Technical paper

Objective Evaluation of Astringent and Umami Taste Intensities of Matcha using a Taste Sensor System

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Received June 6, 2013; Accepted August 13, 2013

Matcha is a kind of Japanese green tea that is traditionally used for the Japanese tea ceremony, Sado, and has, in recent years, also been used as a food ingredient. In addition, Sado and food items containing matcha are becoming popular in countries where matcha drinking is a new experience. Therefore, information on the quality of matcha is important for manufacturers, dealers, and consumers in order to produce, select or purchase a product that meets their purpose. To obtain objective information on matcha tastes, we developed a standardized method for evaluating the astringent and umami tastes of matcha using a taste sensor system with standard substances, (–)-epigallocatechin-3-O-gallate (EGCg) for astringent taste and monosodium glutamate (MSG) for umami taste. The precision of these evaluation results was sufficient for its practical use. The evaluation method was applied to commercial matcha samples, and it was revealed that the method has the potential to characterize, in detail, the taste of matcha for different uses.

Keywords: matcha, green powdered tea, taste sensor, astringent taste, umami taste

Abbreviations: EGCg, (–)-epigallocatechin-3-O-gallate; EIT, estimated intensity of taste; EITast, estimated intensity of astringent taste; EITuma, estimated intensity of umami taste; MSG, monosodium glutamate; PVPP, polyvinylpolypyrrolidone

Introduction

Matcha (green powdered tea) is a Japanese traditional green tea, which is made from specially cultivated shoots of the tea plant, powdered using a stone mill, and mainly used for Sado, the traditional tea ceremony in Japan. In Sado, matcha powder is placed in a tea bowl and hot water is added, stirred with a bamboo tea whisk, and then drunk. In general, matcha is characterized by a rather strong umami taste and mild astringent taste. Furthermore, matcha has recently become popular as a food ingredient. Matcha adds a pleasant astringency and bright green color to various food items, such as sweets and beverages. However, the astringent and umami tastes of matcha as a food ingredient are not necessarily mild and strong, respectively, because of the intended purpose (for example, addition of astringency or green color). Thus, there are various matcha that differ in their characteristics. In addition, Sado is becoming known in foreign countries where matcha drinking is a new experience, and matcha-containing food items are also being produced in those countries. Based on this, manufacturers, dealers, and consumers desire clear and convincing information on the quality of matcha, as well as other foods and beverages, to aid in the production, selection, or purchase of the appropriate matcha to meet their needs.

Taste is one of the most important indicators of tea quality. Traditionally, tea taste has been evaluated by sensory test, which can be an appropriate method if adequate training is carried out. However, the sensory test cannot fully exclude subjectivity. To solve this problem, taste sensor technologies have recently been gaining attention as methods for evaluat-
ing the taste of foods more objectively (Toko, 2005; Habara and Toko, 2006; Ciosek and Wróblewski, 2007; Citterio and Suzuki, 2008; Riul Jr. et al., 2010). We have been developing methods to evaluate the astringent (Hayashi et al., 2006) and umami taste (Hayashi et al., 2008) intensities of Japanese common leaf-type green tea, and the astringent and bitter taste intensities of black and oolong teas (Hayashi et al., 2013) using a commercially available taste sensor system. These methods are not only objective, but can also standardize taste intensity information by calibrating with standard substance solutions prepared with pure chemicals. Therefore, the measurement precision of these methods is superior to that by conventional sensor methods using food samples as standard samples. It appears that our sensor method is also applicable to matcha. However, matcha differs from common leaf-type green tea in that the powdered tea leaves remain in the tea infusion after brewing. In this study, to obtain standardized data of the astringent and umami taste intensities of matcha using the taste sensor system, a new sample preparation procedure was developed, and unification of the evaluation method for matcha with our previous method for common Japanese leaf-type green tea was attempted. In addition, it was demonstrated that commercial matcha samples could be characterized on the basis of the taste sensor results.

Materials and Methods

**Tea samples and chemicals** Commercial matcha samples were purchased from tea shops. (–)-Epigallocatechin-3-O-gallate (EGCg) was obtained by recrystallizing a hot pure water solution of TEAVIGO™ (DSM Nutritional Products, Heerlen, Netherlands). Monosodium glutamate (MSG, pure grade) was purchased from Wako Pure Chemical Industries (Osaka, Japan). Polyvinylpolypyrrolidone (PVPP) was purchased from Sigma-Aldrich (St. Louis, MO). All other chemicals were commercially available special grade reagents. Tea infusions and aqueous solutions were prepared with pure water obtained by a reverse osmosis water purifier.

**Preparation of sample solutions for taste sensor measurement** Two hundred mL of boiling water was poured into a 300-mL glass beaker and stirring with a magnetic stirrer was started. Immediately, 2.00 g of matcha was added to the beaker, and the mixture was stirred for 5 min. The suspension was then centrifuged at 12,020 g for 15 min at room temperature (himac CR20B3, Hitachi, Tokyo, Japan). The supernatant was divided into two portions to measure the two different tastes. For measurement of astringent taste intensity, approximately 60 mL of the supernatant portion was filtered with Advantec No. 2 filter paper (Toyo Roshi, Tokyo, Japan). The filtrate was collected after the first 20 mL was discarded. For measurement of umami taste intensity, 80 mL of the supernatant portion was placed in a 100-mL conical flask and 2% (w/v) PVPP was added to remove polyphenols, which interfere with the umami sensor probe (Hayashi et al., 2008), and the mixture was shaken every 10 min for 30 min. The mixture was then filtered with Advantec No. 2 filter paper. The filtrate, after discarding the first 20 mL, was used as the sensor measurement sample.

**Measurement of astringent taste intensity using the taste sensor system** The electrical potential corresponding to the astringent taste intensity of the sample solution was measured by the SA402B taste sensor system (Intelligent Sensor Technology, Inc., Kanagawa, Japan), fitted with an astringent taste sensor probe (SB2AE1) and a reference probe. The sensor measurement was automatically carried out at 25°C under default conditions. After the taste sensor probes and the reference probe were dipped into sample solutions or standard substance (EGCg) solutions for 30 s, these probes were washed twice for 3 s each in 30 mM KCl and 0.30 mM tartaric acid aqueous (aq.) solutions. Then, the membrane potential of the astringent sensor was detected in 30 mM KCl and 0.30 mM tartaric acid aq. solution. This operation was performed to detect the membrane potential change generated by astringent taste substances adsorbed on the polymer membrane of the sensor probe. The astringent taste intensity of the sample solution was defined as the difference (ΔEast) between the membrane potential changes caused by the sample solution and by a reference solution (0.650 mM EGCg aq. solution including 5.00 mM KCl). The ΔEast value of each sample was obtained from the average of three measurements. The measurement order was 0.650 mM EGCg aq. solution, 0.260 mM EGCg aq. solution, and the sample solutions.

**Measurement of umami taste intensity using the taste sensor system** The electrical potential corresponding to the umami taste intensity of the sample solution after PVPP treatment was measured by the SA402B taste sensor system fitted with an umami taste sensor probe (SB2AAE) and a reference probe. The sensor measurement was automatically carried out at 25°C under default conditions. The sensor probe and the reference probe were dipped into the sample solution or the standard substance (MSG) solutions for 30 s to detect the membrane potential change. The umami taste intensity of the sample solution was defined as the difference (ΔEuma) between the membrane potential changes in the sample solution and in the reference solution (5.00 mM MSG aq. solution including 30 mM KCl and 0.30 mM tartaric acid). The ΔEuma value of each sample was obtained from the average of three measurements. The measurement order was 5.00 mM MSG aq. solution, 2.00 mM MSG aq. solution, and the sample solutions.
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**Precision of evaluation results using the taste sensor system**

The precision of the evaluation results, including the sample preparation process, was assessed by the method of Mizukami et al. (2007) according to the International Conference on Harmonization guideline. In order to investigate the intraday variations of the measurement results, infusions of the matcha samples were prepared in triplicate, and each infusion was measured in triplicate on the same day. The standard deviation (SD) was calculated on the basis of the 9 measurements. Interday variations were assessed by performing the measurements on 3 consecutive days with freshly prepared infusions of the matcha samples (in triplicate). The nine measurements obtained on each day for each of the preparations were treated as single data points. The SD was calculated between days.

**Results and Discussion**

**Optimization of sample preparation method**

Because matcha is a powdered green tea that differs in shape from popular leaf-type green teas, optimization of the sample preparation method is necessary to measure taste intensities of matcha. In the case of leaf-type green teas, the tea leaves were removed by pulling out the filter cup from the glass pot (Hayashi et al., 2006, 2008), by contrast, in this study, the tea leaves could not been removed from the infusion in a similar manner because the matcha powder was placed directly into boiling water and suspended. To develop a method for removing the sample powder from the infusion as promptly as possible, filtration and centrifugation processes were attempted. However, filtration was not suitable because the large amount of fine matcha powder quickly clogged the filter paper, and too much time was required to filter the infusion. In contrast, centrifugation removed the matcha powder in a short time. The supernatant was additionally filtered to remove trace amounts of powder.

It is known that polyphenols present in green tea infusions interfere with the umami sensor probe, SB2AAE (Hayashi et al., 2008). Therefore, before measuring the umami taste intensity of the green tea infusion, it was necessary to remove the polyphenols using PVPP treatment. In our previous experimental procedure, 2% (w/v) PVPP was added to the sample infusion and the mixture was kept for 1 h with shaking every 10 min (Hayashi et al., 2008). In this study, shortening of PVPP treatment time was examined. PVPP was added at 2% (w/v) to aliquots of the matcha infusion, and the samples were kept for 6 different treatment times (15, 30, 60, 90, 120 and 150 min) with regular shaking. After removal of PVPP by filtration through filter paper, the astringent and umami sensor outputs of the filtrates were measured. As a control for astringent sensor measurement, matcha infusion without PVPP treatment (0 min) was filtered and used. A control was not provided for umami taste sensor measurement because the tea infusion without PVPP treatment damages the probe, rendering it unusable. As shown in Fig. 1, the astringent sensor output came down to 0 mV by treating with PVPP for at least 15 min, indicating that astringent substances, including polyphenols, were removed from the matcha solution. The sensor output values of each sample were the average of three measurements.

**Fig. 1.** Outputs of the astringent taste sensor response to matcha infusions with different PVPP-treatment times, in reference to the output of 30 mM KCl and 0.30 mM tartaric acid aq. solution. The sensor output values of each sample were the average of three measurements.

**Fig. 2.** Outputs of the umami taste sensor response to matcha infusions with different PVPP-treatment times, in reference to the output of 30 mM KCl and 0.30 mM tartaric acid aq. solution. Each infusion of three matcha samples (A, B, and C) was treated with PVPP at six different treatment times (15, 30, 60, 90, 120 and 150 min, from left). The sensor output values of each sample were the average of three measurements.
terfere with the umami sensor probe*. Based on these results, although it appeared that 15 min of PVPP treatment was sufficient for umami taste-measurement of matcha samples, in this study, we adopted 30 min as the treatment time for ease of practical operation in the experiments.

**Evaluation of the astringent taste intensity of matcha samples using the taste sensor** The taste intensities of samples are often indicated as non-dimensional values on the scale where one unit is the sensor output difference corresponding to a 20% concentration difference in the standard substance solution (Habara and Toko, 2006). In this article, these values are described as estimated intensity of taste (EIT) values. This concept was drawn from the theory in which the intensity of taste detection is proportional to the logarithm of concentration of taste substances, according to Weber-Fechner’s law, and the fact that humans can generally discriminate a 2-fold concentration difference in taste substances (Pfaffmann, 1959; Schutz and Pilgrim, 1957).

In the case of the astringent taste of common leaf-type green tea, the estimated intensity of astringent taste (EITast) values was calculated by multiplying the sensor outputs (ΔEast) of the sample solutions in reference to the sensor output of 0.650 mM EGCg solution, using the inverse of the slope of line-a in Fig. 3 determined from the sensor outputs of 0.650 mM and 0.260 mM EGCg solutions: EITast = ΔEast × {−log1.2 (0.650/0.260)}/Aast = ΔEast × −5.03/Aast (Hayashi et al., 2006). Here, the sigmoid graph in Fig. 3 shows the relationship between the logarithm of EGCg concentration and the sensor output; “Aast” is the electrical potential difference between the two standard substance solutions for astringent taste (0.650 mM EGCg and 0.260 mM EGCg solutions).

Therefore, to obtain proper EITast values, it is essential that the sensor output range of the sample solution overlaps with the approximately linear portion (indicated by line-a in Fig. 3) of the sigmoid graph of the standard substance solution.

In this study, 28 matcha samples for Sado and 18 matcha samples for food ingredient, shown in Table 1, were used. The ΔEast of the infusions prepared with 2.00 g of matcha samples and 200 mL of hot water ranged from −11.25 to +14.15 mV in reference to 0.650 mM EGCg solution. As shown in Fig. 3, this range overlapped with the approximately linear portion of the sigmoid graph. Therefore, the EITast values of the matcha samples were acquired under the same conditions as common leaf-type green tea samples, and ranged from −3.93 to +1.79.

**Evaluation of the umami taste intensity of matcha samples by the taste sensor** In addition to the astringent taste intensity described above, whether the method for common leaf-type green tea samples was applicable to calculating the estimated intensity of umami taste (EITuna) values of matcha samples was examined. The umami taste sensor outputs (ΔEuma) of the matcha sample solutions ranged from −3.72 to +16.38 mV in reference to 5.00 mM MSG solution, which overlapped with the approximately linear portion of the sigmoid graph (indicated by line-b in Fig. 4) that shows the relationship between the logarithm of MSG concentration and the sensor outputs. Therefore, as to the umami taste intensity of the matcha samples, the evaluation method for common leaf-type green tea was applicable. Because the slope of line-b in Fig. 4 is determined from the sensor outputs of 5.00 mM and 2.00 mM MSG solutions, the EITuma value was

* It was confirmed that the amino acid content in the tea infusion did not change after PVPP treatment based on HPLC analyses.
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The former has higher polyphenol and lower amino acids contents than the latter, even though the shoots are grown under shading (Chutani, 2007). Therefore, matcha for food ingredient tends to have stronger astringent and weaker umami tastes.

Astringent and umami taste intensities of commercial matcha samples used in this study are two-dimensionally mapped in Fig. 5. Black and gray marks indicate matcha samples for Sado, and white marks indicate those for food ingredient. ●: Sado samples recommended for use as thin suspensions (usucha) only, ●: Sado samples that can be used for thick suspensions (koicha), ■ and □: Matcha samples provided by the same manufacturer for Sado (■: thin suspension, ■: thick suspension) and for food ingredient (□), respectively, ○: food ingredient samples.

Fig. 5. Astringent and umami taste intensities of matcha samples used in this study.

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Astringent and umami taste intensities of commercial matcha samples used in this study are two-dimensionally mapped in Fig. 5. Black and gray marks indicate matcha samples for Sado, and white marks indicate those for food ingredient. The Sado samples were distributed in a narrow area with higher umami taste intensity. Their astringent taste intensities were wide ranging, with similar or lower values in comparison to the food ingredient samples. In contrast, in the case of the food ingredient samples, a narrow range of astringent taste intensities was observed with values being high, and the umami taste intensities were distributed in a similar or lower area in comparison to the Sado samples. On the whole, the Sado samples tended to have weaker astringency and stronger umami tastes than the food ingredient samples. This tendency corresponds to the general characteristics of matcha mentioned above.

Matcha for Sado appears to be characterized by stronger umami taste intensity, while matcha for food ingredient appears to be characterized by stronger astringent taste intensity. However, this strong astringency is not thought to be a problem. As a food ingredient, matcha adds a refreshing

Precision of the evaluation results The precision of the evaluation results was assessed by the SD of the EIT values. The SD values were ±0.14 (intraday) and ±0.19 (interday) for the average EIT strength value (0.62), and ±0.04 (intraday) and ±0.17 (interday) for the average EIT umami value (−0.58). These results reveal that both the EIT strength and the EIT umami values have sufficient precision, because these values were kept within one unit on the EIT scale.

Taste characterization of commercially available matcha (samples for Sado vs. for food ingredient) The first-flush shoots of tea plants grown under shading are used as the matcha material for Sado (Takeo, 2009). These high-grade tea leaves consequently have lower polyphenol content and higher amino acid content (Goto et al., 1994, 1996). This means that the tea leaves made from such materials tend to have weaker astringent and stronger umami tastes. Moreover, the cost of manufacturing is reflected in its high price. On the other hand, the material shoot grade of matcha for food ingredient is more variable in comparison with that for Sado. Second- or third-flush shoots grown without shading are often used as a cost-cutting measure. In the case of common Japanese leaf-type green tea, second- and third-flush shoots generate tea leaves of lower quality than first-flush
astringency and characteristic green color to foods. From this viewpoint, astringency is not a negative factor, and umami taste is comparatively not as important. Although the astringent taste of green tea originates from polyphenols, such as catechins, it is known that their astringency is effectively reduced by other constituents in foods and beverages, such as sugar, sweetener and milk (Ares et al., 2009). Therefore, even if matcha is characterized by strong astringency as a food ingredient, this may not be a critical issue, instead it may be preferred. This also makes sense from a cost perspective. Manufacturers advise consumers not to use matcha products labeled as food ingredients in the Japanese tea ceremony (Sado) because of their strong astringent taste. A typical example is provided in Fig. 5. The black, gray and white squares indicate the samples for Sado (black and gray) and for food ingredient (white) provided by the same manufacturer. These results indicated that this manufacturer obviously sells matcha on the basis of differences in astringent taste intensity.

**Taste characterization of matcha for Sado (samples for “koicha” vs. “usucha”)** In the Japanese tea ceremony (Sado), there are two preparation methods for matcha, which differ in the amount of matcha per serving. The first results in a thick suspension, called koicha, and the other in a thin suspension called usucha. The amount of tea used in the former case is usually twice as much as in the latter case: about 3 – 4 g and 1.5 – 2 g per serving, respectively. According to the manufacturer’s instructions, although all the matcha products among their product lineup are usable for usucha, only selected high-quality matcha is suitable for koicha. Among the matcha samples for Sado in Fig. 5, the black marks and gray marks indicate matcha samples for koicha and usucha, respectively. The koicha samples were distributed in a narrow area with stronger umami taste intensities, while the umami taste intensities of the usucha samples were distributed in a wider area than those of the koicha samples. These results suggest that manufacturers focus on umami taste with respect to koicha and select items satisfying a certain required level from their matcha lineup. In Sado, no sweeteners are added to the matcha suspension, and consumers relish the taste of pure matcha. Therefore, manufacturers probably recommend that the matcha with a stronger umami taste intensity among their product lineup is suitable for koicha. As well as the comparison between Sado and food ingredient matcha samples described above, the taste sensor results can reveal such a sales strategy from the scientific data. On the other hand, if these objective data are used, consumers, dealers, and manufacturers will be able to buy and sell matcha to meet their individual requirements.

In conclusion, to objectively evaluate the astringent and umami taste intensities of matcha using the taste sensor system, a new sample preparation method was developed. The finely powdered tea leaves were removed from the infusion samples by centrifugation. In the preparation of the umami samples, the PVPP treatment time for removing polyphenols from the infusion samples was cut in half in comparison to the previously reported process. Furthermore, it was revealed that the standard substance solutions for common leaf-type green teas were usable for standardizing both astringent and umami taste intensities of matcha samples. Therefore, the applicability of the previous methodology was expanded to the astringent and umami taste intensities of matcha. The precision of these evaluation results was sufficient for the practical use of this methodology. In addition, it was demonstrated that many commercial matcha samples could be objectively characterized by the taste sensor data, enabling product selection, quality management, and quality certification. These methods can clearly visualize matcha taste characteristics. Therefore, we are confident that this taste sensor data has great potential to provide invaluable information to manufacturers, dealers and consumers of matcha.

**Acknowledgments** We thank Shigefumi Maeda for technical assistance.

**References**


