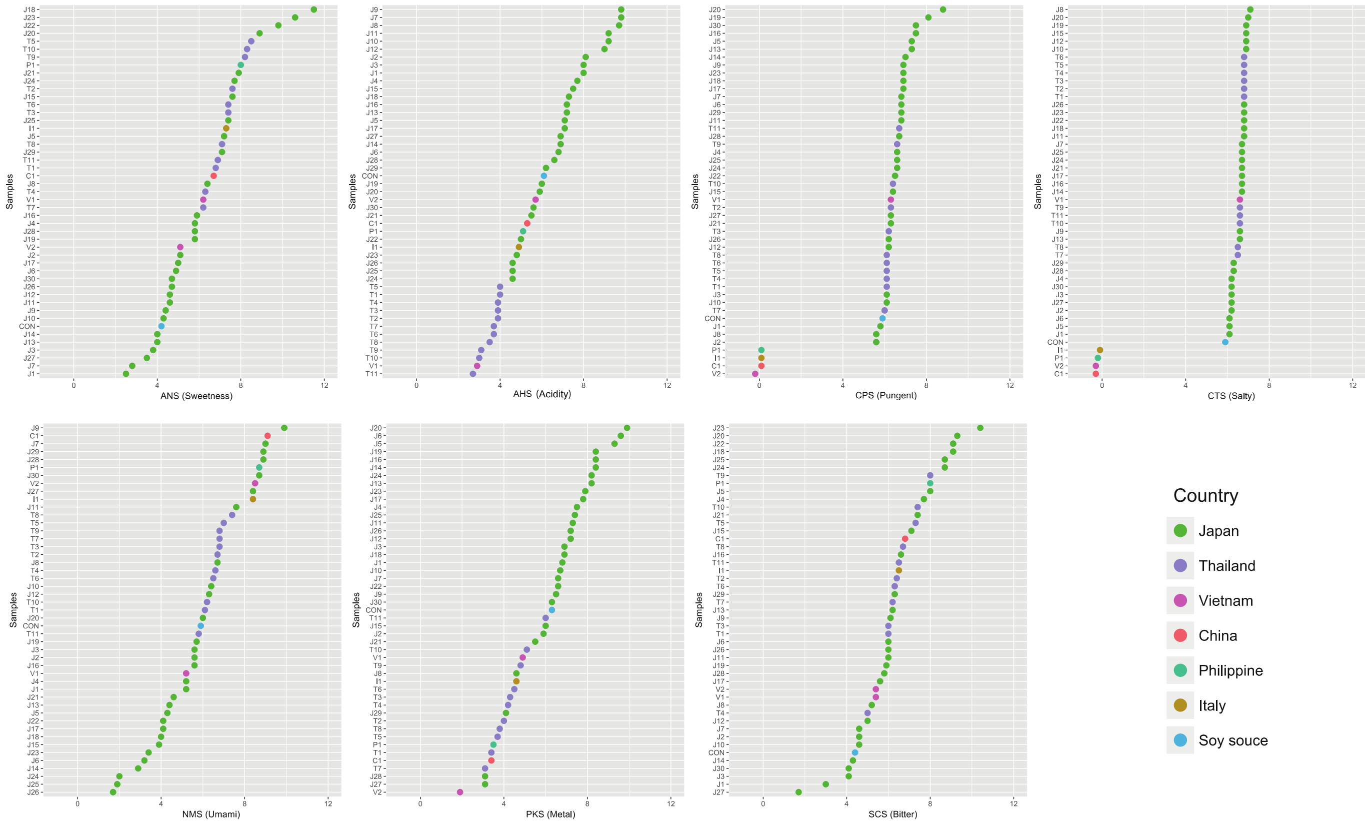

Fig. 1. Results of e-tongue analysis

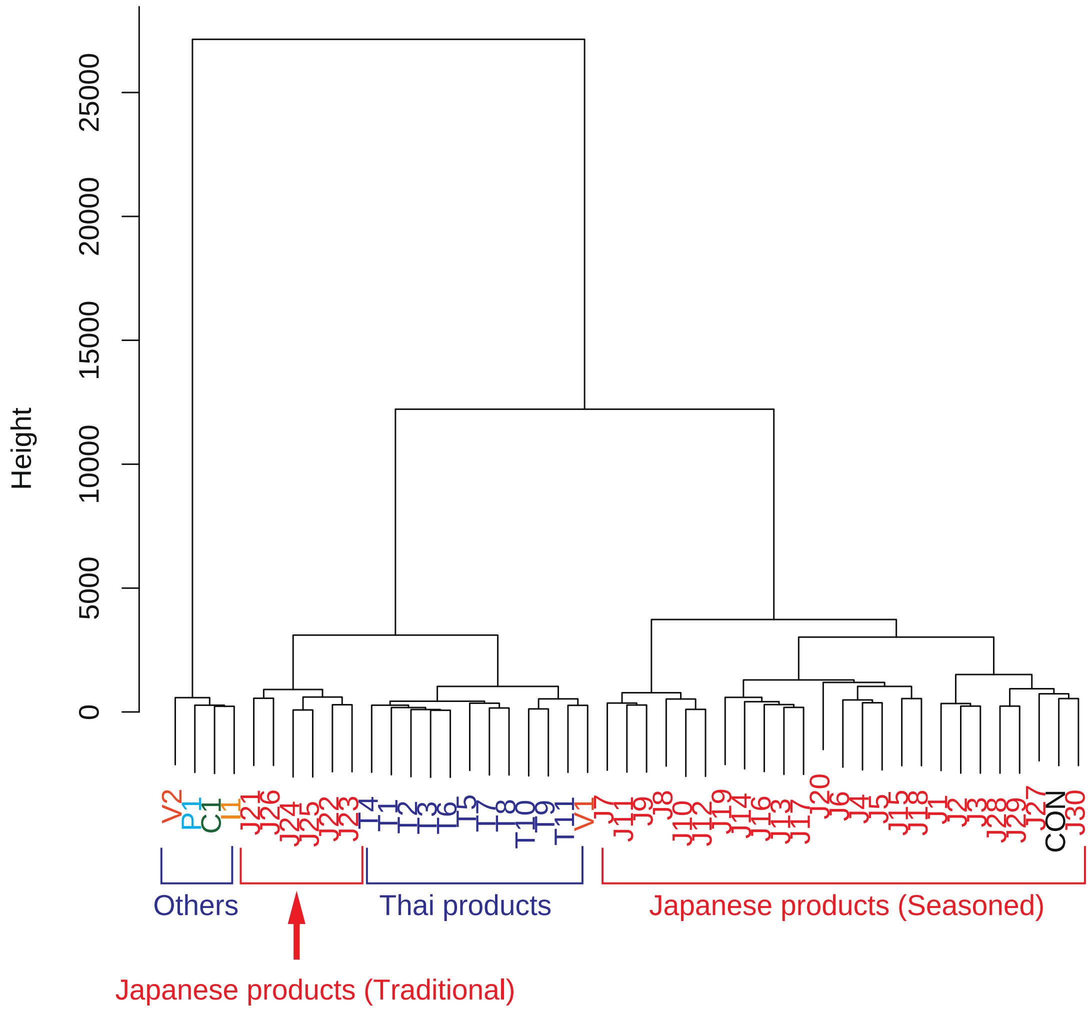

Fig. 2. Clustering of fish sauce products based on the e-tongue analysis

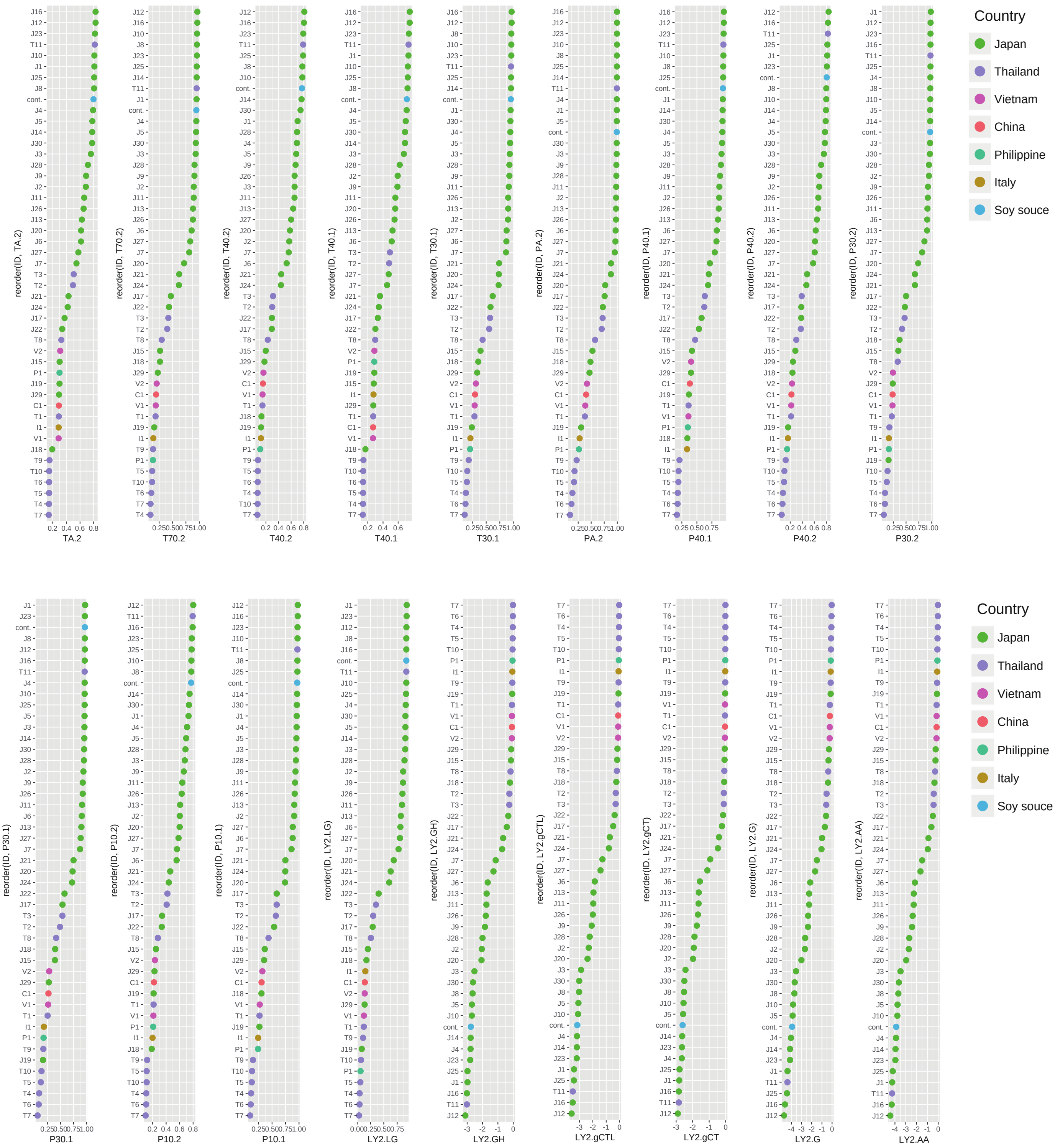

Fig. 3. Results of e-nose analysis

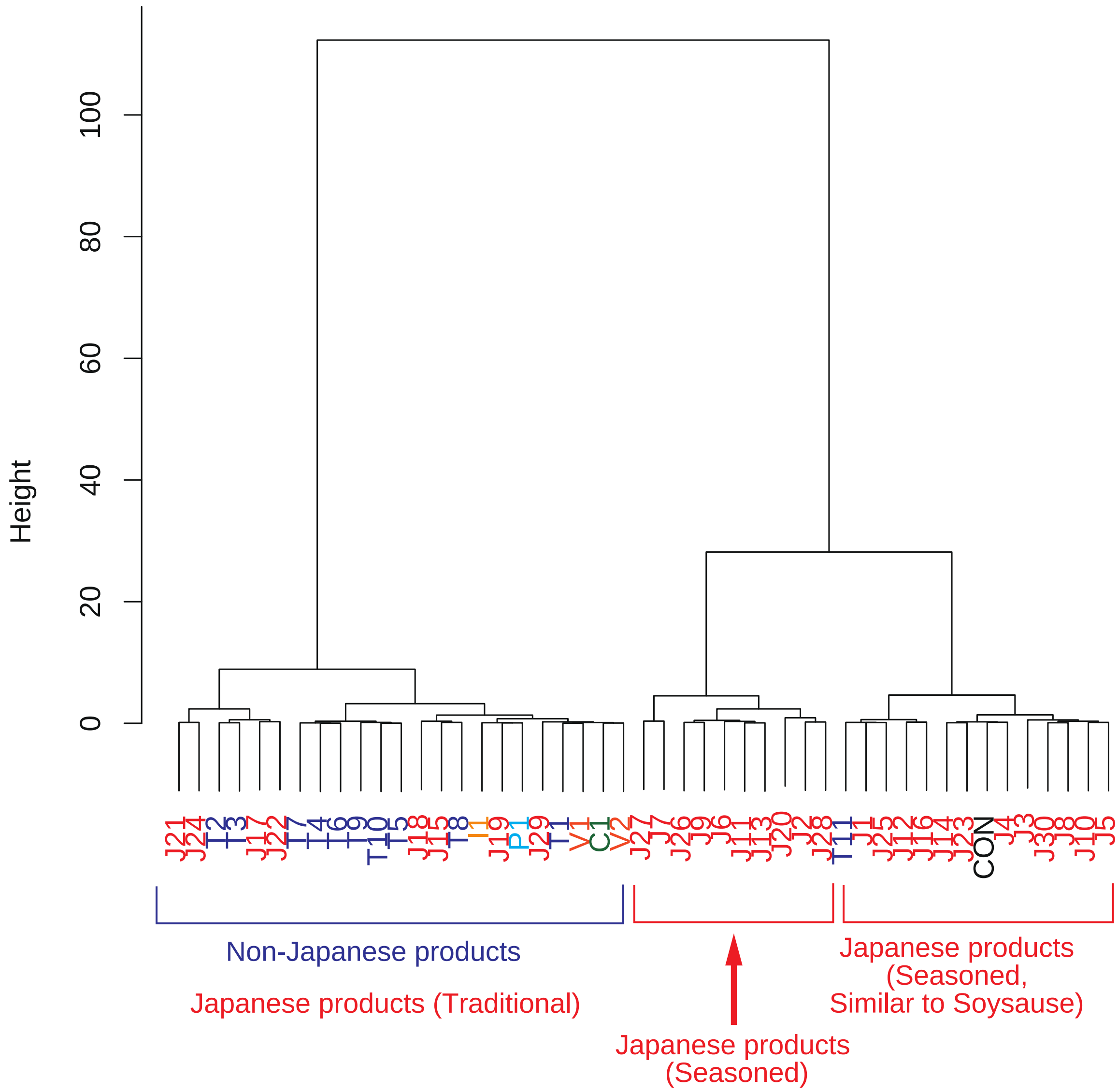

Fig. 4. Clustering of fish sauce products based on the e-nose analysis

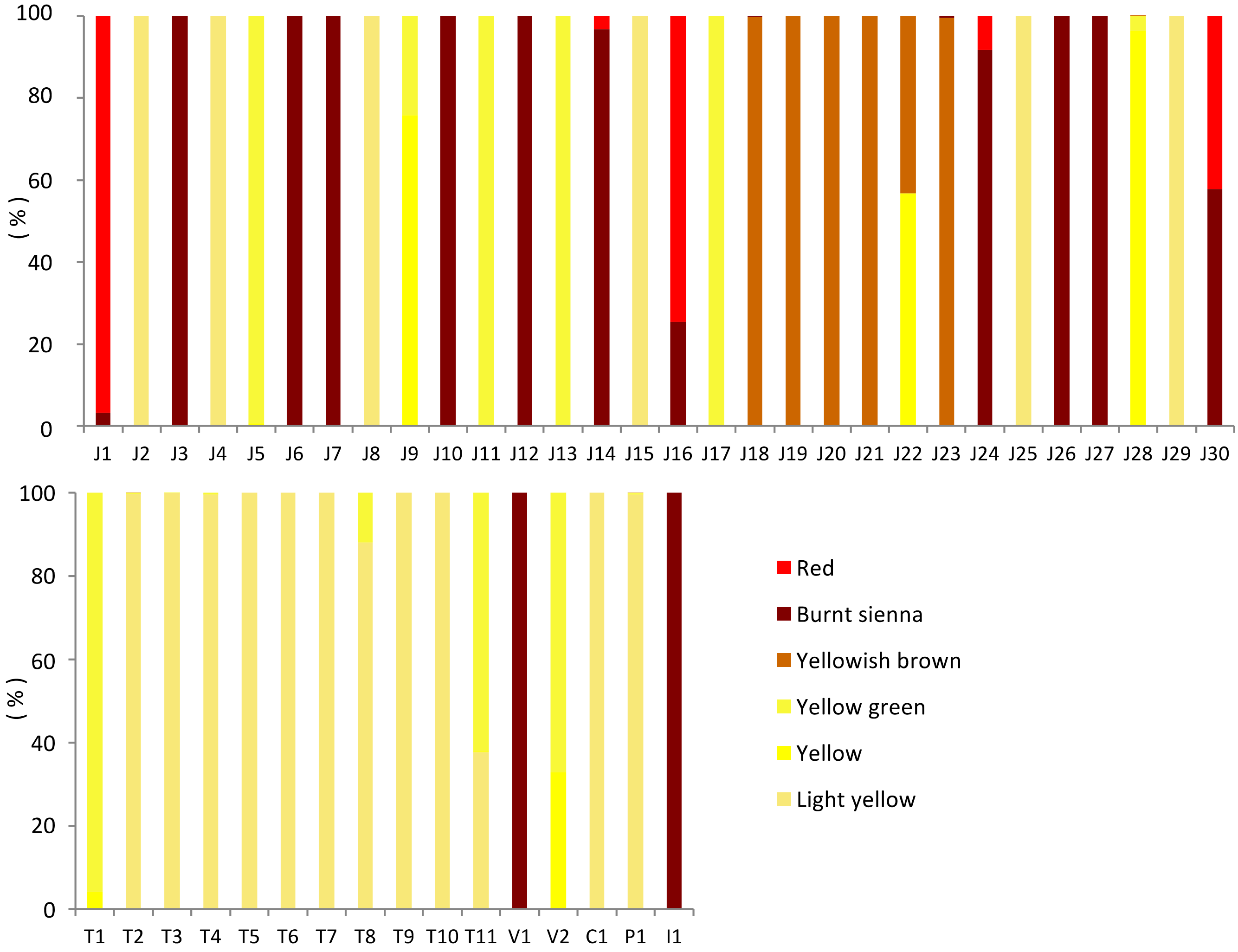

Fig. 5. Results of e-eye analysis

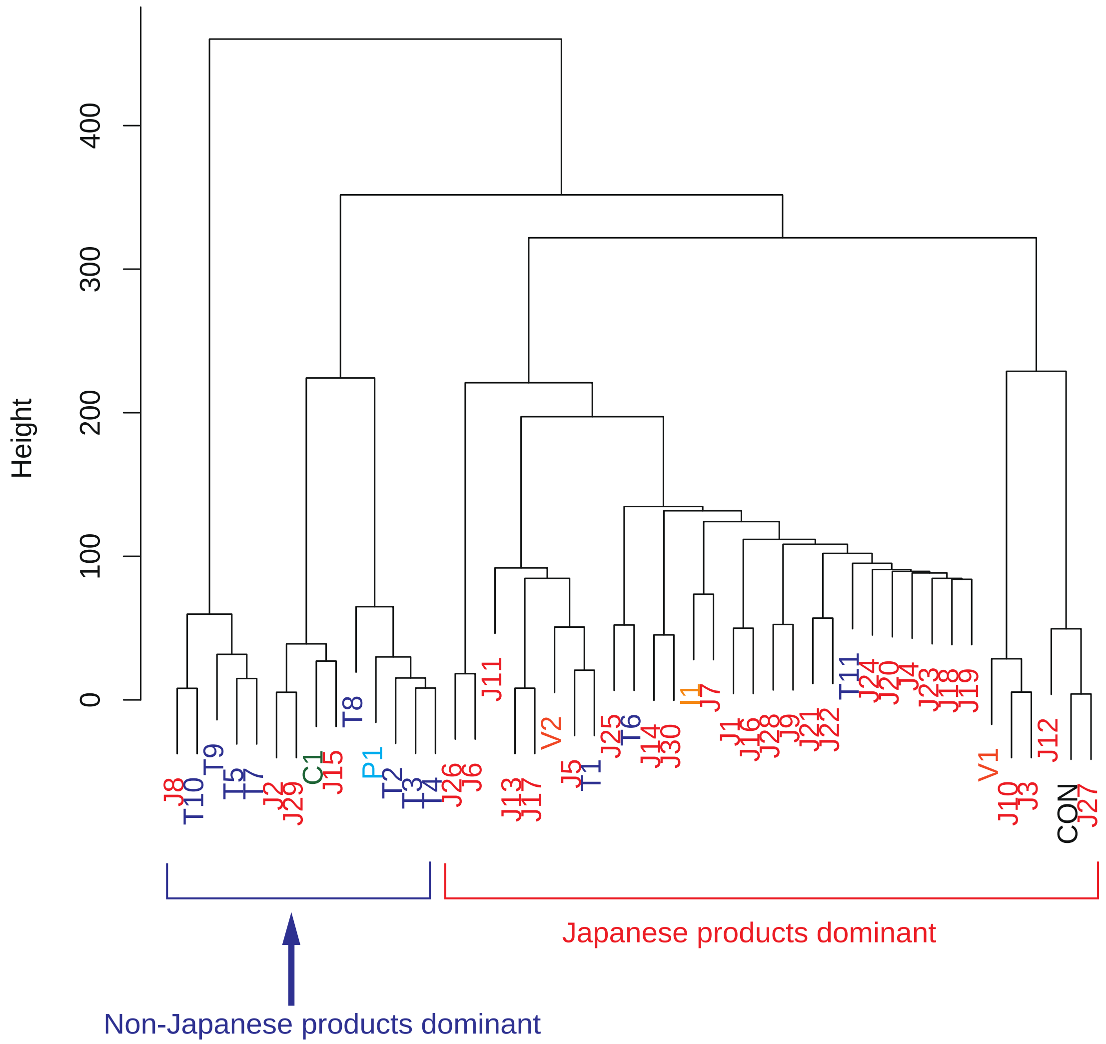

Fig. 6. Clustering of fish sauce products based on the e-eye analysis

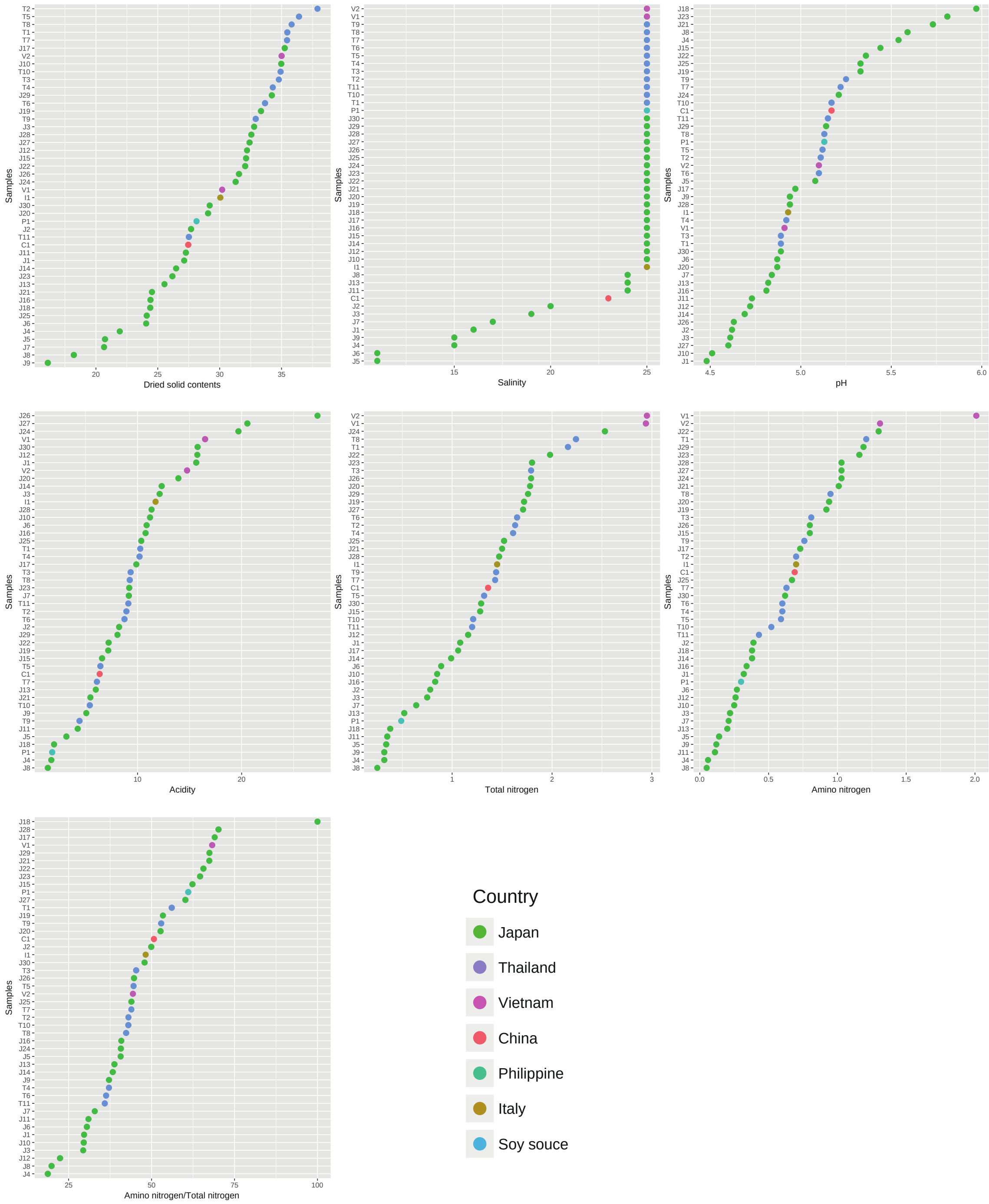

Fig. 7. Results of chemical property analysis

5. Introduction of data-driven approach to food production: a case study of salmon fish sauce

5.1. Introduction

Fish sauce is a brown, liquid seasoning widely consumed in most Southeast Asian countries. In general, fish sauce is produced by the fermentation of a mixture of fish material and salt for more than 6 months at 30–35 ˚C (Fukami et al., 2004). Microorganisms are often employed as a starter to hasten the fermentation. During this period, the proteins in the fish material are hydrolyzed into amino acids and peptides both by endogenous and microorganism proteases, which results in the distinctive taste of fish sauces (Lopetcharat et al., 2001; Taira et al., 2007). The fermentation process also produces volatile compounds responsible for the characteristic odor of fish sauce (Yongsawatdigul et al., 2007; Zheng et al., 2017).

In Japan, fish sauce was widely used as a substitute for soy sauce and miso in the past, especially in coastal areas. However, its consumption declined after the emergence of industrial production and commercial availability of soy sauce brought by the drastic change in Japanese society after the Meiji era (Ishige, 1986). Thereafter, the production of fish sauce was seen in limited areas, *i.e.*, *Shottsuru* in Akita prefecture and *Ishiru* in Ishikawa prefecture. However, the production of fish sauce has recently gained attention, and many local fish sauces are produced to revitalize local communities throughout Japan. One reason that fish sauce production has gained attention is that inedible fish materials and fish with low market values are usable to produce the products.

From a nutritional perspective, fish sauce can be very nutritious due to the presence of essential amino acids (Gildberg, 2004). Additionally, fermented fish sauce has various biological activities, including angiotensin I-converting enzyme inhibitory activity and insulin secretion-stimulating activity (Ichimaru et al., 2003). It has been clarified that the peptides exhibiting such activities are generated by the hydrolysis of proteins in salmon, sardines, and anchovies during fermentation. These findings suggest that fish sauce could function to reduce the risk of hypertension and diabetes. Taking advantage of the amino acid balance and bioactive functional peptides, there have been some attempts at medical applications of fish sauce, including its use as an Fe ion carrier for iron-deficient, anemic women in Southeast Asian countries such as Vietnam (Pham et al., 2003). Therefore, fish sauce has great potential to be a functional food.

Consumers choose foods not only based on their function but also their tastes, flavors, appearances, and package labels, among other things (Borgmeier and Wstenhoefer, 2009). In addition to such factors, familiarity with the food is also an important factor in consumer acceptance (Verneau et al., 2013). To understand consumer preference and acceptance, researchers and developers employ consumer research questionnaires and interviews (Kearney et al., 2000; Honkanen and Frewer, 2009; Milošević et al., 2012). Based on this consumer research, they construct concepts for new products and produce pilot-scale products. Consumer acceptance of foods may be assessed by sensory evaluations using trained panels and pilot-scale products. Pilot products may be selected for production based on the results of such evaluations (upper panel of Fig. 1). In this "traditional" approach to product development, many human subjects are needed for the questionnaire, interview, and sensory evaluations. The quality of the questionnaire and interview analyses highly depends on the prepared questions and capacity of interviewer (Krosnick and Presser, 2010; Bastian et al., 2015).

Furthermore, gathering useful results from sensory evaluations requires the investment of significant time and effort in training the panels (Murray et al., 2001). On the other hand, electronic panel (e-panel) technology, a combination of quantitative sensors that crudely mimics the mammalian nose (e-nose), tongue (e-tongue), and eye (e-eye), allows high-throughput evaluation of the flavor, taste, and appearance of foods (Apetrei et al., 2010; Baldwin et al., 2011) and circumvents many of the problems with the "traditional" approach.

Today, information technology has enabled the accumulation of large amounts of data on social web sites, and withdrawing such data using search engines is simple. This accumulated online data is increasingly used by economists (Carrière-Swallow & Labbé 2013; Choi & Varian 2012; Vosen & Schmidt 2011), politicians (Ripberger 2011), epidemiologists (Carneiro & Mylonakis 2009; Seifter *et al.* 2010), and biologists (Mccallum & Bury 2013; Proulx *et al.* 2013) to understand markets, public opinion trends, the spread of human infectious diseases, and conservation of creatures' behaviors.

In this study, we employed Google Trends, which enables plotting Google search queries related to a given topic, to analyze consumer behaviors associated with fish sauce consumption in Japan. Based on the results, we produced several pilot salmon fish sauce products. The qualities of the products were then assessed by the e-panel techniques.

5.2. Materials and method

Materials

The "*bunasake*" and "*ginke*" salmon (low and high market value, respectively) were purchased at a local market in Abashiri, Hokkaido. *Shio-koji*, a marinated rice malt and fermentation starter containing 12.3% salt (Kurashige jozo Co., Ltd., Abashiri, Japan), and salt (Shokuen, The Salt Industry Center of Japan, Tokyo, Japan) were used for fish sauce production.

Data collection from Google Trends

Temporal trends in web searches containing terms to be analyzed were downloaded from Google Trends (https://trends.google.com/trends/). Google Trends is a public web facility of Google, Inc., which shows how often a term is searched relative to the total number of searches in various countries and languages. The data in this study were collected from the Japanese site. “Food and Drink” was chosen as the search category. The Google search volume is expressed in terms of relative search interest, and the most traffic volume within the terms analyzed is set to 100. The search interest is calculated as follows: search interest = (number of queries for keyword) / (number of total Google search queries). The Japanese terms used as query terms on Google Trends are listed in Table 1.

Fish sauce production

Raw salmon was divided into flesh, viscera, soft roe, and an inedible portion. Each portion was minced using a food processor. Each minced portion was mixed with salt in various proportions (Table 2) and stored for three months in a 37 °C constant-temperature incubator (DG-82, Yamato, Tokyo, Japan). The chemical properties and colors of the *moromi* (unrefined fish sauce) and filtered fish sauce were measured one, two, and three months following the start of fermentation.

Amino acid nitrogen content determination

Amino acid nitrogen content was determined using the formol titration method (Northrop, 1926). Briefly, 5 mL of a fish sauce sample was diluted to 250 mL with distilled water. For the first titration, the diluted sample was titrated to pH 8.5 with 0.01 M NaOH. For the second titration, 20 mL of formaldehyde solution (pH 8.5) was added to the diluted sample, which was then titrated to pH 8.5 with 0.1 M NaOH. The volumes of base consumed in the first and second titration were used for calculating the amino nitrogen content.

E-nose analysis

The e-nose analysis was performed with the αFOX 4000 smell analysis system (Alpha M.O.S., Toulouse, France) with 18 metal oxide gas sensors based on differential sensing. Fish sauce samples of 0.5 g were loaded into 10 mL vials and placed on an autosampler at 40 °C under 500 rpm agitation for 120 s. The conditions for head space gas analysis were syringe at 50 °C, oven at 40 °C, and injection speed at 2000 μL/s.

E-tongue analysis

The e-tongue analysis was performed with the αASTREE taste analysis system (Alpha M.O.S.) with seven liquid potentiometric sensors (SRS, GPS, STS, UMS, SPS, SWS, and BRS) and a reference electrode (Ag/AgCl). Twenty-one-fold diluted fish sauces were collected in beakers and placed on an autosampler. Each sensor was immersed in the samples for 120 s at room temperature during agitation to determine the response. A stable response value was then extracted at 120 s.

E-eye analysis

E-eye analysis of fish sauces was carried out using the IRIS VA300 visual analyzer (Alpha M.O.S.) with a charge-coupled device camera. Five milliliters of a sample were collected in a transparent plastic dish and placed into the measurement chamber. Color data of the sample surface were measured thrice for each sample. The collected color data were presented as IRIS color codes, which comprise 4096 colors.

5.3. Results

Fish sauce-related internet activity of consumers

Google Trends provides a temporal index of the volume of Google search queries in a given geographic area. To analyze consumer behavior related to fish sauce usage in Japan, we examined Google search activity using Google Trends in September 2017. We entered a set of terms, including 魚醤 (*gyosho*; fish sauce) and しょっつる (*shottsuru*), いしる (*ishiru*), and イカナゴ醤油 (*ikanago shoyu*), three varieties of Japanese local fish sauces, to assess search trends for these keywords. Among the keywords employed here, *shottsuru* received the most traffic (data not shown). The temporal trends of the search activity for this term indicated peaks in the winter months of each year followed by valleys in the summer months (Fig. 2A). In a previous report, Ishige suggested that Japanese consumers utilize *shottsuru*, as well as other Japanese fish sauce such as *Ishiru*, in limited dishes such as those found in *nabe* cuisine, which is Japanese-style stew (Ishige, 1986). Google Trends indicated an annual winter peak in searches related to *nabe* (鍋) similar to that in *shottsuru* search trends, (Fig. 2B) which is consistent with Ishige's suggestion. On the other hand, the regression line for *nabe*-related Google searches implied that the popularity of the cuisine gradually increases year after year. According to this trend, we concluded that the popularity of foods used in *nabe* cuisine would also increase. Therefore, we analyzed search volumes for 白子 (*shirako*), the soft roe of fish, which is commonly eaten in *nabe* cuisine. The curves for the trends of *nabe*- and *shirako*-related activity showed very similar appearances. To assess the correlation between these search activities, correlation analysis was performed as shown in Fig. 2. The results showed a significantly high correlation with a 0.88 Pearson's correlation coefficient (r). These findings imply that Japanese consumers associate *shirako* with *nabe* cuisine. Furthermore, Google Trends indicated that the popularity of *shirako* gradually increases year after year, similar to that of *nabe*.

Production of salmon fish sauce

Based on the data from Google Trends, we speculated that Japanese consumers associate fish sauce with *nabe* cuisine. Additionally, the popularity of *shirako*, common in *nabe* cuisine, is gradually increasing. According to these trends, we attempted to produce salmon fish sauce supplemented with salmon *shirako*. Two types of salmon, "*bunasake*" and "*ginke,*" were used to examine the effect of fish quality on fish sauce quality. "*Bunasake*", which is chum salmon after the egg-laying period, has a low market value because these fish abstain from eating during their pre-spawning run upstream, and the fat in their flesh is depleted. On the other hand, "*ginke*", which is chum salmon before the migration and spawning period, has a high market value because the flesh of these fish is relatively high in fat content. Furthermore, we examined the effect of applying *shio-koji*, a salt-marinated rice malt, as a fermentation starter. Altogether, we prepared 10 types of fish sauces, as shown in Table 2. Amino acid nitrogen content was monitored to assess the progress of fermentation, as shown in Fig. 3. The results showed that amino acid nitrogen content increased to 0.7–0.97% during fermentation of all fish sauces. Neither fish quality nor the use of *shirako*- or *shio-koji* as supplements induced significant differences in amino acid production.

Salmon fish sauce qualities assessed by e-panel analyses

The fish sauce products were subjected to e-panel analyses, which employed e-nose, e-tongue, and e-eye sensors, to assess their qualities.

E-nose analysis (Fig. 5) roughly divided the salmon fish sauce products into two groups. One group included products A, B, E, F, G, and H; the other group included C, D, I, and J. The materials used in the latter group were "*bunasake*" and *shirako* or only *shirako*; thus, the odor of the fish sauce products was affected by *shirako*. However, the odors of fish sauces made with "*ginke*" were not affected by *shirako*. On the other hand, the e-nose data indicated that *shio-koji* does not influence the odor of salmon fish sauce products.

E-tongue analysis (Fig. 6) indicates that all products have similar taste profiles, regardless of the quality of salmon fish and presence of *shirako* and *shio-koji*. E-eye analysis (Fig. 7) indicated that the presence of *shio-koji* led to darkening of the color of the fish sauce products. This is demonstrated by the color differences between products A and B, C and D, E and F, G and H, and I and J. On the other hand, the presence of *shirako* did not affect the color of the products.

5.4. Discussion

In recent decades, consumer demands in the food-production industry have changed considerably. Foods are intended not only to satisfy hunger and provide necessary nutrients, but also to prevent lifestyle-related diseases and to improve the quality of life of their consumers (Siró et al., 2008). In the case of fish sauce, data-mining of internet search activity indicated that interest in fish sauce has gradually declined among the Japanese people, even though fish sauce has good amino acid balance and bioactive peptides that affect vascular function and blood glucose levels, both of which meet the healthcare-related demands of consumers (Ghaly et al., 2013). Despite waning consumer demand, it seems that several varieties of fish sauce are produced throughout Japan. This indicates that there is a large gap between consumer demand and supply.

As shown in the upper panel of Fig. 1, food products are often developed based on the results of consumer research. In this study, we employed a web data-mining approach to analyze consumer behavior related to fish sauce consumption, as shown in lower panel of Fig. 1. Although interest in fish sauce has declined, temporal trends in internet searches for the term *Shottsuru* indicated that interest rises in the winter. Taking these results together with the previous report by Ishige (1986), we concluded that Japanese consumers use fish sauce as an ingredient in *nabe* cuisine, which is often eaten in the winter. Internet search activity for *nabe* increases year after year, implying that its popularity is increasing. This suggests that usage of fish sauce, even in *nabe* cuisine, has also decreased recently. On the other hand, we found that popularity of *shirako* as an ingredient in *nabe* cuisine has increased recently. Based on these findings, we constructed a concept for salmon fish sauce products supplemented with *shirako*.

In the "traditional" approach, pilot products are prepared, and then subjected to sensory evaluation using human panels trained to distinguish between the tastes of the products. However, there are some problems with the use of human panels, such as the cost of their formation and training, the difficulty of evaluating large numbers of samples, and the several-day delay in the receipt of the results (Apetrei et al., 2010). The e-panel system, comprised of e-nose, e-tongue, and e-eye sensors, is an alternative electronic method that assesses the flavor, taste, and color of foods. Its advantages when compared with human panels include higher objectivity and invariable responses over time, which contribute to the success of routine analysis (Apetrei et al., 2010). In this study, we prepared 10 pilot salmon fish sauces products with different material proportions. The results indicated that *shirako* influenced the odor of fish sauce only when the material fish was of low quality, but did not influence the taste or appearance of products.

Unfortunately, market acceptance of our salmon fish sauce products was not assessed in this study. However, the data-mining method we used is widely employed in the economic and business fields. Although the e-panel evaluation of food products is relatively new in the field of food science research, large amounts of data regarding “digital deliciousness” have been accumulated in recent studies. Mouritsen et al. (2017) suggested that data-driven methods of food-related research, in which data-mining from social media and electronic sensor analysis are included, aid the understanding of food perception, consumption, and the influences on food choices and habits. Our combined data-driven approach including consumer behavior-related data-mining of internet search activity and e-panel-based evaluation of a large number of pilot products will be helpful in the creation of food products with higher consumer acceptance.

Table 1. Translations and Romanization of Japanese words used for Google Trends analysis.

Japanese term	Romanization	Translation
魚醤	*gyosho*	Fish sauce
しょっつる	*shottsuru*	Local fish sauce produced in Akita prefecture, Japan
いしる	*ishiru*	Local fish sauce produced in Ishikawa prefecture, Japan
イカナゴ醤油	*ikanago shoyu*	Local fish sauce produced in Kagawa prefecture, Japan
鍋	*nabe*	Originally, *nabe* means pots or pans for cooking. In turn, *nabe* took on another meaning, that is, the stew-style Japanese cuisine cooked by using *nabe*. In this study, these two meanings were not distinguished.
白子	*shirako*	Soft roe of fish.

Table 2. Proportions (%) of the materials used in fish sauce production.

Product ID	Fish material	Flesh	Viscera	Inedible portion*	Soft roe	Salt	*"Shio-koji"*	Total
A	*'Bunasake'*	55.0	5.0	15.0	-	25.0	-	100
B		49.5	4.5	13.5	-	22.5	10.0	100
C		35.0	5.0	15.0	20.0	25.0	-	100
D		31.5	4.5	13.5	18.0	22.5	10.0	100
E	*'Ginke'*	55.0	5.0	15.0	-	25.0	-	100
F		49.5	4.5	13.5	-	22.5	10.0	100
G		35.0	5.0	15.0	20.0	25.0	-	100
H		31.5	4.5	13.5	18.0	22.5	10.0	100
I	Soft roe	-	-	-	75.0	25.0	-	100
J		-	-	-	67.5	22.5	10.0	100

*Inedible portion includes fish heads, backbones, and fins.

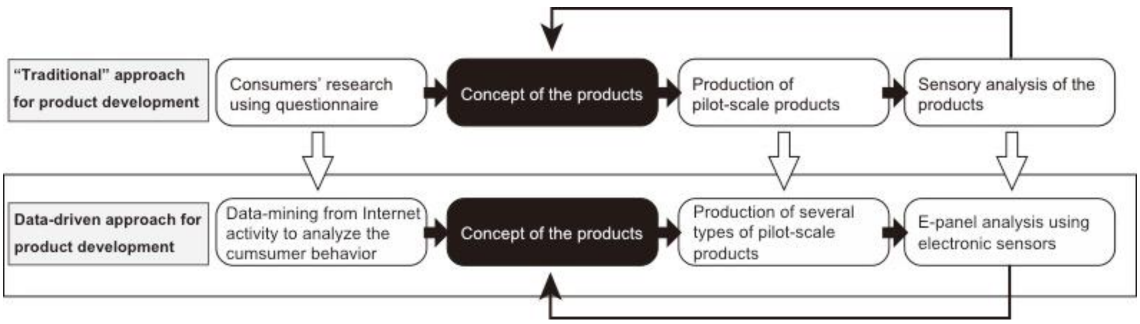

Figure 1. Diagrams for two approaches in product development manner. Upper panels indicate "Traditional" approach. To construct the concept of the product, consumers' research using questionnaire are performed to gather the consumers' needs. The pilot products are prepared based on the concept, and then assessed by the sensory evaluation using human panels. Lower panels indicate data-driven approach. Instead of the

questionnaire based research, consumers' behavior-related trends are analyzed by data-mining from the Internet activity. Additionally, e-panels are employed instead of human panels.

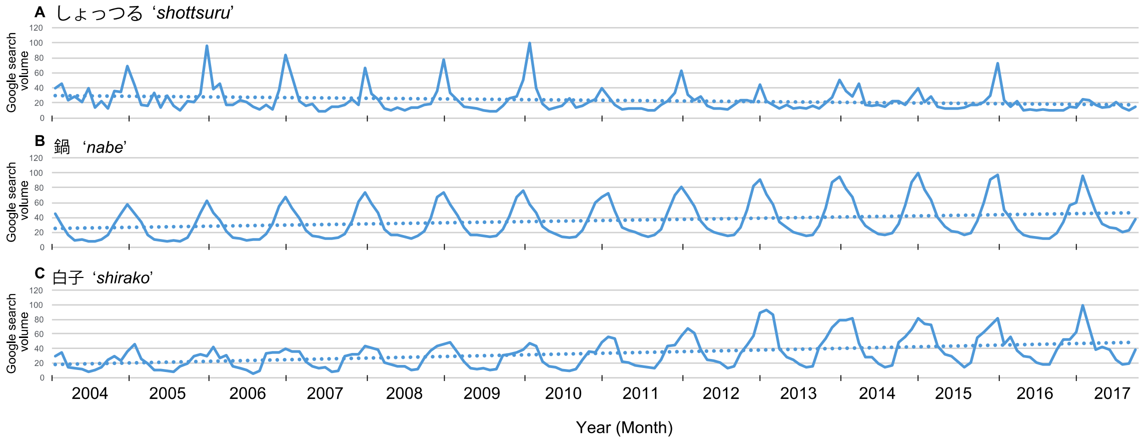

Figure 2. Japanese peoples' interests in *Shottsuru* fish sauce (A), *Nabe* cuisine (B) and fish soft roe *Shirako* (C) represented by Google search volume on the query term しょっつる, 鍋 and 白子, from 2004 to 2017. Solid lines and dotted lines indicate monthly search volumes and regression lines calculated from the monthly volumes.

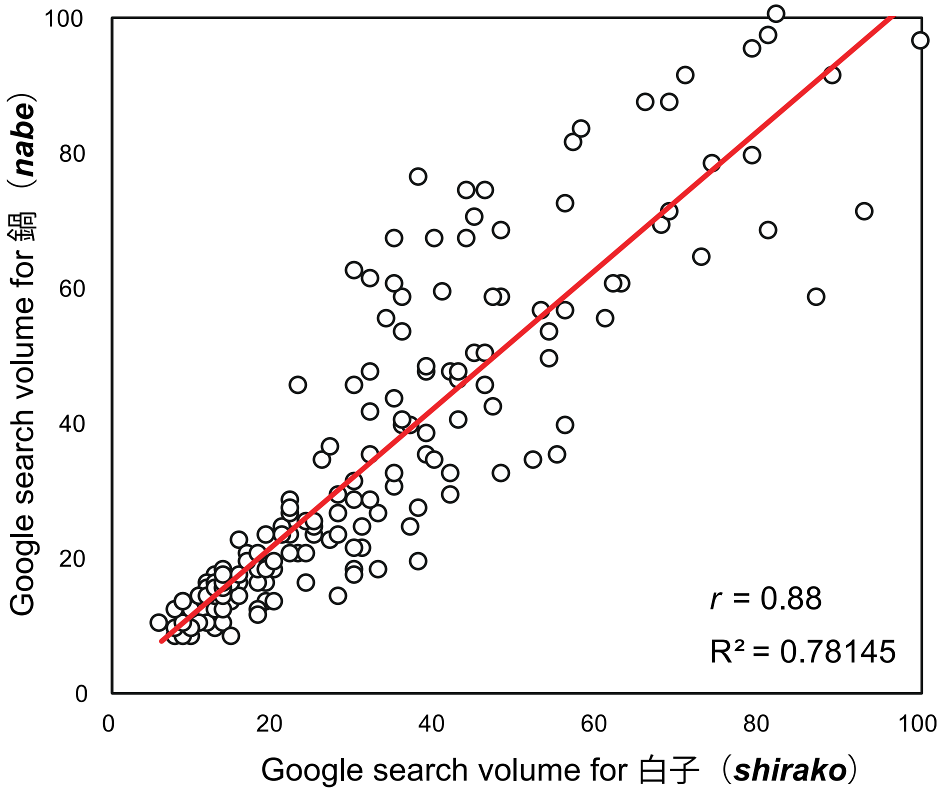

Figure 3. Scatter plot showing correlation between Google search volumes for the terms 白子 and 鍋. Linear regression with 0.78145 of coefficient of determination (R^2) is indicted with red line. Pearson's correlation coefficient (*r*) was 0.88 with *p*-value < 0.05.

Figure 4

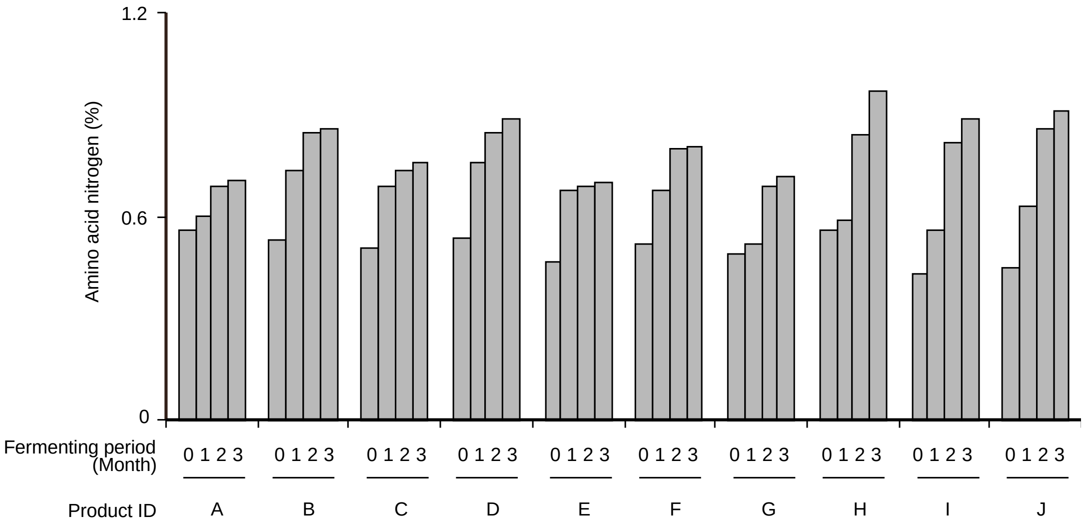

Figure 4. Changing in amino acid nitrogen in the fermentation of fish sauce production. Amino acid nitrogen was determined in 0 to 3 months after initiation of the fermentation of the fish sauce materials.

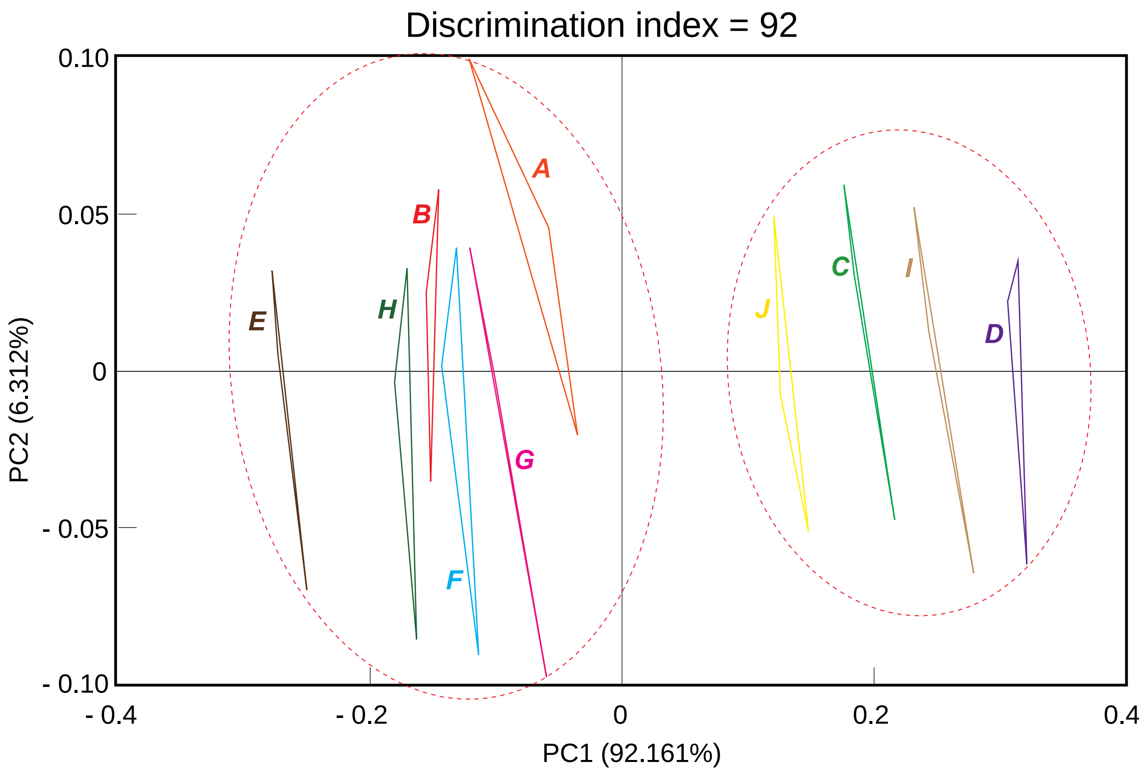

Figure 5. Principal component analysis score plot of e-nose analysis results. Circles with dotted line indicate the groups having similar smelling patterns. Vertexes of triangles indicates each of the triplicated analyses for the sample.

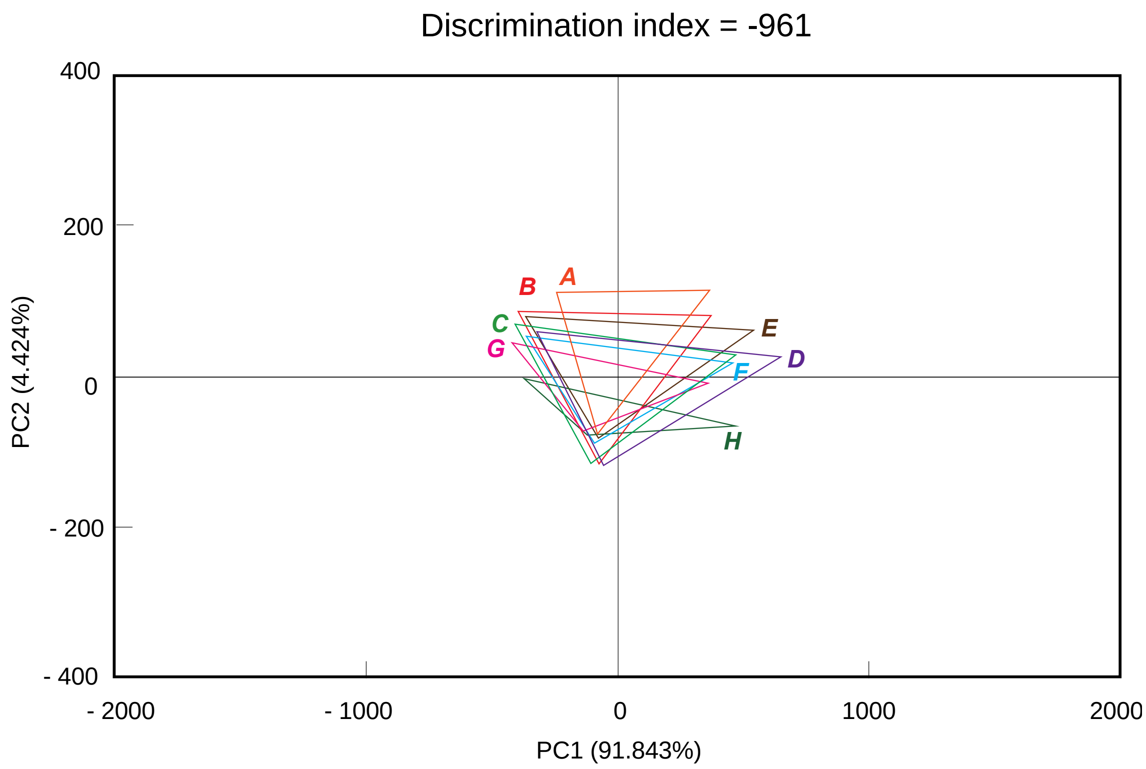

Figure 6. Principal component analysis score plot of e-tongue analysis results. Vertexes of triangles indicates each of the triplicated analyses for the sample.

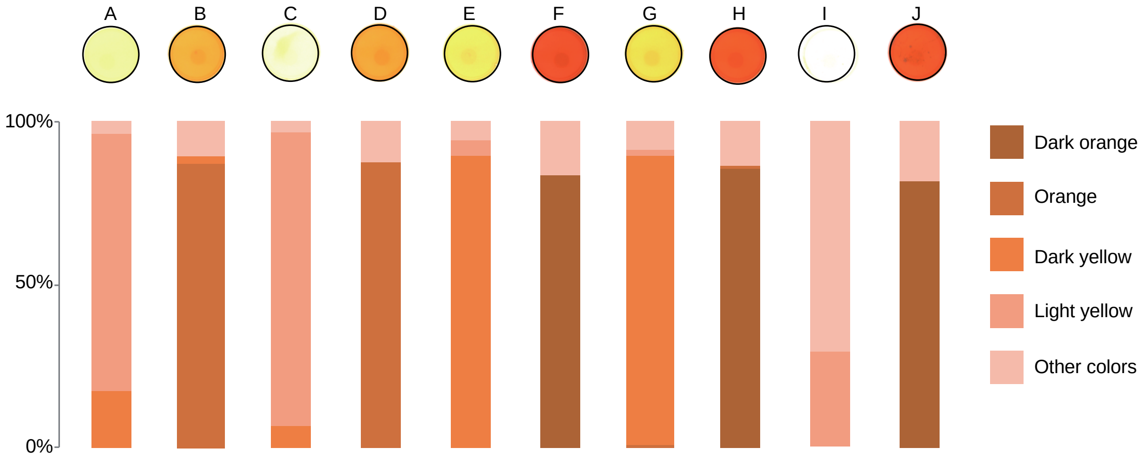

Figure 7. Results of e-eye analysis. Colors in the circles are fish sauce product colors after 3 months from initiation of fermentation. Bar graphs indicate ratio of color components that represent the color of each fish sauce product. Component colors are indicated in left panels.

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Abstract (in Japanese)

近年、情報技術の発展によって、インターネット検索記録やソーシャルネットワークサービス（SNS）等のオンラインデータ、あるいは、センサー等を用いた計測データなど、生活やビジネスに関わる様々なデータが記録されており、その利活用が注目されている。すでに、医療や教育、スポーツなど多くの分野において、これらのデータを活用した判断や意思決定が行われており、ビジネスの分野では、多種多様なデータを基に、複雑に多様化する消費者ニーズや多数の製品の品質を効率的に解析し、製品開発やマーケティングにおける課題を解決する「データドリブンアプローチ」が着目されている。しかし、地域活性化を目的とした 6 次産業化の現場では、企業規模が小さいことや生産できる製品が限られていることから、事業者が製造可能な製品にのみ依存した、いわゆる「プロダクトドリブン」な事業展開にならざるを得ず、消費者ニーズとのミスマッチや競合製品と差別化が図れない等の問題が見受けられる。本論文では、その一つの例として、「魚醤」を取り上げた。

魚醤は、生の魚介類を塩と混合して熟成させた発酵食品である。エラやヒレなどの非可食部や商品価値の低い魚介類を材料として利用できるため、日本の各地で新たな魚醤が開発・販売されている。しかし、日本産魚醤は広く家庭で利用されるには至っておらず、需要と供給の不均衡が生じている。本研究では、データドリブンアプローチを魚醤の市場解析に導入し、魚醤の市場可能性について検討した。最初に、Google 検索やクックパッドなどの Web サイトから消費者意識や動向に関するデータを収集・解析し、日本における魚醤の消費動向を明らかにした。次に、アジア各国で製造された市販魚醤 46 種の「香り」「味」「色」

を「嗅覚センサー」「味覚センサー」「視覚センサー」によって多角的に解析し、食品化学的な分析結果と総合して、それぞれの国の魚醤の特徴を明らかにした。一方、オンラインデータ解析の結果から、日本産魚醤は、冬季にのみ「鍋料理」の調味料としての需要が高まっていること、さらに、「鍋料理」の具材として魚介類の「白子」の人気が上昇していることを明らかにした。その結果を基に白子を含む魚醤を試作し、その「香り」「味」「色」をセンサー分析により解析した。

1.　オンラインデータ解析による魚醤の消費動向解析

情報技術の発達に伴い、インターネット検索エンジンやオンラインレシピサイトなどを使った献立のプランニングが家庭でも広く用いられるようになってきた。本章では、日本における魚醤の消費動向を明らかにするため Google 検索数および日本最大手のオンラインレシピサイト「クックパッド」でのレシピ検索数から日本産、タイ産およびベトナム産魚醤の 2004 年以降の検索トレンドを相関分析等の統計学的解析により分析した。その結果、日本産およびベトナム産魚醤の検索数は、年々減少傾向にあるのに対し、タイ産魚醤「ナンプラー」の検索数が 2011 年以降、顕著に上昇していることが明らかとなった。さらに、ナンプラーを含むレシピの使用件数も同様に上昇しており、特に 2016 年以降は、「ガパオ」をはじめとしたタイ料理への利用が家庭でも急速に浸透し始めていることが示唆された。

2.　味覚センサーデータによるアジア産魚醤の味特性の比較

日本、タイ、ベトナム、フィリピンおよび中国産の市販魚醤の味特性を嗅覚センサーによって解析した。その結果、日本産魚醤は、その他の国の魚醤と比較し、酸味および金属味が強く、旨味と甘味が弱い傾向があることが示された。さらに、センサーデータを用いたクラスター解析の結果、日本産魚醤の大部分は、外国産魚醤とは、異なるクラスターを形成したことから、それぞれが、異なる味特性を示すことが明らかとなった。しかし、日本産魚醤でも、伝統的製法で製造された製品は、海外産の魚醤と同じクラスターに分類されたことから、

伝統的な魚醤は、他の国の魚醤と同じ味特性を持つことが示唆された。

3. 嗅覚センサーデータによるアジア産魚醤の香り特性の比較

市販魚醤の香り特性は、嗅覚センサーによって解析した。その結果、18 個のセンサーのうち、13 個のセンサーは日本産魚醤に対し、高い値を示し、一方、5 個のセンサーは、海外産魚醤に対して高い値を示した。センサー強度のデータをもとにクラスター解析した結果、日本産魚醤とその他の国の魚醤は、異なるクラスターに分類され、明確に香りが異なっていることが明らかにされた。また、日本産魚醤は、醤油と同じクラスターに分類されたことから、日本産魚醤は、醤油に近い香り特性を持つことが示された。このことから、日本では、魚醤独特の「香り」を抑えた商品が増加している傾向が見られた。

4. 視覚センサーデータによるアジア産魚醤の色特性の比較

市販魚醤の色特性は、視覚センサーによって解析した。魚醤の色は、黄色から茶褐色系を示した。タイ産魚醤は、全てが黄色系の色を示していたが、日本産を含むその他の国の魚醤は、黄色から茶褐色系で様々な色を有していた。センサーデータを基に、クラスター解析を行った結果、生産国ごとに明確にクラスターを形成されることはなかったことから、製品の色に関しては、味や香りとは異なり、生産国による特徴はないことが示された。

5. 化学分析データによる魚醤の各種成分解析

本項目では、固形成分量、塩分量、pH、酸度、総タンパク質量、アミノ酸量の分析を行い、各市販魚醤の化学特性を分析し、比較した。その結果、タイ産の魚醤は、固形成分量が高い傾向が見られたことから、呈味成分が比較的多く含まれている可能性が示された。一方、日本産魚醤には、塩分濃度が低いものが多く、減塩の製品が好まれる傾向があることが関連しているものと考えられた。また、ベトナム産魚醤は、総タンパク質量が多い傾向が見られ、これは、製造法の違いによるものと考えられた。

6. データドリブンアプローチを導入した新規魚醤の試作

本項目では、日本の市場にあわせた新規魚醤製品の作製するため、インターネット検索数を基に日本産魚醤に着目した消費動向を解析した。日本産魚醤には、秋田県の「しょっつる」、石川県の「いしる」や香川県の「イカナゴ醤油」など、いくつかの地域で魚醤が製造されているが、「Google 検索」を対象に、これらの魚醤や海産物、魚醤に関連する料理の検索トレンドを集計し、それぞれの相関解析を行った結果、日本の消費者は、魚醤をごく限られた料理、すなわち鍋料理に利用していることが示唆された。さらに、鍋料理の素材としての「白子」の人気が近年上昇していることが明らかとなった。以上の結果から、著者らは白子を素材とした鮭の魚醤の製造を試みた。さらに、市場価値の低い鮭からの魚醤の製造も合わせて行い、それら試作品を「嗅覚センサー」「味覚センサー」「視覚センサー」の 3 種を合わせた解析によって評価した。その結果、商品価値の低い鮭を利用した場合でも商品価値の高い鮭から製造された魚醤と比較し、味、香り、色に遜色がないことが示された。このことは、安価な原材料からも一定の品質の魚醤が製造できることを示している。一方、原材料として白子を加えた魚醤は、白子無添加の魚醤と比較し、同様の味、香り、色を示したことから、魚醤の品質を低下させることなく、白子が持つ「鍋料理にあう」「高級感がある」等のイメージによる付加価値を導入することができることが示唆された。

著者は、本研究において、今まで学術的に解析されることのなかった魚醤の市場解析に、データドリブンアプローチを導入することで、魚醤に関する生産者と消費者の動向を明確に示した。すなわち、市販魚醤の香り特性を解析した結果、本来の日本産魚醤はタイ産魚醤と比較的類似した風味を有していたが、近年、日本産魚醤の多くが魚醤独特の香りを抑える戦略をとっていることが明らかとなった。これは、魚醤の独特な風味が家庭での利用を敬遠させているとの見方に基づくものと考えられる。しかし、2011 年以降のタイ料理の急速な普

及が、タイ産魚醤の日本の家庭への浸透を加速させたことを明らかにした。このことは、日本産魚醤を活用したタイ風料理を開発するなど、新たな戦略による魚醤市場開拓のための重要な知見となった。さらに、本研究で用いたデータドリブンアプローチは、他の食品や農作物を利用した製品の開発やマーケティングに広く応用が可能であり、今後、これらの手法の活用が期待される。

APPENDIX