GREEN TEA: FLAVOR CHARACTERISTICS OF A WIDE RANGE OF TEAS INCLUDING BREWING, PROCESSING, AND STORAGE VARIATIONS AND CONSUMER ACCEPTANCE OF TEAS IN THREE COUNTRIES

by

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B.S., Pusan National University, 2002
M.S., Kansas State University, 2004

AN ABSTRACT OF A DISSERTATION

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Abstract

A green tea descriptive sensory lexicon was developed by a highly trained panel, which identified, defined, and referenced 31 flavor attributes of green tea. The attributes were categorized as “green” (asparagus, beany, Brussels sprout, celery, parsley, spinach, green beans, and green herb-like), “brown” (ashy/sooty, brown spice, burnt/scorched, nutty, and tobacco), “fruity/floral” (fruity, floral/perfumy, citrus, and fermented), “mouthfeel” (astringent and tooth-etching), “basic tastes” (overall sweet and bitter), and other attributes (almond, animalic, grain, musty/new leather, mint, seaweed, and straw-like).

Using the green tea lexicon, the flavor differences that exist among a wide range of green teas (n=138) produced in various countries were determined. Roast-processed teas were mostly responsible for brown-related flavors and steam-processed teas were mostly responsible for green-related flavors.

Aroma analyses of green tea showed that the concentration of volatile compounds were much lower than stated in the literature.

Brown, brown-related attributes, bitterness, and astringency became stronger and green and green-related attributes become weaker as the brewing time lengthened (1, 2, 5, and 20 min) and the water temperature increased (50, 70, 95℃).

The flavor characteristics of roast-processed, steam processed, or roast-steam-processed Korean green teas differed only in their characterizing green flavors.

The flavor and aroma of green teas change after sequential brewings. Green teas in leaf form can be brewed four times: the first two brews providing stronger flavor and aroma characteristics whereas the third and fourth brews will provide milder flavor and aroma characteristics.

The flavor and aroma change in green teas that are stored over two years were observed at 3, 6, 12, 18, and 24 months after their original packaging dates. Green tea changes minimally during the first year of storage and only slightly more during the first two years of storage.

Consumer studies and descriptive evaluations were conducted to understand what green tea flavor characteristics influence US consumers’ liking. Twelve green tea samples were

evaluated by three consumer groups from Korea, Thailand, and the United States. The current research suggests that familiarity plays a role in tea acceptance. However, various flavor profiles may be acceptable to consumers who are familiar with other flavors of green tea.

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CHAPTER 1 - Literature Review

Green Tea

Tea is a beverage brewed from the leaves of a plant, *camellia sinensis*, which originated in Asia. There are three major forms of tea: green tea, oolong tea, and black tea. They all originate from the same plant but are processed differently (Rinzler 2001).

There are 2 major tea tree species, *camellia sinensis var. sinensis* and *camellia sinensis var. assamica*. *Camellia sinesis var. sinensis* is also known as China tea. It is relatively resistant to cold and therefore is grown in moderate weather regions like China, Japan, southern Korea, the former Soviet Union, Turkey, Iran, and northern India. This variety produces small amounts of tea because they grow slowly and have smaller leaves. On the other hand, *camellia sinensis var. assamica*, known as assam tea, is faster-growing and has larger leaves, resulting in higher yields. This variety is less resistant to cold and the tea is not as delicately flavored as *sinensis*. One variety may be better than the other for particular kinds of tea (Segal 1996). Generally, *camellia sinensis var. sinensis* is used for green tea production (Taylor 2003).

Green tea is processed with fresh leaves; the process starts with roasting or steaming to disable polyphenol oxidase activity, particularly cathechins, to prevent oxidation (Owuer 2003). The leaves are dried and processed immediately after harvesting so that no fermentation occurs. Green tea leaves often remain green with a subtle flavor after the process (Macrae and others 1993; Rinzler 2001).

Among green teas, different processing methods, harvest times, tea tree varieties, and regions produce different flavors (Jung 2004).

Health benefits of green tea

Green tea is considered to be a functional food. To prove green teas' health benefits, intensive research has been conducted on green tea; drinking green tea increased plasma total antioxidant activity in humans (Erba and others 2005), showed potential for maintaining normal body weight and supporting healthy glucose levels (Weber 2004), presented anticarcinogenic effects (Friedman and others 2007), had anticarcinogenic actions (Hara 2001), showed an inverse relationship with all-cause mortality and cardiovascular disease mortality (Kuriyama and others

2006), and had a likely advantageous influence on breast cancer (Kumar and others 2009). These positive research results drive green tea consumption in the U.S. (Ong 2005) and the U.K. (Nutraingredients.com 2005).

Geographical differences of green tea

Most green teas are produced in Asia. More than 30 countries grow tea, among them are China, India, Burma, Thailand, Laos, Vietnam, Japan, Indonesia, Sri Lanka, Turkey, Iran, Taiwan, Bangladesh, Malaysia, Malawi, the former Soviet Union, south Russia, and Argentina. India is the largest tea producer followed by China, Kenya, and Sri Lanka. In 1998, 644,900 tons of green tea were produced globally and 641,200 tons were grown in Asia, specifically in China, Indonesia, Vietnam, and India. Of that amount, 126,500 tons of green tea were exported from Asia. The exporting countries included China (111,700 t), India (3000 t), Indonesia (3500 t), Japan (600 t), Sri Lanka (500 t), Taiwan (400 t), and Vietnam (6,800 t) (Taylor 2003). According to the Food and Agriculture Organization of the United Nations (FAO 2001), the actual production of green tea in 2000 was 500,000 tons in China, 90,000 tons in Japan, 38,000 tons in Vietnam, 38,000 tons in Indonesia, adding up to 681,000 tons worldwide. FAO projected that green tea production would increase to 900,000 tons by 2010.

Green teas from different countries

Green teas from different countries may have different appearance, aroma, and flavor characteristics. Even though green tea originated in China, introducing it to other parts of world contributed to the differences. Even within China itself, famous Chinese green teas differ from region to region within the country because China is a large country. According to Ukers (1935), Chinese green tea could be divided by district; roughly into Country greens, Hoochows and Pingsueys; the smaller principal districts are Anhwei, Chekiang, Kiangsi, Fukien, Kwangtung, and Hunan. Manufacturing styles further divide green teas into gunpowder, imperial, young hyson, hyson, hyson skin, twankay, and dust. So in trade, the region and the manufacturing style are used as the name of the green teas. Each kind of green tea is also divided by grade. The earlier teas are the better grades. Gunpowder uses young to medium leaves rolled into balls. Imperial uses older leaves and is made much like gunpowder except it has a looser roll. Young hyson is made with young to medium leaves and looks like twisted thread. Hyson uses older leaves. Twankay and hyson skin are lower quality green teas (Ukers 1935). In China, pan-firing is the most common initial processing. On the other hand, Japanese green teas are mostly steamed initially (Xu and Chen 2002). In Japan, *sencha* accounts for approximately 75% of the green tea production followed by *bancha* (about 14%) (Hara 2001). *Bancha* is a lower grade version of *sencha*. Other Japanese green teas include *Gyokuro, Kabusecha, Tencha, Matcha, Hojicha*, *Kamairicha*, and *Tamaryokucha.* Unlike other Japanese green teas, *Kamairicha* and *Hojicha* are pan-fired (roasted).

Green tea consumption

Many people drink tea for cultural reasons, while others drink it for its desirable sensory properties or its probable health benefits. Teas are popular around the world with claimed benefits to slimming, beauty, and relaxation. Specific health claims in various countries promote green tea for respiratory health, reducing cholesterol, and balancing blood pressure (Mintel 2005a).

North America

Segal (1996) reported that about 94% of the tea consumed in the U.S. was black, followed by 4% green, 1% oolong, and 1% flavored. Before World War II, green tea accounted for about 40% of the U.S. market. However, World War II made importing green tea from China and Japan impossible, so the U.S. had no choice but to import black tea from British controlled India. When World War II was over, almost 99% of Americans drank black tea. The U.S. tea sales in retail volume approached 34,000 tons in 2004 (Euromonitor.com 2005), although most of that tea was black or some type of fermented tea. Many stores now carry green tea products, green tea is available to purchase on-line and a number of books have been published on green tea, all of which may reflect increased consumption or demand for green tea in the U.S. market as well as other western countries. In addition, many ready-to-drink iced teas have been formulated using green tea as a base (Mintel 2005b). Recently, the number of green tea products or products containing green tea in retail food stores has increased tremendously in many parts of the world. Starbucks launched green tea frappuccinos and helped transform green tea into a mainstream trend (Ong 2005); they now serve several drinks that use green tea as an ingredient. In 2005, a telephone survey conducted for the American Institute for Cancer Research (ICR 2005) reported that 8.3% of respondents drank green tea beverages 5 or more times a week, 5.6% drank such beverages 3-4 times a week, 8.2% drank green tea products once or twice a week, 8.4% answered they drank them once or twice a month, and 67.9% answered they rarely or never drank green tea beverages.

Asia

Green tea is popular in Japan. In a cohort study (Kuriyama and others 2006) to examine the relationship between green tea consumption and mortality due to cardiovascular disease, cancer, and all causes in Japan, 40,530 Japanese adults between 40 to 79 years old with no history of stroke, coronary heart disease, or cancer were recruited. Green tea consumption was divided into five different frequencies; never, occasionally, one to two cups a day, three to four cups a day, and five or more cups a day. The researchers combined never and occasionally into the less than one cup a day because only 7% of the respondents said they never drank green tea and 19% said they drank green tea occasionally. Of 40,530 participants, 10,702 (26.4%) answered they drank less than one cup of green tea a day (Never drank green tea and occasionally drank green tea, combined), 8,803 (21.7%) answered they drank one to two cups of green tea a day, 8,839 (21.8%) answered they drank three to four cups of green tea a day, and 12,186 (30.1%) answered they drank more than five cups of green tea a day. In Japan, the typical cup volume is 100 mL.

Tea consumption has been on the rise in Korea. Park and others (1996) conducted a survey in 1994 to learn consumer attitudes about green tea in five different cities in Korea. A total of 1184 consumers responded to the survey. Two hundred eleven (17.8%) consumers answered that they didn't drink green tea at all. Consumers who said they drank green tea were asked their frequency of consumption. Of these consumers, 48.8% answered they drank green tea once a week, 31.6% answered two to three times a week, 13.6% answered once a day, and 6.1% drank green tea more than two times a day. The survey indicated that among respondents, 58.2% of consumers preferred green tea to oolong tea and black tea. Per capita tea consumption increased from 10 grams in 1990 to 80 grams in 2003 (Tea Experiment Station 2007). Euromonitor (2006) reported that Korean consumers prefer locally produced tea over Chinese imports because Chinese teas violated Korean food standards.

In Thailand, cold drinks are preferred because of the hot climate. Green tea is the fastest growing non-alcoholic drink in Thailand. The green tea market grew from USD 650,000 in 2001 to USD 150 million in 2004 (BeverageDaily.com 2006). Nookabkaew and others (2006) noted that jiaogulan, green tea, and mulberry tea were the main herbal teas consumed among Thai consumers for health benefits.

Europe

In an epidemiology study conducted by Mennen and others (2007) in France, 954 men and 1639 women were asked about their green tea consumption. Only 6% (58 out of 954) men and 12.1% (198 out of 1639) of women answered that they drank more than 150 mL of green tea per day.

In the United Kingdom, green tea products consumption increased by 87% from 2000 to 2003. In 2003, 1,150 tons of green tea were consumed. The positive health benefits may be driving consumption of green tea (Nutraingredients.com 2005).

How green tea is evaluated

Ukers (1935) described tea evaluation using expert judges of teas. He suggested that tea tasters needed training but had to have ‘a delicate palate and an exquisite sense of smell.’ Judges should evaluate green tea on three aspects: appearance, twist, and odor of the dry tea; the color, brightness, and smell of the infused leaf; and the color, thickness, strength, pungency, and flavor of the infused tea. Tea experts should be able to evaluate individual teas as well as know how different teas would blend.

Owuor (2003) stated that judging tea quality and tasting is subjective and rather elusive. Tea tasting has been used over centuries to evaluate tea quality; it is fast and affordable, which was necessary for the tea trade. Also tea tasting allows many samples to be evaluated quickly. When tasting, tea is sucked rather than sipped, so that

> “the liquor is drawn to the back of the mouth, on an inward breath, and up to the olfactory nerve in the nose. The liquor is then swished backwards and forwards and brought into contact with the tongue, palate, and other areas of the mouth where sensory receptors are located. Using this skillful, if somewhat noisy, technique, the taster can feel, taste, and smell the liquor virtually simultaneously and is thus able to determine its briskness, strength, body, and flavor.”

The author stated that this was a subjective method and may be largely influenced by tasters’ health, personal preferences, and prejudices.

The sensory characteristics of green tea

According to Ukers' book, *All About Tea* (1935), green tea possesses "a clear, greenish-yellow or greenish-golden color, bright and lustrous to the bottom of the cup" for a young, early picked leaf and "a dull, lifeless, dark or brownish yellow color" for a green tea made from an old or low-grade leaf. However, the author stated that it was difficult to describe words used for tasting teas. The terms that he listed were brisk, full, rich, thick, insipid, grassy, fishy, smoky, flavor, harsh, metallic acrid, pucker, toasty, malty, brassy, point, body, strength, pungency, bite, and cream down.

Recently, Ellis (2002) used a range of words to explain green tea flavor in her book, which was intended for the public. Words were sweet, fragrant, malty, strong, full-bodied, spicy, fragrantly fruity, fresh, herbaceous, smoothly fragrant, deep, astringent, grassy-tasting, smoky, savory strength, bitter, and refreshing.

Processing Affecting Flavor of Green Tea

Many steps are required for processing green tea. When fresh tea leaves are harvested, the leaves are usually spread out, followed by a fixing process of either roasting or steaming. Next is rolling to shape the green tea leaf, followed by drying (Xu and Chen 2002). Depending on the manufacturer, roasting or steaming and drying are repeated (Jung 2004). Each step contributes to the flavor of the final product. Laying fresh leaves out for 1-3 hours helps reduce grass-like odor and evaporate water in the leaves (Xu and Chen 2002). In the leaves, enzymes remain active; they are polyphenol oxidase, catalase, peroxidase, and ascorbic acid oxidase. During fixing, enzymes are deactivated (Cheng 1982). At the same time, the cholorophyll content decreases because of high temperature and the pH changes (Xiao 1963). During processing, tea polyphenols go through oxidation, hydrolysis, polymerization, and transformation (Xu and Chen 2002). Proteins hydrolyze into free amino acids due to high temperature and moisture, resulting in an increased amino acid content in green tea. Soluble carbohydrates increase during processing, especially during roasting. Starch is hydrolyzed and becomes soluble sugars. More than 600 volatile compounds have been identified in green tea, most of them produced during processing because only a few of the volatile compounds come from fresh leaves (Xu and Chen 2002).

Volatile compounds contributing to green tea flavor

Volatile compounds in green tea have been studied extensively using gas chromatography-mass spectrometry (GC-MS) to understand the differences in the composition of green teas. More than 600 volatile compounds have been identified in green tea (Xu and Chen 2002). Yamanishi and others (1973), Nguyen and Yamanishi (1975), Takei and others (1976), Yamanishi (1978), and Kawakami and Yamanishi (1981, 1983) studied aroma of various green teas, including *Hojicha* (roasted green tea), *Kabusecha*, *Kamairicha*, spring green tea, *Sencha*, *Bach-Mao* tea (Vietnamese green tea), Vietnamese green tea, and *Longjing* tea (Chinese green tea).

In *Hojicha* (roasted green tea), researchers identified 66 volatile compounds, of which 21 were pyrazines (Yamanishi and others 1973). Pyrazines are major components of roasted flavor. In addition to pyrazines, furans and pyrroles were detected at higher concentrations than in *sencha* (Yamanishi 1978).

Kabusecha is a green tea made from tea leaves grown in the shade. Alpha-ionone, β-ionone, 2,6,6-trimethylcyclohex-2-en-1-one, 4-(2,6,6-trimethyl-1,2-epoxycyclohexyl)-e-buten-2-one, and *cis*-2-pentenol were dominant volatile compounds in Kabusecha (Kawakami and Yamanishi 1981).

Kamairicha was characterized with 62 volatile compounds (Kawakami and Yamanishi 1983). Indole, nerolidol, benzyl alcohol, cis-jasmone, methyl palmitate, cadinol, hexanoic acid, β-ionone, linalool, and cis-3-hexenol were the most abundant.

Spring green tea from Japan had aroma compounds of linalool, octanol, cis-3-hexenyl-hexanoate, α-terpineol, β-sesquiphellandrene, linalool oxides, calamenene, geranylacetate, benzylalcohol, β-ionone, cis-jasmone, 5,6-epoxy-β-ionone, nerolidol, dihydroactinidiolide, and indole (Takei and others 1976). According to Yamanishi (1978), *Sencha* is the most popular tea in Japan because of its briskness, suggesting that *cis*-3-hexe-1-ol, hexanoate, *trans*-2-hexenoate, and dimethyl-sulfide contributed to the briskness. In another study (Kawakami and Yamanishi, 1981), *Sencha* had 40 identified peaks and linalool, linalool oxide (trans, pyranoid), nerolidol, β-ionone, and 4-(2,6,6-trimethyl-1,2-epoxycyclohexyl)-3-buten-2-one had the highest concentrations.

In *Bach-mao* tea, which is the highest quality green tea produced in Vietnam, linalool, *cis*, *trans*-linalool oxides, 3,7-dimethyl-1,5,7-octatriene-3-ol, 2,5 (or 2,6)-dimethyl pyrazine and 1-

ethyl-2-formylpyrrole were the major volatile compounds (Nguyen and Yamanishi 1975). In another study, Yamanish (1978) found similar results for *Bach-mao* tea; most volatile compounds in this case were pyrazines and pyrroles produced during pan-firing (Yamanishi 1978).

There were 76 compounds identified in *Longjing* (Chinese green tea) tea. Many of the volatile compounds were pyrazines, linalool oxides, carboxylic acids, lactones, geraniol, 2-phenylethanol, and ionone; researchers suggested that these compounds contributed to the pan-fired, floral, and sweet aroma (Kawakami and Yamanishi 1983).

More recently, Choi (1991) identified 41 peaks from Korean commercial green teas. Samples that had been steamed were characterized with linalool, nerolidol, cis-jasmone, 2,6,6-trimethyl-2-hydroxycyclohexanone, and indole. Green teas that had been roasted had mostly the following volatile compounds: linalool, geraniol, benzylalcohol, phenylethanol, and phenol. Choi (1995) evaluated the volatile compounds of green tea picked in August and identified 32 peaks. The major aroma compounds were1-penten-3-ol, *trans, trans*-2,4-heptadienal, linalool, β-ionone, and nerolidol.

Kumazawa and Masuda (2002) used GC-MS and gas chromatography-olfactometry (GC-O) and found 54 peaks from two pan-fired green teas (Japanese *Kamairi-cha* and Chinese *Longing* tea) and a steamed green tea from Japan, *Sencha.* A total of 49 peaks were identified. Some of these compounds could be perceived as animal-like, burnt, buttery, caramel-like, cucumber-like, earthy/musty, fatty, floral, fruity, grape-like, green, hay-like, honey-like, meaty, metallic, mushroom-like, nutty, orange-like, phenolic, popcorn-like, potato-like, roasty, spicy, sweet, and vanilla-like characteristics.

Verrastro and others (2006) reported that bitterness is highly correlated with phenol concentration in green tea ($r=0.991$, $p=0.008$).

Recently, Liang and others (2008) found 18 volatile compounds in 23 Chinese green teas that related with consumer liking. The 18 compounds were n-valeraldehyde, n-caproaldehyde, 1-penten-3-ol, ethyl caproate, 2-methyl heptenone, linalool oxide I, linalool oxide II, linalool, phenyl aldehyde, terpineol, benzyl acetate, citral, citronellol, nerol, geraniol, geranial, β-ionone, and benzoic acid.

Non-volatile compounds contributing to green tea flavor

According to Yaminishi (1990), the most desirable tea is abundant in various components like catechin, caffeine, and amino acids. Tea flavor is more affected by interactions among the components, rather than one particular group.

Catechins

Catechins are a type of polyphenol found in the tea plant itself. It is a flavonoid, with a C_6-C_3-C_6 structure (Hara 2001). There are eight different types of catechins: catechin, epicatechin, gallocatechin, epigallocatechin, epicatechin gallate, catechin gallate, epigallocatechin gallate, and gallocatechin gallate (Wang and others 2000). According to Yamanishi (1990), catechin content in *Camellia Sinensis var. Sinensis* is around 10%. Nakagawa (1970b) studied taste characteristics of different types of catechins and measured the threshold of each kind. (+)-Catechin, (-)-Epicatechin, and (-)-Epigallocatechin were bitter with sweet aftertaste with thresholds of 51.05mg/100mL H_2O, 45.53mg/100mL H_2O, and 35.19mg/100mL H_2O, respectively. (-)Epicatechin gallate and (-)-Epigallocatechin gallate were bitter and astringent with 18.12mg/100mL H_2O and 20.15mg/100mL H_2O as threshold, respectively. In brewed tea, there are approximately 0.57% of (-)-Epicathechin, 2.15% of (-)-Epigallocatechin, 0.61% of (-)-Epicatechin gallate, 2.03% of (-)-Epigallocatechin gallate (Yamanishi 1990).

Tannin

Tannin has a strong astringent or pungent taste (Ukers 1935). Tea has high tannin content. It congeals proteins on the top of the mucous membrane layer of one’s mouth and makes the tissues contract (Rinzler 2001).

Caffeine

Caffeine is the stimulant in green tea (Ukers 1935). Caffeine possesses a bitter taste, and the detection threshold is 3 ppm in water, which is 0.0003%. It is important in tea flavor and briskness (Yaminishi 1990). The caffeine concentration of brewed teas from Japan, *Gyokuro* and *Sencha*, were 45 mg/100mL and 20.5-29.9mg/100mL, respectively (which converts to 0.045% and 0.0205-0.0299%). Three grams of tea leaves were brewed with 180 mL of boiling water for 2 minutes for this test (Nakagawa 1970a). Hicks and others (1996) evaluated the caffeine that was released from a Lipton bag of green tea and Korean green tea leaves. Boiling water was used and the samples were brewed for 5 minutes. Brewed tea from the Lipton bag green tea had 44.5mg/177 mL (0.025%) caffeine and brewed tea from Korean green tea leaves had 56.1mg/177 mL (0.032%) caffeine. In this study, 2.3g of tea was used for preparation. Another reference (Rinzler, 2001) reported green tea contained 24mg/100mL (in original document, 36 mg/150mL) caffeine when brewed 5 minutes. Japanese green tea contained less caffeine: 14 mg/100mL (in original document, 21 mg/150 mL); it was brewed for 5 minutes. Both green teas were loose. The author stated that tea brewed from loose leaves had more caffeine than tea brewed from tea bags or made from instant tea.

Amino acids

The amino acids in green tea are a major factor in its quality (Choi 2002), with about 20 different amino acids contributing to the overall content. Theanine accounts for more than 60% of the amino acids; theanine, glutamic acid, asparagines, arginine, and serine account for about 90% of total amino acids (Kim 1996). Amino acids are mainly responsible for brothy taste (Nakagawa 1975). Syu and others (2008) found theanine, γ-aminobutyric acid, serine, threonine, glycin, alanine, valine, tryptophan, phenylalanine, isoleucine, leucine, and tyrosine from green teas from China and Taiwan. Theanine again was the most abundant, ranging from 1307.86 to 3029.98 μg/g in green tea leaves and from 686 to 936 μg/g in powdered green tea, while other amino acids ranged from 2.42 to 254.23 μg/g. L-theanine is an amino acid found exclusively in green tea. Its effect on taste includes umami, sweet, and bitter (Narukawa and 2008). When tea leaves were exposed to sun, theanine changes to catechins. Therefore, green teas made with tea leaves harvested later in the season have less theanine but more catechins (Choi 2002).

Sugars

Sugars are responsible for sweetness of green tea (Nakagawa 1975).

Descriptive Sensory Studies, Consumer Studies, and Instrumental Studies on Flavor of Green Teas

Descriptive sensory studies on flavor of green teas

A number of sensory terminologies have been used for tea. Many researchers have studied green tea flavor using descriptive sensory methods and have provided some sensory terminology (Yamanishi 1977; Yaminishi 1990; Park and others 1996; Park and others 1998; Park and others 1999). These authors also included terms related to the appearance (e.g., color of dried green tea leaves, shape of tea leaves, and color of infused green tea), flavor (fresh floral, sweet floral, citrus, sweet fruity, fresh green, sweet, resinous, roasted, dimethyl sulfide-like, green, burned, acidic, fermented, oily, earthy, moldy, seaweed, dried leaf, nutty, juice of motherwort, acrid), fundamental tastes (bitter, sweet, aftertaste, umami), and mouthfeel properties (astringent, biting/pungent).

Togari and others (1995) used 16 sensory terms developed by Yamanishi (1977) to evaluate green, oolong, and black tea. Their flavor characteristic terms were fresh floral, sweet floral, citrus, sweet fruity, fresh green, sweet, resinous, roasted, dimethyl sulfide-like, green, burned, acidic, fermented, oily, earthy, and moldy. However, the authors did not present references to help explain the attributes.

Cho and others (2005) compared 10 ready-to-drink tea products in cans, using 17 attributes: floral, lemon, roasted tea, roasted rice tea (artificial), sweet odor, green tea, oolong tea, black tea, boiled milk, arrowroot/rooty, sour taste, sweet taste, chestnut shell, oily, burnt leaf, bitter taste, and astringency. Perhaps because the products tested in this study were processed canned products, the attributes included somewhat generic names of tea such as green tea, oolong tea, and black tea to describe tea products. Character references were used, but the intensities of the references were not given.

All of the earlier studies included a limited number of samples that may not represent the extensive variety of green teas.

Studies on green tea brewing methods

Many factors influence the brewing of green tea: water to tea ratio, water, water temperature, brewing length, brewing equipment, use of water bath while brewing, etc. Earlier research on green tea brewing methods varied in their approach to brewing and what they wanted to learn. In instrumental studies on brewing methods (Lee and others 1989; Kwon and others 1990; Jang and others 2006), authors recognized that sensory evaluations of green tea were important. Recently, Lee and others (2008) studied methods of preparing green tea with two water temperatures (60 and 80℃) and six brewing times (0.5, 1.5, 2.5, 3.5, 4.5, and 5.5 minutes). The authors suggested that the optimal brewing method was 60℃ for 3 minutes or 80℃ for 1 minute based on just-about-right evaluations from consumers. Descriptive sensory analysis was used to determine if these two brewing methods worked for discriminating green tea samples. The flavors of other preparation methods were not studied.

Taste is important to consumers who buy functional food for the health benefits. Thus, if the literature suggests that different brewing methods may result in different flavors for green tea, then how brewing methods change green tea flavor is also important. Previous research has rarely studied this.

Studies on multiple brews of green tea

Some literature shows contradictions in the conclusions about brewing green tea multiple times. Schapira and others (1982) recommended using fresh tea leaves or a tea bag for more tea, instead of using already brewed tea leaves or a used tea bag. The authors also stated that "spent leaves have nothing more to offer you than a little color and a little bitterness." In contrast, in Asia, high quality green tea may be brewed multiple times and many pricy products suggest brewing multiple times in their infusion directions. Kim (1996) stated that green tea could be brewed up to three times. Astill and others (2001) stated that the first brew is discarded and the second and succeeding brews are consumed in the Far East.

Most researchers have only studied the first brew of green tea. Only limited numbers of scientific researchers have used tea brewed more than once in their studies (Byun and Kim 2006; Hicks and others 1996). As yet, any changes in the flavor of green tea when brewed multiple times are not known.

Consumer studies on flavor of green teas

Park and others (1998) compared green teas from Korea, Japan, China, and Vietnam in their chemical components as well as sensory quality using Korean judges. They concluded that, although Japanese *Gyokuro* green tea is high quality tea, it did not suit Koreans' palates. Koreans also preferred tea made from pan-fired green tea over steamed green tea.

Park and others (2004) conducted a liking test of a Korean canned green tea product with US 294 consumers from New York, Atlanta, Chicago, and San Francisco. Although most of the

US consumers liked the flavor of green tea (14.6% answered excellent, 43.5% answered good, and 34.4% answered moderate), positive answers for flavor liking and overall liking were generally lower than answers to other questions such as liking the package, package design, etc. Also, consumers commented that the green tea should be sweeter and/or the flavor and aroma should be improved. Based on these results, researchers recommended modifying the flavor of green tea to better suit US consumers.

Cho and others (2005) tested commercial canned tea products: 5 green, 2 oolong, and 3 black teas. They found that black teas were generally preferred when no information was provided at the time of tasting.

Instrumental studies on flavor of green teas

Volatile fractions of various green teas have more than 50 active aroma compounds, including ones that could yield nutty, popcorn-like, metallic, floral, meaty, fruity, potato, green, cucumber-like, and hay-like characteristics (Kumazawa and Masuda 2002). Wang and others (2000) found that epigallocatechin gallate and epigallocatechin appeared to play the key role in changes in sensory qualities of a processed green tea beverage. Age and processing had clear effects on volatile flavor compounds in those teas containing the youngest leaves and certain processing parameters generally having the highest amounts of catechins and amino acids, which could result in off flavors (Kinugasa and others 1997). In Vietnamese green tea, linalool; cis- and trans-linalool oxides; 3,7-dimethyl-1,5,7-octatriene-3-ol; 2,5 (or 2,6)-dimethylpyrazine; and 1-ethyl-2-formylpyrrole were the predominant components but anethole and dimethoxybenzene, which can give licorice-like flavor, were also found (Nguyen and Yamanishi 1975). Gas chromatography mass spectrometry (GC-MS) incorporates both the qualitative identification and the quantitative measurement of character components in complex mixtures. Internal standards help in obtaining accurate quantification (Hites 1997).

Studies on green tea brewing methods

Lee and others (1989) studied how brewing methods changed green tea constituents and learned that tannin, free sugar, and total nitrogen in green tea increased as water temperature and brewing time increased. Kwon and others (1990) studied the caffeine content of coffee, black tea, and green tea where these were prepared using different brewing times (5, 10, 15, 20 minutes) and water temperatures (40, 60, 80, 100°C). These authors found that caffeine content in green tea increased noticeably at higher water temperatures. Caffeine content increased as brewing length increased, but the increment was minimal. Brewing time may have had a minimal effect because it was studied with the water temperature set at 100℃. Jang and others (2006) studied brewing methods at differing water temperature (60, 70, 80, 90, 100℃) and brewing times (0.5, 2.5, 4.5, 6.5, and 8.5 minutes). These authors found soluble solids, phenolics, and flavonoids increased in brewed green tea when the water temperature and brewing length increased.

Studies on multiple brews of green tea

Hicks and others (1996) measured the concentrations of caffeine, theobromine, and theophylline from three repeated brews of four different types of tea. In their study, two samples were green tea. One was Lipton green tea in tea bags and the other was Korean green tea in loose form. About 2.3g of each sample was brewed in 177 mL of boiling water for 5 minutes. The brewed tea bag or leaves were brewed two more times using the same brewing conditions. The caffeine and theobromine released in each brew of tea decreased as they were brewed repeatedly. The decrease in caffeine content from Brew 1 to Brew 2 was very sharp.

Byun and Kim (2006) evaluated the amount of ascorbic acid and chlorophyll in infused tea when different water temperatures (60, 70, 80℃) and brewing times (first brew, second brew) were used, finding that the chlorophyll content differed due to brewing water temperature. Japanese green teas had two to three times higher chlorophyll contents than Korean teas. On the other hand, Korean green teas had higher ascorbic acid content than Japanese teas.

Studies on effect of green tea storage

Horita (1987) reported changes in the volatile compounds of green tea during storage. All 14 compounds increased with storage. Fourteen compounds were 1-penten-3-ol, 1-pentanol, (Z)-2-penten-1-ol, 6-methyl-5-hepten-2-one or 1-hexanol, (Z)-3-hexen-1-ol, (E,Z)-2,4-heptadienal or linalool oxide or (E)-furanoid, (E,E)-2,4-heptadienal, 1-octanol, 2,6,6-trimethyl-2-hydroxycyclohexanone, β-cyclocitral, α-ionone, or geranylacetone, β-ionone, 5,6-epoxy-β-ionone, and dihydroactinidiolide.

Studies on effect of green tea processing

Kawakami and Yamanishi (1983) compared *Longjing* and *Kamairi Cha*. Longjing is a Chinese green tea and Kamairi Cha is a Japanese one. Both were roasted. However, *Longjing* had higher peak area % for all roasting process related compounds such as pyrazines (2,5-dimethylpyrazine, 2-methyl-5-ethylpyrazine, trimethylpyrazine, and 2,5-dimethyl-3-ethylpyrazine), pyrroles (1-ethyl-2-formylpyrrole, 1-ethyl-2-acetylpyrrole, and 2-acetylpyrrole), and ionone related compounds (2,6,6-trimethyl-2-OH-cyclohexanone, β-cyclocitral, 2,6,6-trimethylcyclohex-2-1,4-dione, β-ionone, cis-jasmone, 5,6-epoxy-β-ionone, teaspirone, and dihydroactinidiolide).

Yamanishi and others (1989) compared green teas that were processed differently. Two lower grade green teas, *Bancha* and *Hojicha*, and a roasted *Bancha* were compared. Only area percentage was provided and *Hojicha* was markedly higher in percentage area for furans (furfuryl alcohol, furfural, 2-acetylfuran, and 5-methylfurfural) and pyrroles (2-acetylpyrrole, 2-formylpyrrole, 1-ethyl-2-formylpyrrole, and a pyrrole derivative).

Relating sensory analysis studies, consumer studies, or instrumental studies

Togari and others (1995) evaluated green tea using sensory terms and volatile compounds composition. Stepwise multiple linear regression analysis, principal component regression, and partial least squares were used to relate the sensory data to the chromatographic data.

Recently, Liang and others (2008) explored the relationship between green tea preference data and chemical compositions and volatile compounds. Preference was measured using six people to judge dry tea appearance, aroma, liquor color, taste, and infused tea. The authors developed a regressive formula and suggested that this could be used to simplify evaluating green tea.

Conclusions

Some publications have studied the sensory characteristics and volatile compound composition of green teas from different countries of origin, tea tree varieties, harvesting times, processing methods, and brewing methods. Many researchers who have studied the aroma characteristics of green tea stated the need for sensory evaluation. There were some efforts to use sensory evaluation to understand the flavor of green tea. However, researchers used subjective terms, did not define terms precisely, used small numbers of green tea samples, and often used inappropriate methods. A well defined, referenced sensory lexicon for the category of green tea would be useful in reliably evaluating flavor characteristics of green tea. Also, minimal to no research has been conducted on flavor changes due to multiple brewing times, different brewing methods, different processing methods, and various storage times. Moreover, no research has been done on what flavor characteristics drive consumers' liking of green tea.

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CHAPTER 2 - A Lexicon for Flavor Descriptive Analysis of Green Tea

A lexicon for describing green tea was developed using descriptive analysis methods. A highly trained, descriptive sensory panel identified, defined, and referenced 31 flavor attributes for green tea. One-hundred and thirty eight green tea samples from 9 countries: China, India, Japan, Kenya, Korea, Sri Lanka, Taiwan, Tanzania, and Vietnam were selected to represent a wide range of green teas. Attributes could be categorized as “Green” (asparagus, beany, Brussels sprout, celery, parsley, spinach, green beans, green herb-like), “Brown” (ashy/sooty, brown spice, burnt/scorched, nutty, tobacco), “Fruity/Floral” (fruity, floral/perfumy, citrus, fermented), ”Mouthfeel” (astringent, tooth-etching), “Basic Tastes” (sweet aromatics, bitter) and other attributes (almond, animalic, grain, musty/new leather, mint, seaweed**,** straw-like). Some attributes such as green, brown, bitter, astringent, and toothetching were found in most samples, but many attributes were found in only a few samples. Green tea processors, food industry, researchers, and consumers will benefit from this lexicon with precise definitions and references that reliably differentiate and characterize the sensory attributes of green teas.

Introduction

The fastest growing beverage category in the United States (US) in the next few years is expected to be that of wellness or “functional” beverages to meet consumer demands for drinkable nutrition and health benefits (Miller 2005). Mintel (2004) expects functional beverage sales will grow from $10 billion in 2004 to $12.8 billion in 2009 and Sloan (2005) reported that premium and exotic teas are expected to grow from $6.8 to $10 billion by 2010. Teas are popular around the world with claimed benefits such as slimming, beauty, and anti-stress. Specific health claims in various countries promote respiratory health, reducing cholesterol, and balancing blood pressure (Mintel 2005a). Many people drink tea for the place it holds in their culture, while others drink it for its desirable sensory properties or its probable health benefits.

Green tea is one of the three major forms of tea (green, black, and oolong). For green tea, leaves are processed and dried immediately after harvesting so that no fermentation occurs and the tea leaf often remains reasonably green (Rinzler 2001; Macrae and others 1993). Different green teas exist because of different processing methods, harvest times of tea leaves, tea tree species (*Camellia sinensis* var. sinensis or var. assamica), and region (Jung 2004).

US tea sales in retail volume approached 34,000 tons in 2004 (Euromonitor.com 2005), although most of that tea was the black or fermented type. Many stores now carry green tea products, green tea is available to purchase on-line, and a number of different books have been published related to green tea, all of which may reflect increased consumption or demand for green tea in the US market as well as other western countries. In addition, a large number of ready-to-drink iced teas have been formulated using green tea as a base (Mintel 2005b). In recent years, the number of green tea products or green tea containing products in retail food stores has increased tremendously in many parts of the world. However, while there have been increasing sales volume of green tea, the US palate, in particular, appears quite variable in its response to the flavor and acceptance of green tea.

The flavor of green tea has been studied using both chemical and sensory methods. Volatile fractions of various green teas showed more than 50 aroma active compounds including ones that could yield nutty, popcorn-like, metallic, floral, meaty, fruity, potato, green, cucumber-like, and hay-like characteristics (Kumazawa and Masuda 2002). Wang and others (2000) found that epigallocatechin gallate and epigallocatechin appeared to play the key role in the changes of sensory qualities of a processed green tea beverage. Age and processing had clear effects on volatile flavor compounds with those teas containing the youngest leaves and certain processing parameters generally having the highest amounts of catechins and amino acids, that could result in off-flavors (Kinugasa and others 1997). In Vietnamese green tea, linalool; cis and trans linalool oxides; 3,7-dimethyl-1,5,7-octatriene-3-ol; 2,5 (or 2,6)-dimethylpyrazine; and 1-ethyl-2-formylpyrrole were the predominant components, but anethole and dimethoxybenzene, which can give licorice-like flavor also were found (Nguyen and Yamanishi 1975)

A number of sensory terms have been used for tea. Ellis (2002) used a variety of terms to describe green tea flavor in her book intended for the public. Terms included: sweet, fragrant, malty, strong, full-bodied, spicy, fragrantly fruity, fresh, herbaceous, smoothly fragrant, deep, astringent, grassy-tasting, smoky, savory strength, bitter, and refreshing. No precise definitions or references were provided. Other publications, intended for a scientific audience (Yamanishi 1977; Park and others 1996; Park and others 1998; Park and others 1999) also have provided some sensory terminology. Those authors included terms related to appearance (e.g. color of dried green tea leaves, shape of tea leaves, and color of infused green tea), flavor (fresh floral, sweet floral, citrus, sweet fruity, fresh green, sweet, resinous, roasted, dimethyl sulfide-like, green, burned, acidic, fermented, oily, earthy, moldy, seaweed, dried leaf, nutty, juice of motherwort, acrid), fundamental tastes (bitter, sweet, aftertaste, umami), and mouthfeel properties (astringent, biting/pungent). Togari and others (1995) used the16 sensory terms developed by Yamanishi (1977) to evaluate and differentiate among green, oolong, and black tea, but did not provide references to help with understanding of the attributes. Cho and others (2005) used descriptive analysis to compare 10 canned tea products using 17 different attributes, including floral, lemon, roasted tea, roasted rice tea (artificial), sweet odor, green tea, oolong tea, black tea, boiled milk, arrowroot/rooty, sour taste, sweet taste, chestnut shell, oily, burnt leaf, bitter taste, and astringency. Perhaps because the products tested were processed canned products, the list included somewhat generic names of tea such as green tea, oolong tea, and black tea to describe tea products. Character references were used, but intensities of the references were not given. All of the studies found were conducted on a limited number of samples that may not represent a broad range of green teas.

A sensory lexicon for the category of green tea can help in identifying the characteristics common to major varieties of green tea, can provide more useful sensory data to track experimental modifications, can be better compared to instrumental measures of sensory properties such as flavor compounds, and may help identify flavor characteristics that appeal to particular subsets of the global marketplace, e.g. US versus Asian consumers. At present, no such lexicon appears to exist. A lexicon needs to cover the wide range of green tea available in the category, provide terms that are appropriately defined, have references to assist in describing the flavor notes and anchor attribute intensities consistently, and demonstrate their reliability in distinguishing the flavor properties across the category of samples.

Precisely defined and referenced lexicon can be reproduced at different places or at different times (Drake and Civille 2003). A number of such lexicons have been developed: e.g., Prell and Sawyer (1988), Johnson and others (1987), and Chambers and Robel (1993) for fish; Johnson and Civille (1986) for warmed-over flavor in meat; Lyon (1987) for chicken flavor;

Heisserer and Chambers (1993), Drake and others (2001), and Retiveau and others (2005) for natural cheeses; Smith and others (1994) for off-odors in raw grains; Lotong and others (2000) for wheat sourdough bread; Day N'Kouka and others (2004) and Chambers and others (2006) for soymilk, and Vara-ubol and others (2004) and Bott and Chambers (2006) for beany chemicals.

The purpose of this study was to develop a lexicon for describing green tea, including a definition and reference for each attribute.

Materials and Methods

Tea Samples

One-hundred and thirty eight green teas (leaf form) were used to represent a wide range of various tea species, countries of origin, manufacturing methods, and prices. "White" tea, the very earliest and tiniest leaves of the larger green tea category, recently has been suggested by some people to be a separate tea category, but is included in the green tea category for this research. This large number of teas was used to ensure the lexicon would include the widest range of flavor characteristics that may be present in the category of green teas, a tenet proposed by Drake and Civille (2003). Samples were purchased or donated by companies and were obtained either by mail or personal delivery from China, India, Japan, Kenya, Korea, Sri Lanka, Taiwan, Tanzania, and Vietnam. Those countries and regions within those countries represent most of the major tea growing areas that produce green tea for commercial sale. The largest number of samples in this study came from China, Japan, and Korea. Samples included a range of leaf "age" from the first picking of very young leaf buds (now sometimes called "white" tea) to older leaf teas picked at the end of the season (approximately 6-7 months older). Teas also represented different production methods including steaming and roasting, hand processing and machine processing, and crushing, rolling, or tying leaves together into bunches. Tea samples included "fresh" samples (brewed within several months of picking and processing) and older samples (aged up to 2 years after picking and processing). Specific age and processing details were not available for approximately half the samples tested, but general information was gathered from most manufacturers to ensure a range was present. Retail prices for the samples ranged from approximately $2 per 100g (older leaves, machine processed, large growers/manufacturers) to over $400 per 100g (1st picking, organic, wild plants, hand processed, small high-mountain growers). All tea leaf samples were stored at 4°C for less than 2 months before evaluation.

Tea Preparation

Green tea samples were removed from the refrigerator at least one hour before brewing and allowed to reach room temperature. For each "pot" of tea, a 6g portion of green tea leaves was measured and set aside for brewing. Brewing was done in a small white porcelain teapot, approximately 350 mL in volume, representative of those typically used for preparation of tea in many Asian countries. Reverse osmosis, deionized, carbon filtered water was heated to 70°C and small amounts were poured into the teapot and each serving cup to warm the containers. After pouring out the "warming" water from the teapot, the 6g of green tea was placed inside the pot followed by 300 mL of the 70°C water. The green tea was brewed for 2 minutes and while it was brewed, the pot was swirled 10 times. The green tea was poured into a bowl through a porcelain strainer and approximately 45 mL of brewed tea was poured into each pre-warmed white porcelain teacup. These processes are typical of green tea preparation in homes and restaurants in Asia, where the largest amount of green tea is consumed. The water temperature used in this study represents a common temperature recommended for brewing green tea. Boiling water, typically used for brewing black or oolongs teas, is not recommended and typically is not used for green teas.

Panelists

A six-member highly trained panel from the Sensory Analysis Center at Kansas State University participated in this study. The panelists had completed 120 hours of general training and had a minimum of 1200 hours of general sensory testing including beverages, vegetables, and other food products with descriptors similar to those that might be found in tea.

Serving Procedure

Samples were served coded with 3-digit random codes in a random order, in part dictated by the availability of the samples. The order was controlled to ensure that panelists did not see all samples for a particular country, a specific age, or other specific variable close to each other in the design. One sample was served at a time. The same sample was prepared again 10 minutes later to provide a second, warm sample for the panelists to examine. Panelists generally tasted in 1½ hr sessions, although some were only 1 hr in length. Development of the lexicon with references took a total of 60 hours.

Panelists ate carrots and mozzarella cheese (Kraft® Natural Low-moisture part-skim Mozzarella cheese, Kraft Foods North America, Inc. Glenview, IL, USA) to reduce build-up of any flavors from one sample to the next. After eating those products, panelists used unsalted-top crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water as a final rinse before the next green tea sample.

Development of Definitions and References

The panel was instructed that a lexicon for green tea needed to be developed and some attributes may be universal to all green teas and some attributes may be unique to one or a only few green teas. The panel was asked to be as specific as possible in identifying attributes. General procedures for developing definitions and references were adapted from the flavor profile method (Caul 1957; Keane 1992).

Panelists were not told anything about the teas, (e.g. country of origin, type of tea leaf, and method of processing) they were drinking in order to reduce any possible biases. The panelists evaluated each green tea individually and first made notes on the descriptors present. After all the panelists were done, the panel leader led a conversation to reach agreement on the descriptors present in the green tea sample. Once the panel came to an agreement on the descriptors, they started to define the flavor note more precisely and suggest references for each of the descriptors. As much as possible, panelists attempted to use references products that were representative and exhibited a specific attribute as suggested by Piggott (1991). Specific attention was given to references because they can be used to overcome communication difficulties (Barcenas and others 1999), are helpful in lowering judge variability, allow calibration of the panel in the use of intensity scale (Stampanoni 1993), and help reduce the time needed to train a panel (Rainey 1986).

Results and Discussion

Lexicon

Generally, the sensory characteristics of green tea are comprised of the shape of tea leaves, color of tea leaves, color of brewed tea, aroma, and flavor (Jung 2004). The flavor lexicon developed in this research is shown in Table 2.1.

Green/Brown Flavors

For this study, color of the brewed tea was noted as green, yellow, brown, and/or red. Color was noted only to aid in determining if certain flavor characteristics were associated with specific colors. Correlation analysis shows that color helped only in determining whether green tea had "green" or "brown" flavor characteristics since green and brown color showed moderate correlation with green (0.795), and brown (0.74) flavor respectively. Yellow color was not correlated with any particular flavor attribute.

Table 2.1 Definition of Attributes for Green Tea Evaluation

Attributes	Definition	Reference
Green	Sharp, slightly pungent aromatics associated with green plant/vegetable matter, such as asparagus, Brussels sprouts, celery, green beans, parsley, spinach, etc.	Fresh parsley water = 9.0 (flavor) 25 gram of fresh parsley, rinse, chop, and add 300 ml of water. Let it sit for 15 minutes. Filter and serve liquid part.
Asparagus	The slightly brown, slightly earthy aromatics associated with cooked green asparagus.	Asparagus water = 6.5 (flavor) Weigh 40 g of fresh asparagus, wash, dice, add 300 ml of water, cover, microwave for 3 minutes on high. Serve liquid part.
Beany	The brown, somewhat musty earthy aromatics associated with cooked legumes such as garbanzo beans and lima beans.	Kroger Small Green Lima Beans = 5.0 (flavor) Measure juice out of can. Dilute: take 1 part of lima beans juice, and mix with 4

		part of water.
Brussels Sprouts	The somewhat sharp, slightly sour, pungent aromatics associated with cooked cabbage, Brussels sprouts, and cauliflower.	Brussels sprout water = 6.5 (flavor) Weigh 20g, wash, dice, add 300 ml of water, cover, microwave for 3 minutes. Filter and serve liquid part.
Celery	The slightly sweet, green, brown, slightly bitter aromatics associated with cooked dried celery leaves.	McCormick Celery Flakes water = 6.5 (flavor) Weigh 1.5g, add 300 ml of water, cover, microwave for 3 minutes on high. Filter and serve liquid part.
Green Beans	A viney, green, slightly brown, woody aromatics associated with processed green beans.	Del Monte Cut Green Beans (No Sodium) = 5.5 (flavor) Measure juice out of can. Dilute: take 1 part of green beans juice; mix with 4 part of water.
Green Herb-like	The aromatics associated with dry green herbs such as bay leaves, thyme, basil.	Mixture of McCormick bay leaves, McCormick ground thyme, and McCormick basil = 6.0 (aroma) Mix 0.5 g of each herb. Grind using mortar and pestle. Add 100 ml of water. Mix well. Put 5 ml of herb water in a medium size snifter. Add 200 ml water. Cover.
Parsley	The clean fresh green, bitter, pungent aromatics associated with cooked parsley.	Parsley water = 5.5 (flavor) Weigh 15g, rinse, chop, put in 300 ml of water, cover, and microwave for 3 minutes on high. Filter and serve liquid part.

Spinach	The brown, green, slightly musty, earthy aromatics associated with fresh spinach.	Spinach water = 6.0 (flavor) Weigh 35g of spinach, rinse, chop. Add 300 ml of water, cover, microwave for 3 minutes on high.
Brown	A sharp, caramel, almost burnt aromatic.	Sethness AP100 Caramel color = 7.0[a] (aroma) 4 drops on a cotton ball in a medium snifter, cover.
Ashy/Sooty	The light smokey/ashy aroma associated with burning tobacco such as cigarette smoke.	Camel Filters (Turkish and Domestic Blend) Cigarette smoked filter = 7.0 (aroma) Place 0.02 gram of smoked filter in a medium snifter. Add 100 ml of water. Cover.
Brown Spice	Aromatics associated with a range of brown spices such as cinnamon, nutmeg, allspice	Spice blend = 9.0 (aroma) Place ¼ teaspoon of McCormick Allspice, ¼ teaspoon of Cinnamon, and ¼ teaspoon of Nutmeg in medium snifter.
Burnt/Scorched	The somewhat sharp, acrid notes associated with burned or scorched vegetables or grains	FMV Wheat Puffs Cereal = 7.0 (flavor)
Nutty	Nutty characteristics are: sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent, bitter, etc. Examples: nuts, wheat germ.	Diamond® Shelled Walnut = 6.5 (flavor) Grind for 1 minute on high using blender.
Tobacco	The brown, slightly sweet, slightly pungent aromatic	Camel Filter cigarettes (Turkish and Domestic Blend) = 7.0 (aroma)

	associated with cured tobacco	Break cigarette and place 0.2 gram of tobacco in a medium snifter. Cover.
Almond	Aromatics associated with almonds that may be slightly cherry-pit like.	California grown shelled almond = 7.5 (flavor) McCormick Almond Extract = 5.0 (flavor) Place 100 ml of water in medium snifter. Add 1 mL of imitation almond extract. Cover.
Animalic	A combination of aromatics associated with farm animals and live animal habitation.	1-Phenyl-2-thiourea (aroma): Eastman Organic Chemicals 1-Phenyl-2-thioures in Fisher Scientific Propylene Glycol (character reference) 5,000 ppm (0.5 g in 100 g propylene glycol). Dip perfume strip (3 mm) in the solution and place in 20 ml test tube and cap.
Citrus	The aromatics associated with commonly known citrus fruits such as lemons, limes, oranges, could also contain a peely note.	McCormick Lemon Grass = 4.5 (aroma) Weigh 0.1 g of McCormick Lemon Grass. Place in a medium snifter. Add 100 ml of room temperature water. Cover.
Fermented	The yeasty notes that are associated with fermented fruits or grains that may be sweet, sour, slightly brown, and overripe.	Private Selection Burgandy Cooking Wine = 7.0 (aroma) Dilute 1 part wine with 1 part water. Serve 1 tablespoon in a 1 ounce cup, covered.
Floral/Perfumy	The somewhat sweet aromatics generally associated with fruit and flowers.	Geraniol Pure = 8.0 (aroma) Put 1 drop geraniol in 200 ml distilled water in large size snifter. Cover.

Fruity	A sweet, floral, aromatic blend, reminiscent of variety of ripe fruits such as apricots, peaches.	Blackberry WONF 3RA654 (Character reference) Place one drop of chemical on a cotton ball in a medium size snifter. Cover.
Grain	An overall grain impression that may or may not be accompanied by specific grain identities.	FMV Wheat Puffs Cereal = 6.0 (flavor)
Medicinal	Aroma characteristics of antiseptic-like products such as Band-aid, alcohol and iodine.	Band-aid adhesive Bandage = 6.0 (aroma) Place a bandage in a medium snifter, cover.
Mint	Aromatics associated with fresh mint; somewhat reminiscent of toothpaste. The sweet, green, earthy, pungent, sharp, mentholic aromatics associated with mint oils.	Fresh crushed mint leaf = 7.0 (aroma) Weigh 0.1 g of mint leaves. Crush. Place in a medium snifter, cover.
Musty- New Leather	New leather (like new shoes or purses)	2-6-Dimethylcyclohexanol (Character reference): 5 ppb (0.5% w/w: 0.5 g in 100 g propylene glycol) Place 1 drop of the chemical on a cotton ball in a medium snifter. Cover.
Seaweed	The aromatics associated with shellfish, fresh fish and ocean vegetation.	Pacific Foods Dried Sea Weed (Brown seaweed) = 6.5 (aroma) Weigh 1 g, add 300 ml of water; let it sit for 10 minutes. Jin Han International Dried Laver (Green) = 8.0 (aroma) Weigh 1 g, add 300 ml of water; let it sit

		for 5 minutes.
Straw-Like	The dry, slightly dusty aromatics with the absence of green; associated dry grain stems.	Walgreen Finest Natural Lecithin 1200mg (Character reference) Break 1 lecithin softgel and place in medium size snifter, cover.
Bitter	A basic taste factor of which caffeine in water is typical.	0.02% Caffeine Solution = 3.5 0.035% Caffeine Solution = 5.0 0.05% Caffeine Solution = 6.5 0.06% Caffeine Solution = 8.5
Astringent	The drying, puckering sensation on the tongue and other mouth surfaces.	0.03% Alum Solution = 1.5 0.050% Alum Solution = 2.5 0.10% Alum Solution = 5.0 0.15% Alum Solution = 7.5
Toothetch	A chemical feeling factor perceived as a drying/dragging when the tongue is rubbed over the back of the tooth surface.	0.1% Alum Solution= 4.0 Diluted Welch's Grape Juice = 6.0 1:1 with deionized water 0.2% Alum Solution= 9.0
Sweet Aromatics	Aromatics associated with the impression of sweet substances such as fruit or flowers.	Fischer Scientific Vanillin = 5.5 (aroma) Place 0.5 gram of Fischer Scientific Vanillin in 250 ml water in large snifter. Cover.

[a] Intensity, 0 to 15 point scale, 0 = none, 15 = extreme. Intensities of references are not based on a universal scale and may be relevant only to green tea evaluation.

Expected colors were green, yellow, and perhaps brown. Taylor (2003) stated that when green tea is infused, the color of tea should be greenish, pale primrose, or lemon-yellow color without any trace of red or brown and Chen and others (2002) identified chlorophyll A (green) and B (yellow-green) as the main contributing factors to the green tea color. Red should be found in black tea and the few tea samples that had a red color often got comments from panelists that the flavor of those green tea samples was closer to black tea than green tea. All the samples that showed any reddish color were purchased over the internet and were labeled as green tea. Red color did not correlate with any particular flavor attribute and no attribute was found only in green teas with a reddish color.

The term “green”, which has been used previously in some lexicons, was too general to describe the tea samples. The panel more precisely defined the various “green” notes in the tea samples and found specific vegetable references for each note. Consequently, in the early stages of lexicon development, many vegetable references were served to find appropriate references. Early on, panelists sometimes disagreed on the precise meaning of certain flavor attributes in the lexicon development process. For example, some panelists may have thought a sample was spinach-like, while others thought it was parsley-like. As lexicon development continued, they came to agreement on the precise meaning of the terms. For tea, green was broken down to various plant-like flavor attributes: asparagus, beany, Brussels sprouts, celery, green beans, green herb-like, parsley, and spinach. The most often used “green” terms were spinach, parsley, green beans, and asparagus. Other green attributes, green herb-like, celery, beany, and Brussels sprouts, were found in a fewer than 8 green tea samples. Asparagus was one reference that clearly was noted in some tea samples. It was the most commonly used “green” attribute to describe samples that were expected to be higher in quality based on age, processing, or cost.

The term “brown” also was separated into specific attributes: ashy/sooty, brown spice, burnt/scorched, nutty, and tobacco. Ashy/sooty and tobacco were found in more than 25% of the green tea samples while brown spice and nutty were found in a fewer than 6 samples.

All Other Flavors

Fruity/Floral-related attributes were also found: floral/perfumy, fruity, citrus, and fermented. Fruity was found in about 17% of samples, floral/perfumy and citrus were found in less than 10% of samples, and fermented was found in only one sample.

A straw-like attribute was found in more than 30% of green tea samples tested. This attribute, which may be associated with dry plant materials, may be the result of processing variations. About 30% of the green tea samples also had seaweed characteristic, varying in intensity from threshold to moderate. Seaweed was mentioned by other researches (Jung 2004; Kim 1996) as green laver aroma which often identified as dimethyl sulfide. In this study, seaweed was used to describe the aromatics associated with shellfish, fresh fish and ocean vegetation. Other flavor attributes such as almond, animalic, grain, medicinal, mint, and musty/new-leather were found in fewer than 12 green tea samples. However when those attributes were found, the intensity always was above threshold and was obvious to panelists, which indicates the importance of those attributes to specific samples.

Bitter and astringent were found for almost all of the green tea samples served. Choi (2002) and Chen and others (2002) indicated that catechin (the main polyphenol in tea) is the primary compound responsible for the bitter and astringent flavor notes. However, caffeine and saponin also contribute to bitterness of green tea. Epicatechin (a catechin derivative) and epigallocatechin (a catechin derivative) contribute to strong bitter and astringency and are the primary compounds for off-notes found in shelf-stable heat-processed green tea beverages (Wang and others 2000). These two kinds of gallate and gallic acid tend to be present in higher amounts as the leaves become larger (i.e. older) with later picking times.

More than 63% of green tea samples exhibited toothetch, although the intensity often was slight. Twenty percent of green tea samples had an overall sweetness. Previous researchers (Choi 2002) suggest that sweetness in green tea comes from amino acids and carbohydrates. Amino acids are present in green tea leaves at 2-4% of dry weight, while the content of carbohydrates (fructose, glucose, sucrose) in green tea leaves can be 3-5% dry weight (Chen and others 2002).

Wang and others (2002) classified volatiles found in green tea into categories such as green odor, floral aroma, roasted and nutty aroma, off-flavor (stale flavor, photo-induced flavor, retort smell, smoky-burnt odor). Many of those categories are similar to the categories found in this research. However, off-flavor is hard to define and measure because of the wide-ranging flavor of green tea. Off-flavor also is not a particularly helpful attribute because it is not clear what specific flavor defect needs to be corrected. Thus, off-flavor was not defined in this research.

Attribute References

In this research, a 15-point numerical scale with half-point increments was used with 0 meaning "None" to 15 meaning "Extremely Strong." Since green tea does not have a strong flavor compared to general food products in the U.S., references were scored on a product specific scale to differentiate green tea samples on subtle flavor characteristics (Table 2.1). Muňoz and Civille (1998) indicated that product specific scaling enables sample differences to become larger compared to the universal scaling since product specific scaling allows users a wider range of scale. However, products outside the category cannot be compared using this method. Thus, the intensity references for this study assume that only green tea is being evaluated. Intensities may need to be adjusted if non-green tea samples are measured.

Principal Component Analysis

To determine if the individual flavor attributes could be combined into a smaller set of flavor components, a principal component analysis was conducted. The first twelve principal components for this study on green tea flavor had Eigenvalues greater than 1 and explained 66 % of the variation. Each included at least two attributes with factor loadings greater than 0.25 (Table 2.2). In order to explain 99% of the variability in the study, 29 principal components were required. Six characteristic attributes (Brussels sprout, almond, fermented, beany, animalic, and celery) were present in only one to three samples, and thus, may not be needed when testing a more focused set of samples. When those attributes were removed from the PCA, the variability explained increased from 66% to 70.8%. However further elimination of attributes reduced variability explained. Lotong and others (2000) suggested that the loss in variability caused by reducing the number of attributes indicated that attributes cannot be reduced to smaller numbers when a detailed analysis of the flavor is necessary.

Table 2.2 Rotated Principal Component Analysis of 33 Attributes of Green Tea Flavor Scored on 138 Green Teas

Principal Component	Attributes
1	Ashy/sooty (–), brown (–), musty/new leather (–), medicinal (–), green (+), tobacco (–), spinach (+), seaweed (+), parsley (+), asparagus (+)
2	Toothetch (+), astringent (+), bitter (+), almond (+), parsley (+), green (+)
3	Overall sweet (–), fruity (–), tobacco (–), green (+), almond (–), spinach (+), floral/perfumy (–), brown (+), seaweed (+), ferment (–)
4	Burnt/scorched (–), grain (–), brown (–)

5	Citrus (–), brown spices (–), floral/perfumy (–), tobacco (+)
6	Mint (–), nutty (–)
7	Parsley (–), Brussels sprout (–), metallic (+), seaweed (+), asparagus (+)
8	Straw-like (–), spinach (+), floral/perfumy (–)
9	Beany (–), green beans (–)
10	Green herb (–), brown spice (–), medicinal (–)
11	Celery (–), ferment (+), seaweed (+), asparagus (–), almond (–)
12	Animalic (–), asparagus (–)

"+" = positive loading on the principal component

"–" = negative loading on the principal component

Conclusion

A lexicon of 31 flavor descriptive attributes was developed, defined, and referenced for green tea. Green teas can be described using this set of objectively determined sensory attributes instead of being judged subjectively by quality alone. Using the lexicon from this study, researchers can more accurately describe sensory green tea flavor and aftertaste and relate it to other sensory, physical, or chemical information.

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CHAPTER 3 - A Comparison of Green Teas from around the World

The objective of this study was to determine what flavor differences exist among a wide range of green teas (n=138) produced in various countries. Green teas can be grouped based on their flavor profiles. The country of origin appears to have a strong influence on the flavor of green tea probably because similar processing methods are widely used within each particular country and flavor is dependent, in part, on processing. In this study we found that roast-processed teas were mostly responsible for brown-related flavors and steam-processed teas were responsible for green-related flavors. The prices of the green teas did not differentiate the flavors of the samples. Often highly priced green teas were grouped with low-priced green teas from the same manufacturer or country of origin according to their flavor attributes. Differences in the tea plant varieties or cultivars seem to affect the flavors in green tea. However, such information was not known for many of the green teas in this research, and more study will be needed to determine the differences due to varieties or cultivars.

Introduction

The flavor of green tea may differ due to the differences in tea plant varieties, regions of origin, climates, harvesting seasons, processing methods, and other factors (Xu and Chen 2002). However, only limited data on the flavors of green tea were found and that information was mostly discussed for Korean teas (Cho and others 2005; OH Lee and others 2008; SM Lee and others 2008; Lee and others 2009). Recently a lexicon for green tea flavor was developed (Lee and Chambers 2007) that can be used to test a wide range of green teas in order to help researchers, processors, green tea retailers, beverage industrialists, and consumers better understand the flavors of various green teas.

There are 2 major tea plant varieties, *Camellia Sinensis O. Kuntze var. Sinensis* and *var. Assamica* (Kim 1996). The *sinensis* variety produces small amounts of tea because the plants grow slowly and have smaller leaves. On the other hand, *var. Assamica,* also known as Assam tea, is faster-growing and has larger leaves, resulting in a higher yield (Ukers 1935; Choi 2002). It has been suggested that one variety may be better than the other for particular kinds of tea

(Segal 1996; Choi 2002) and the *sinensis* variety commonly used for green tea production (Taylor 2003). However, countries that produce the *Assamica* variety have also started producing green tea because the demand for green tea has increased markedly in recent years.

Green teas from different countries may have different appearances, aromas, or flavor characteristics (Choi 2002). Variations caused by the origin of the tea may be inclusive of tea plant varieties, climate, processing methods, age, and other issues. Clearly, environmental effects, such as temperature, sunlight, and rain will vary from country to country and within a country. Also, processing methods vary from country to country. For example, in China, pan-firing is the most common initial processing method, while Japanese green teas usually are steamed (Xu and Chen 2002). Chinese green tea leaves that are roast-processed tend to be curly whereas Japanese green tea leaves that are steam-processed tend to be thin and straight (Kim 1996). Even within China itself, green teas differ from region to region because teas are processed using slightly different methods (Ukers 1935).

The processing methods that various manufacturers employ contribute to the flavor of the final product. The methods that manufacturers generally use are roasting, steaming or both. Multiple processing (e.g. repeating the roasting process) is also common (Jung 2004). During roasting or steaming, enzymes in fresh leaves such as polyphenol oxidase and peroxidase are deactivated (Hara and others 1995). At the same time, the chlorophyll content decreases because of the high temperature and pH changes (Xu and Chen 2002). During processing, tea polyphenols go through oxidation, hydrolysis, polymerization, and transformation (Xu and Chen 2002). The proteins hydrolyze into free amino acids due to the high temperature and moisture, resulting in an increased amino acid content in green tea. Soluble carbohydrates also increase during processing, especially during roasting. Starch is hydrolyzed and becomes soluble sugar. All of these changes occur during processing and may affect the flavor of green tea.

The harvesting seasons of tea leaves affect the flavor of green tea because the amount of nutrients differs according to the age of tea leaves. For example, theanine is a major amino acid in green tea and it causes much of the tea's umami, sweet, and bitter tastes (Narukawa and others 2008). When tea leaves are exposed to the sun, theanine changes to catechins, which are polyphenols (Hara 2001). Catechins are responsible for 70-75% of the bitterness and astringency in tea (Chen and others 2002). Green teas made with tea leaves harvested later in the season have less theanine but more catechins and, therefore, have more astringency and bitterness (Choi 2002). Thus, green teas made with leaves harvested early in the season may have umami and sweet taste whereas green teas made with leaves harvested later in the season will be more bitter and astringent.

The price of green tea often is used as an indication of the quality (Hattori and others 2005) and green teas produced with earlier harvested tea leaves generally are more expensive than green teas made with leaves harvested later in the season. High quality green teas are associated with higher amino acid content, leaves that have been harvested earlier in the season, hand-processed using traditional methods, wild tea plants, or organically grown tea leaves. The first harvesting happens during April and early May and green tea made in this season has the best quality and, therefore, the highest price tag (Hara 2001).

The objective of this study was to evaluate a large group of green tea samples, focusing on brewed leaf green tea to understand the sensory differences that exist among a wide range of green tea samples that vary in countries of origin, prices, varieties and cultivars, and manufacturing methods.

Materials and Methods

Tea Samples

One hundred thirty-eight teas, representing at least nine countries of origin, different manufacturing methods, and a wide range of prices were used in this study. The green tea samples came from 9 different countries: China (n = 46), India (n = 6), Japan (n = 40), Kenya (n = 3), Korea (n = 31), Sri Lanka (n = 4), Taiwan (n = 4), Tanzania (n = 1), Vietnam (n = 1), and 2 samples of unknown origin. Different processing methods included steaming, roasting, baking, hand processing, machine processing, crushing, rolling, and/or tying leaves together into bunches. The price for the samples ranged from approximately USD 2/100 g to more than USD 400/100 g.

Tea Preparation

Porcelain tea pots (approximately 350 mL in volume), tea bowls, strainers, and tea cups, all used in the lexicon's development (Lee and Chambers 2007), were used. The International Organization for Standardization (ISO3103 1980) recommended using white porcelain tea wares to maintain reliable results. Reverse osmosis, deionized, carbon filtered water was used for brewing. The samples were prepared by following the brewing method used in Lee and Chambers (2007). Six grams of each green tea sample were brewed in 300 mL of 70°C water for 2 min. The tea pot was swirled 10 times clockwise while brewing. When the brewing process was finished, the green tea was poured through the porcelain strainer into the porcelain bowl. Approximately 45 mL of tea was poured into each pre-warmed tea cup.

Panelists

Six highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University (Manhattan, KS, USA) participated in the study. Each panelist had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing. The panel participated in developing the green tea lexicon (Lee and Chambers 2007), thus they were already familiar with it.

Serving Procedure

Green tea samples were served with 3-digit random codes and one sample was presented at a time. The same green tea sample was prepared and served again 10 min after the first sample was served to provide enough tea for the panelists to evaluate. The serving order was randomized as much as possible but was partly influenced by the availability of the samples. Generally, testing sessions were 90 min long, although some sessions were 60 or 120 min long. Usually 4 samples were tested in a session. Unsalted crackers (Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water were provided for palate cleansing. Unsalted crackers is the most effective cleanser for perceived reduction of astringency carryover (Ross and others 2007). The primary concern in carryover is for bitterness and astringency.

Sample Evaluation

The green tea lexicon developed by Lee and Chambers (2007) was used in the current study. A modified flavor profile method (Caul 1957; Keane 1992; Rétiveau and others 2005; Lee and Chambers 2007; Hongsoongnern and Chambers 2008; Thompson and others 2009) was used. The panelists evaluated each green tea sample independently and made notes on the descriptors that were present and each descriptor’s intensity. After all of the panelists finished their evaluations, the panel leader led a conversation to arrive at a consensus on the intensity of each attribute of the profile. A 0-15 point scale was used with 0.5 increments, where 0 equals none and 15 equals extreme intensity. To reduce any potential biases, the panelists had no information on the green tea samples they were evaluating nor did they know the specific objectives of this study.

Statistical Analyses

The number of times an attribute was detected in the 138 green tea samples was recorded to show how common each attribute was in the wide variety of teas that are currently available through international trade. In addition, data from the green tea samples was subjected to a principal components analysis, conducted using PROC PRINCOMP in SAS ® (version 8.2, SAS Institute Inc., Cary, NC, USA). Then, cluster analyses were conducted using either the raw scores or the principal component scores to determine if the green tea samples can be partitioned into groups based on their flavor characteristics. Various clustering methods were used, including Centroid (central distance measures) and Wards (minimum variance method), using the CLUSTER procedure, and K-means clustering, using the FASTCLUS procedure of SAS®. Hierarchical tree diagrams and the cubic clustering criterion were plotted to help decide the numbers of clusters.

Results and Discussion

Flavor Attributes Describing Green Teas

The number of attributes and the times they were used to describe the 138 green teas is shown in Table 1. In the current study, 31 attributes were used to describe the teas. Bitterness was detected in all of the teas. Brown, astringent, and green attributes were present in more than 75% of the teas. Some attributes, such as beany, Brussels sprouts, celery, green herb-like, brown spice, nutty, almond, animalic, citrus, fermented, floral/perfumy, grain, medicinal, and mint, were present in less than 10% of the teas, often providing unique, characterizing flavors in those teas.

Most of the teas in the current study were from China, Japan, and Korea. Thus the occurrence of teas from these countries of origin are noted separately (Table 3.1). In the Chinese green tea samples, 28 attributes were used, excluding beany, Brussels sprouts, and almond. A total of 22 attributes were used to describe the Japanese green teas and only 20 attributes were needed to evaluate the Korean green tea samples. The tea samples from India and other subcontinents needed 19 attributes and the green tea samples from Africa used 16 attributes based on the tea samples included in the current study. Thus, some attributes in the green tea lexicon can be excluded when testing a focused set of green tea as Lee and Chambers (2007) suggest.

Table 3.1 A Sample Table

Attributes	Entire World Sample	China subset	Japan subset	Korea subset	India and subcontinent subset	Africa subset
Green	109	34	38	29	5	3
Asparagus	21	6	6	9	-	-
Beany	2	-	-	2	-	-
Brussels sprouts	1	-	1	-	-	-
Celery	4	1	2	1	-	-
Green beans	24	2	11	11	-	-
Green herb-like	9	4	3	-	1	1
Parsley	37	6	16	10	1	3
Spinach	58	12	25	20	-	1
Brown	127	43	32	31	11	4
Ashy/sooty	35	24	4	5	1	-
Brown spice	5	4	-	-	1	-
Burnt/scorched	27	6	7	10	1	1
Nutty	4	2	-	-	1	1
Tobacco	41	25	2	6	4	-
Almond	1	-	-	-	1	-
Animalic	2	1	-	1	-	-
Citrus	5	2	-	-	2	1
Fermented	1	1	-	-	-	-
Floral/perfumy	11	3	-	-	8	-
Fruity	23	9	1	-	9	1

Attributes	Entire World Sample	China subset	Japan subset	Korea subset	India and subcontinent subset	Africa subset
Grain	7	1	3	2	-	1
Medicinal	7	4	-	-	1	-
Mint	5	2	2	1	-	-
Musty/new leather	12	8	2	-	-	1
Seaweed	42	10	21	11	-	-
Straw-like	44	9	9	17	5	2
Bitter	138	45	40	32	11	4
Astringent	123	36	36	32	10	4
Tooth-etch	90	20	33	21	8	4
Sweet aromatics	29	14	2	2	8	1
Total	138	45	40	32	11	4

Cluster Analyses

Cluster analyses were conducted to group the green tea samples based on their flavor profiles using various clustering methods. When the raw scores (profile data) were used, Centroid and Wards methods produced 21 and 22 clusters, respectively. When the scores data from PCA was used for cluster analysis, Centroid and Wards methods resulted in 1 and 16 clusters, respectively. With the exception of the Centroid method's use of the PCA scores data, green tea samples assigned to subgroups were compared and we found that assignments were similar across clustering methods and when different types of data were used. To obtain additional confirmation that those clusters existed, K-means clustering was conducted and 16 and 22 were used for the number of clusters. The samples in various clusters also were similar to other findings. It is evident that green tea samples can be divided into smaller groups based on their flavor profiles. Because the results of several clustering methods were similar, only the results of the Wards cluster analysis are presented in the current manuscript. The origins, processing methods, price, harvesting seasons and variety or cultivar of the green teas in each cluster were examined to determine if the clustering was logical. Also, the mean scores were calculated for each cluster in all of the results (Table 3.3 and 3.5).

Clustering with Principal Component Scores

Wards clustering analysis with PC scores divided the green tea samples into 16 groups (Table 3.2 and 3.3) and the sizes of clusters varied. Half of the groups had 10 or more green teas in each cluster and the other half had less than 10 green teas in each cluster. Most clusters included green teas from more than 2 countries except the clusters with only a few samples (Table 3.2). For example, Cluster 1 included Chinese green teas almost exclusively with a few Korean teas, while Cluster 7 was comprised of teas from 5 different countries and 1 unknown. This suggests that some flavor profiles may be origin specific.

Cluster 1 included green teas that have higher brown flavors than green flavors. Most of the samples in Cluster 1 were from China and only a few were from Korea. Chinese teas generally are roast-processed (Kim 1996) and Cluster 1 included 1 *Longjing* (Choi 2002) and 3 *Huang-shan-mao-feng* (Jung 2004), which are famous roast-processed Chinese green teas. Three Korean teas also were roast-processed and were found in this cluster. The prices of green teas in this cluster ranged from USD 1.78/100g to USD 28.90/100g. Harvesting season information for the Chinese samples was not available but the Korean samples in this cluster were harvested in mid May or later, indicating they had a more mature leaf.

On the other hand, Cluster 2 was characterized by higher green flavors, including spinach and low brown flavors. Seaweed notes in this cluster were the highest of any of the clusters, but were still in the low range. There were 9 Japanese, 3 Korean, and 2 Chinese green teas in Cluster 2. All the Japanese samples in this cluster were steam-processed. Japanese green tea samples included *Gyokuro* (n = 2), *Kabuse-cha* (n = 1) and *Tencha* (n = 1). *Gyokuro* is the highest quality green tea in Japan and tea plants are kept in 90% darkness and shade for about 2 weeks before they are harvested. *Kabuse-cha* is good quality green tea and the tea plants that are used to make it are also kept under 50-80% darkness and shade for 1-2 weeks. *Tencha* is used to make *Matcha*, a powdered green tea for ceremonies. Even though all of the Korean green teas in this cluster (n = 3) were roast-processed, green flavors were higher than brown flavors, perhaps indicating minimal processing or roasting at low heat. Information on processing methods for

Table 3.2 Origin Of Green Teas in 16 Clusters Obtained From Wards Clustering Analysis Using Principal Component Scores

Cluster	Number of teas	China	India	Japan	Kenya	Korea	Sri Lanka	Taiwan	Tanzania	Vietnam	unknown
1	14	11				3					
2	14	2		9		3					
3	15	9		1		2	2				1
4	7	1		5		1					
5	10	2		5		3					
6	16	2		6		8					
7	12	2	5		1		2			1	1
8	10	3		6					1		
9	18	2		3	1	10		2			
10	6	4			1			1			
11	5	1		3		1					
12	4	3	1								
13	3	2						1			
14	2			2							
15	1	1									
16	1	1									
Total	138	46	6	40	3	31	4	4	1	1	2

the Chinese teas in this cluster was not available, but marketing information on the website where they were purchased described them as delicate, subtle, smooth or refreshing suggesting minimal processing temperatures. The prices for the teas in Cluster 2 ranged from USD 5.75/100g to USD 83.25/100g. The prices of 5 samples were at least USD 40/100g, including *Gyokuro, Kabuse-cha*, and *Tencha* from Japan, all of which are generally rather expensive (Hara 2001). In Japan, about 85% of green tea plants are Yabukita cultivar (Hara 2001). Interestingly, all three Korean samples were from one tea farm on Jeju Island, which also uses the *Yabukita* cultivar.

The samples in cluster 3 can be noted as 'low flavor' green teas because all of the attributes, including bitterness, were in the low intensity range. The origins included China (n = 9), Korea (n = 2), Japan (n = 1), Sri Lanka (n = 2), and one of the unknown samples (n = 1). Four of the samples were white tea, an unofficial subcategory that includes teas made using the early harvest of buds and 1-2 leaves (Hara *et al*. 1995). White tea is described as having a delicate flavor (Ellis 2002). The prices for white teas varied substantially with 2 samples being priced around USD 50-60/100g and the other 2 being priced around USD 7-11/100g. The other teas were priced between USD 4.01/100g and USD 25.45/100g. Three of the samples were rolled tightly or multiple tea leaves were tied during processing, which may have prevented releasing flavor constituents efficiently.

Cluster 4 had a moderate intensity of overall green with green beans as the major green characteristic. Brown flavors were low. Of the 7 teas in this cluster, 5 were Japanese green teas from the same manufacturer. And 4 samples were either *Sencha* or *Gyokuro*, which were all steam-processed. The Chinese green tea sample in this cluster was oven-baked and made with early spring leaves. The Korean sample was steam-processed. Steam processing, and apparently the oven-baking, do not introduce brown roasted notes that occur in other processing methods. The prices of tea samples in cluster 4 ranged from USD 12.93/100g to USD 66.07/100g.

Cluster 5 had green flavor qualities accompanied with parsley and spinach notes and mild, brown flavors. A total of 10 green tea samples were included in cluster 5 and they were from Japan (n = 5), Korea (n = 3), and China (n = 2). The five Japanese samples in this cluster were all *Sencha*, which is steam-processed, and three of them were termed 'premium,' probably referring to leaves harvested early in the season. Two of the 3 Korean green tea samples were roast-processed by hand using tea leaves harvested either in April and May. The prices of green teas in Cluster 5 ranged between USD 7.14/100g and USD 77.05/100g. The most costly teas in this price range were the two Korean green teas that were hand-processed.

Green teas in Cluster 6 had asparagus and spinach as the primary green flavors. Half of the samples were from Korea and the other half were mostly from Japan (n = 6) with a couple from China (n = 2). Most of the Korean samples were roast-processed. The Japanese green tea samples in this cluster were mostly *Sencha*, but processing information for Chinese samples was not available from the retailer. Six of the 8 Korean samples in this cluster were all highly priced, quality teas and the prices ranged from around USD 50/100g to over USD 150/100g. Tea leaves used for these 6 Korean samples were picked during the earliest stage of the season. The prices for the Japanese samples ranged from USD1.50/100g to USD 33.93/100g and four of the samples were made using leaves harvested during the first flush. The two Chinese green tea samples in this cluster were priced at USD 30/100g which was in the highest range of prices for Chinese samples in this study. Both were made using leaves harvested during the earliest part of the season. Asparagus, a green flavor found in this cluster, is often noted as indicative of premium green tea and is a desirable attribute among connoisseurs.

Cluster 7 is characterized by almost no green flavors, low brown flavors, and low, but obvious, floral/perfumy and fruity notes. This cluster included teas from India, Sri Lanka, Vietnam, and Kenya where manufacturers have recently started to make green tea using leaves from the *Assamica* variety. Of the 2 Chinese samples in this cluster, one was made using tea leaves picked in late March or early April and another was made in Japanese style *Sencha*. The prices ranged from USD 3.50/100g to USD 25.45/100g. One exception, a white tea from India, was priced at USD 50/100g. The *Assamica* variety may be the reason for floral/perfumy and fruity notes, which was found at appreciable levels only in this cluster and a unique sample from China (cluster 16).

Cluster 8 had a higher intensity of green flavors than brown and was scored higher in bitterness than teas in many other clusters. Most of the samples from Japan were steam-processed, but one sample from Japan was roast-processed, and a few from China were roast-processed. The main characteristics for this cluster were higher bitterness regardless of the processing method used. Green teas in this cluster were priced between USD 4.90/100g and USD 32.75/100g.

Cluster 9 was the largest cluster containing 18 green teas. The teas in this cluster had "delicate" flavors characterized by low levels of all attributes including green, spinach, brown, burnt/scorched, and straw-like flavors. However, the brown notes had scores in the mid-range of brown flavor for all samples. Most of the teas in this group were roasted, which increases the brown flavor of the teas. Most of the Korean samples were roast-processed, often by hand. Of the 10 Korean green teas, most were priced well above USD 40/100g, including several that were priced around USD 100/100g. Two hand-processed green teas which used the leaves picked at the earliest season were among the highest priced samples in the study, costing more than USD 200/100g. Ironically, two similar teas were *Hojicha* from Japan, which are roasted *Bancha*, and they were both among the lowest priced samples between USD 2.69/100g to USD 3.99/100g. Not surprisingly several Chinese samples were part of this group because most Chinese green teas are roast-processed (Kim, 1996). The Kenyan tea was “fired,” a term used for roast-processing. It is possible that the burnt/scorched notes and straw-like flavors in these teas are produced by the hand roasted-processing that can result in delicately flavored, high quality teas, but also can result in less controlled processing.

The characterizing flavor notes for Cluster 10 included brown, ashy/sooty, and musty/new leather notes at low intensities and bitterness at a moderate intensity. Most of these samples were from China and their prices ranged from USD 3.83/100g to USD 12.93/100g. The higher level of bitterness in these samples would suggest that older leaves were used to produce lower quality teas that may not appeal to a wide range of consumers.

Cluster 11 had both green beans and parsley notes contributing to its green flavor and burnt/scorched for brown flavors with the green flavors predominant. These were from Japan (n = 3), China (n = 1), and Korea (n = 1). The green tea samples in this cluster varied in their processing methods. One Japanese sample was *Bancha*, which is a low grade green tea for everyday consumption (Ukers 1935). Another Japanese green tea was processed using twigs and stems from the first harvest. The Korean green tea was roast-processed by hand using tea leaves harvested in early May. The tea samples were generally priced between USD 3.12/100g to USD 10.71/100g for all the samples. The Korean sample was an exception and was priced at USD 48.16/100g. It appears that the main criteria for this cluster are the common flavor characteristics of green beans and parsley and the cluster is not explained by either the processing method or price.

The green teas in Cluster 12 had moderate brown flavors with ashy/sooty and tobacco notes. Two of the Chinese green tea samples were sold as 'gun-powder' teas. Such teas are classified as roast-processed and made into round balls (Ukers 1935; Hara and others 1995). One Chinese sample and the Indian sample do not have information about their processing methods, but they must have been processed similar to the way gunpowder green teas are processed because all of the samples have the same ashy/sooty and tobacco notes, which were at the highest intensities among all of the clusters. The description on the retailer's website for the gunpowder green tea included 'smokiness' which may be similar to ashy/sooty and tobacco notes in the current study. The tea samples were priced around USD 8.00/100g.

Cluster 13 contained teas that had very low green flavors but moderate brown flavors, accompanied by ashy/sooty and medicinal notes. The medicinal notes had the highest intensities among all teas in the other clusters. There were 2 samples from China and a Gunpowder tea from Taiwan in this group. Medicinal flavors were found in all of the teas in this group. The intensities are at low levels, but are still obvious. The samples were priced between USD 3.75/100g to USD 11.15/100g. Other than the low prices suggesting lower quality, they do not share noticeable characteristics in origin or processing methods. Information on the harvest season was not available. They may have been older samples, but it is not clear what characteristics induced the medicinal flavor.

There were 2 green teas in Cluster 14 both with moderate brown, burnt/scorched, and grain notes. They were both *Hojicha*, which is a roasted green tea using low grade *Bancha* from Japan. In comparison to the *Hojicha* samples in Cluster 9, the teas in Cluster 14 had a higher intensity of a grain-like flavor. The grain-like flavor may have been induced during processing. Even though there were only a few teas with grain-like flavor in this study, most of the samples that had a grain-like flavor were roast-processed. The prices of *Hojicha* in this cluster were USD 4.49/100g and USD 8.93/100g.

Clusters 15 and 16 contained only one tea each. Both were Chinese teas, one of which had a level of astringency that was higher than the level of bitterness (Cluster 15) and the other (Cluster 16) had a floral/perfumy character unlike any other green tea. The prices for these teas were USD 6.75/100g and USD 11.15/100g, respectively. It is hard to speculate on reason why the Chinese green tea in Cluster 15 had higher astringency than bitterness. It was generically

Table 3.3 Mean Scores of 16 Clusters Obtained from Wards Clustering Analysis Using Principal Component Scores.

Cluster	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of teas	14	14	15	7	10	16	12	10	18	6	5	4	3	2	1	1
Green	1.29	4.61	1.23	5.57	4.45	3.97	0.46	3.80	1.69	1.33	5.10	0.13	0.83	0.50	2.00	0.00
Asparagus	0.14	0.00	0.03	0.00	0.25	2.66	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beany	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brussels sprouts	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.00	0.17	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	0.25	0.14	0.10	3.07	0.00	0.31	0.00	0.15	0.22	0.00	3.70	0.00	0.00	0.00	0.00	0.00
Green herb-like	0.11	0.04	0.23	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00
Parsley	0.21	0.43	0.23	0.21	2.65	0.25	0.13	1.50	0.19	0.42	2.40	0.00	0.00	0.00	1.00	0.00
Spinach	0.43	2.75	0.13	3.43	2.70	1.97	0.00	0.15	0.97	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Brown	2.82	1.14	1.53	1.00	1.10	1.22	3.88	1.20	2.64	3.83	1.90	5.50	5.50	7.00	4.00	1.00
Ashy/sooty	2.64	0.36	0.27	0.00	0.10	0.00	0.00	0.65	0.31	1.67	0.00	4.25	3.50	0.00	4.00	0.00
Brown spice	0.00	0.00	0.27	0.00	0.00	0.00	0.17	0.20	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
Burnt/scorched	0.11	0.21	0.00	0.00	0.45	0.75	0.13	0.00	1.14	0.00	1.40	0.00	0.00	6.25	1.50	0.00
Nutty	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tobacco	1.57	0.14	0.90	0.36	0.15	0.00	1.08	0.00	0.72	0.75	0.00	3.50	0.00	1.50	0.00	0.00
Almond	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Animalic	0.04	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Citrus	0.00	0.07	0.30	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fermented	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Floral/perfumy	0.00	0.00	0.10	0.00	0.00	0.00	1.00	0.25	0.11	0.00	0.00	0.00	0.00	0.00	0.00	8.00
Fruity	0.00	0.00	0.67	0.00	0.10	0.00	2.08	0.35	0.06	0.42	0.00	0.63	0.00	0.00	0.00	2.00
Grain	0.18	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.22	0.00	0.00	0.00	0.00	5.00	0.00	0.00
Medicinal	0.14	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	1.13	4.67	0.00	0.00	0.00

Mint	0.00	0.00	0.23	0.00	0.10	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Musty/new leather	0.11	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	2.92	0.00	0.63	1.17	1.25	0.50	0.00
Seaweed	0.14	3.07	0.10	1.36	0.25	0.72	0.00	1.70	0.42	0.25	0.30	0.00	0.50	0.00	0.00	0.00
Straw-like	0.46	0.36	0.27	0.00	0.80	0.56	0.96	0.15	1.75	0.33	0.00	0.75	0.00	0.00	1.50	0.00
Bitter	5.25	5.50	3.60	6.00	5.75	5.56	5.67	6.10	5.50	6.17	5.60	5.88	5.67	5.75	2.00	3.00
Astringent	1.25	1.54	0.60	1.57	2.30	1.59	2.29	1.90	1.56	1.83	1.40	2.00	0.83	2.00	5.50	0.00
Toothetch	0.54	0.79	0.20	1.00	1.35	0.97	1.67	1.25	0.81	1.25	0.80	1.00	0.00	1.25	2.00	0.00
Sweet Aromatics	0.07	0.07	0.70	0.00	0.00	0.00	1.29	0.00	0.25	0.00	0.30	1.38	0.00	0.00	1.00	2.00

labeled as a Chinese green tea. The only noticeable difference from the other samples was that the tea leaves were chopped into small pieces and perhaps the larger surface area is related to the extracted constituents having astringency. The sample in Cluster 16 was a white tea from the *assamica* variety and a floral/perfumy note may have been induced during the withering period because Hara and others (1995) indicated that the leaves for white tea may become fragrant after withering. It also is possible that the sample was mixed with a floral essential oil, although it was not labeled as having added flavor. If the sample in Cluster 16 actually has a naturally higher level of floral/perfumy, this could form the basis of teas that might provide a desirable consumer characteristic without mixing with other teas of flavorings.

Clustering with Raw Profile Data

Wards cluster analysis with raw profile data provided 22 clusters of green teas, with more individual clusters. Only 6 clusters had 10 or more tea samples in the clusters and 16 clusters had less than 10 samples in each cluster, made up mostly of 1 (4 clusters) or 2 (7 clusters) samples (Table 3.4).

Cluster A had the most samples at 23 green teas and was similar to the flavor characteristics of Cluster 1 (numbered clusters as clusters using PCA scores). In fact, this cluster was composed of samples from Clusters 1 (n = 11), 2 (n = 2), 3 (n = 5), 4 (n = 1), and 8 (n = 2).

Cluster B had very similar flavor characteristics that Cluster 2 because Cluster B was composed of 10 green teas that were included in Cluster 2.

The flavors of Cluster C were somewhat similar to Clusters 4 and Cluster 11. Both Cluster 4 and 11 had moderate intensities for green flavor which are higher than other clusters, but different characterizing green attributes, either spinach or parsley. Cluster C was composed of 6 samples from Cluster 4 and 3 teas from Cluster 11.

Cluster D resembles Cluster 9 for flavor characteristics because 12 green teas were from Cluster 9 and 2 green teas were from Cluster 11.

Cluster E holds similar flavor characteristics to Cluster 6. This cluster is composed of green tea samples from Cluster 5 (n = 1), Cluster 6 (n = 14), and Cluster 9 (n = 4).

Cluster F was similar to Cluster 5 for the flavor characteristics and was composed of the green teas from Clusters 1 (n = 1), 2 (n = 2), 5 (n = 8), and 8 (n = 5).

Table 3.4 Origin of Green Teas in 22 Clusters Obtained from Wards Clustering Analysis Using Raw Profile Data

Cluster	Number of teas	China	India	Japan	Kenya	Korea	Sri Lanka	Taiwan	Tanzania	Vietnam	Unknown
A	23	20		1		1	1				
B	10			7		3					
C	9			8		1					
D	14	1		3	1	7		2			
E	19	4		5		10					
F	17	2		10	1	4					
G	7	6						1			
H	10	3	4				2				1
I	4	1		2		1					
J	2			1					1		
K	3	3									
L	2					2					
M	2	1				1					
N	2	1				1					
O	4	2	1					1			
P	2			2							
Q	2		1				1				
R	2	1			1						
S	1	1									
T	1			1							

U	1										1
V	1									1	
Total	138	46	6	40	3	31	4	4	1	1	2

Table 3.5 Mean Scores of 22 Clusters Obtained from Wards Clustering Analysis Using Raw Profile Data

Cluster	A	B	C	D	E	F	G	H	I	J	K
Number of teas	23	10	9	14	19	17	7	10	4	2	3
Green	1.37	4.90	6.17	1.46	3.71	4.24	1.00	0.45	3.00	4.00	1.67
Asparagus	0.07	0.00	0.00	0.00	2.24	0.00	0.00	0.00	0.63	0.00	0.00
Beany	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brussels sprouts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.00	0.00
Green beans	0.07	0.20	3.56	0.46	0.34	0.21	0.00	0.00	0.38	0.00	0.00
Green herb-like	0.13	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.13	3.50	1.17
Parsley	0.00	0.15	1.28	0.39	0.21	2.53	0.14	0.15	0.50	2.00	0.00
Spinach	0.61	2.65	2.33	0.43	2.03	1.85	0.00	0.00	1.25	0.00	0.00
Brown	2.28	0.95	0.72	3.14	1.37	1.26	4.64	3.80	1.38	0.50	1.67
Ashy/sooty	1.87	0.00	0.00	0.32	0.05	0.21	3.36	0.35	0.00	0.00	0.00
Brown spice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Burnt/scorched	0.00	0.15	0.00	1.89	0.76	0.21	0.21	0.15	0.00	0.00	0.00
Nutty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00

Tobacco	1.43	0.00	0.00	0.79	0.00	0.21	1.64	1.80	0.50	0.00	0.33
Almond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Animalic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Citrus	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fermented	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Floral/perfumy	0.00	0.00	0.00	0.00	0.00	0.15	0.00	1.20	0.00	0.00	0.00
Fruity	0.33	0.00	0.00	0.07	0.00	0.06	0.00	2.05	0.00	1.00	1.17
Grain	0.11	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medicinal	0.15	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mint	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.13	0.00	0.00
Musty/new leather	0.09	0.00	0.11	0.00	0.00	0.12	2.36	0.00	0.00	0.00	0.00
Seaweed	0.46	3.60	1.22	0.18	0.87	0.88	0.21	0.00	0.00	1.00	0.83
Straw-like	0.07	0.40	0.00	1.57	1.00	0.53	0.50	0.95	0.63	0.00	0.00
Bitter	4.78	5.40	5.89	5.68	5.42	6.24	5.57	5.60	4.88	5.00	3.83
Astringent	1.02	1.30	1.33	1.79	1.50	2.29	2.64	2.00	1.25	1.50	0.67
Toothetch	0.39	0.75	0.89	1.14	0.71	1.56	1.50	1.35	0.63	1.00	0.00
Sweet Aromatics	0.20	0.00	0.17	0.07	0.11	0.00	0.64	1.15	0.38	0.00	1.00

Cluster	L	M	N	O	P	Q	R	S	T	U	V
Number of teas	2	2	2	4	2	2	2	1	1	1	1
Green	2.25	3.50	1.50	0.63	0.50	0.50	1.00	0.00	5.00	0.00	0.00

Asparagus	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beany	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brussels sprouts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	1.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green herb-like	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	1.00	0.75	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00
Spinach	1.00	1.75	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00
Brown	2.00	2.25	1.00	5.00	7.00	3.50	4.50	1.00	0.00	3.50	5.00
Ashy/sooty	1.50	1.75	0.00	3.13	0.00	0.00	0.00	0.00	0.00	2.50	0.00
Brown spice	0.00	0.00	0.00	0.38	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Burnt/scorched	0.00	1.25	0.00	0.00	6.25	0.00	0.00	0.00	0.00	0.00	0.00
Nutty	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.00	0.00	0.00	0.00
Tobacco	0.00	0.25	0.50	0.00	1.50	0.00	0.00	0.00	0.00	2.50	2.00
Almond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50
Animalic	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Citrus	0.00	0.00	0.00	0.00	0.00	3.50	0.75	0.00	0.00	0.00	0.00
Fermented	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
Floral/perfumy	0.00	0.00	0.00	0.00	0.00	1.75	0.00	8.00	0.00	0.00	0.00
Fruity	0.00	0.00	0.00	0.00	0.00	1.75	1.25	2.00	0.00	2.00	2.00
Grain	0.00	0.00	0.00	0.00	5.00	0.00	2.25	0.00	0.00	0.00	0.00
Medicinal	0.00	0.00	0.00	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Mint	0.00	0.00	1.50	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00
Musty/new leather	0.00	0.75	0.00	0.88	1.25	0.00	0.00	0.00	0.00	0.00	0.00
Seaweed	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Straw-like	0.75	1.50	0.75	0.75	0.00	0.00	1.75	0.00	0.00	0.00	0.00
Bitter	5.25	5.50	3.50	5.50	5.75	4.00	6.50	3.00	5.50	4.00	6.00
Astringent	1.75	1.75	0.75	1.00	2.00	1.00	3.00	0.00	2.00	1.00	3.00
Toothetch	1.25	0.75	0.00	0.00	1.25	0.75	2.25	0.00	1.00	0.00	2.00
Sweet Aromatics	0.00	0.00	0.00	0.00	0.00	1.50	1.75	2.00	0.00	2.00	2.50

Cluster G has similar characteristics and similar products to Clusters 10, 12, 13, or 15 having brown and ashy/sooty notes. The samples in Cluster G were composed of green tea samples from Clusters 10 (n = 5), 12 (n = 2), and 15 (n = 1). Interestingly, Cluster 15 was a single sample group when analyzed using PCA scores but included 7 other green tea samples when analyzed using the raw profile data.

The flavor characteristics of Cluster H were similar to Cluster 7. Essentially green tea samples in Cluster H are also belong mainly in Cluster 7 (n = 8) and two additional samples belong to either Cluster 9 or 12. The rest of the clusters using the raw profile data, from Cluster I to Cluster V, are more individual clusters with a low number of samples within each cluster, often only 1 or 2 samples. While some of these are similar to the small clusters produced using PCA scores, some of the clusters highlight green teas with defining flavor notes such as almond, citrus, fermented, floral/perfumy, grain, medicinal, or mint or simply higher intensities for other attributes that are usually found in lower intensities in other green teas. Using the raw data for cluster analysis enabled us to identify these green teas with characterizing flavor notes, perhaps outliers, and group samples based on individual flavor profiles.

Conclusions

Green tea flavors differ and can be grouped based on their flavor profiles. Cluster analysis conducted using scores obtained from principal component analysis provided information on what flavors are common in green tea. On the other hand, cluster analysis conducted using raw flavor intensity data provided groupings based on the individual flavor profiles and, thus, was better at defining unique teas or identifying outliers. Processing methods or the countries of origin seemed to influence the flavor of green teas the most. The roast-processed teas were mostly responsible for brown-related flavors and the steam-processed teas were responsible for green-related flavors. The Chinese samples were mostly roast-processed and, thus, had higher brown flavors than green flavors. The Japanese samples were mostly steam-processed with a few exceptions and they had more green flavors than brown ones. The Korean samples were either roast-processed or steam-processed and had both green and brown flavors. The prices of green teas did not differentiate the flavors of the samples. Often highly priced green teas were grouped with low price green teas from the same manufacturer or origin. Differences in tea plant varieties or cultivars seem to affect the flavors in the green teas, however, more research may be needed to determine the effect of differences in varieties or cultivars. Such information can help researchers and companies create teas with specific sensory properties or to understand specific effects of growing and processing.

This research also suggests that green teas could be developed, marketed and sold to meet the needs of many different consumers. The clusters found in the this study could be used as marketing segments for green tea, enabling consumers to select teas that meet their personal flavor preferences. These findings may help green tea processors, marketers, retailers and ultimately consumers better understand the green tea choices they have.

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CHAPTER 4 - Comparison of Volatile Aroma Compounds in Various Green Teas

The present study was carried out to identify and quantify aroma volatiles in brewed green tea samples. Previous researchers have mostly used solvent extraction methods for concentrating the aroma volatiles from green tea leaves and, therefore, many non-polar compounds might not be present in brewed green tea. The objectives of this study were to identify common volatile compounds in the brewed liquor of a wide range of green tea samples from various countries using a gas chromatograph-mass spectrometer (GC-MS) paired with a headspace solid-phase microextraction (HS-SPME) and to determine if green teas from the same region have similarities in volatile composition when samples are prepared how green tea might be prepared for consumption. Twenty-four green tea samples from 8 countries were brewed in a manner similar to how most consumers would brew their own green tea. The aroma volatiles were extracted by HS-SPME, separated on a gas chromatograph and identified using a mass spectrometer. Thirty eight compounds were identified and the concentrations were quantified. The concentrations were much lower than what other researchers have found in green tea samples. In a principal components analysis biplot, 18 samples were grouped together because the most volatile compounds were either present in very low quantities or absent in those green teas.

Introduction

Aroma, along with flavor and appearance, is an important aspect of the evaluation of green teas (Ukers 1935). Many researchers have studied green teas for their aromatic volatile compounds and to understand the aroma characteristics of green teas (Yamanishi 1978; Kawakami and Yamanishi 1981; Cho 1983; Choi 1991 and 1995; Shimoda and others 1995a and 1995b; Kumazawa and Masuda 2002; Hattori and others 2005). However, most of the previous research used limited numbers of green tea samples and the sample preparation method often did not reflect how green tea would generally be prepared by consumers (Kim 1996; Ellis 2002; Lee and Chambers 2007). For example, Hattori and others (2005) brewed 60 g of green tea in 60℃, 1L water for 5 min; the green tea liquor was steam distilled and concentrated to 10μL for gas-chromatography analysis. Typical brewing methods recommend using 2 g of green tea in 55 mL of water at 60-70℃ for 1-2 min (Jung 2004).

Various green teas are available to consumers that have different processing methods, harvest times, tea plant varieties and growing regions, all of which may produce different aroma characteristics in each tea (Kim 1996). Studying aromatic volatile compounds from brewed green tea liquor may be helpful to researchers as a way of helping them understand the aroma characteristics of various green teas.

Volatile compounds in green teas extracted with solvents have been studied extensively using gas chromatography-mass spectrometry (GC-MS) to understand the differences of green teas' aroma components (Hara and others 1995). Xu and Chen (2002) reported that more than 600 volatile compounds have been identified through extensive research on green tea. Researchers have studied green tea aroma in *Hojicha*, a roasted green tea from Japan, (Yamanishi and others 1973), *Bach-Mao* tea, a Vietnamese green tea, (Nguyen and Yamanishi 1975), *Sencha*-type spring green teas, a steamed green tea from Japan, (Takei and others 1976), *Kabusecha*, a Japanese green tea made from tea leaves grown in the shade, and *Sencha*, a steam-processed green tea from Japan (Kawakami and Yamanishi 1981). More recently, Choi (1991) identified 41 volatile compounds from 4 commercial Korean green teas; 2 samples were steam-processed while the other 2 were roast-processed. Kumazawa and Masuda (2002) used GC-MS and found 54 compounds from *Kamairi-cha* (a Japanese tea; roast-processed), *Longing* tea (a Chinese tea; roast-processed) and *Sencha.* Liang and others (2008) found 18 volatile compounds in 23 Chinese green teas where 1-penten-3-ol, linalool, terpineol, citral, citronellol, nerol, geraniol and others were commonly present.

Solid phase microextraction (SPME) is a type of headspace sampling, which studies the volatile compounds in the space above a sample in a sealed container (Burgard and Kuznicki 1990). Thus, SPME extracts volatile compounds in the space above a brewed green tea liquid, which consumers may smell as they consume green tea. SPME is a convenient technique because there is no complicated sample preparation. It is also environmentally friendly as it does not require any solvents. Using SPME also allows for the extraction of volatile compounds from brewed green tea liquor.

The objectives of this study were to use GC-MS paired with SPME to 1) identify common volatile compounds in the brewed liquor of a wide range of green tea samples from various countries and 2) determine if green teas from the same region have similarities in volatile composition when samples are prepared similar to how green tea might be prepared for consumption.

Materials and Methods

Tea Samples

A total of 24 green teas, China (7), India (1), Japan (6), Kenya (2), Korea (4), Sri Lanka (2), Tanzania (1) and Vietnam (1), were selected for analysis (Table 4.1). Samples were selected from a pool of more than 130 samples and represent a range of green tea products from around the world. Although specific information other than origin was not known for every tea tested, it is likely that based on origin and price information, the teas represent different processing methods, different ages at picking, and different storage times.

Sample Preparation

Twelve grams of green tea were placed in a pre-warmed tea pot and 300 mL of 70°C distilled water was added. The tea was brewed for 2 min and swirled 10 times clockwise while brewing. After 2 min, the tea was poured through a porcelain strainer into a pre-warmed porcelain bowl. This is similar to how consumers would brew green teas in many Asian countries (Kim 1996; Jung 2004) and recommended in a book intended for the public (Ellis 2002).

Solid-phase Microextraction

For the extraction of the volatile compounds, 10 mL of each brewed green tea sample was transferred into a 40 mL amber headspace vial (Supleco; Bellefonte, PA, USA). We used 1,3-dichlorobenezene (Sigma-Aldrich, Milwaukee, WI, USA) as an internal standard for quantification of the volatile compounds from the samples. One micro liter of internal standard (concentration: 1µg/Kg) was added. An octagonal, magnetic stir bar (Diameter 8 mm × length 13 mm; Fisher; Pittsburgh, PA, USA) and analytical grade sodium chloride (ca 3 g; Sigma-Aldrich) were added to the vial to help with the extraction. An open-center screw cap with a

Table 4.1 List of 24 Green Tea Samples

	Label[a]	Product name	Purchased from
1	China 1	*Star of China*	Imperialteagarden.com
2	China 2	*Gosancha*	XingHua Food Co., Ltd
3	China 3	*Imperial Hwangshan Maofeng*	Enjoyingtea.com
4	China 4	*Buddha's Eyebrow*	Sevencups.com
5	China 5	*Myeng Ding Sweet Dew*	Sevencups.com
6	China 6	*Shanghai Special Gun Powder*	Shanghai Tiantan Int'l trading Co., Ltd.
7	China 7	*Longjing (Dragonwell)*	Adagio.com
8	India	*Assam Sewpur Estate*	Simpson & Vail Inc. (svtea.com)
9	Japan 1	*Tencha*	Harney & Sons (Harney.com)
10	Japan 2	*Honyama Sencha*	The Fragrant Leaf (thefragrantleaf.com)
11	Japan 3	*Sencha Overture*	Adagio.com
12	Japan 4	*Uji Mecha*	Itoen.com
13	Japan 5	*Uji Gyokuro*	Japanesegreenteaonline.com
14	Japan 6	*Inakacha*	Itoen.com
15	Kenya 1	*Kapchorua Green*	Culinaryteas.com
16	Kenya 2	*Kapchorua Green*	Barkingside.com
17	Korea 1	*Ssanggye Okchun*	Lotte Department Store, Busan, Korea
18	Korea 2	*Sulloc Sejac*	Donated by Amorepacific Co.
19	Korea 3	*Chungmyungcha*	Lotte Department Store, Busan, Korea
20	Korea 4	*Tobu Goku (Guyu)*	Tobu tea farm, Sunchon, Korea
21	Sri Lanka 1	*Iddalgashinna Estate Ceylon*	Uptontea.com
22	Sri Lanka 2	*Dumbara Curls*	Barkingside.com
23	Tanzania	*Tanzania Luponde Estate*	Simpson & Vail Inc. (svtea.com)
24	Vietnam	*Ha Giang Green Tea*	Thompsons (fineteas.com)

[a] Label of samples is composed of 'country of origin' and a number when there were more than one sample from the same country.

silicone/PTFE septum (22 mm diameter × 3.2 mm thickness, Supleco) was used to close the amber vial. Each sample was allowed to equilibrate at 60°C in a Reacti-Therm™ heating block

(Pierce Biotechnology, Inc.; Rockford, IL, USA) for 5 min. Volatile odor compounds from the sample were extracted using a StableFlex 50/30 µm three phase (DVB/CAR/PDMS) SPME fiber (Supelco) at 60°C for 20 min.

Gas Chromatograph-Mass Spectrometry

After extraction, the SPME fiber was retracted and the holder was moved to the splitless injection port of a 5890 Series II Gas Chromatography (Hewlett-Packard Co.; Palo Alto, CA, USA) for manual injection. The fiber was desorbed for 5 min and the injection port was maintained at 225°C. The volatiles were separated on an Rtx® -5 (Crossbond® 5% diphenyl-95% dimethyl polysiloxane; 30m length × 0.25 mm internal diameter × 0.25 µm film thickness) capillary column (Restek; Bellefonte, PA, USA). The temperature program for the separation was as follows: 60°C for 1 min, 18°C/min of ramp rate to 250°C and held for 1 min. The total time was 12 min 34 s. The identification of the compounds was done using an HP 5890 Series II GC/HP 5972 mass selective detector (MSD, Hewlett-Packard Co.; Palo Alto, CA, USA) with the following parameters: interface temperature, 250°C; ionization energy, 70 eV; mass range, 33-350 a.m.u.; scan rate, 2.2 scans/s. Ultra high purity Helium (AirGas; Westpoint, MS, USA) was used as a carrier gas at a constant flow rate of 0.96 mL/min. The mass spectra of the volatile compounds were compared using the Wiley138K Mass Spectral Database (Version B00.00, 1990; John Wiley and Sons, Inc.; New York, NY, USA). Volatile compounds were analyzed in triplicate for each sample. Concentrations for green tea volatile compounds were calculated and reported on the basis of the internal standard concentration.

Data Analysis

The mean concentrations (ng/kg) for the quantified volatile compounds were calculated and used for Principal Components Analysis (PCA; Unscrambler® 9.7, CAMO Software Inc.; Woodbridge, NJ, USA). A covariance matrix was used for the PCA.

Results and Discussion

Volatile Compounds in Green Teas

Thirty-eight aroma volatile compounds were identified from the 24 green tea samples (Table 4.2). Of the 38 volatile compounds identified and quantified in the current study, 15

Table 4.2 38 Volatile Compounds Identified in 24 Green Tea Samples and Their Odor Characteristics Reported in the Literature

Volatile Compounds	Odor characteristics	Reference
Aliphatic Alcohols		
1-Penten-3-ol	Butter, mild, green odor	Ash & Ash, 2006
1-Pentanol	Somewhat sweet, balsamic odor	Ash & Ash, 2006
2-Penten-1-ol	Powerful, jasmine-like odor Green, plastic, rubber	Ash & Ash, 2006 Acree & Arn, 2004
(Z)-3-Hexen-1-ol		
Linalool	Odor similar to bergamot oil, French lavender	Ash & Ash, 2006
Geraniol	Pleasant geranium odor	Ash & Ash, 2006
Aromatic Alcohols		
Benzeneethanol	Floral, rose odor	Ash & Ash, 2006
1-α-Terpineol	Lilac-like odor	Ash & Ash, 2006
2-Methoxy-4-methylphenol		
2,6-Dimethyl-cyclohexanol		
Aliphatic Aldehydes		
3-Methyl-butanal	Unpleasant odor	Ash & Ash, 2006
Pentanal	Pungent fragrance Almond, malt, pungent	Ash & Ash, 2006 Acree & Arn, 2004
Hexanal	Fruity odor	Ash & Ash, 2006
cis-3-Hexenal	Strong herbal apple odor, green leafy flavor	Ash & Ash, 2006
Nonanal	Strong fatty odor Fat, citrus, green	Ash & Ash, 2006 Acree & Arn, 2004
1H-Pyrrole-2-carboxaldehyde		
Aromatic Aldehydes		
Benzaldehyde	Bitter almond odor	Ash & Ash, 2006
Benzeneacetaldehyde	Hyacinth, lilac odor	Ash & Ash, 2006

Other Aromatic Compounds		
Toluene	Paint	Acree & Arn, 2004
1,4-Dimethoxy benzene	(Aromatic ether) sweet clover odor	Ash & Ash, 2006
1,4-Bis(1,1-dimethylethyl)-benzene		
Styrene	Penetrating odor Balsamic, gasoline	Ash & Ash, 2006 Arn & Acree, 2004
2-Hydroxy methyl ester benzoic acid		
Ketones		
3,5-Octadien-2-one		
Jasmone	Jasmine odor	Ash & Ash, 2006
α-Ionone	Woody, violet odor	Ash & Ash, 2006
β-Ionone	Woody odor	Ash & Ash, 2006
2-Methyl-5-(1-methylethenyl)-2-cyclohexen-1-one (=Carvone)	Mint	Acree & Arn, 2004 Ash & Ash, 2006
Furans		
Tetrahydro-2,2,5,5-tetramethyl furan		
4-Methyl-2-propyl furan		
N-Furfuryl adenine		
Pyridine		
3-Butyl-1-oxide-pyridine		
Pyrazine		
3-Ethyl-2,5-dimethyl-pyrazine		
Furanone		
5,6,7,7a-Tetra 2(4)-benzofuranone		
Acids		
Benzoic acid	Aromatic acid	
2-Hydroxy methyl ester benzoic acid		
Nonanoic acid	Fatty odor Green, fat	Ash & Ash, 2006 Acree & Arn, 2004

Ester		
Isopropyl myristate	Odorless	Ash & Ash, 2006

aroma volatiles, which were present in more than 4 samples, are shown in Table 4.3 and the remaining compounds, found in only a few samples, are shown in Table 4.4.

Green teas produced in the Africa region commonly had 1-penten-3-ol, 2-penten-1-ol, linalool, hexanal, and benzaldehyde. These green teas may provide green, floral, fruity and nutty aroma during infusion and consumption. No other information on volatile compounds of green tea from Africa was found.

Green teas from Southeast Asia and the Indian subcontinent generally had linalool and nonanal and half of the samples had 2-penten-1-ol, hexanal and β-ionone. Based on these common volatile compounds, these green teas may have green, floral, woody and citrus aroma. Information on volatile compounds of green teas from these areas was limited and only 2-Penten-1-ol has been reported from Vietnamese green tea (Nguyen and Yamanishi 1975).

Green teas from Northeast Asia (China, Japan, and Korea), the most common growers of green tea in international trade, typically had linalool, hexanal and nonanal, which will provide green and floral aromas. These compounds have been reported by others (Baptista and others 1999; Choi and others 2003; Sawai and others 2004) from the samples produced in the same region. Additionally, about half of Chinese green teas had geraniol, benzaldehyde and Jasmone. These compounds previously have been reported from Chinese green tea (Kawakami and Yamanishi 1983; Baptista and others 1999; Zhu and others 2008) can provide floral and nutty aromas. About half of Japanese green tea had toluene and β-ionone in addition to the aforementioned compounds. Toluene (Yamaguchi and Shibamoto 1981) and β-Ionone (Sawai and others 2004; Hattori and others 2005) have been reported in teas from Japan. Korean green teas also had benzeneethanol, benzaldehyde, and jasmone, which have been reported previously (Choi 1991) and may provide floral, fruity, and nutty aromas.

The concentrations of the quantified compounds in this study were much lower than what has been reported elsewhere which is probably because of the differences in brewing and extraction. Extracting volatile compounds using organic solvents generally leads to the extraction of most of the volatiles, whereas brewing green tea in warm/hot water which is what consumers do is not efficient in terms of solubilization of many of the non-polar volatiles.

Although, the concentration is much smaller, it probably is more useful in terms of understanding what compounds are present when consumers decide whenever they like or don't like a particular tea. In our finding, concentrations of most volatile compounds generally were lower than thresholds reported elsewhere. The threshold values in the literature may vary because different measuring methods were employed and the sensitivity of assessors (Rychlik and others 1998). Also the thresholds in the literature were measured at room temperature of 21±1℃ (Czerny and others 2008) or not specified (Rychlik and others 1998) whereas green tea is consumed at higher temperatures which may result in lowering thresholds of aroma compounds. Another aspect to consider is that thresholds in the literature were evaluated in a single compound dilution while volatile compounds in green tea do not work in solitude. The interrelationships of the compounds may result in an aroma or flavor even when the individual compounds are at a very low level.

The 1-penten-3-ol in 6 samples was at a level less than 1ng/kg. This compound is described as having a powerful, grass-green and very diffusive odor, but the recognition threshold for this compound was not reported (Arctander 1969). Green tea samples and green teas made with leaves harvested in June, when compared to those harvested in April, have higher levels of 1-penten-3-ol (Choi 1991). In a later study, Choi (1995) compared steamed and roasted green teas and found that the steam-processed sample had twice the amount of 1-penten-3-ol as that found in the roast-processed sample. The same trend was reported earlier by Horita (1987) who recorded that 1-penten-3-ol was prevalent in stored and/or lower quality green teas. Our findings differ from previous research in that the steam-processed green tea samples from Japan did not have 1-penten-3-ol, although other C5 compounds (pentanal or 2-penten-1-ol) were present. Our research did show that 1-penten-3-ol was present in Korea 3, which is made from tea leaves from the first pick in April and roast-processed. The 1-penten-3-ol compound can be considered as off-flavor because it has a pungent odor, but the amounts found in our samples were well below its recognition threshold value of 400μg/L (Rychlik and others 1998).

Seven samples had 2-penten-1-ol at various concentrations ranging from 0.48ng/kg to 1.52ng/kg. Research (Choi 1991and 1995) has found *cis*-2-penten-1-ol in green tea samples and it was classified as an off-flavor characteristic. However, direct comparison of the concentrations was not possible as only peak area was reported in Choi's studies (1991 and

Table 4.3 Average Concentration of 14 Volatile Compounds Identified in the Brewed Green Tea Samples (ng/kg) [a,b]

Sample	1-Penten-3-ol	2-Penten-1-ol	Linalool	Geraniol	Benzeneethanol	2,6-Dimethyl-cyclo hexanol	Pentanal
Africa							
Kenya 1	0.56	1.07	1.35	-	-	-	0.76
Kenya 2	0.22	0.52	3.21	0.34	-	-	-
Tanzania	- [c]	-	1.56	-	-	-	-
Southeast Asia and Indian Subcontinent							
India	-	-	0.96	-	-	-	-
Sri Lanka 1	-	0.65	2.35	-	-	-	0.39
Sri Lanka 2	-	-	0.83	-	-	-	-
Vietnam	0.80	0.64	0.74	-	-	0.33	-
Northeast Asia							
China 1	-	-	-	-	-	-	-
China 2	0.14	-	-	-	-	0.48	-
China 3	-	-	0.45	0.94	-	-	-
China 4	-	-	1.34	-	-	-	-
China 5	-	-	0.58	0.43	0.88	-	-
China 6	0.29	1.52	0.45	-	-	-	0.92
China 7	-	-	0.55	0.42	0.42	-	-
Japan 1	-	-	0.50	-	-	0.66	-
Japan 2	-	-	0.27	-	-	-	-

Japan 3	-	-	0.27	0.23	1.18	-	0.22
Japan 4	-	-	-	-	-	-	-
Japan 5	-	-	0.37	-	-	0.50	0.52
Japan 6	-	0.48	-	-	-	-	-
Korea 1	-	-	0.32	-	0.54	-	-
Korea 2	-	-	0.39	-	-	0.40	0.31
Korea 3	0.32	1.07	2.34	0.84	0.54	-	-
Korea 4	-		0.98	0.60	0.58	-	-

Sample	Hexanal	Nonanal	Benzaldehyde	Toluene	2-Hydroxy-3-methyl benzoic acid	Styrene	Jasmone	β-Ionone
Africa								
Kenya 1	-	1.32	0.45	-	-	-	-	-
Kenya 2	0.61	-	0.51	-	-	-	-	0.31
Tanzania	0.44	-	0.54	-	-	-	-	-
Southeast Asia and Indian Subcontinent								
India	-	0.77	-	-	-	-	-	-
Sri Lanka 1	0.96	0.32	-	-	0.72	-	-	0.61
Sri Lanka 2	-	1.17	-	-	-	-	-	-
Vietnam	0.61	-	0.74	-	-	-	-	0.80
Northeast Asia								
China 1	-	0.38	-	-	0.43	-	-	-

China 2	0.37	0.22	-	-	-	-	-	0.62
China 3	0.30	0.38	-	0.42	-	-	0.31	0.22
China 4	0.28	-	-	-	0.52	-	-	-
China 5	0.53	0.57	0.36	3.04	-	-	0.66	-
China 6	0.73	0.61	0.65	-	-	-	-	-
China 7	0.53	0.49	0.41	-	-	-	0.50	-
Japan 1	0.54	0.48	-	0.86	-	0.25		1.21
Japan 2	-	0.41	-	0.35	-	0.21	-	-
Japan 3	0.29	0.36	0.40	3.40	-	-	1.13	0.25
Japan 4	-	-	-	-	-	-	-	-
Japan 5	0.45	-	-	-	-	0.22	-	0.97
Japan 6	0.36	0.34	-	-	0.55	-	-	0.53
Korea 1	0.45	-	-	-	-	-	-	-
Korea 2	0.43	0.37	0.27	-	-	0.18	0.52	-
Korea 3	0.70	0.47	0.84	-	-	-	0.55	0.76
Korea 4	0.96	0.62	0.33	0.70	-	-	1.06	-

[a]The volatiles were separated on an Rtx® -5 (Crossbond® 5% diphenyl-95% dimethyl polysiloxane; 30m length × 0.25 mm internal diameter × 0.25 μm film thickness) capillary column (Restek; Bellefonte, PA, USA).

[b]Concentration is reported in nanogram in kilogram of green tea when 1 kg of green tea is brewed in 25 kL of 70℃ water for 2 min.

[c]- = not detected

Table 4.4 Average Concentration of 24 Volatile Compounds Identified in the Brewed Green Tea Samples (ng/kg) [a,b]

Volatile Compounds	Green tea sample (Concentration)
Aliphatic Alcohols	
1-Pentanol	Korea 4 (0.27)
(Z)-3-Hexen-1-ol	China 7(0.33); Korea 4 (0.47)
Aromatic Alcohols	
1-α-Terpineol	China 4 (0.27); Sri Lanka 1 (0.45); Tanzania (0.48)
2-Methoxy-4-methylphenol	Vietnam (1.00)
Aliphatic Aldehydes	
3-Methyl-butanal	Kenya 2 (0.21); Korea 3 (0.33)
cis-3-Hexenal	Kenya 2 (2.57); Korea 3 (5.34)
1H-Pyrrole-2-carboxaldehyde	Korea 2 (0.56)
Aromatic Aldehydes	
Benzeneacetaldehyde	Kenya 2 (1.21); Korea 3 (2.69)
Other Aromatic Compounds	
1,4-Dimethoxy benzene	Vietnam (0.35)
1,4-Bis(1,1-dimethylethyl)-benzene	China 5 (0.40); Korea 3 (0.29)
Ketones	
3,5-Octadien-2-one	Korea 2 (0.58)
α-Ionone	China 2 (0.23); Japan 1 (0.38)
2-Methyl-5-(1-methylethenyl)-2-cyclohexen-1-one	Tanzania (0.67)
Furans	
Tetrahydro-2,2,5,5-tetramethyl furan	China 1 (0.53); Japan 4 (0.35); Japan 6 (1.21)
4-Methyl-2-propyl furan	Sri Lanka 1 (0.60)
N-Furfuryl adenine	China 5 (0.30); Japan 3 (0.18)
Pyridine	
3-Butyl-1-oxide-pyridine	Chana 3 (0.29); Korea 4 (0.26)
Pyrazine	

3-Ethyl-2,5-dimethyl-pyrazine	Korea 3 (0.46)
Furanone	
5,6,7,7a-Tetra 2(4)-benzofuranone	China 2 (0.22); Japan 1 (0.43)
Acids	
Benzoic acid	Sri Lanka 1 (11.58)
2-Hydroxy methyl ester benzoic acid	Kenya 2 (0.93); Korea 3 (1.94)
Nonanoic acid	Korea 4 (0.85)
Ester	
Isopropyl myristate	China 4 (0.23)

[a]The volatiles were separated on an Rtx® -5 (Crossbond® 5% diphenyl-95% dimethyl polysiloxane; 30m length × 0.25 mm internal diameter × 0.25 μm film thickness) capillary column (Restek; Bellefonte, PA, USA).

[b]Concentration is reported in nanogram in kilogram of green tea when 1 kg of green tea is brewed in 25 kL of 70°C water for 2 min.

[c]nd = not detected

1995). The compound was found in green tea (Yanagimoto, Ochi, Lee & Shibamoto, 2003) at a much higher concentration of 1.35 mg/kg than found in our research. This difference is probably because of the variations in sample extractions. The sample was prepared by solvent extraction directly from green tea in the study conducted by Yanagimoto and others (2003) whereas in our study the tea samples were brewed in water.

Twenty green tea samples had linalool which is classified as a terpene alcohol. Linalool has a "light, refreshing, floral-woody with a faintly citrusy note" (Arctander 1969). Concentrations of linalool in final products ranged from 2 to 10 μg/L in candy and beverages and could be as high as 40 μg/L in meat products (Arctander 1969). Concentrations of linalool in the green tea samples in our study were much lower and ranged from 0.27 ng/kg to 3.34 ng/kg. These concentrations are roughly 1000 times lower than the orthonasal and retronasal thresholds, which are 5-6 μg/L and 1.5μg/L in water, respectively (Rychlik and others 1998). The parch-processed tea samples in Choi's study (1991) showed higher concentrations of linalool than steam-processed samples which agrees with our study. Linalool concentrations in Chinese and Korean samples generally were higher than concentrations in Japanese samples. Chinese and

Korean green teas are mostly roast-processed while Japanese green teas are steam-processed (Kim 1996). For instance *Longjing* (roast-processed Chinese green tea) contained linalool at much higher concentrations than *Sencha* (steam-processed Japanese green tea) (Kumazawa and Masuda 2002). China 7, which is a *Longjing* tea, had higher concentrations (0.55 ng/kg) than the *Sencha* teas from Japan (Japan 2 and 3 both at 0.27 ng/kg) (Table 3).

Geraniol, which also is a terpene alcohol, was present in 7 samples at concentrations below 1 ng/kg. It has been found in green tea by other researchers (Choi 1991; Choi 1995; Baptista and others 1999; Hattori and others 2005; Wang and others 2008; Zhu and others 2008) and is a colorless, oily liquid with a flowery-rose like aroma (Arctander 1969). Orthonasal threshold previously reported for geraniol varies from 5 to 75 μg/L in water (Rychlik and others 1998) and concentrations of geraniol in our samples were well below the reported threshold values. In previous research *Longjing* had more geraniol than *Sencha* (Kumazawa and Masuda 2002) which was true for our study also where China 7 (*Longjing*) had a higher concentration than Japan 3 (*Sencha*).

Benzeneethanol was present in 6 green tea samples. Concentrations in these samples were much lower than the thresholds which are 1000 μg/L for orthonasal evaluation and 45 μg/L for retronasal evaluation (Rychlik and others 1998). This compound has a floral rose odor (Ash and Ash 2006).

Five green tea samples had 2,6-dimethyl-cyclohexanol. It was detected in green tea when the sample was extracted using a dynamic headspace technique but was not found when extracted by the simultaneous distillation-extraction technique (Lee and others 1997). Comparison with our results is not possible because researchers only reported peak areas in percentage. Threshold information is not available.

Six samples in our study had pentanal, which typically has a woody, vanilla-like and nutty odor (Wang and others 2008). Pentanal was detected in green tea when the sample was extracted using the dynamic headspace technique but was not detected when it was extracted by simultaneous distillation-extraction technique (Lee and others 1997). There is not much evidence in the literature about the presence of pentanal in green tea. The reason for this could be because pentanal is one of the first compounds to emerge from a GC column during separation and it may be introduced with other compounds from the column and/or trapped residue.

Hexanal was found in 8 samples at concentrations below 1ng/kg. Other researchers found hexanal in green teas in trace amounts (Choi 1991; Baptista and others 1999; Hattori and others 2005) or around 5% (Choi 1995). Aroma of hexanal has been described as being similar to freshly cut grass and unripe fruits in extreme dilution and its concentration in final food products is generally between 1 and 5 μg/L (Arctander 1969). The threshold of hexanal ranged from 4.5 μg/L to 50 μg/L for orthonasal evaluation and from 10.5 μg/L to 16 μg/L for retronasal evaluation (Rychlik and others 1998). These are at least 10^4 times higher than the concentrations found in any of the samples in our study. Even though the concentrations are lower than threshold, hexanal may contribute to aroma in combination with other volatile compounds in green tea (Bott and Chambers 2006)

Seventeen green tea samples had nonanal and concentrations varied from 0.22 ng/kg to 1.32 ng/kg. Nonanal has a tallowy and fruity odor (Rychlik and others 1998). The typical concentrations in final products range from 0.2 to 6 μg/L (Arctander 1969). The threshold of nonanal is ~1 μg/L for orthonasal evaluation (Rychlik and others 1998). Nonanal is widely reported in green tea (Kawakami and Yamanishi 1983; Lee and others 1997; Hattori and others 2005). However, a direct comparison of concentrations between the samples in previous research and our green tea samples is not possible because only relative quantities have been reported in the form of peak area percentages.

Eleven green tea samples had benzaldehyde at concentrations below 1ng/kg. Benzaldehyde has a dominantly sweet aroma of freshly crushed almonds. The typical concentrations in final products usually range from 150 to 160 μg/L (Arctander 1969). Benzaldehyde is a common volatile compound that has been identified in green tea by many researchers (Yamanishi and others 1973; Kawakami and Yamanishi 1983; Choi 1991 and 1995; Baptista and others 1999; Hattori and others 2005) evaluating samples from Azores, China, Japan, Korea, and Taiwan. However benzaldehyde was not reported in a study evaluating 23 Chinese green teas (Liang and others 2008).

Seven green teas had jasmone in concentrations that ranged from 0.31 ng/kg to 1.13 ng/kg. Jasmone has a floral odor (Arctander 1969) and has been found in many green tea samples (Kawakami and Yamanishi 1983; Choi 1991; Hattori and others 2005; Zhu and others 2008). Korean green teas processed from leaves picked in April were found to have more jasmone than samples harvested in June (Choi 1991). A similar trend was found in our study in that Korea 2, 3 and 4 (all of which were picked in April) had jasmone but the compound was not detected in the Korea 1 sample (which was picked in May). Jasmone was not detected in most of the green tea samples in our study including Japan 5 (*Gyokuro*). Jasmone has been reported in *Gyokuro* having 4.16% of volatile compounds extracted (Yamaguchi and Shibamoto 1981).

Ten samples had β-ionone in concentrations ranging from 0.25 ng/kg to 1.21 ng/kg. β-Ionone has a violet-like odor and can be detected at concentrations as low as 0.007μg/L (Rychlik and others 1998) in water. Another source (Arctander 1969) stated that the typical concentration in final products ranged from 1 to 10 μg/L. β-ionone is commonly found in green teas (Choi 1991 and 1995; Hattori and others 2005; Liang and others 2008; Wang and others 2008; Zhu and others 2008). The peak area ranged from 1.36 to 4.49% in Japanese green teas (Hattori and others 2005). And 65% of Chinese green teas had β-ionone (Liang and others 2008). In the current study, β-ionone was most commonly found in the Japanese green teas (4 out of the 6 samples).

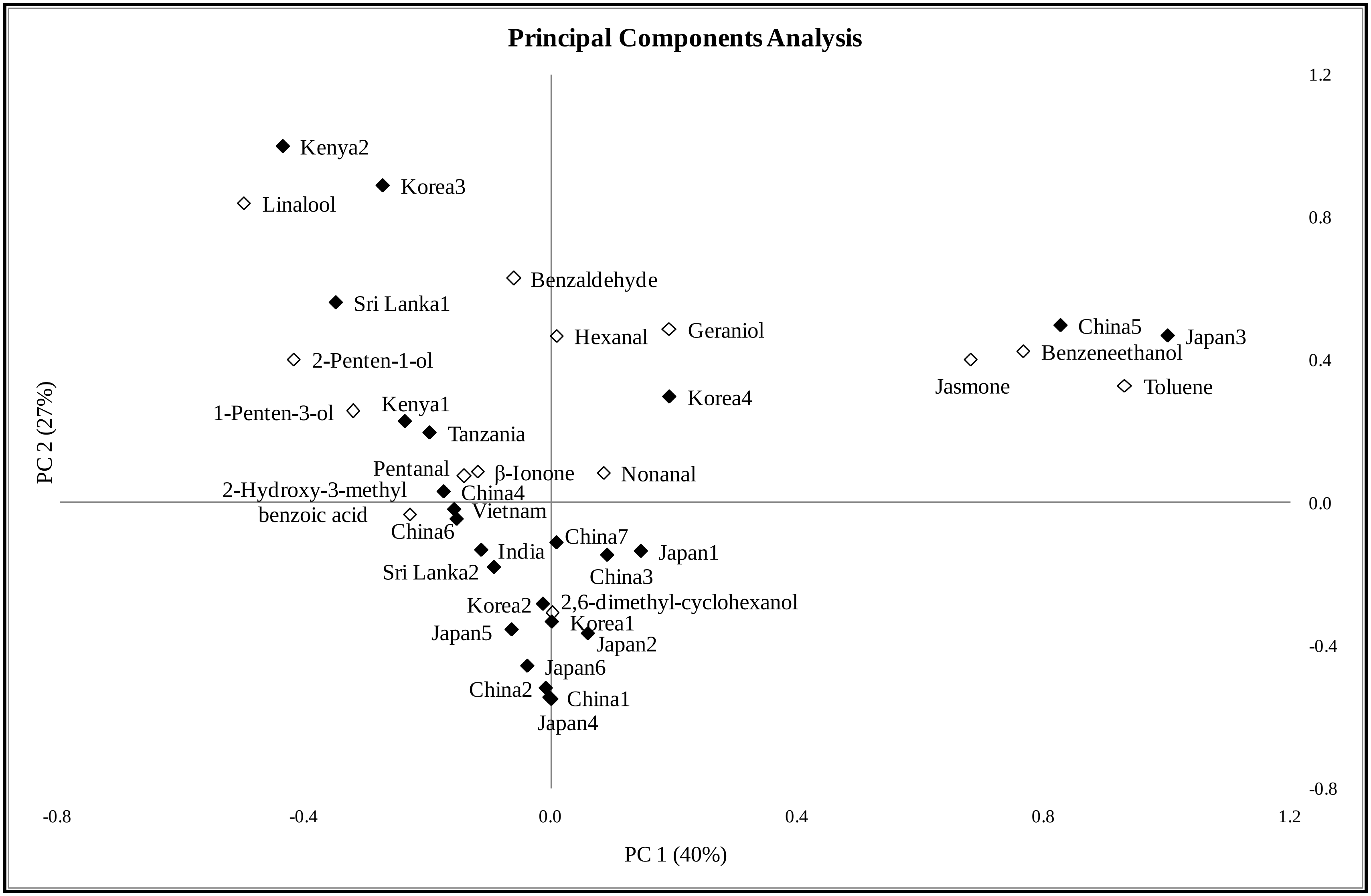
Six samples had toluene. Toluene has a sweet-grassy odor (Arctander 1969). Toluene was reported by a limited number of researchers studying green tea (Yamanishi and others 1973; Wang and others 2008). Styrene was detected in 4 samples. In this study 2-Hydroxy-3-methyl benzoic acid was present in 4 samples: china 1, china 4, Japan 6 and Sri Lanka 1. No information was available in the literature about this compound.

Principal Components Analysis of the Green Tea Samples

Principal components analysis was conducted using the mean concentrations for the 14 compounds reported in Table 2. Because the volatile compounds found in fewer than 4 samples were not included in PCA, many of the green teas could have unique flavors that would differentiate them from other teas in ways not shown on the PCA biplot (Figure 4.1). Principal components (PC) 1 and 2 explained 40% and 27% of the variation on the data, respectively. Toluene, benzene ethanol, jasmone, and linalool were the main vectors for PC 1. PC 2 explained linalool, benzaldehyde, geraniol and hexanal.

Benzeneethanol, toluene, benzaldehyde, hexanal, nonanal, geraniol and jasmine were commonly present in China 5 and Japan 3 tea samples. Concentrations of toluene, benzeneethanol and jasmone in these two samples were higher than most of samples in the study.

Figure 4.1 Principal Component Analysis Biplot Showing Relationship Between the Green Tea Samples (♦) and the Volatile Compounds (◊).



Kenya 2 and Korea 3 had a similar composition of aroma volatile compounds and were distinct from the rest of the samples. Concentrations of linalool were especially high in these 2 samples. Sri Lanka 1 had a volatile compound profile comparable to Kenya 2 and Korea 3, but the concentrations were generally low. In Korea 4 hexanal, jasmone and linalool were the main volatile compounds.

Eighteen samples, China 1, China 2, China 3, China 4, China 6, China 7, India, Japan 1, Japan 2, Japan 4, Japan 5, Japan 6, Kenya 1, Korea 1, Korea 2, Sri Lanka 2, Tanzania and Vietnam, were grouped together in the PCA biplot. This was probably because of the absence of some of the 14 volatile compounds that were quantified in these tea samples. Also the concentrations of the compounds present in these samples (7 out of 14) were much lower than the rest of the samples.

Conclusion

Common volatile compounds in brewed green tea liquor were identified. Linalool and hexanal were detected in almost all of the green tea samples regardless of their origin. In addition to these 2 compounds, green teas produced in the Africa region commonly had 1-penten-3-ol, 2-penten-1-ol and benzaldehyde. Green teas from Southeast Asia and the Indian subcontinent generally had nonanal. Green teas from Northeast Asia typically had nonanal and a few other compounds, such as benzene ethanol and jasmine not found in teas from other regions. Most volatile compounds found in our study have been reported elsewhere, although there were variations both qualitatively and quantitatively. Most of the previous research used green tea extracts as samples so direct comparison for compounds and their concentrations were not possible. However, a number of compounds detected in prior literature that were not detected in our study was probably because of differences in green tea samples or because of the differences in the sample extraction and preparation. The current study is an effort to understand volatile compounds in brewed green tea used for consumption. Further analysis is needed to determine compounds present in other green teas, ages of tea, and processing methods.

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CHAPTER 5 - Sensory Descriptive Evaluation: Brewing Methods Affect Flavor of Green Tea

Commercially available green tea products provide various brewing directions based on the tea's type, origin, purpose, etc. The flavor and basic taste of green tea may vary when using different brew styles. The objective of this study is to describe flavor changes of green tea when it is prepared with different water temperatures and brewing times. Green tea samples were brewed at 3 different temperature levels (50, 70, and 95°C) for 1, 2, 5, and 20 min using 3 different green teas from Korea. Highly trained panelists participated in the descriptive sensory analysis using a previously developed green tea lexicon. Canonical Variates Analysis (CVA) is used to compare green tea flavor for each combination of brewing time and temperature. CVA, across all 3 green tea samples at 12 different brewing temperature and time combinations, suggested that brown, brown-related attributes (ashy/sooty, burnt/scorched), bitterness, and astringent become stronger; and green and green-related attributes (green beans, spinach) become weaker as the brewing time and water temperature increased.

Introduction

Constituents such as catechins, caffeine, tannin, amino acids and free sugar in green tea contribute to the flavor. Especially, catechins are known to contribute to 70-75% of bitterness and astringency (Chen and others 2002; Choi 2002). Caffeine has a bitter taste (Yamanishi 1990) and tannin has a strong astringent or pungent taste (Ukers 1935). Amino acids are responsible for brothy taste and free sugars contribute to sweetness (Nakagawa 1975).

There is some evidence that brewing temperature and length may influence the extraction of aforementioned constituents. In a study conducted to determine how different brewing conditions change green tea constituents, researchers found that the amounts of tannin, free sugar and total nitrogen in green tea increased as the water temperature and brewing time increased (Lee and others 1989). Research studying the caffeine content of brewed coffee, black tea and green tea found that caffeine content in green tea markedly increased as the water temperature increased (Kwon and others 1990). In the same study, researchers used 100℃ to compare brewing time and found a minimal effect on caffeine content of the tea. Caffeine has a bitter taste (Yamanishi 1990) thus, from this study it can be determined that the bitterness of green tea increases as the brewing water temperature increases.

Green tea is considered a functional food with catechins providing the majority of the antioxidants in green tea and the potential health benefits (Hara 2001; Kumar and others 2009). Thus, green tea products in some countries bear statements such as 'rich in antioxidants' and 'good for your health' on their packages; some products even specify how much antioxidant consumers could potentially receive through consumption of their product. As the release of catechins into brewing water can be affected by the temperature of brewing water and the brewing time, the health benefits of green tea can depend on the brewing methods. Thus, some green tea products recommend using boiling water and 3-5 minutes brew for maximum health benefit, which may result in bitter and astringent green tea.

However, consumers are not willing to trade taste for food functionality (Verbeke 2005). If this applies to green tea, consumers would not enjoy the bitterness and astringency of green tea that could occur when tea is brewed with boiling water for a longer time (Lee and others 1989) even though it might be healthier for them. The literature suggests that different brewing methods may result in different flavors for green tea (Kim 1996; Choi 2002). Therefore how the flavor of green tea changes at different brewing conditions is important. Though there has been limited research on the subject.

Researchers have sought to find optimal brewing conditions using green tea bags (Jang and others 2006) and loose green tea leaves (Lee and others 2008). Using tea bags, researchers found that soluble solids, phenolics, and flavonoids in green tea increased when the temperature of the water and the brewing time increased. Using physicochemical and acceptability data authors concluded that optimal brewing methods are a combination of 73-83℃ water and 5.3-6.3 minutes of brewing time (Jang and others 2006).

Using loose green tea leaves, a total of 12 green tea preparation methods (2 water temperature points for 6 brewing lengths) were studied using consumer just-about-right scaling (Lee and others 2008). Researchers recommended optimal brewing at 60℃ for 3 minutes or at 80℃ for 1 minute based on the just-about-right evaluation from consumers. Interestingly, 70℃, one of the commonly recommended temperatures for brewing green tea leaves was not used in the research. After the consumer study, tea brewed using the two recommended temperatures was analyzed by a descriptive sensory panel who found that these two brewing methods discriminated among green tea samples. Unfortunately, green tea flavor of only two brewing methods was described. Thus, it appears that flavor of green tea brewed under different conditions needs more thorough research.

The objective of this study was to describe flavor changes of green tea when prepared with different water temperatures and brewing times.

Materials and Methods

Tea Samples

Three Korean commercial green tea products were selected as samples because of their availability in large quantities for the same harvest date and processing methods. Two samples were obtained from *Amore Pacific Co.* (Yongin, Korea), a major green tea producing company in Korea. *Sulloc Tea Ouksu (Ouksu)* is a high grade green tea and *Sulloc Tea Soon (Soon)* is a medium grade green tea. Green teas made with tea leaves harvested earlier in the season generally have higher amino acid contents and are considered as higher grade teas. The third sample, *Myungsul Sejac (Sejac)*, was obtained from *Myungsulwon* (Suncheon, Korea) and it is a high grade green tea. All three samples were in leaf form because that form is commonly used for green tea brewing in Asian countries and is more appropriate to test the effects of brewing length. The green teas in tea bags is processed and finely chopped to release flavor and nutrients in a shorter time and may not be appropriate for testing different lengths of brewing time. The three green tea samples, with a normal shelf life of 2 years, were stored at 4°C before being tested and evaluated within three months of packaging.

Tea Preparation

Packaged green tea samples were taken from the refrigerator and allowed to reach room temperature to prevent dew from collecting on the tea leaves when the package was opened. The tea samples were prepared using a small white porcelain tea pot (approximately 350mL in volume), a porcelain strainer, and a porcelain bowl, which are widely used in Asian countries to brew teas (Kim 1996; Choi 2002). In addition, using porcelain equipment will not impart any additional flavors to the tea. Reverse osmosis, deionized, carbon filtered water was heated to brewing water temperatures and used for warming the pot prior to brewing the tea. Warming is typical procedure of brewing tea and was done to prevent the acute temperature of brewing water from dropping. After warming the pot, the water was poured into the bowl to warm the bowl; Ten grams of tea was used with 3 different water temperatures and 4 different lengths of brewing times resulting in 12 different combinations.

Three different water temperatures represented hot tap water at 50˚C; 70˚C, the most commonly recommended temperature for brewing; and "boiling water" at 95˚C. Brewing times were 1, 2, 5, and 20 min long. One, 2, and 5 min are the most commonly recommended brewing times from various package directions. In addition, 20 minutes was added to examine an extreme length of brewing time. All three of the green tea samples were prepared using the 12 different brewing combinations and each tea was evaluated in triplicate. The tea was placed in the teapot, followed by 300 mL of water at the desired temperature setting and then brewed for the appropriate length of time. While the tea was brewing, the pot was swirled clockwise 10 times within the first minute to assimilate the typical brewing of tea. After the first minute, the teapot was left undisturbed until the brewing time ceased. The brewed tea was then poured through a strainer into the warmed bowl. Approximately 45 mL of brewed green tea was poured into each pre-warmed white porcelain tea cup.

Panelist

Six highly trained panelists from the Sensory Analysis Center at Kansas State University served as the panel in this study. The panelists had completed 120 hours of general training and had a minimum of 1,000 hours of general sensory evaluation experiences including a variety of beverages including green tea and vegetables. This panel was similar to the panel that developed a standardized green tea lexicon (Lee and Chambers 2007).

Serving Procedure and Sample Evaluation

Green tea samples were coded with three-digit random codes and served one at a time. The same sample was prepared a second time, 5 min later, to ensure a warm sample for the panelists to evaluate. Each evaluation session lasted 1.5 h with 15 min for each sample evaluation. Panelists used unsalted crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ) and reverse osmosis, deionized, carbon-filtered water to cleanse the palate before evaluating the next sample. The panel had three 90-minutes sessions for orientation and evaluated all three samples for 12 conditions in eighteen 90-minutes sessions. The standardized green tea flavor lexicon (Lee and Chambers 2007) was used for the descriptive analysis in this study.

Test Design

The effects of two factors, water temperature (50, 70, and 95℃) and brewing time (1, 2, 5, and 20 minute(s)) were studied for the brewing of green tea. A 3 × 4 factorial design was used. A total of 12 design points were evaluated in triplicate. Design points were evaluated in random order within each replicate.

Data Analyses

The main effects of water temperature and brewing time, and the interaction between water temperature and time were studied using PROC GLM, LSMEANS statement in SAS® (Version 9.1; SAS Institute, Cary, NC, U.S.A.). Multivariate Analysis of Variance and Analysis of Variance was conducted using PROC GLM in SAS (Johnson 1998). Canonical Variates Analysis (CVA) was conducted to show the significance among samples and brewing method combinations using canonical space with confidence regions (SAS® PROC CANDISC). Ninety five percent confidence spheroids were calculated using $\sqrt{(\chi_{\alpha,k}/n)}$, where α=0.05, k=2 (number of dimensions), and n=number of observation (Johnson 1998). CVA biplots give visual information on data for easier understanding of overall differences or similarities among products. Circles in figures denote 95% confidence spheroids; when 2 circles are overlapping, they are not statistically different at 95% confidence level. The distance between circles shows differences among samples. In other words, if one sample is quite different from another sample, the distance between these 2 circles will be further apart.

Results and Discussion

Of 31green tea flavor attributes in the standardized green tea flavor lexicon (Lee and Chambers 2007), only 22 attributes were detected in the three samples in this study: green, asparagus, celery, green beans, green herb, parsley, spinach, brown, ashy/sooty, burnt/scorched, citrus, grain, medicinal, musty/new leather, nutty, seaweed, straw-like, tobacco, bitter, astringent, toothetch and sweet aromatics.

All multivariate statistics and F approximations for CVA were significant (e.g. both Wilk's Λ and the Hotelling-Lawley trace had P-values less than 0.00001) which shows similarity to the univariate analysis where all attributes were significant. The first and second CVs were plotted separately for each green tea product (Figure 5.1) to simplify the plot. The first canonical variate dimension explained 54.65% of the variability in the sample means and the second dimension explained another 9.95% of the variability. It is evident from CVA biplots that flavor of green tea changes as water temperature and brewing length change.

Effects of Water Temperature and Brewing Time

Bitter and brown were explained mostly in CV1, probably because intensities of bitterness and brown flavor note differed markedly when different brewing methods were used. The intensities of bitterness and brown note increased as both water temperatures and brewing times increased and the differences were almost 6 points on a 0 to 15 scale, which is much larger than the change of other attributes (Table 5.1, 5.2, and 5.3). CV2 explained more flavor terms than CV1 and included terms such as green, asparagus, celery, green beans, green herb-like, spinach, ashy/sooty, seaweed, straw-like, tobacco, seaweed and sweet aromatics attributes. CV1 and CV2 explained almost the same variability for parsley, citrus, medicinal, nutty, tooth-etch and burnt/scorched.

Water Temperature and Brewing Time Interaction

Twenty attributes had significant interactions with water temperature and brewing time: green, asparagus, celery, green beans, green herb-like, parsley, spinach, brown, ashy/sooty, burnt/scorched, citrus, grain, medicinal, musty/new leather, nutty, tobacco, bitter, astringent, tooth-etch and sweet aromatics. Only seaweed and straw-like did not show significant interaction between water temperature and brewing time, but main effects for both factors were significant.

However, interactions of asparagus, celery, green herb-like, parsley, ashy/sooty, citrus, grain, medicinal, nutty, tobacco, sweet aromatics may not be meaningful because these attributes were perceived only in some of the samples of each brewing method.

Figure 5.2 shows some important interactions between water temperature and brewing time: green, spinach, green beans, brown, burnt/scorched, musty/new leather, bitter, astringent, and tooth-etch. As expected, the highest intensity was reached at different temperatures within

Table 5.1 Mean Scores of *Ouksu* Green Tea Sample At 12 Brewing Conditions Differing Water Temperatures and Brewing Time.

Attributes	50℃				70 ℃				95 ℃			
	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min
Green	2.08	3.25	4.42	4.00	3.56	3.81	3.56	2.47	4.64	3.47	2.72	2.47
Asparagus	0.00	0.00	0.50	1.03	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	0.00	0.00	0.69	0.00	0.56	0.56	1.08	0.00	0.91	0.83	0.00	0.75
Green herb-like	1.06	0.72	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.67	0.00	0.00	0.00
Spinach	0.89	1.94	2.83	2.08	1.69	2.69	1.55	1.72	2.75	2.19	2.08	1.14
Brown	0.00	0.92	1.67	4.14	0.86	1.81	3.83	5.64	2.25	4.36	5.75	6.08
Ashy/Sooty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	1.89
Burnt/Scorched	0.00	0.00	1.03	3.25	0.00	0.75	2.94	4.89	1.56	4.00	4.78	5.81
Citrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.00	0.61	0.00	0.00	0.00	1.06	0.00	1.33	0.00	0.00
Medicinal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Musty/new leather	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.78	0.00	0.61	2.00	0.00
Nutty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seaweed	0.00	0.53	1.25	1.56	0.00	0.00	1.64	0.92	1.73	0.75	1.56	0.81
Straw-like	0.00	0.00	1.50	0.72	0.97	1.25	1.72	2.19	1.53	1.94	1.78	1.75
Tobacco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Bitter	3.31	5.72	6.72	8.78	4.31	5.86	8.69	9.11	6.61	8.42	10.06	10.11
Astringent	0.00	1.06	1.75	2.50	1.03	1.86	2.83	2.81	2.11	2.69	3.22	3.28
Tooth etch	0.00	0.58	0.97	1.69	0.00	0.78	1.81	1.97	1.47	1.83	2.00	2.11
Sweet aromatics	0.67	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.2 Mean Scores of Sejac Green Tea Sample At 12 Brewing Conditions Differing Water Temperatures and Brewing Time.

	50℃				70 ℃				95 ℃			
Attributes	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min
Green	2.67	3.58	4.67	2.92	3.96	3.89	2.94	2.08	3.86	2.28	1.69	1.44
Asparagus	0.00	0.50	1.19	0.83	0.67	0.81	0.00	0.00	0.81	0.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	0.67	0.94	1.81	1.25	1.00	1.31	0.92	0.97	1.86	0.75	0.97	0.50
Green herb-like	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spinach	1.72	2.08	2.08	1.64	1.67	2.22	1.89	1.44	1.42	1.42	1.39	0.97
Brown	0.83	1.75	2.83	5.36	2.38	2.89	4.42	6.28	3.97	5.72	6.58	6.97
Ashy/Sooty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.00	1.42	0.50	1.08
Burnt/Scorched	0.00	0.00	1.33	3.78	0.00	2.03	3.28	3.72	2.81	4.08	4.81	4.81
Citrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.00	1.25	0.00	0.00	0.61	0.00	0.92	1.03	0.50	0.00
Medicinal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

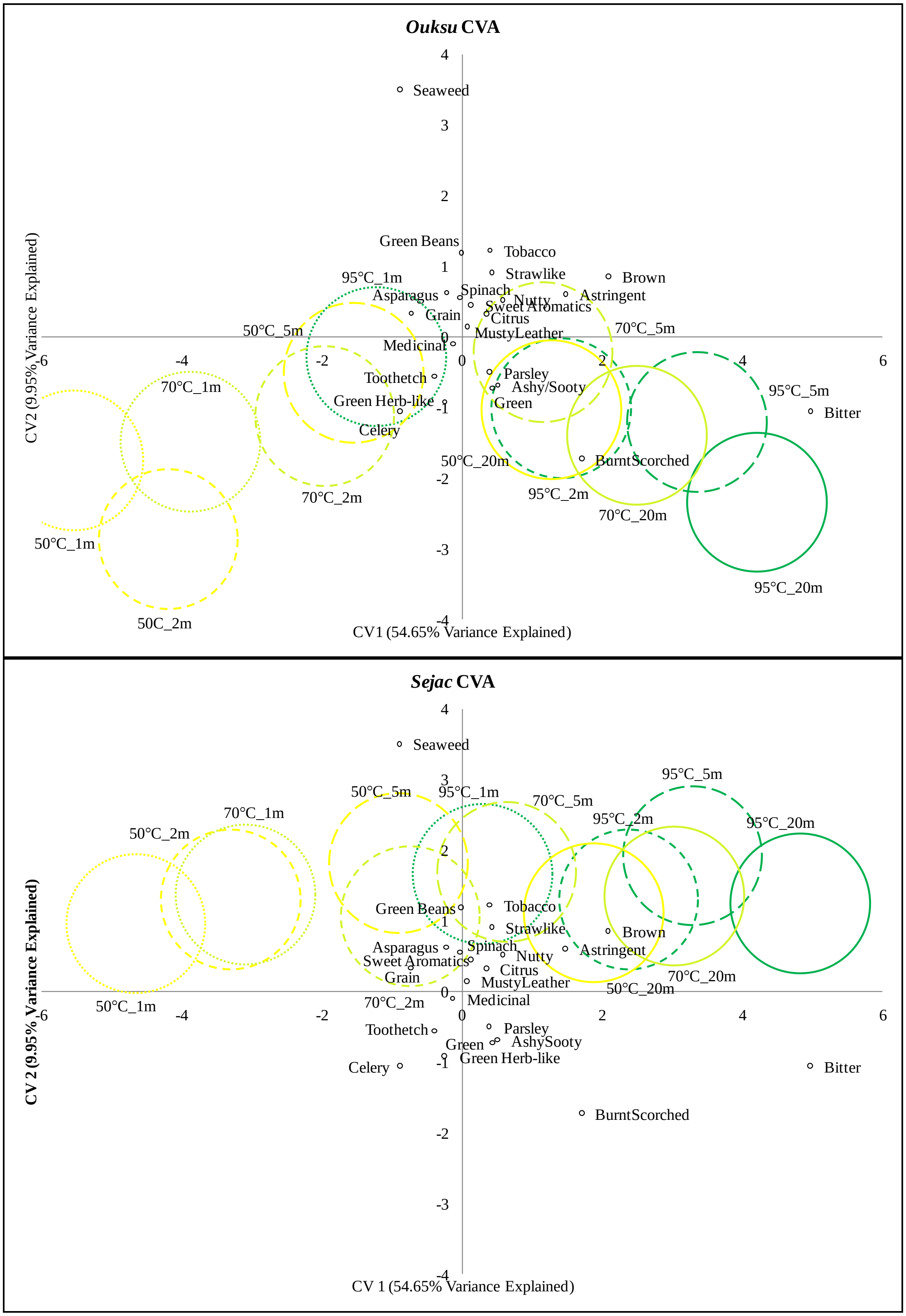
Musty/new leather	0.00	0.00	0.00	0.00	0.00	0.56	0.00	2.67	0.00	1.28	0.64	1.00
Nutty	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.89	0.56	0.69	0.58	1.78
Seaweed	2.17	2.61	3.33	2.72	3.33	2.64	4.22	2.92	3.22	3.06	3.94	2.00
Straw-like	1.19	1.11	2.06	2.28	1.67	1.94	1.92	2.22	2.22	2.33	2.75	2.14
Tobacco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	1.06	0.00	2.56
Bitter	3.78	5.03	7.36	8.97	5.38	7.03	8.28	9.50	7.92	8.94	9.69	10.03
Astringent	1.17	1.26	2.06	2.92	1.50	2.36	2.64	3.42	2.17	2.97	3.50	3.83
Tooth etch	0.00	0.53	1.03	1.72	0.50	1.58	1.61	1.99	1.06	1.83	2.31	2.14
Sweet aromatics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

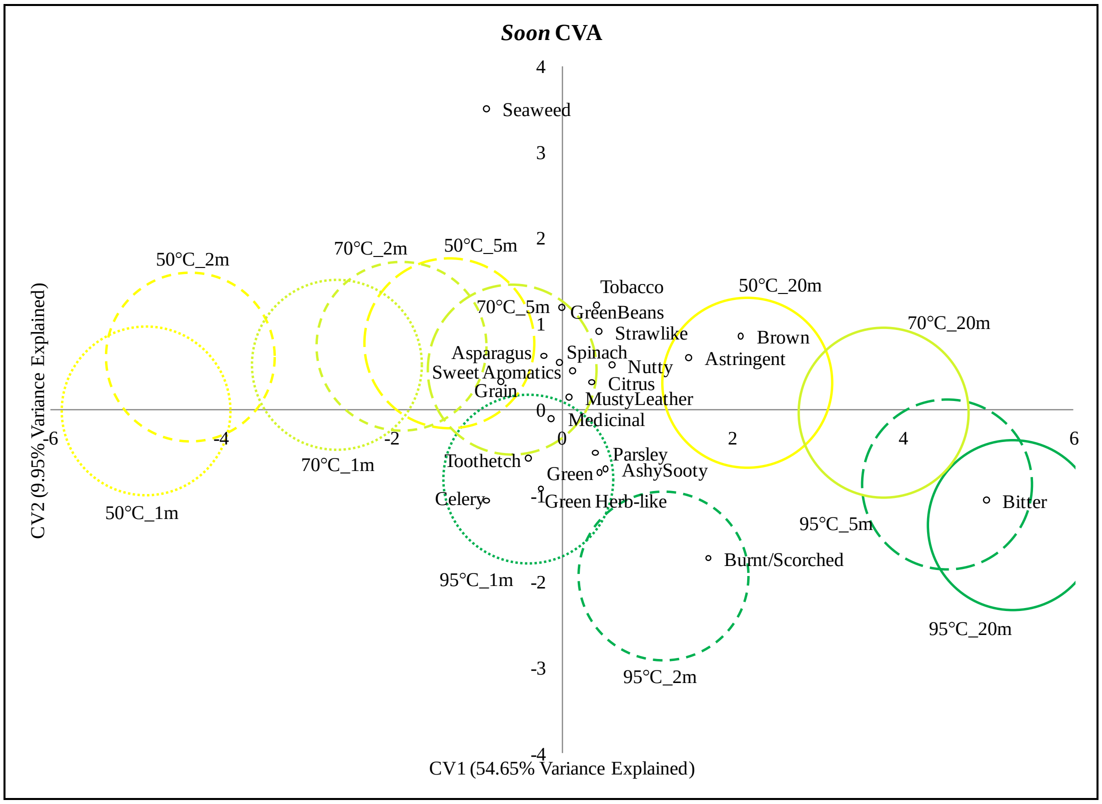
Table 5.3 Mean Scores of Soon Green Tea Sample At 12 Brewing Conditions Differing Water Temperatures And Brewing Time.

	50℃				70 ℃				95 ℃			
Attributes	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min	1 min	2 min	5 min	20 min
Green	2.56	2.76	3.53	3.39	3.53	3.83	3.18	2.36	3.31	3.17	1.94	1.94
Asparagus	0.00	0.00	0.00	0.00	0.00	0.89	0.60	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	0.58	0.65	1.41	1.19	1.32	1.08	1.44	1.19	0.97	1.31	1.21	1.03
Green herb-like	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	0.00	0.00	1.25	0.62	0.00	0.00	0.00	0.75	0.00	0.88	0.50
Spinach	0.89	1.32	2.06	1.61	1.97	2.08	1.62	1.22	1.67	2.11	0.88	1.53
Brown	0.97	1.47	2.47	4.19	1.94	2.28	3.06	6.06	3.42	4.08	6.18	6.68

Ashy/Sooty	0.58	0.00	1.59	1.17	0.00	0.58	0.62	1.81	0.94	1.50	1.47	0.00
Burnt/Scorched	0.00	0.00	1.15	2.39	0.00	0.86	1.85	5.33	0.97	3.75	4.74	5.62
Citrus	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.00	0.81	0.00	0.00	0.91	2.22	0.00	1.28	2.00	0.71
Medicinal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Musty/new leather	0.00	0.00	0.00	0.64	0.00	0.00	0.00	2.58	1.39	1.03	1.29	4.03
Nutty	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.58	0.00	0.00	1.74	1.41
Seaweed	1.39	1.74	2.38	1.00	1.53	1.89	1.09	1.75	0.00	0.00	0.76	0.00
Straw-like	0.78	1.35	1.38	1.78	1.59	1.75	2.00	2.00	2.03	1.89	2.26	2.21
Tobacco	0.00	0.00	0.00	1.42	0.00	0.00	0.85	0.64	0.00	0.00	0.00	0.00
Bitter	3.39	3.35	6.18	8.17	4.94	5.78	6.65	9.67	6.17	8.11	10.15	10.53
Astringent	1.25	1.35	2.53	3.50	2.06	2.36	2.74	4.31	3.22	3.17	4.59	4.74
Tooth etch	0.75	0.59	1.62	1.97	1.15	1.69	1.93	2.61	1.76	1.92	2.85	2.94
Sweet aromatics	0.75	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 5.1 Canonical Variates Analyses of *Ouksu, Sejac* and *Soon* Brewed Differently for Water Temperature[a] and Brewing Time[b]





[a]The colors of line reflect the water temperature.

50℃

70℃

95℃

[b]The line styles reflect brewing time.

1 min

2 min

5 min

20 min

each length of brew time for green-related attributes such as green, spinach, and green beans. The highest intensity was reached more quickly with higher brewing temperatures and then decreased. This suggests that flavor compounds responsible for green-related flavors are leached from the leaves fairly quickly and then dissipate. This leaching occurs faster at higher temperatures.

Interestingly, for brown, burnt/scorched, bitter, astringent, and toothetch the intensity increased as the water temperature and the length of brew increased. This suggests that more compounds responsible for the flavor notes related to processing in green tea (brown and burnt/scorched) and those potentially related to the functional composition (bitter, astringent, and toothetch) continue to be leached from the leaves as the samples brew. Musty/new leather was only detected at the longest brewing time (20 minutes) at 50℃ and 70℃. Musty/new leather was detected at all brewing times with 95℃ water, and its intensity increased as the time of brewing increased. This finding indicates that the compound responsible for this off-flavor note is only released at high temperature or a long brewing time. This gives one possible reason that the brewing of green tea is recommended at lower temperature levels.

Water Temperature

Because most flavor attributes had an interaction among water temperature and length of brewing, only seaweed and straw-like are discussed for water temperature. When green tea was brewed with 50℃ or 70℃ water, the flavor intensity of seaweed did not change. However, when 95℃ water was used for brewing, the intensity of seaweed flavor in the tea was significantly lower than the intensity of tea brewed with 50℃ or 70℃ water. The intensity of straw-like flavor increased as the water temperature increased.

Length of Brewing

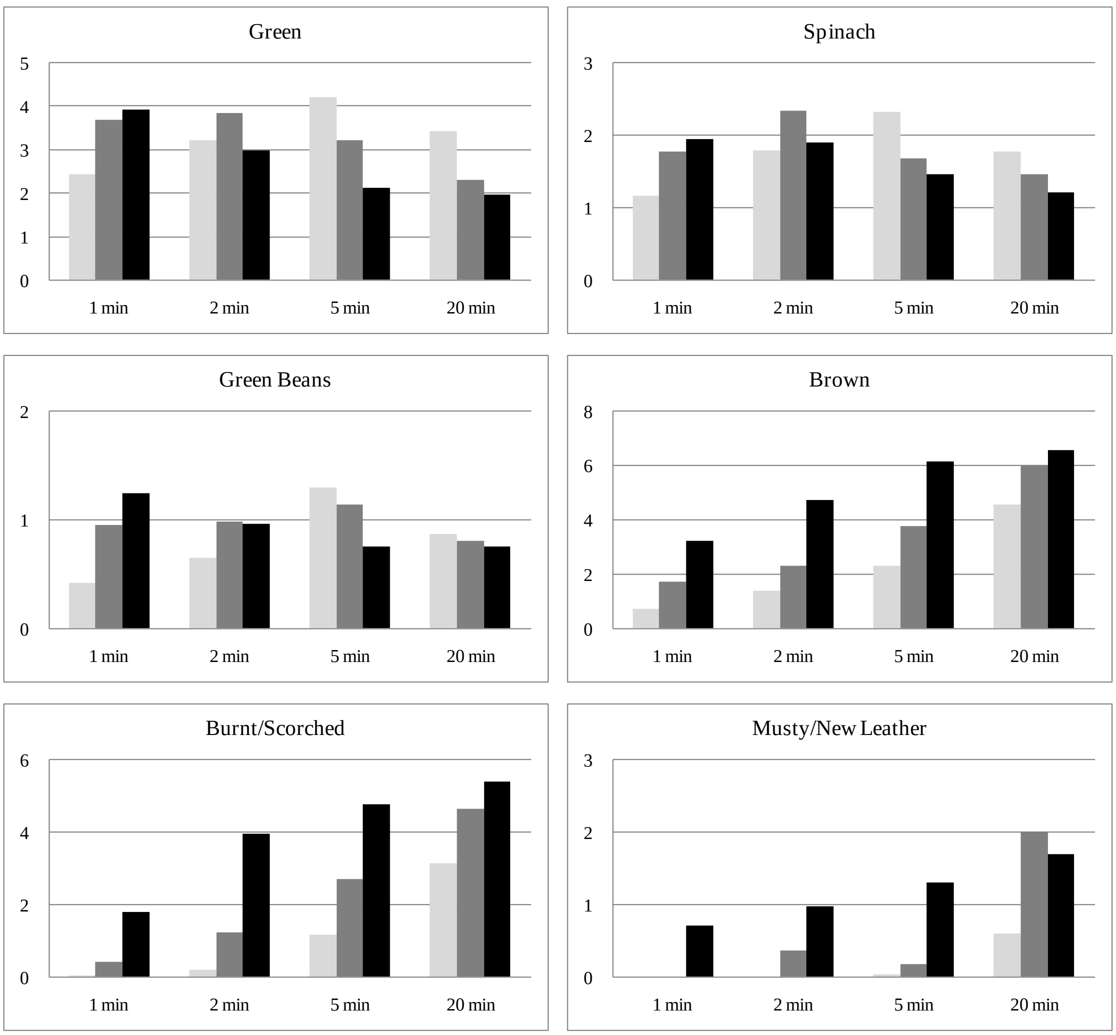
The intensity of the seaweed flavor note was highest when green tea was brewed for 5 minutes. One, 2, and 20 minutes of brewing time of the green tea resulted in a similar intensity for seaweed note, suggesting that the compounds for seaweed flavor take time to become apparent, but then dissipate. The intensity of straw-like flavor did not change with 1 or 2 minute(s) of brewing and then increased to a higher level at 5 and 20 minutes.

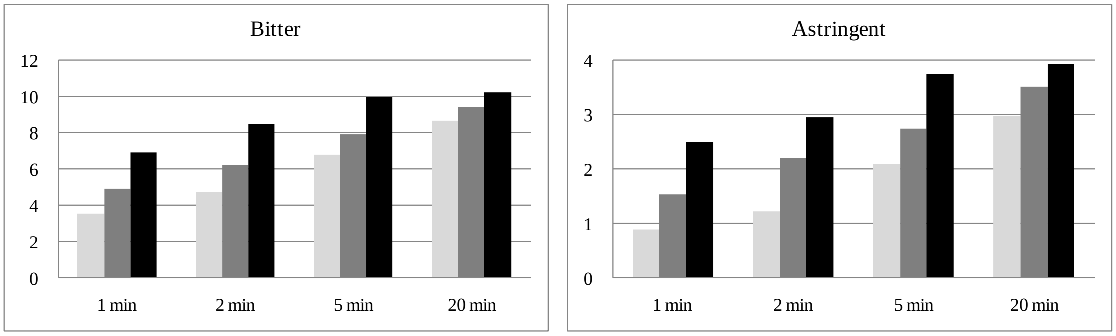
Green Tea Products

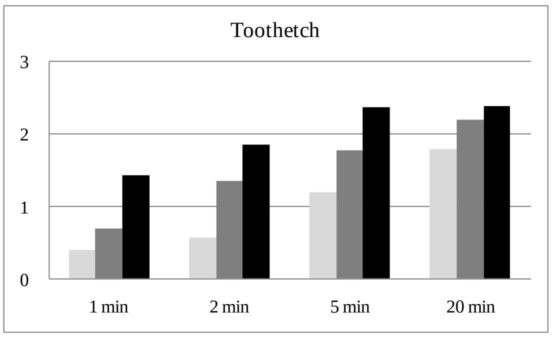
Bitter, brown, burnt/scorched and astringent were markedly affected by the brewing methods. Generally, green tea brewed at 50℃ for 1 minute, at 50℃ for 2 minutes, and at 70℃ for 1 minute had low to moderate intensity for bitterness and other flavor attributes. Green tea brewed at 50℃ for 20 minutes, at 70℃ for 20 minutes, at 95℃ for 5 minutes, and at 95℃ for 20 minutes had a moderate to high intensity for bitterness and low to moderate intensity for the rest of attributes.

All three green tea samples had distinct flavors regardless of how they were brewed (Figure 5.1). *Ouksu* had more green-related attributes but did not have citrus, medicinal, nutty, and tobacco flavor in any brewing method (Table 5.1). *Sejac* had more brown, asparagus, and seaweed notes than the other samples and did not present celery, parsley, citrus, medicinal, and sweet aromatics (Table 5.2). The *Soon* product was more astringent and toothetching and had more ashy/sooty and musty/new leather flavor than the other samples. Also, the panel did not find celery and green herb-like flavor attributes in the *Soon* samples (Table 5.3).

Figure 5.2 Interaction of Water Temperature[a] by Brewing Time for Green, Spinach, Green Beans, Brown, Burnt/Scorched, Musty/New Leather, Bitter, Astringent, and Toothetch Attributes[b].







[a] The colors of bar in the chart reflect the water temperature.

[b] 0 to 15 intensity scale: 0 = none, 15 = extreme.

Recommendation

Brewing methods using different water temperatures and length of brew result in different flavors in green tea liquor. Consumers may brew green tea using 50-70℃ water for 1 to 5 min and have more green-related flavor, less brown-related flavor, and low to moderate bitterness in their green tea with no off-flavor such as musty/new leather and medicinal. Brewing green tea longer than 5 min and/or using 95℃ water may result in a stronger brown-related flavor than green-related flavor. Also, brewing green tea longer than 5 min and/or using 95℃ water may result in bitter and astringent tea. In some green teas, brewing at 95℃ or longer than 5 min may induce a musty/new leather flavor and brewing at 95℃ for 20 min may cause off-flavor such as medicinal. Green tea retailers may use this information to recommend proper brewing direction for consumers so that consumers can avoid creating off-flavor while brewing. Ready-to-drink green tea manufacturers may brew green tea at 70℃ for 1 or 2 min to obtain a like flavor profile to green tea brewed using 50℃ for 2 or 5 min with no risk of inducing off-flavors during brewing.

Conclusion

The flavor of green tea changed when different brewing methods were used. Green-related flavors are leached promptly and then dissipate. As water temperature increases, bitterness, astringency, and tooth-etch increase. At high brewing temperatures, brown flavors overtake green flavor notes that should be present in green tea. Increasing brewing time also provides similar results, depending in part on brewing temperature, with brown flavor, bitter, astringent, and tooth-etch intensity increasing as brewing time lengthens. Musty/new leather note was only released at high temperature or a long brewing time, which may be a reason why it is recommended that green tea be brewed at lower temperatures. Most green teas in leaf form should be brewed for 1 to 5 min using 50-70℃ water. This information can be used to find at optimal brewing condition by green tea consumers, green tea retailers, and RTD green tea manufacturers depending on what flavor characteristics they desire from green tea.

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CHAPTER 6 - Sensory and Instrumental Flavor Changes of Green Tea when Brewed Multiple Times

Green teas in leaf form can be brewed multiple times. However, the aroma and flavor changes of green teas that have been brewed multiple times are unknown. The objectives of this study were to determine how the aroma and flavor of green teas change the more times they are brewed, to determine if a relationship exists between green tea flavors and green tea volatile compounds, and to determine the number of times that green tea leaves can be brewed.

The first and second brews of green tea samples provided similar flavor intensities. The third and fourth brews provided milder flavors and lower bitterness and astringency when measured using descriptive sensory analysis. In the brewed liquor of green tea mostly linalool, nonanal, geraniol, jasmone, and β-ionone volatile compounds were present at low levels (using Gas Chromatography-Mass Spectrometry). The geraniol, linalool, and linalool oxide compounds in green tea may contribute to the floral/perfumy flavor.

Green teas in leaf form can be brewed four times: the first two brews providing stronger flavor, bitterness, and astringency whereas the third and fourth brews will provide milder flavor, bitterness, and astringency. This research provides a basis for future research on multiple brews of green teas.

Introduction

Flavor, aroma, and appearance are the basic sensory components of green tea (Ukers 1935). Green tea is consumed by many people living in Asia for its flavor, cultural connotations, and health benefits. Recently, Western countries are embracing green tea as a beverage because of the possible health benefits (Buss 2006). In addition to the health effects of green tea, researchers have studied the flavors of green tea using descriptive sensory methods (Yamanishi 1977; Park and others 1996; Park and others 1998; Park and others 1999). Recently, a green tea lexicon was developed evaluating over 100 green tea samples (Park and others 1999). The aromatic volatile composition of green teas also has been studied extensively by researchers

(Yamanishi 1978; Kawakami and Yamanishi 1983; Choi 1991; Choi 1995; Shimoda and others 1995a and 1995b; Kumazawa and Masuda 2002; Hattori and others 2005).

While the results of previous research has been valuable, researchers evaluated only the first brew of green tea. It is generally believed in Asia that a high quality green tea can be brewed multiple times. A Chinese poet sang about tea drinking and mentioned the first through the seventh brew (Ukers 1935). Many premium and high end products suggest brewing their tea multiple times (up to 5 times) in the brewing directions. Kim (1996) suggested that green tea can be brewed up to 3 times. However, some of the literature on the multiple brewing of green tea is contradictory. Several researchers recommend using fresh leaves or a tea bag when wanting more tea instead of using already brewed tea leaves or a new tea bag and stated that used leaves do not provide much more than a little bitterness (Schapira and others 1982). This may be true for green tea bags because such products are processed specifically to increase the surface area to extract the flavor and nutrients quickly. But no such study has been made on the similar properties of green tea that is brewed from tea leaves.

A limited number of researchers have reported on teas that have been brewed more than once (Hicks and others 1996; Byun and Kim 2006). The concentrations of caffeine, theobromine, and theophylline were measured in tea samples brewed 3 times (Hicks and others 1996). The percentage of caffeine released in each brew of tea decreased as they were brewed repeatedly. However, the flavor and aroma changes of green tea as it is brewed repeatedly were not discussed in the research literature.

Investigating the aroma and flavor characteristics of green tea liquors that have been brewed repeatedly can help determine how many times green teas can be brewed for consumption. No literature was found indicating how the aromatic volatile compounds and the flavor characteristics change when green tea is brewed multiple times. Thus, the objectives of this study were to: 1) determine how the flavor changes as green tea is brewed multiple times, 2) determine how the aromatic volatile compounds change as green tea is brewed multiple times, 3) relate the descriptive flavor analysis of green tea flavors to the aromatic volatile compounds data at each brew and 4) suggest the number of times that green tea leaves can be brewed and still maintain their major flavor notes.

Materials and Methods

Descriptive Sensory Evaluation

Tea Samples

Six green tea samples were obtained from 4 different Korean green tea manufacturers (Table 6.1). These were selected based on availability, package directions having various brews recommended, and tea quality. The tea quality was based on its retail price, with higher prices reflecting higher tea qualities (Hattori and others 2005). All six samples are considered either premium or high quality.

Table 6.1 Product Name, Manufacturer, Harvest Date, and Price for Green Tea Samples Evaluated.

Green Tea Samples	Manufacturer	Harvest Date	Retail Price (KRW[1])	Retail Price[2] (USD[3]/ 100g)	Recommended Number of brews
Deahan Ujeon	Daehan Tea	~ April 20	70,000/100g	69.14	Up to 3 times
Daehan Ujeon wild	Daehan Tea	~ April 20	Not available for retail sale	n/a[4]	n/a
Illohyang	Amorepacific	~April 5	100,000/60g	164.62	Multiple times to taste
Myoungjeon	Myoungsul Cha	~ April 20	150,000/80g	185.19	4-5 times
Ouksu	Amorepacific	May 26	20,900/80g	25.80	2-3 times
Ujeon Okro	Hwagae Jeda	April 16	50,000/40g	123.46	n/a

[1]Korean Won

[2]Exchange rate: USD 1.00 = KRW 1012.46 (average exchange rate at time of donation or purchase).

[3]United States Dollar

[4]Not available

Tea Preparation and Serving Procedure

Ten grams of each green tea sample was placed in a warmed porcelain tea pot. Then 300 mL of 70°C reverse osmosis, deionized, carbon-filtered water was added to the pot. The tea was brewed for 2 min and, while it brewed, the pot was swirled 10 times. The tea was poured through a porcelain strainer and served in white porcelain tea cups. The International Organization for Standardization (ISO 3103 1980) suggested the porcelain tea wares to maintain a consistent result. After the first brew the tea leaves remained in the pot. Brewing was repeated until a total of five brews from the same tea leaves had been tested. Because of the nature of multiple brews, the serving order could not be randomized. Each tea sample was randomly assigned to a day and the 5 brews of the same tea were served in order as they were brewed. Between tea samples, unsalted-top crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water were used to cleanse the palate. Three replications were completed on all the samples.

Descriptive Panel

Six highly trained panelists from the Sensory Analysis Center at Kansas State University served as the panel. The panelists had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing including beverages, vegetables, and tea. Similar panels and testing procedures have been used recently for other products such as UHT milk (Oupadissakoon and others 2009), toothpaste (Hightower and Chambers 2009; Suwonsichon and others 2009), tomatoes (Hongsoongnern and Chambers 2008), and cheese (Talavera-Bianchi and Chambers 2008). The Sensory Analysis Center uses Compusense *five* (Compusense, Guelph, Ontario, Canada) for sensory data collection.

Gas Chromatography/Mass Spectrometry

Tea Samples

The green tea samples were prepared in the same manner that they were prepared for the descriptive sensory analysis panel except for the type of water. Distilled water (Cincinnati, OH, USA) was used.

Extraction of volatile compounds by SPME: For the extraction of the volatile compounds 10 mL of each green tea sample was transferred into a 40 mL amber headspace vial

(Supleco; Bellefonte, PA, USA). Authors used 1,3-dichlorobenezene (Sigma-Aldrich, Milwaukee, WI, USA) as an internal standard for the quantification of the volatile compounds from the samples. One micro liter of the internal standard (concentration: 1µg/Kg) was added. An octagonal, magnetic stir bar (Diameter 8 mm × length 13 mm; Fisher; Pittsburgh, PA, USA) and analytical grade sodium chloride (ca 3 g; Sigma-Aldrich) were added to the vial to help with the extraction. An open-center screw cap with a silicone/PTFE septum (22 mm diameter × 3.2 mm thickness, Supleco) was used to close the amber vial. Each sample was allowed to equilibrate at 60℃ in a Reacti-Therm™ heating block (Pierce Biotechnology, Inc.; Rockford, IL, USA) for 5 min. The volatile odor compounds from the sample were extracted using a StableFlex 50/30 µm three phase (DVB/CAR/PDMS) SPME fiber (Supelco) at 60℃ for 20 min.

Gas Chromatography/Mass Spectrometry (GC-MS)

After extraction, the SPME fiber was retracted and the holder was moved to the splitless injection port of a 5890 Series II Gas Chromatography (Hewlett-Packard Co.; Palo Alto, CA, USA) for manual injection. The fiber was desorbed for 5 min and the injection port was maintained at 225℃. The volatiles were separated on an Rtx® -5 (Crossbond® 5% diphenyl-95% dimethyl polysiloxane; 30m length × 0.25 mm internal diameter × 0.25 µm film thickness) capillary column (Restek; Bellefonte, PA, USA). The temperature program for the separation was as follows: 40℃ for 1 min, 13℃/min of ramp rate to 250℃ and held for 1 min. The total time was 18.15 min. The identification of the compounds was done using an HP 5890 Series II GC/HP 5972 mass selective detector (MSD, Hewlett-Packard Co.; Palo Alto, CA, USA) with the following parameters: interface temperature, 250℃; ionization energy, 70 eV; mass range, 33-350 a.m.u.; scan rate, 2.2 scans/s. Ultra high purity Helium (AirGas; Westpoint, MS, USA) was used as a carrier gas at a constant flow rate of 0.96 mL/min. The mass spectra of the volatile compounds were compared using the Wiley138K Mass Spectral Database (Version B00.00, 1990; John Wiley and Sons, Inc.; New York, NY, USA). The volatile compounds were analyzed in triplicate for each sample. The Kovats retention indices (RI) were calculated to confirm the identification of the compounds. The concentrations for the green tea volatile compounds were calculated and reported on the basis of the internal standard concentration.

Data Analyses

The descriptive data were analyzed using a repeated measures analysis of variance (ANOVA) to compare the subsequent brews to the first brew within each tea sample (SAS® Version 9.1; SAS Institute; Cary, NC, USA). The mean scores of the volatile compounds concentration were calculated. To understand the flavor changes during multiple brews, a principal component analysis was conducted with the covariance matrix using PROC PRINCOMP statement in the SAS program.

The mean scores of the descriptive analysis and the instrumental GC-MS evaluation at each brew were analyzed using the partial least square regression (PLSR2; Unscrambler® 9.7, CAMO Software Inc.; Woodbridge, NJ, USA.) to determine the relationship between the descriptive data and the instrumental data. This method is used often to determine the relationship between the instrumental data (X-matrix) and the descriptive sensory data (Y-matrix). The covariance matrix was used in the PLSR analysis.

Results and Discussion

Descriptive Sensory Analysis

Twenty-five of the attributes previously reported for green tea (Lee and Chambers 2007) were detected and evaluated for the 6 samples tested in this study. Those attributes were green, asparagus, celery, green herb-like, parsley, spinach, brown, ashy/sooty, burnt/scorched, tobacco, citrus, floral/perfumy, fruity, grain, medicinal, musty/new leather, nutty, seaweed, straw-like, sweet aromatics, bitter, astringent, and tooth-etch. Some attributes were similar to those found in three other Korean green teas (SM Lee and others 2008). These attributes were bitter, floral, cut grass, roasted grain, dried straw, burnt leaf, and astringency. The mean scores for all 25 attributes are shown in Table 6.2.

Green, brown, bitter, and astringent attributes were perceived throughout all 5 brewings of the green tea samples with a few exceptions at the fifth brew. Spinach, straw-like, and toothetch usually were present in at least the first 3 brews (Table 6.2). The intensity of the green flavor generally decreased as the samples were brewed repeatedly. The change in the intensity of spinach flavor was similar to the pattern of the green flavor. In general, the brown flavor

Table 6.2 Mean scores and separation of flavor attributes in green tea brewed five times

	Daehan Ujeon					***Daehan Ujeon Wild***					***Illohyang***				
	Brews					Brews					Brews				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Green	4.03^{a1}	3.31^{b}	1.81^{c}	0.91^{d}	0.00^{e}	2.67^{a}	1.64^{b}	1.44^{b}	0.83^{c}	0.64^{c}	2.17^{a}	1.42^{b}	1.50^{b}	0.94^{c}	0.53^{d}
Asparagus	1.66^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green beans	0.75^{a}	0.78^{a}	0.00^{b}	0.00^{b}	0.00^{b}	1.36^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00
Green herb-like	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00^{b}	0.63a	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spinach	1.88^{a}	1.34^{b}	0.69^{c}	0.00^{d}	0.00^{d}	1.58^{a}	1.22^{ab}	0.82^{b}	0.00^{c}	0.00^{c}	1.39^{a}	0.72^{b}	0.00^{c}	0.00^{c}	0.00^{c}
Brown	2.75^{a}	2.66^{ab}	2.06^{b}	1.13^{c}	0.67^{c}	3.83^{a}	3.58^{a}	2.03^{b}	1.17^{c}	0.53^{d}	3.33^{a}	3.47^{a}	1.69^{b}	1.00^{b}	0.69^{c}
Ashy/sooty	0.00^{b}	0.50^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{c}	0.00^{c}	0.94^{a}	0.50^{b}	0.00^{c}	0.53^{a}	0.86^{a}	0.50^{a}	0.00^{b}	0.00^{b}
Burnt/scorched	0.81^{a}	1.09^{a}	0.00^{b}	0.00^{b}	0.00^{b}	1.11^{a}	1.42^{a}	0.00^{b}	0.00^{b}	0.00^{b}	1.31^{a}	1.22^{a}	0.00^{b}	0.00^{b}	0.00^{b}
Straw-like	1.41^{a}	1.59^{a}	1.25^{a}	0.81^{b}	0.00^{c}	1.86^{a}	1.89^{a}	1.28^{b}	0.72^{c}	0.00^{d}	1.44^{a}	1.08^{b}	0.92^{b}	0.00^{c}	0.00^{c}
Tobacco	0.00^{b}	0.00^{b}	0.63^{a}	0.00^{b}	0.00^{b}	1.00^{ab}	1.36^{a}	0.72^{b}	0.00^{c}	0.00^{c}	1.19^{a}	0.56^{b}	0.00^{c}	0.00^{c}	0.00^{c}
Citrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00^{b}	0.00^{b}	0.75^{a}	0.00^{b}	0.00^{b}
Floral/perfumy	0.00^{b}	0.69^{a}	0.84^{a}	0.63^{a}	0.56^{a}	0.00	0.00	0.00	0.00	0.00	0.83^{bc}	1.19^{a}	1.17^{ab}	0.83^{bc}	0.56^{c}
Fruity	0.72^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00^{b}	0.64^{a}	0.00^{b}	0.00^{b}	0.00^{b}
Medicinal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Musty/new leather	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutty	0.00^{b}	0.66^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seaweed	2.28^{a}	0.56^{b}	0.00	0.00	0.00	2.28^{a}	0.86^{b}	0.00^{c}	0.00^{c}	0.00^{c}	2.28^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Sweet aromatics	0.57a	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.53^{a}	0.50^{a}	0.00^{b}	0.00^{b}	0.00^{b}

Bitter	6.91^{b}	7.38^{a}	5.63^{c}	3.69^{d}	2.34^{e}	6.14^{b}	6.72^{a}	5.22^{c}	3.64^{d}	2.33^{e}	6.44^{a}	6.72^{a}	5.47^{b}	3.60^{c}	2.47^{d}
Astringent	1.81^{a}	2.22^{a}	2.06^{a}	1.28^{b}	0.53^{c}	1.81^{ab}	2.14^{a}	1.69^{ab}	1.53^{b}	0.72^{c}	1.58^{b}	2.06^{a}	2.03^{a}	1.31^{b}	1.00^{c}
Tooth-etch	0.88^{a}	1.31^{a}	1.06^{a}	0.59^{b}	0.00^{c}	1.14^{a}	1.17^{a}	0.89^{ab}	0.67^{bc}	0.50^{c}	0.61^{b}	1.03^{a}	0.89^{ab}	0.53^{b}	0.00^{c}

	Myoungjeon					***Ujeon Okro***					***Ouksu***				
	Brews					Brews					Brews				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Green	3.97^{a}	2.36^{b}	2.03^{bc}	1.64^{c}	1.11^{d}	2.51^{a}	1.17^{b}	0.57^{c}	0.00^{d}	0.00^{d}	4.21^{a}	4.24^{a}	2.77^{b}	1.62^{cd}	1.42^{d}
Asparagus	0.00	0.00	0.00	0.00	0.00	0.59^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00
Celery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00^{b}	0.00^{b}	0.50^{a}	0.00^{b}	0.00^{b}
Green beans	1.14^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.94	0.00	0.00	0.00	0.00^{b}	1.03^{a}	0.97^{a}	0.00^{b}	0.00^{b}
Green herb-like	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.64^{a}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00^{b}	1.12^{a}	0.00^{b}	0.00^{b}	0.00^{b}
Spinach	2.08^{a}	1.92^{a}	1.28^{b}	0.72^{c}	0.00^{c}	1.78	0.00	0.00	0.00	0.00	2.59^{a}	2.53^{a}	0.89^{b}	0.79^{b}	0.56^{b}
Brown	3.97^{a}	4.44^{a}	2.36^{b}	1.47^{c}	1.11^{c}	3.25^{ab}	3.75^{a}	3.03^{ab}	2.59^{c}	1.69^{d}	2.28^{ab}	2.64^{a}	1.14^{c}	1.55^{bc}	0.00^{d}
Ashy/sooty	0.00^{c}	1.39^{a}	1.00^{ab}	0.67^{b}	0.00^{c}	0.00^{d}	2.59^{a}	2.63^{a}	1.88^{b}	1.28^{c}	0.00^{b}	0.00^{b}	0.00^{b}	0.59a	0.00^{b}
Burnt/scorched	2.17^{a}	2.33^{a}	0.69^{b}	0.00^{c}	0.00^{c}	1.63^{a}	0.50^{b}	0.00^{c}	0.00^{c}	0.00^{c}	1.26^{b}	2.35^{a}	0.00^{c}	0.00^{c}	0.00^{c}
Straw-like	1.17^{bc}	2.00^{a}	1.50^{ab}	0.89^{cd}	0.64^{d}	1.90^{a}	1.77^{ab}	1.43^{b}	1.43^{b}	0.74^{c}	1.52^{a}	1.44^{a}	0.94^{b}	0.76^{b}	0.00^{c}
Tobacco	0.00	0.00	0.00	0.00	0.00	0.00^{c}	1.06^{a}	0.94^{ab}	0.50^{b}	0.00^{c}	0.00^{b}	0.00^{b}	0.00^{b}	0.65^{a}	0.00^{b}
Citrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Floral/perfumy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fruity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medicinal	0.00^{b}	0.89^{a}	0.94^{a}	0.53^{a}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Musty/new-leather	0.00^{c}	1.58^{a}	0.72^{b}	0.53^{b}	0.00^{c}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Nutty	0.00^{b}	0.56^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seaweed	4.19^{a}	0.69^{b}	0.00^{c}	0.00^{c}	0.61^{b}	2.22^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	1.91^{a}	0.85^{b}	0.00^{c}	0.00^{c}	0.00^{c}
Sweet aromatics	0.00	0.00	0.00	0.00	0.00	0.00^{b}	0.00^{b}	0.56^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.71^{a}	0.00^{b}	0.59^{a}
Bitter	7.14^{b}	8.56^{a}	6.25^{c}	4.75^{d}	3.42^{e}	6.08^{ab}	6.39^{a}	5.61^{b}	4.48^{c}	3.54^{d}	6.99^{b}	7.84^{a}	5.46^{c}	3.93^{d}	2.69^{e}
Astringent	1.78^{b}	2.83^{a}	2.00^{b}	1.42^{c}	0.92^{d}	1.32^{b}	1.79^{a}	1.54^{b}	0.75^{c}	0.57^{c}	1.64^{b}	1.97^{a}	1.38^{b}	0.94^{c}	0.00^{d}
Tooth-etch	0.81^{b}	1.78^{a}	1.06^{b}	0.83^{b}	0.00^{c}	0.53^{a}	0.81^{a}	0.66^{a}	0.00^{b}	0.00^{b}	0.53^{b}	0.81^{a}	0.66^{b}	0.00^{c}	0.00^{c}

[1]a-e Means within same row of each green tea sample with different superscripts are different ($P < 0.05$) when analyzed using repeated measures analysis of variance.

intensity decreased from the second brew onward. The intensity of brown note in the first brew and the second brew were not statistically different. The intensity of straw-like decreased as green tea was brewed repeatedly except in the *Myoungjeon* sample where the highest intensity occured in the second brew. Bitterness increased significantly from the first brew to the second brew in the *Daehan Ujeon*, *Daehan Ujeon Wild*, *Myoungjeon,* and *Ouksu* samples. The *Illohyang* and *Ujeon Okro* samples had similar bitterness intensities in both the first and the second brews. After the second brew, bitterness decreased significantly for each brew for all the samples. This is in partial agreement with findings that the percentage of caffeine, which is the major bitter substance in green tea, found in the green tea liquor decreased as the tea was brewed 3 times (Hicks and others 1996). The astringency and toothetch had similar patterns to bitterness with the intensity being the highest at the second brew and then decreasing slightly with each subsequent brew.

In addition to the green and spinach flavor notes, other green-related attributes were perceived: asparagus, celery, green beans, green herb-like, and parsley. The asparagus note was barely detected in the first brew in both of the *Daehan Ujeon* and *Ujeon Okro* samples. All the samples, except *Illohyang*, had green beans barely detected at low levels in the first, the second, or the third brew. The celery was present in the third brew of the *Ouksu* sample. The fifth brew of the *Myoungjeon* sample had a green herb-like note at the threshold level. Parsley was present in the *Daehan Ujeon* and *Ouksu* samples in their second brew.

Besides the brown and straw-like attributes, the perceived brown-related attributes were were ashy/sooty, burnt/scorched, and tobacco. An ashy/sooty note was perceived in all of the samples but mainly in the second, third, and fourth brews. The burnt/scorched flavor was barely detected, the intensity ranging 0.5 to 2.35, mainly in the first and the second brews of all the Korean green teas. The tobacco attribute was perceived in all the samples other than *Myoungjeon*, mostly in the second and the third brews.

Other attributes that were detected in the samples included citrus, floral/perfumy, fruity, grain, medicinal, musty/new leather, nutty, and seaweed. The citrus was detected in the third brew of the *Illohyang* sample. A low intensity floral/perfumy note was detected in only the *Daehan Ujeon* and *Illohyang* samples, and was present from the second brew onward for the *Daehan Ujeon* sample and in all the five brews for the *Illohyang* sample. The *Daehan Ujeon* sample was the only one perceived as having a fruity note, and it only occurred in the first brew.

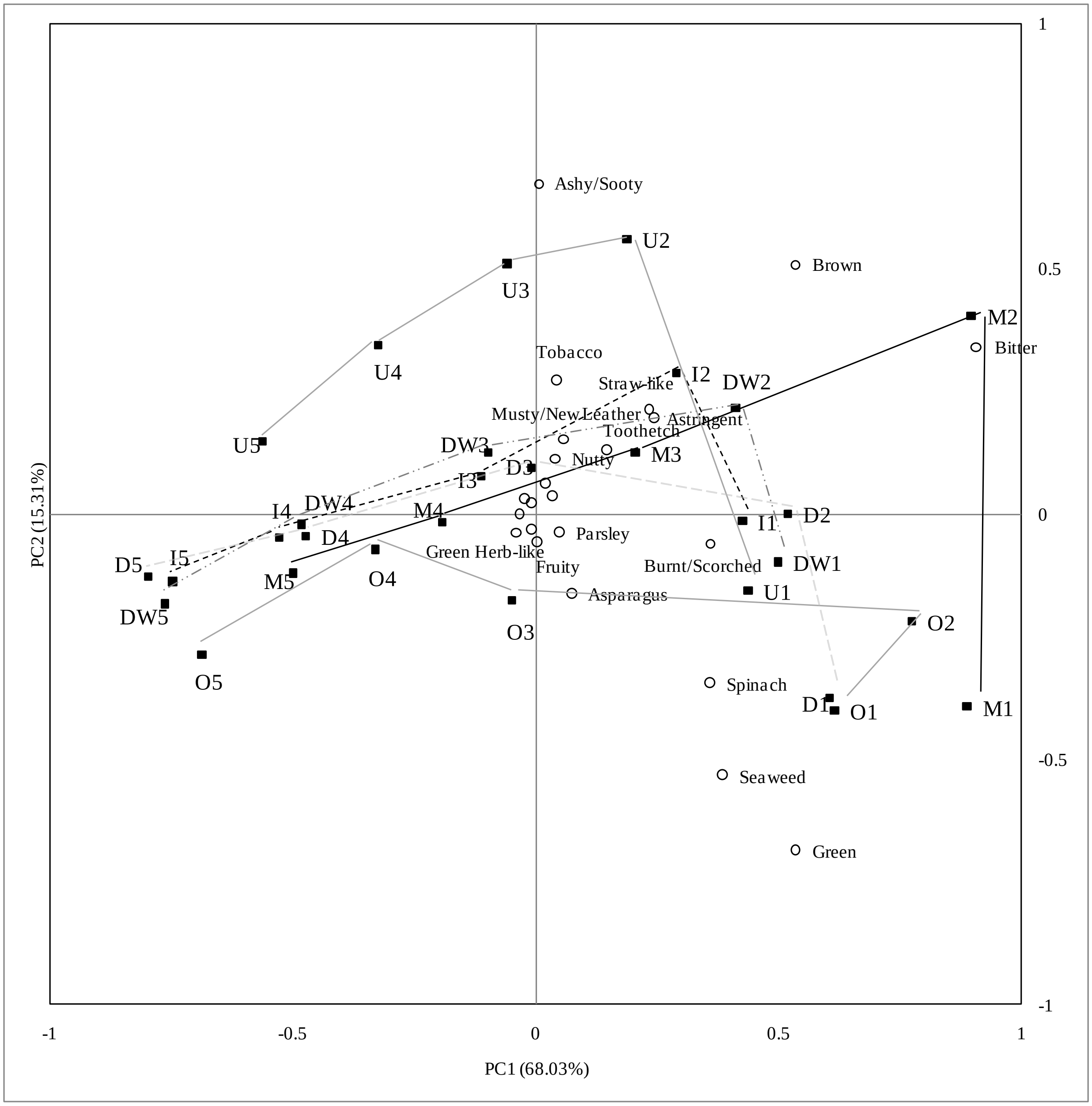
Grain flavor was found only in the second brew of the *Illohyang* sample. The *Myoungjeon* sample was perceived to have medicinal note at a threshold level in the second, third, and fourth brews. The musty/new leather note was only detected at very low levels in *Myoungjeon* in the second brew to the fourth brew. The nutty flavor was only present in the second brews of the *Daehan Ujeon* and *Myoungjeon* samples. All 6 green tea samples had low seaweed flavors in the first brews and the *Daehan Ujeon*, *Daehan Ujeon Wild*, *Myoungjeon,* and *Ouksu* samples were perceived to have seaweed flavor at a low level in their second brews. Seaweed was also present in the fifth brew of the *Myoungjeon* sample. The seaweed flavor was first researched and documented in 1977 (Yamanishi 1977) and was later defined and referenced (Lee and Chambers 2007) to describe the flavor of some green teas. However, it was not reported by researchers who have previously studied Korean green tea (SM Lee and others 2008; OH Lee and others 2008). A sweet aromatics note was present at the threshold level in four of the samples (*Daehan Ujeon*, *Illohyang*, *Ujeon Okro* and *Ouksu*) at various brews.

The flavor of the green loose leaf tea samples changed when they were brewed multiple times. Generally, the flavor decreased as the number of brews increased in all the green tea samples in the current study. This trend is shown in a PCA biplot (Figure 6.1). The first two brews appear to provide similar intensities of the flavor attributes, except for the intensities of the green-related attributes which actually decreased and the intensities of bitterness, astringency, and toothetch which increased from the first to the second brew. While flavor attributes and their intensities decreased after the second brew, the third brew and even the fourth brew may be enjoyed by consumers who prefer a milder flavor and low bitterness and astringency in their green tea. The fifth brew presented a few flavor notes at low levels and low bitterness and astringency suggesting that most of the flavor is gone by the fifth brew. Also, as shown in Figure 6.1, the flavor changes occurring during the multiple brews of green tea is rather continuous and, because the flavors get weaker each time, the change of flavor may appeal to some consumers.

Aroma Volatile Compounds

Fourteen aroma volatile compounds were identified and quantified in the green tea samples brewed 5 times (Table 6.3). There were 2 aliphatic alcohols ((z)-4-hexen-1-ol and 2-ethyl-1-hexanol), 2 aromatic alcohols (benzenemethanol and benzeneethanol), 2 terpene alcohol

Figure 6.1 Principal Component Analysis Biplot of Descriptive Sensory Analysis of Green Teas[a,b]



[a]D=*Daehan Ujeon*; DW=*Daehan Ujeon Wild*; I=*Illohyang*; M=*Myoungjeon*; O=*Ouksu*; U=*Ujeon Okro*. Numbers following the sample name denotes number of brew.

[b]Lines connect consecutive brews of the same green tea samples to show the trend of flavor change.

(linalool and geraniol), 1 aliphatic aldehyde (nonanal), 2 aromatic aldehydes (benzaldehyde and phenylacetaldehyde), 3 ketones (4-methyl-3-penten-2-one, jasmone, and *β*-ionone), 1 furan (linalool oxide), and 2 other compounds (1H-indole and 1-ethyl-1H-Pyrrole-2-carboxaldehyde). The concentrations of these compounds are shown in Table 6.4. The concentrations of the volatile compounds in the current study are generally lower than the threshold levels reported in previously published literature. We hypothesize that the reason for this is that green tea generally is consumed at a higher temperature whereas the typical threshold evaluation by previous researchers has been conducted at room temperature. Also, the volatile compounds in tea are present in a complex matrix of volatiles whereas reported thresholds are for the simple compounds. The Kovats RI's calculated based on retention time and previous reports by other researchers are shown in Table 6.3.

Table 6.3 Volatile Compounds Found in Six Korean Green Teas and Kovats Retention Indices.

Compounds	Kovats RI calculated	Kovats RI reported	Kovats RI References
4-methyl-3-penten-2-one	815.8	800	Tellez and others 1999
(z)-4-hexen-1-ol	873.3	868	Estimated value in NIST library
Benzaldehyde	985.3	962	Beaulieu and Grimm 2001
2-ethyl-1-hexanol	1047.6	1028	Gómez and others 1993
Benzenemethanol	1058.3	1033	Sakho and others 1997
Benzeneacetaldehyde	1058.3	1045	Gómez and others 1993
Linalool oxide	1094.8	1070	Choi 2003
Linalool	1126.5	1100	Reverchon and others 1997
Nonanal	1122.5	1103	Tellez and others 1999
Benzeneethanol	1140.5	1113	Flamini and others 2002
Geraniol	1234.0	1259	Viña and Murillo 2003
1H-indole	1328.3	1286	El-Sakhawy and others 1998
Jasmone	1421.6	1394	El-Sakhawy and others 1998
β-ionone	1405.4	1482	Gómez and others 1993

Table 6.4 Average Concentrations of the Volatile Compounds in Six Green Teas (ng/kg).

Compounds	Brew 1	Brew 2	Brew 3	Brew 4	Brew 5
Daehan Ujeon					
Benzenemethanol	0.75	-[a]	-	-	-
Linalool	-	0.54	2.01	2.68	-
Nonanal	1.14	1.80	2.10	3.85	1.01
1H-Indole	0.56	-	-	-	-
Jasmone	0.63	-	1.69	2.03	-
Daehan Ujeon Wild					
2-Ethyl-1-hexanol	-	0.36	-	-	-
Benzenemethanol	0.53	0.66	-	-	-
Linalool	-	0.60	-	-	-
Nonanal	0.63	0.77	0.96	-	1.05
1H-indole	-	0.85	-	-	-
Jasmone	-	1.06	-	-	-
Illohyang					
(z)-4-Hexen-1-ol	0.44	0.29	-	-	-
Linalool oxide	0.63	0.51	-	-	-
Linalool	1.82	1.87	2.34	1.55	1.16
Nonanal	0.57	0.47	0.75	0.54	0.78
Geraniol	2.57	3.04	2.90	2.52	1.50
Jasmone	0.53	0.63	0.60	0.45	-
Myoungjeon					
4-methyl-3-penten-2-one	0.22	-	-	-	-
Benzaldehyde	0.14	-	-	-	-
2-Ethyl-1-hexanol	-	-	-	-	0.70
Benzeneacetaldehyde	0.36	-	-	-	-
Nonanal	-	-	-	-	1.68
Jasmone	0.40	-	-	-	-
Ouksu					

4-methyl-3-penten-2-one	0.41	0.38	-	-	-
Benzeneacetaldehyde	0.27	-	-	-	-
Linalool	-	-	0.49	-	-
Nonanal	0.27	0.58	0.69	-	1.21
Geraniol	0.19	-	-	-	-
Jasmone	0.52	0.39	-	0.57	-
β-Ionone	0.36	0.55	0.37	0.29	-
Ujeon Okro					
4-methyl-3-penten-2-one	0.59	-	-	-	-
Linalool	-	2.13	1.44	0.97	1.06
Nonanal	-	1.52	0.74	0.97	1.41
Benzeneethanol	-	0.68	-	-	-
Geraniol	-	1.12	0.71	0.48	-
Jasmone	-	0.85	0.55	0.40	-
β-Ionone	0.35	-	-	-	-

[a]Not detected

The compound (z)-4-hexen-1-ol was present in the *Illohyang* sample at the first and the second brews. However, no literature on green tea volatiles reported this compound and no information regarding the aroma or flavor characteristics was found.

The compound 2-ethyl-1-hexanol was detected in the *Daehan Ujeon Wild* sample at the second brew and in the *Myoungjeon* sample at the fifth brew only. The concentrations of the compound in these two samples were at 0.36 ng/kg and 0.72 ng/kg, respectively. It was previously reported in a Japanese green tea (Hattori and others 2005) but no other literature has reported 2-ethyl-1-hexanol in green teas. It has a mild, oily, sweet and slight rose fragrance (Ash and Ash 2006).

Benzyl alcohol (benzenemethanol) was found in a few brews of the *Daehan Ujeon Wild Tea* sample and the *Daehan Ujeon* sample. It has a faint aromatic odor (Ash and Ash 2006) and has previously been found in Korean tea (Baptista and others 1999). Phenethyl alcohol (benzeneethanol) has a floral and rose odor (Ash and Ash 2006) and was found in the second brew of the *Ujeon Okro* sample.

Linalool has been reported in green tea by many other researchers (Baptista and others 1999; Hattori and others 2005; Choi and others 2003; Liang and others 2008). As expected, it was detected in all five samples except *Myoungjeon* and was present in more than three consecutive brews in the *Daehan Ujeon*, *Illohyang*, and *Ujeon Okro* samples. However, the trend of changes in the concentration for repeated brews differed among these samples. Linalool's odor is similar to bergamot oil (Ash and Ash 2006) and citrus (Czerny and others 2008). It is detectable at a level as low as 0.087 μg/Kg and recognizable at as low as 0.17 μg/Kg (Czerny and others 2008), which both are much lower than our findings ranging from 0.49 ng/kg to 2.34 ng/kg.

Geraniol is another terpene alcohol and has a geranium odor (Ash and Ash 2006). It was found in the *Illohyang* and the *Ujeon Okro* samples. The concentrations of geraniol in these two samples were the highest in the second brew and declined as they were brewed repeatedly. Geraniol has been found commonly in green teas (Baptista and others 1999). Its thresholds were reported as 1.1μg/L for detection and 2.5 μg/L for recognition (Czerny and others 2008).

Nonanal was present in all 6 samples in our study. However, the concentrations of nonanal in each brew did not have any perceivable trend. It has a tallow, fruity (Rychlik 1998), strong, fatty odor (Ash and Ash 2006), citrus-like and soapy (Czerny and others 2008). Its detection threshold was reported as 2.8 μg/L and its recognition threshold was reported as 8.0 μg/L (Czerny and others 2008). The nonanal was reported in a Korean commercial green tea made with tea leaves harvested in July and roast-processed (Lee and others 1997) but was not reported in the other studies with Korean green teas (Choi 1991 and 1995).

Benzaldehyde was only detected in the first brew of the *Myoungjeon* sample. It is an aromatic aldehyde and has an almond odor (Ash and Ash 2006) and commonly is used in artificial cherry flavor to provide a strong fruity note. Benzaldehyde was commonly found in green teas from Korea in previous literature (Choi 1991 and 1995; Lee and others 1997). Benzaldehyde may not have been detected in more of our samples because of the sample preparation and the extraction technique. In the current study, brewed green tea liquor was used as a sample and the volatile compounds were extracted using SPME, which can detect concentrations ranging from pg/g (ppt) to μg/g (ppm). The concentration of benzaldehyde in the second brew of the *Myoungjeon* sample was 0.14 ng/kg, which is 0.14 ppt.

Phenylacetaldehyde (benzeneacetaldehyde) was present in the first brews of the *Myoungjeon* and the *Ouksu* samples. It is an aromatic aldehyde and has a pungent, green, hyacinth-like, apricot, and berry-like flavor (Ash and Ash 2006).

The compound 4-methyl-3-pentene-2-one was detected in the *Myoungjeon*, *Ujeon Okro* and *Ouksu* samples. The concentrations ranged between 0.23 and 0.53 ng/kg. It has sweet, fruity odor and it is somewhat water soluble (Ash and Ash 2006). It was reported in the Korean green tea along with a *Chunmee* green tea and a *Gorreana* green tea (Baptista and others 1999).

Jasmone was found in all 5 samples except *Myoungjeon*. However, it is hard to find any trend in the concentrations. Jasmone was reported in the previous research (Choi 1991; Choi and others 2003). Jasmone is an aliphatic ketone and has a jasmine odor and a fruity flavor (Ash and Ash 2006).

The compound *β*-Ionone was detected in two brews of the *Ouksu* sample. Others have found this compound in Korean green teas (Choi 1995; Choi and others 2003) as well as green teas from China (Liang and others 2008) and Japan (Hattori and others 2005). It has a woody odor (Ash and Ash 2006), flowery and violet-like (Czerny and others 2008). It was reported that one can detect the odor at 3.5 μg/L and can recognize it at 8.4 μg/L (Czerny and others 2008).

Linalool oxide was found in the first two brews of the *Illohyang* and the concentrations were around 0.5 ng/kg. The linalool oxides were reported in the commercial Korean green teas made with tea leaves harvested in April and June (Choi 1991) but not in August (Choi 1995). It has a sweet, lemon, cineol flavor (Ash and Ash 2006).

The compound1H-indole was detected in a few brews of the *Daehan Ujeon, Ujeon Okro* and *Daehan Ujeon Wild* samples. The concentrations were all below 1 ng/kg. It has a floral, animal, jasmine and earthy odor and it is volatile with steam (Ash and Ash 2006). The indole was also reported as having a fecal, mothball-like odor and the detection threshold was reported as 11 μg/L. In a previous study indole was reported as the most abundant volatile compound in the commercial Korean green tea samples, which were made with the tea leaves picked in April and June, but the concentrations were not reported (Choi 1991).

Relationships Between Descriptive and Aroma Volatiles Analyses in Green Tea Samples

The partial least square regression (PLSR) was conducted to relate the instrumental data to the descriptive data for each brew. The PLSR biplots of the first and the second brews are shown in Figure 6.2 and Figure 6.3. Of 25 descriptive attributes, only the aromatic attributes were included for the analysis (excluding bitter, astringent, and tooth-etch, which are not dependent on volatile compounds). Generally, the number of sensory attributes perceived, their intensities, and the number of volatile compounds detected decreased markedly from the second brew to the third brew.

Twelve volatile compounds were detected by GC-MS and 16 sensory attributes were perceived by the trained panelists in the first brew (Figure 6.2). The PLSR map shows that 95% of the instrumental data explained 38% of descriptive sensory data when the first 2 principal components were considered. The geraniol and linalool were explained mainly in the PC 1 and nonanal and benzenemethanol were explained in the PC 2. The geraniol, linalool and linalool oxide compounds were correlated with the floral/perfumy note. The nonanal, jasmone, and benzenemethanol compounds were related to the fruity and sweet aromatics notes.

Twelve volatile compounds and 16 sensory attributes were found in the second brews of the green tea samples (Figure 6.3). The PLSR results indicated that 84% of the instrumental data explained 51% of the descriptive sensory data in the first 2 PCs. Geraniol and linalool were the main vectors in PC 1 and PC 2 was explained by nonanal, geraniol, and linalool. Geraniol, nonanal, and linalool oxide were also related to the floral/perfumy attributes.

Only 5 volatile compounds, but 14 sensory terms, were used to describe the third brews of green tea samples. Around 96% of the instrumental data explained 25% of the descriptive data in the first 2 PC’s. It appears that the floral/perfumy attributes are related to the presence geraniol, linalool, and jasmone but it is hard to know for sure because the explanation rate of the descriptive data by the instrumental data was only 25%.

Five volatile compounds and 9 sensory descriptive attributes were present in the samples brewed four times. The PLSR data showed that 88% of the instrumental data explained 37% of the descriptive sensory data. As expected, nonanal, linalool, jasmone, and geraniol were related to the floral/perfumy notes.

Figure 6.2 Partial Least Square Regression Analysis of Descriptive Sensory and Gas Chromatography Data for the First Brew of Green Tea Samples

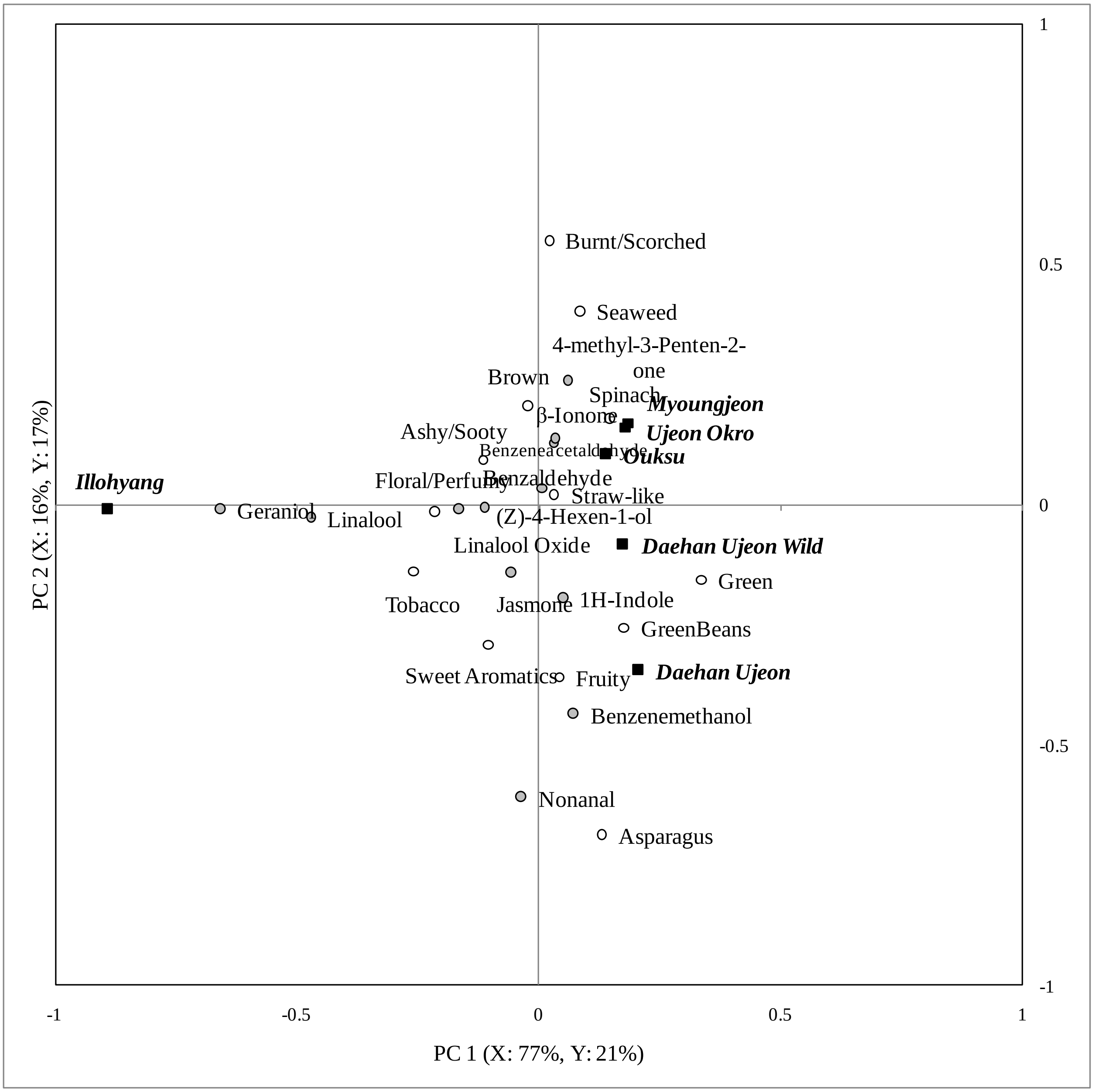
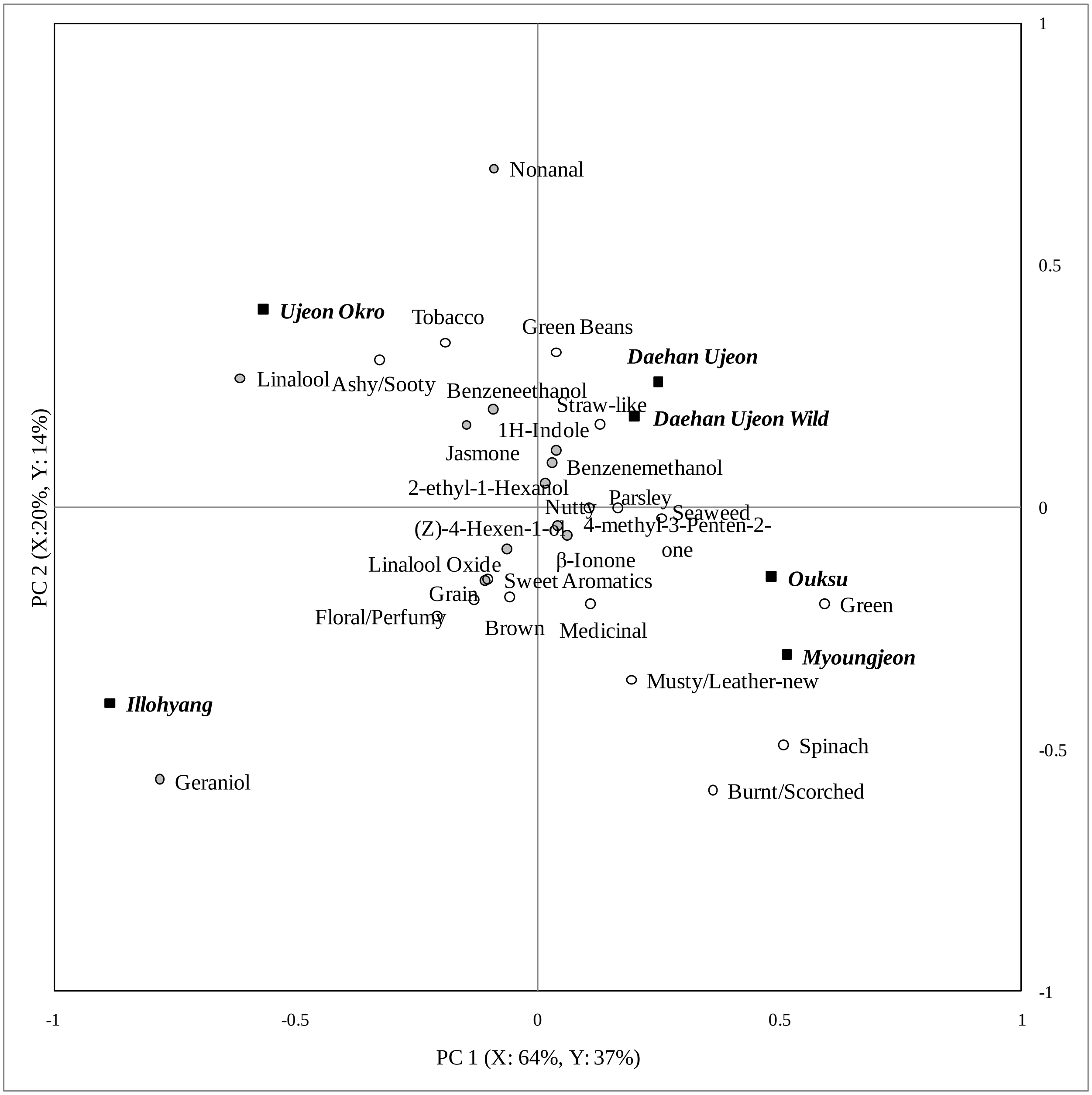


Figure 6.3 Partial Least Square Regression Analysis of Descriptive Sensory and Gas Chromatography Data for the Second Brew of Green Tea Samples



Only four volatile compounds were detected using GC-MS and nine flavor attributes were perceived in the fifth brew of green tea samples. The PLSR analysis showed that 87% of the instrumental data explained 54% of the descriptive sensory data. In the PLSR biplot, it was hard to draw any relationship between the volatile compounds and the descriptive attributes probably because of the low levels of both the attributes and the aroma compounds that were found in the fifth brew.

Conclusion

The flavor changes of Korean green tea (leaf form) when brewed multiple times were measured using descriptive sensory analysis and GC-MS. According to our findings, the first and the second brews of green tea provided similar strengths of flavor intensities and the third and the fourth brews provided mild flavor, low bitterness, and low astringency. The fifth brew had a few flavor notes at low intensities, low bitterness, and low astringency, suggesting that the primary green tea flavors were gone by the fifth brew. Thus, based on this initial study, four brews would seem to be the maximum number of brews that can be recommended. In the brewed liquor of green tea mostly linalool, nonanal, geraniol, jasmone, and β-ionone volatile compounds were present at low levels. The geraniol, linalool, and linalool oxide compounds in green tea may contribute the floral/perfumy flavor. This result is true for high quality green teas produced in South Korea. Further research is needed to confirm our findings using different qualities of green tea from other sources and grades.

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CHAPTER 7 - Flavor Characteristics of Green Tea Processed Using Steaming, Roasting, or Steam-Roasting

It has been suggested that different processing methods can affect the flavor of green tea. Although some research has been performed in order to understand the differences among green teas that have been processed differently, the samples in these studies had confounding characteristics such as different countries of origin, different times of harvest, or different cultivars. We used leaves from the same source to process green teas in three ways, steaming, roasting, and steam-roast, in order to study how the flavors change based on various processing methods.

The roast-processed, steam-processed, and steam-and-roast-processed green tea samples differed in their characterizing green flavors. Perhaps because these teas were not highly roasted, the brown and burnt/scorched attributes were not affected by the processing methods. Only green-related attributes such as asparagus, beany, green beans, parsley, and spinach differed among the green tea samples. Further investigation is needed to determine how processing methods affect different qualities of tea leaves but this research serves as a beginning to a better understanding of the effect of tea processing on the flavor of green tea.

Introduction

Green tea quality is influenced by the processing methods that manufacturers employ as well as many other factors (Xu and Chen 2002). Roasted green teas and steamed green teas have different aromatic compounds (Wang and others 2002), which may influence the flavor of the green teas and result in different and distinctive flavors between the two types of processing methods.

After harvest, the processing of green tea involves several steps: fixing, rolling, and drying (Hara and others 1995). During the first step enzymatic actions are stopped (Hara and others 1995). Oxidative enzymes such as polyphenol oxidase, catalase, peroxidase, and ascorbic acid oxidase are deactivated by the high temperatures of the fixing step (Xu and Chen 2002).

There are two types of fixing used by tea manufacturers: roasting or steaming. Fixing with roasting starts at 370-380℃ and the temperature gradually drops to 140-200℃ based on the type of fixing machine used. Fixing with steam keeps the temperature of the tea leaves at 95℃ for longer than 20 sec to ensure the inactivation of the enzymes (Kim 1996).

After fixing, the tea leaves go through different rolling processes. The rolling processes help to equally distribute moisture in the leaves and to sever cells in the leave, which releases constituents into the brewed liquor of the final green tea products. Less pressure is used for younger leaves that have been harvested earlier in the season and more pressure is applied to bigger leaves that have been harvested later in the season (Kim 1996). Tea leaves that are fixed by roasting go through a longer period of rolling than the steamed leaves because they undergo the rolling process only once (Kim 1996), whereas the tea leaves that were fixed using steaming go through several rolling stages in order to shape the leaves like needles (Hara 2001).

Lastly, the tea leaves are dried so that the moisture content in the final product is less than 4% (Kim 1996; Choi 2002) or about 4-5% (Hara and others 1995). Roast-fixed green tea is dried in three different stages. Hot air or heat conduction may be used for the first drying, which may result in a nutty flavor or green color in the final product, respectively. The second drying is done in a rotating drum to further shape the tea leaves. Lastly the roast-fixed leaves are dried using hot air (Kim 1996). Depending on factors such as roasting temperature, time, and how fast the leaves are stirred during the roasting process, the leaves may develop ashy-like, burnt, nutty, scorched, or soot-like aroma and/or flavor (Kim 1996; Choi 2002). Drying steam-fixed leaves involves hot air and pressure initially to further balance the moisture within the leaves and on their surface. The second drying process further shapes the leaves into needle-like shapes by using heat and pressure. Finally, hot air is used to dry the steam-fixed leaves until the moisture content is below 4% (Kim 1996).

There has been some effort to understand the effects of processing by comparing the volatile compounds in *Longjing,* a Chinese roast-processed green tea, with the volatile compounds in *Kamairi-cha,* a Japanese roast-processed green tea (Kawakami and Yamanishi 1983). These two green teas differ in their composition of volatile compounds and peak area percentage especially when compared with the typical heat generated aroma compounds such as pyrazines, pyrroles, and ionone-related compounds. Later, researchers compared the volatile compounds of *Ban-cha* (a lower grade Japanese green tea) and *Hojicha* (a roasted green tea using *Ban-cha*) in addition to *Longjing* and *Kamairi-cha*. Furans and pyrroles compounds in *Hojicha* markedly increased because of roasting compared to *Ban-cha* (Yamanishi and others 1989). Although the processing methods differ among the previously tested samples, there are many other factors that may affect the aroma characteristics of green teas and ultimately affect their flavor.

Recently, three different processing methods were compared to determine how the chemical compositions of green teas have been affected using the same fresh tea leaves harvested on the same day from Japan (Asuda and others 2003). The methods are steam-processed, roast-processed traditionally by hand, and a pan-fired Eguchi style method (a mixed method of pan-fired and steam-processed). Researchers did not find any difference caused by the different processing methods in the contents of minerals, amino acids, and caffeine in green tea liquid but there was some difference in the contents of catechins. Because catechins are responsible for most of the bitterness and astringency of green tea (Chen and others 2002), the bitterness and astringency in green teas in this study may have varied. However, sensory characteristics and aroma volatile compounds were not measured in the study by Asuda and others (2003).

A lexicon to describe the flavor characteristics of green tea has been developed (Lee and Chambers 2007) and descriptive sensory analyses have been conducted to understand the flavor of green tea (Cho and others 2005; O.H. Lee and others 2008; S.M. Lee and others 2008; Lee and others 2009). Another group of researchers evaluated the sensory characteristics of several green tea samples that were roasted at different temperatures and varied in their amino acid content. The researchers reported that green teas roasted at higher temperatures had higher intensities for brownness, roasted barely, and burnt leaf flavors (O. H. Lee and others 2008). We did not find any literature comparing flavor characteristics of green teas from the same origin and similar in quality, but processed differently.

The objective of this study was to determine how sensory flavor characteristics differ among green teas that are roast-processed, steam-processed, or steam- roast-processed when tea leaves of the same quality and from the same origin are used.

Materials and Methods

Tea Samples

Three green tea samples, one that was roast-processed, one that was steam-processed, and one that was steam-and-roast-processed, were prepared by Amorepacific Co. (Yongin, South Korea). All of the leaves for these teas were *Camellia Sinensis var. Yabukita*, grown at the Jeju Island in Korea, the same age at picking, and selected to represent high quality leaves whose amino acid content was 3.3% in dry basis.

The roast-processed green tea sample was fixed using roasting, followed by rolling, and then dried to a moisture content below 2%. The drying process for the roast-processed green tea included three stages which are termed *Jung-yu*, *Jae-gun*, and *Su-gun*. The *Jung-yu* step lowered the moisture content from around 50% to 26% (Kim 1996). The *Jae-gun* step defined the curly shape of the roast-processed green tea sample. The *Su-gun* is a third step to further dry the leaves. Lastly, the leaves were dried to a moisture content below 2%. The steam-processed green tea sample was fixed using steaming. After fixing, the leaves were dried in order to eliminate excess water from the steaming process. Then the leaves were rolled and two steps of the drying process (*Jung-yu* and *Jeong-yu*) were followed. During the *Jeong-yu* process, pressure was applied to form the leaves into needle-like shapes. Lastly, the leaves were further dried to a moisture content below 2%.

The steam-roast-processed green tea sample undergoes a partial process of both steam and roast processing. The steam-roast-processed sample was fixed using steam first. The excess water was dried and then the leaves were rolled. The leaves were dried using the first two steps of the roasting process (*Jung-yu* and *Jae-gun*) and finally the leaves were dried to the moisture content of under 2% as for the other samples.

After processing, a minimal blending of various lots of tea was done in order to maintain a typical flavor for commercial products and to ensure that all of the samples had the same amount of amino acids, 3.3% on a dry weight basis. The amino acid content is often an indication of the tea's quality and the higher the content, the higher the quality and, thus, the higher the retail prices (Hara 2001; Hattori and others 2005). The amino acid content in green tea samples ranged from 0.50% to 3.00% in previous research by O. H. Lee and others (2008).

Tea Preparation

The green tea liquid samples used in this study were prepared following Lee and Chambers' directions (2007) with a few modifications. Ten grams of each green tea were placed in a pre-warmed white porcelain tea pot. And 300 mL of 70℃ water was added. The tea was brewed for 2 min and during the infusion the pot was swirled 10 times clockwise. After the infusion, the tea was poured into a pre-warmed bowl through a porcelain strainer. Then the tea was poured into pre-warmed tea cups and presented to the panel. Reverse osmosis, deionized, carbon filtered water was used for the pre-warming and brewing.

Descriptive Sensory Analysis

Five highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University participated in this study. The panelists had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing including beverages, vegetables, and green tea.

The green tea flavor lexicon developed by Lee and Chambers (2007) was used for the descriptive analysis in this study. The panelists evaluated green tea samples individually and recorded intensities for each attribute using a 0-15 intensity scale where 0 meant none and 15 meant extreme intensity. Similar panels and testing procedures have been used for other products such as cheese (Talavera-Bianchi and Chambers 2008), UHT milk (Oupadissakoon and others 2009), tomatoes (Hongsoongnern and Chambers 2008), and toothpaste (Hightower and Chambers 2009; Suwonsichon and others 2009).

The green tea samples were coded with three-digit random numbers. One sample was presented at a time. To provide an additional warm sample for the panel to evaluate, an identical sample was brewed and served 5 min after the first. The panel had 15 min for each evaluation, typically 10 min to evaluate and 5 min to rinse and recover. The panelists used unsalted crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water to reduce the build-up from one sample to the other and to cleanse their palates before the next evaluation. The Sensory Analysis Center uses Compusense *five* (Compusense Inc., Guelph, Ontario, Canada) for data collection.

Data Analysis

Analyses of variance of the individual attributes and multivariate analysis of variance comparing the three samples overall were conducted. All of the analyses were conducted using SAS® (Version 9.1; SAS Institute, Cary, NC, U.S.A.).

Results and Discussion

Seventeen attributes were present in the green teas (Table 7.1). MANOVA showed that the three green tea samples were significantly different overall from each other. Of the 17 attributes, asparagus, beany, green beans, parsley, tobacco, grain, musty/new leather, seaweed, bitter, and sweet aromatics showed significant differences among the three green tea samples. Because green tea is a delicately flavored product, as expected, all the intensities were low except for bitterness, which was moderate in all three samples.

Although the intensity of the overall 'green' attribute was similar among the three samples, the characterizing green flavors differed. Asparagus, beany, green beans, and spinach were present in the roast-processed green tea. Green beans and spinach were detected in the steam-processed green tea sample. Green beans, parsley, and spinach were present in the steam-roast-processed green tea sample.

Significant differences for asparagus, beany, parsley, tobacco, grain, musty/new leather, and sweet aromatics were because one or two processing methods gave certain attributes at threshold levels, while the other method(s) produced none of that attribute. The asparagus and beany flavors were only found in the roast-processed green tea sample. The parsley, tobacco, grain, and sweet aromatics notes were found only in the steam-roast-processed sample. The musty/new leather flavor was found only in the steam-processed green tea sample.

The green, green beans, spinach, brown, burnt/scorched, seaweed, straw-like, astringent, and tooth-etch attributes were detected at low intensities in all three samples. The steam-processed green tea sample had a significantly higher green bean flavor than the roast-processed sample, but the steam-roast-processed sample was not different from either of the other processing methods for green bean flavor. The roast-processed sample had a higher seaweed flavor compared to the steam-roast process sample, but it was not significantly different from the steam-processed sample.

Table 7.1 Analysis of Vvariance of Attributes[a] Present in Three Green Tea Samples

	Roast-processed	Steam-processed	Steam-roast-processed	LSD[b]
Green	2.50	2.73	2.77	ns[c]
Asparagus	0.53 a	0.00 b	0.00 b	0.27
Beany	0.57 a	0.00 b	0.00 b	0.45
Green Beans	0.77 b	1.50 a	1.00 ab	0.50
Parsley	0.00 b	0.00 b	0.57 a	0.23
Spinach	1.37	1.47	1.75	ns
Brown	2.23	2.27	2.37	ns
Burnt/Scorched	1.03	0.97	1.07	ns
Tobacco	0.00 b	0.00 b	0.60 a	0.30
Grain	0.00 b	0.70 a	0.63 a	0.27
Musty/New Leather	0.00 b	0.67 a	0.00 b	0.30
Seaweed	1.30 a	0.90 ab	0.63 b	0.48
Straw-like	1.50	1.43	1.53	ns
Bitter	6.03 b	6.60 a	6.43 ab	0.46
Astringent	2.23	2.50	2.53	ns
Tooth-etch	2.18	2.40	2.43	ns
Sweet Aromatics	0.00 b	0.00 b	0.60 a	0.25

[a]Means with the same letter designation in the same row are not statistically significantly different (alpha = 0.05)

[b]LSD = Least significant difference

[c]ns = not significant

Although there were differences among the various processing procedures, the differences frequently were less than a half point on the 0 to 15 point intensity scale. That suggests that the differences in flavor resulting for the three processing methods we used were minimal. Based on statements by Kim (1006) we expected differences in flavor characteristics in the green tea products in both green and brown related attributes. However, we found differences were attributed more to the characterizing the flavors of green: asparagus, beany, green beans, and spinach for the roast-processed green tea; green beans, and spinach for the steam-processed green tea sample; and green beans, parsley, and spinach for the steam-roast-processed green tea sample.

Brown and burnt/scorched attributes did not show any significant differences among the samples. This may imply that the differences between the processing methods used in this study may not heavily influence the flavor in the final products. Researchers have reported that green teas in Korea have similar intensities for green and brown attributes in general (Lee and others 2007). Perhaps this may be because of the innate flavor characteristics in green teas processed in Korea. On the other hand, Japanese green teas that were steam-processed had moderate intensities of green flavors and low brown flavors while roast-processed green teas had no green flavor and low to moderate intensities of brown flavor (Lee and others 2007). Chinese green teas generally had low intensities of green flavors and two thirds of the samples had higher brown flavor intensities compared to green flavor intensities (Lee and others 2007). Clearly, more research is needed to evaluate if the same pattern is found using different qualities of tea leaves when the leaves are roast-processed, steam-processed, or steam-roast-processed or when the processing temperatures or procedures vary more than the ones we used.

Conclusion

The flavor characteristics of the green teas samples were influenced by the processing methods. Although the three green tea samples in this study differed in their flavor, the differences were small. Green-related attributes such as asparagus, beany, green beans, parsley, and spinach differed most among the green tea samples. The intensities of the overall green, brown, and burnt/scorched attributes were not affected by the processing methods used in the current study. Further investigation is needed to evaluate whether the differences among processing are affected by more intense processing methods, by production in countries other than Korea, or in samples representing other tea qualities.

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CHAPTER 8 - Flavors of Green Tea Change Little during Storage

The objective of the current study was to determine how flavor changes in green teas that are stored over a period of two years (a commonly noted shelf-life for green tea products in loose leaf form). Two Korean green teas were packaged in metalized multi-layer polyethylene film and stored at an ambient temperature of ~20℃. Both green tea samples were evaluated by six highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University at 3, 6, 12, 18, and 24 months after their original packaging dates. The intensity of the major attributes changed minimally among the samples as they were evaluated over the two year period. The green tea samples that were stored for 6 months did not change, up to 12 months they changed little, and after 12 months the samples sometimes developed low levels of off-flavors such as musty/new leather or they become higher in characteristics such as tooth-etch. Overall, the findings of this study indicate that green tea will change minimally during the first year of storage and will change slightly more during the first two years of storage. However, these changes appear to be minimal when the samples are packaged in metalized multi-layer polyethylene film.

This research provides the first evidence that, even though the flavors of green tea may change, the change will be minimal during the first one to two years of storage in metalized multi-layer polyethylene film. This research indicates that green tea leaves do have an extended storage time, at least in terms of sensory quality, and can be held for extended periods of time at room temperature.

Introduction

Green tea is consumed for its aroma, flavor, and health benefits (Ukers, 1935). If its aroma and flavor change during storage, the value of green tea can diminish for consumers who enjoy these specific qualities of green tea. Commonly, loose leaf green tea is given a “best if used by” date of 2 years after picking.

Literature suggests that the constituent and aromatic volatile compounds of black tea change over time and the changes were described by reduced flavor and astringency, sometimes inducing ‘taints’ (Stagg 1974). Later, Horita (1987) reported that the aroma and flavor of green teas generally deteriorated as the samples used in the study were stored. The main constituents that relate to changes in the aroma and flavor of green tea include chlorophyll, catechins, lipids, carotenoids, and vitamin C (Chen and others 2002). The auto-oxidation of these constituents results in changes in the color, flavor, and aroma of green tea (Kim 1996).

A few researchers have studied how the flavors of green teas change over short periods of time. Takeo (1982) found that off-flavors in stored green tea were more prominent than in fermented teas, such as oolong tea and black tea, because green tea initially has less aroma components than fermented teas. Another researcher described the flavor changes of green tea during storage using terms such as good tea aroma, reversion flavor, and deterioration flavor, descriptions that are subjective and hard to replicate (Horita 1987). The green tea sample was described as ‘firing’ green tea, probably referring to roast-processed green tea. However, the researchers found that green teas packaged in moisture proof pouches and filled with nitrogen gas retained ‘good tea aroma’ during 4 months of storage, whereas green teas packaged in the same pouch, but filled with air, developed ‘slightly reversion flavor’ of the green note by 2 months of storage and ‘reversion flavor’ of the green note at the 3 and 4 month evaluations. Green teas packaged using common packaging at the time of the study, which was cellophane-metalized polyethylene laminated tea pouches (not moisture proof), developed ‘slightly deterioration flavor,’ (sic) having an acidic note by the 2 month evaluation and ‘deterioration flavor’ of the acidic note at the 3 and 4 month evaluations. In Horita’s (1987) same study, the off-flavor compounds in green teas over a 4-month period of storage also were determined. The author compared the aroma components of four different grades of green teas and found that the concentrations of 1-penten-3-ol, (Z)-2-penten-1-ol, (E,Z)-2,4-heptadienal, and (E,E)-2,4-heptadienal increased as the green tea samples were stored longer. The green tea samples made with tea leaves picked later in the season had higher concentrations of these four compounds than the samples made with tea leaves picked earlier in the season. No literature is available that investigates the changes in the flavor or aroma compounds of green tea over more than a 4 month periods of storage.

There were a few researchers that tested the effects of various packaging materials during tea storage, including a clear glass bottle, a wooden box (Wickremasinghe and Perera 1972), a can, an aluminum/polythene laminate, a polythene film, a paper/plastic laminate, waxed papers (Stagg 1974), and plastic films (Fukatsu 1978). However, findings from earlier research may not be applicable today because packaging materials have improved since those studies were performed.

Even though green teas generally have a two year expiration date (Kim 1996), the flavor changes during those two years have not been studied previously. Thus, the objective of this study was to determine how the flavor attributes change over a two year period using descriptive sensory analysis.

Materials and Methods

Tea Samples

Two Korean commercial loose leaf green teas were chosen as samples: *Sulloc Tea Ouksu* (*Ouksu*), a high grade loose leaf green tea, and *Sulloc Tea Soon* (*Soon*), a medium grade loose leaf green tea. The *Ouksu* sample was made using tea leaves harvested in early May and mid May and was steam-and-roast -processed. The *Soon* sample was a blend of leaves harvested in mid May and late June. The tea leaves for the *Soon* sample were either roast-processed or steam-and-roast-processed and blended after processing. Both teas were obtained from Amorepacific Co. (Yongin, South Korea) with an exact packaging date. Amorepacific Co. is a major green tea manufacturer in Korea and the company has more than 40% of the market share for green tea products in Korea.

The samples were packaged in 100 g units in a bag made of metalized multi-layer food grade laminated polyethylene film. This packaging material serves as an excellent moisture, aroma and oxygen barrier and it has high resistance to chemicals and extreme high or low temperatures. All of the packages were randomly assigned to the length of time they were stored and the replications were labeled. The samples were stored at an ambient temperature (approximately 20℃) in their original pouches until their respective evaluations. The green tea samples were evaluated at 3, 6, 12, 18, and 24 months. The earliest time period of 3 months was chosen because it represents the earliest time that typical fresh tea leaf samples become available to consumers after production (Hara and others 1995). The latest time period of 24 months was chosen because it is the longest typical ‘best before’ period for green teas. Three new packages were opened at each storage period for three replications of the test for each storage period.

Tea Preparation

The green tea samples were prepared following brewing directions similar to those developed by Lee and Chambers (2007). White porcelain tea pots, approximately 350 mL in volume, porcelain strainers, porcelain bowls, and white porcelain tea cups were used in the sample preparation. The International Organization for Standardization (ISO3103 1980) suggests using porcelain tea wares to maintain consistent results. Reverse osmosis, deionized, carbon filtered water was used to pre-warm and brew the samples. Ten grams of each green tea were measured and placed in a pre-warmed tea pot and 300 mL of 70°C water was added. The pot was brewed for 2 min and swirled 10 times clockwise while it brewed. When the 2 min were up, the tea was poured through the porcelain strainer into the pre-warmed porcelain bowl and then into the pre-warmed tea cups.

Descriptive Sensory Analysis

Six highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University participated in this study. The panelists had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing including beverages, vegetables, and green tea.

The green tea flavor lexicon developed by Lee and Chambers (2007) was used for the descriptive analysis in this study. The panelists evaluated the samples individually, compared them to the reference standards developed for the lexicon, and recorded the intensities for each attribute using a 0-15 intensity scale where 0 means none and 15 means extreme intensity. Comparisons to the reference standards used in the lexicon were necessary to ensure that the panelists did not drift in their assessments over the nearly two year testing period. Similar panels and evaluation procedures have been utilized for other products such as cheese (Talavera-Bianchi and Chambers 2008), UHT milk (Oupadissakoon and others 2009), tomatoes (Hongsoongnern and Chambers 2008), and toothpaste (Hightower and Chambers 2009; Suwonsichon and others 2009).

The green tea samples were coded with 3-digit random numbers. One sample was presented at a time. To provide additional warm samples for the panelists to evaluate, an identical sample was brewed and served 5 min after the first. The panel had 15 min for each sample evaluation, typically 10 min to evaluate and 5 min to rinse and recover. The panelists were given unsalted crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water to reduce any build-up from one sample to the other and to cleanse their palates before the next evaluation. The Sensory Analysis Center uses Compusense *five* (Compusense, Guelph, Canada) for data collection.

Data Analysis

For the descriptive analysis data, a repeated measures ANOVA was conducted to determine if any flavor changes existed at different lengths of storage within the same sample. The analysis was conducted using SAS® (Version 9.1; SAS Institute, Cary, NC, USA).

Results and Discussion

Of the 31 green tea flavor attributes in the green tea lexicon (Lee and Chambers 2007) the panel detected 20 in the two Korean green tea samples (Table 8.1). Generally, the *Ouksu* sample was similar in its flavor profiles over the five different evaluations except in the 12 month evaluation. The *Ouksu* samples evaluated at 12 months were perceived to have higher intensities for brown, burnt/scorched, and bitter attributes than the samples that were evaluated at other times. The flavor of the *Soon* samples was similar over the time of testing except in the evaluation at month 3. This is mainly because of a higher bitter intensity at the 3-month evaluation. The slight differences in both teas may be because of a variation in the specific samples taken at each time period.

Table 8.1 shows the mean scores of all the attributes for each product. The mean intensities at the 6, 12, 18, and 24 month evaluations were compared to the mean of the 3-month evaluations. Generally, the intensities of most of the attributes stayed comparable within each sample throughout the two years of storage when they were evaluated at different storage lengths. A few exceptions include attributes such as brown, burnt/scorched, bitter, astringent, and tooth-etch for the *Ouksu* sample and green, asparagus, brown, tobacco, and bitter for the *Soon* sample. Most of these exceptions differed less than 1 point on 0-15 point scale (Table 8.1),

Table 8.1 Repeated Measures ANOVA of for *Ouksu* and *Soon* at Five Different Stored Times, Measured Using Descriptive Sensory Evaluation.

Attribute	3 months	6 months	12 months	18 months	24 months
Ouksu					
Green	3.67	3.14 *	3.14 *	3.67	3.18 *
Asparagus	0.00	0.00	0.58 *	0.92 **	0.00
Green beans	1.08	1.36	1.83 **	1.39	1.47
Green herb-like	0.00	0.00	0.00	0.00	0.00
Parsley	0.00	0.00	0.00	0.00	0.00
Spinach	1.97	2.36	2.00	1.72	1.79
Brown	1.72	2.42 **	4.31 **	2.06	2.77 **
Ashy/Sooty	0.00	0.00	0.00	0.00	0.67 **
Burnt/Scorched	1.44	1.86 *	2.33 **	1.58	1.05
Floral/Perfumy	0.00	0.00	0.00	1.19 **	0.00
Grain	0.00	0.81 *	0.00	0.00	0.57
Medicinal	0.00	0.00	0.58 **	0.00	0.00
Musty/New leather	0.00	0.00	0.64 **	0.00	0.77 **
Nutty	0.00	0.00	1.08 **	0.61 **	0.00
Seaweed	1.50	1.36	1.89	1.78	0.55 **
Straw-like	2.08	1.89	2.14	1.61 **	1.88
Tobacco	0.00	0.00	1.22 **	0.00	0.81 **
Bitter	6.06	6.83 **	7.36 **	5.31 **	6.14
Astringent	1.94	1.94	2.75 **	2.61 **	2.67 **
Tooth-etch	0.92	1.03	2.39 **	1.69 **	1.94 **
Soon					
Green	3.42	2.75 **	3.94 *	4.39 **	3.07
Asparagus	0.00	0.89 **	0.00	1.17 **	0.00
Green beans	1.72	1.31 *	0.77 **	1.50	1.17 **
Green herb-like	0.00	0.00	0.50 **	0.00	0.00
Parsley	1.06	0.53 *	1.32	0.00 **	0.00 **

Spinach	1.81	1.56	2.80 **	1.83	1.93
Brown	3.31	2.33 **	2.10 **	1.47 **	1.67 **
Ashy/Sooty	0.00	0.00	0.00	0.00	0.00
Burnt/Scorched	0.89	0.78	1.15	0.72	0.65
Floral/Perfumy	0.00	0.00	0.00	0.00	0.00
Grain	0.00	0.00	0.72	0.53	0.62
Medicinal	0.00	0.00	0.00	0.00	0.00
Musty/New leather	0.00	0.00	0.00	0.92 **	0.00
Nutty	0.00	0.00	0.77 **	1.06 **	0.00
Seaweed	0.00	0.00	0.00	0.72 *	0.51
Straw-like	2.17	1.64 **	1.69 *	1.64 **	1.36 **
Tobacco	2.03	0.94 **	0.00 **	0.00 **	0.00 **
Bitter	7.47	5.83 **	5.05 **	5.97 **	6.05 **
Astringent	2.14	2.00	2.76 **	2.89 **	2.13
Tooth-etch	1.56	1.44	2.19 **	2.47 **	1.79

** Mean score is different when compared to the mean of 3 months evaluation at alpha = 0.01

* Mean score is different when compared to the mean of 3 months evaluation at alpha = 0.05

a small, but significant difference. Eighteen attributes were used to describe the flavor of the *Ouksu* sample and for all the attributes at least one evaluation was significantly different from the 3 months evaluation. In the *Ouksu* sample, the brown-related attributes, including burnt/scorched, straw-like, and tobacco, tended to increase in their intensities until the 12 month evaluation after which they began to decrease. The small differences presented in the *Ouksu* sample throughout the 24 months of storage may have been because of variations in the product rather than changes occurring during storage, especially because few trends in differences (consistently increasing or decreasing) were found over time. Bitterness, astringency, and tooth-etching of the *Ouksu* sample increased slightly from the 3 month to 6 or 12 month evaluation. Grain, medicinal, and musty/new leather flavors, which may be considered off-flavors, developed at the 6, 12, or 24 month evaluations in the *Ouksu* sample but the levels were low and were inconsistent.

Seventeen attributes were used to describe the *Soon* sample and 15 attributes showed significant differences in comparison to the 3 month evaluation. The intensities of brown, straw-like, and tobacco flavors decreased over time and the differences compared to the 3 month evaluation were significant. The grain note was detected at the 12 month evaluation and onward but the intensities were very low. Musty/new leather was detected only at the 18 month evaluation of the *Soon* sample. In the *Soon* sample the bitterness was significantly lower for all of the evaluations when compared with the 3 month evaluation. Other attributes, however, did not show any tendency of increasing or decreasing in intensities as storage time increased for the *Soon* sample.

We found minimal flavor change of green teas when stored at an ambient temperature for up to two years. This result is different from the previous literature where researchers found that the aroma and/or flavor of green tea deteriorated within the first few months (Wickremasinghe and Perera 1972; Stagg 1974; Fukatsu 1978). In fact, Fukatsu (1978) mentioned that green tea was generally consumed within one year after manufacturing, which is only a half of the current 'best by' period. The reason for the different findings in this study could be because of the advancement in packaging.

Factors that may change the flavor of the tea include humidity, temperature, oxygen, light, or transmissions from other foods (Choi 2002). The two green tea samples in the current study were packaged in metalized multi-layer polyethylene film, which would have blocked most of these factors except temperatures and interior oxygen.

Conclusions

The flavors of two Korean green teas packaged in metalized multi-layer polyethylene film changed minimally within the first year of storage and both green teas developed musty/new leather, medicinal, or grain flavors at low levels when stored for 12 months or longer. The flavor changes in brown-related attributes and bitterness may be because of variations in the samples rather than the results of storage. The current study offers significant information that green tea flavor changes minimally during the two years of 'best before' date when left undisturbed at an ambient temperature. Tea retailers should consider using metalized multi-layer polyethylene film for packaging their green tea products to keep the contents from moisture, air, oxygen, light, and other factors which may disturb the flavors of green tea. Further investigation is needed to determine if these changes in the flavor influence the flavor of green tea perceived by consumers.

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CHAPTER 9 - Descriptive Analysis and US Consumer Acceptability of Six Green Tea Samples from China, Japan, and Korea

In the past, green tea has been one of the least popular non-alcoholic beverages for US consumers. However, green tea has been receiving attention because of its potential health benefits. Knowing which green tea flavor attributes contribute to consumer liking will help the fast growing green tea business including green tea importers, tea shops, and beverage companies to understand which characteristics are most accepted by US consumers. The objectives of this study were a) to examine differences in acceptability of commonly available loose leaf and bagged green teas available from the major exporters to the US: Japan, Korea, and China and b) to determine which green tea flavor characteristics are related to consumers' liking. In the study, consumers from the United States evaluated six green tea samples from China, Japan, and Korea for acceptability. A highly trained panel also evaluated the green tea samples to provide descriptive sensory attributes that might be related to acceptability.

We found that United States consumers liked green tea samples with lower flavor intensity and lower bitterness intensity. Consumers' acceptability of green tea was negatively correlated with spinach and animalic flavor and bitterness and astringency of green teas evaluated using descriptive sensory analysis, but the correlation was only moderate. To learn what green tea flavor characteristics influence consumers' liking, future studies using more green tea samples with different flavor profiles are needed.

Introduction

The flavor of green teas from China, Japan, and Korea may differ even though these countries are geographically close and the same species of green tea plants are grown in each country (Kim 1996). The flavor differences may occur because the variation in cultivars of the tea plant, picking season, processing methods, growing location, and the appearance of the final product may contribute to the flavor of green tea (Ukers 1935; Kim 1996; Choi 2002).

The tea plant, *Camellia Sinensis var. Sinensis*, has many cultivars. To produce green tea, China cultivates diverse cultivars of the *Sinensis* variety. In Korea, the *Sinensis* variety accounts for 44% and the *Yabukita* cultivar, a Japanese bred tea plant, accounts for 20% of cultivation area (Tea Experiment Station 2008). The Japanese bred the *Sinensis* variety in order to diversify cultivars and the *Yabukita* accounts for 85% of tea plants in Japan (Hara 2001). The Japanese usually introduce one or two new cultivars each year (Tea Experiment Station 2008). Different cultivars of tea may result in diverse green tea products (Kim 1996).

Processing methods are a factor that contributes to the flavor of green tea. Roasting, steaming, and a combination of the two methods are the major processing methods of green tea. Generally, Chinese green tea is known to be processed using roasting and rolling (Choi 2002), Korean tea is produced mostly using roasting but some steaming depending on the production facility (Kim 1996). Japanese green tea is processed mostly using the steaming method (Hara 2001; Choi 2002). The appearance of the final green tea products are closely related to processing, as is the flavor (Kim 1996; Choi 2002).

Loose leaf green tea usually keeps the whole leaf intact whereas green tea leaves in the tea bags are cut into small pieces. Less green tea is required when green tea products have small pieces, to make a cup of tea (Kim 1996). That author recommended a shorter brewing time (1-2 min) for tea in bags than loose leaf green tea (2-3 min). Many authors discussed the processing of loose leaf green tea and how the processing may influence the flavor of green tea (Kim 1996; Choi 2002). However, no information was found on the flavor of green tea in bags.

Researchers have studied green tea to understand aroma and flavor characteristics and related constituents. The volatile compounds of green tea have been extensively studied to determine which compounds were responsible for different green tea aromas (Yamanishi 1977; Kinugasa and others 1997; Wang and others 2002). Kumazawa and Masuda (2002) found that Japanese green tea (*Sencha*) was lacking a few volatile compounds compared to Chinese green tea (*Longjing* tea). Those compounds included 2-acetyl-1-pyrolline, 2-acetyl-2-thiazoline, 2-ethyl-3,5-dimethylpyrazine, and 2,3-diethyl-5-methylpyrazine, which authors found responsible for nutty and popcorn-like flavor. These researchers suggested that this difference might have been caused due to different processing. Togari and others (1995) have shown correlations between the sensory properties of tea aroma and volatile compounds concentrations. Differences in aroma of green tea may imply differences in flavor as well. Green tea flavor has been researched using sensory descriptive evaluation (Lee and Chambers 2007; Lee and others 2008b) and the results showed large differences in green tea flavors using sensory descriptors.

Only a few consumer acceptability test of green teas have been conducted (Cho and others, 2005; Lee and others 2008a; Lee and others 2009). And no research is available to understand liking of green tea using consumers in the United States of America.

For US consumers, green tea has not been a popular beverage (AICR 2005). However, green tea has become more popular because of its potential health benefits (Buss 2006). Green tea products used to be available only from international markets and Asian groceries. Currently, many green tea products are available at grocery stores, on-line shops, and local health stores.

Knowing what green tea flavor attributes contribute to consumer liking will help the fast growing green tea business including green tea importers, tea shops, and beverage companies by enabling us to understand which flavor characteristics of green tea contribute to consumers' acceptability. Such relationships have been used to better understand other product categories (e.g. mozzarella cheese, Pagliarini and others 1997; walnut syrup, Matta and others 2005; buiscuit, Vázquez and others 2009).

The objectives of this study are to examine differences in acceptability of commonly available loose leaf and bagged green teas available from Japan, Korea, and China and to determine which green tea flavor characteristics are related to consumers' liking.

Materials and Methods

Tea Samples

A total of 6 green tea samples from 3 countries in northeastern Asia, China, Korea, and Japan, were selected (Table 9.1). The tea samples are representative of green teas from each country based on literature or market share. A loose leaf green tea product and a tea bag green tea product were selected from each country. A loose leaf *Dragonwell (Chinese L)* was chosen because it was one of 8 well-known green teas in China and the most representative roasted green tea (Choi 2002). Alvita Chinese green tea in a tea bag (*Chinese TB*) is commonly available at US healthy food stores and is labeled 'Chinese green tea.' For Japanese tea samples, *Sencha Overture* loose leaf (*Japanese L*) was selected because Ukers (1935) classified *Sencha* as a tea of commerce (the principal tea exported). And *Traditional Medicinals Organic Bancha*

Japanese green tea bag tea (*Japanese TB*) was selected as *Bancha* is considered a low grade tea for home consumption (Ukers 1935). For Korean tea, *Sulloc Premium Tea Ouksujin* loose leaf tea (*Korean L*) is a high-grade tea and *Sulloc Tea Saeroktea (Korean TB)* was the tea bag product selected. Both were donated by *Amorepacific Co.* (Yongin, Korea), the major green tea manufacturer in Korea. Tea samples were stored at room temperature until testing and were used in the study within 2 weeks of their delivery.

Table 9.1 Green Tea Samples

Label	Country of Origin	Form	Name of product	Available at
Chinese L	China	Loose leaf	*Dragonwell* (a.k.a. *Longjing* tea)	*Adagio teas*; http://www.adagio.com
Chinese TB	China	Tea bag	*Alvita Chinese green tea (Plain)*	Local health store (Manhattan, KS, USA)
Japanese L	Japan	Loose leaf	*Sencha Overture*	*Adagio teas*; http://www.adagio.com
Japanese TB	Japan	Tea bag	*Traditional Medicinals Organic Bancha*	local health store (Manhattan, KS, USA)
Korean L	Korea	Loose leaf	*Sulloc Premium Tea Ouksujin*	*Amorepacific Co.* (Seoul, Korea)
Korean TB	Korea	Tea bag	*Sulloc Tea Saeroktea*	*Amorepacific Co.* (Seoul, Korea)

Sensory Analysis

Descriptive Analysis:

Six highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University (Manhattan, KS, USA) participated in this study. The panelists had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing including beverages, vegetables, and tea. All panelists had participated in a previous green tea lexicon development (Lee and Chambers 2007) and were already familiar with the lexicon and green tea as a product. The panel was given a 2-hour re-orientation to the products and lexicon for this study. The panelists used a numerical scale from 0-15 with 0.5 increments where 0 meant none and 15 meant extremely high intensity. The panelists individually scored their findings on ballots. There were three replications. Panelists used unsalted tops premium saltine crackers (Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water to cleanse their palate. The Sensory Analysis Center uses Compusense *five* (Compusense Inc., Guelph, Ontario, Canada) for data collection.

Consumer Hedonic Test

A total of 410 consumers from the Manhattan, KS area participated in this study. Consumers, who were willing to participate in the taste test and had no allergies to foods and medication were recruited and were compensated for their time. As green tea was a less-familiar beverage at the time of evaluation, consumers did not have to be green tea drinkers. Consumer evaluated two of the six samples in a balanced incomplete block design. Consumers were given 8 minutes to evaluate each sample. Each green tea sample was evaluated by a similar number of consumers depending on the number recruited who actually came to the test; a minimum of 128 and maximum of 144 consumers. Consumers evaluated green tea samples for overall liking and liking of the strength of flavor using a 9-point box scale with anchors from dislike extremely to like extremely. They also were asked to rate the intensity of the overall flavor and bitterness using a 9-point intensity scale, with anchors from none to extreme. Consumers cleansed their palate between evaluations by eating unsalted tops premium saltine crackers (Nabisco, East Hanover, NJ, USA) and rinsing with reverse osmosis, deionized, carbon-filtered water.

Upon completion of the evaluation, consumers completed a demographic questionnaire that obtained information on gender, age range, ethnicity, drink selections, consumption frequency of black tea (either hot or iced) and green tea, their interest in increased mental or physical awareness/capacity, modifying bodyweight, and promoting good health.

Tea Preparation

For loose tea leaves samples, 6 grams of green tea leaves were placed in 300 mL of reverse osmosis, deionized, carbon filtered water at 70°C and brewed for 2 minutes in porcelain pots. During infusion, the pot was swirled 10 times clockwise. The green tea was poured into a warmed bowl through a porcelain strainer (Lee and Chambers, 2007).

For samples in tea bags, a single tea bag was brewed in 240 mL of reverse osmosis, deionized, carbon filtered water in glassware at 70℃. The tea bag was moved 10 times with up-and-down motion during infusion. The tea bag was pressed with spoon before removed from the glassware. The tea bags were brewed in 240 mL of water because in the United States many green tea products recommend using 8 oz. or one cup of water which is equivalent to 240 mL.

Tea Serving

Descriptive Analysis

Approximately 40-45 mL of brewed green tea was poured into a 240 mL Styrofoam cup (James River Corp. C12A) labeled with 3-digit random numbers. The samples were served to the panelists at 45℃ ±2℃ monadically in random order. Tea samples were prepared a second time and served to the panelists 10 minutes later to provide enough warm samples for the evaluation. Panelists were given 25 minutes to evaluate each sample for each replication.

Consumer Test

Samples were prepared using the same methods as for the descriptive evaluation. Brewed green tea was poured into thermos pumps (1.9 L, Arcosteel Air pump pot, Gardena, CA) and kept at 55 ℃ ± 2℃ temperature until served. Approximately 30 mL of brewed green tea was poured into a 240 mL Styrofoam cup (James River Corp. C12A). The samples were served to the panelists at 45℃ ±2℃, one sample at a time in random order. All samples were prepared within one hour of testing, and poured 2 minutes prior to serving.

Statistical Analysis

Analysis of variance was conducted using the SAS® system (version 9.1.3; SAS Institute Inc., Cary, NC, USA) of PROC GLM for descriptive data and consumer data. For principal component analysis (PCA) and correlation analyses, means computed from aforementioned analyses were used. PCA was conducted using PROC PRINCOMP of the SAS® system, version 9.1.3. Correlations were computed between descriptive and consumer means using PROC CORR (the SAS® system, version 9.1.3.).

Results and Discussion

Descriptive Analysis of Green Tea

Eighteen attributes from a green tea lexicon developed by Lee and Chambers (2007) were used to describe the 6 green tea samples: green, asparagus, celery, green beans, green herb-like, parsley, spinach, brown, ashy/sooty, burnt/scorched, tobacco, animalic, musty/new leather, seaweed, straw-like, bitter, astringent, and toothetch. All samples had brown and green flavor, but at different intensities (Table 9.2).

Both Chinese green tea samples, *Chinese L and Chinese TB*, had higher brown flavor than green flavors (Table 9.2). Both of the Chinese samples had ashy/sooty, musty/new leather and tobacco flavors, whereas the samples from the other countries did not have these flavor characteristics. This may be caused by differences in processing. Chinese teas commonly are roasted which may have contributed to ashy/sooty, burnt/scorched, and tobacco flavors.

Korean green tea Samples, *Korean L* and *Korean TB*, had more green-related flavor than brown-related flavor, although intensities for both were at low (Table 9.2). Common green-related attributes included asparagus, parsley and spinach.

Japanese green tea samples had higher green-related flavor than brown-related. Green-related notes in *Japanese L* included spinach and parsley (Table 9.2). This was the only sample having seaweed flavor. *Japanese TB* had green-related flavor including parsley, celery, and green herb-like. *Japanese L* had the highest bitterness and *Japanese TB* had the lowest bitterness among green tea samples in the current study. Similar information on green tea flavors among countries was noted by Lee and others (2007) who found that Japanese teas had more green flavor notes and Chinese teas had more brown flavor notes.

Generally, green teas in tea bags had similar flavor profile and intensities to leaf form even though a lower amount of green tea was used in bags than loose leaf. This shows that green teas in the tea bag may be more effective in releasing flavor constituents than green teas in the leaf form because the green teas in tea bags are finely chopped and so have larger surface area. Another possibility is that we squeezed the bags at the end of brewing, which would force water out of the chopped leaves whereas no physical force was applied to loose leaf green teas at the end of brewing.

Table 9.2 Analysis of Variance; Means of Descriptive Analysis Data[a,b,c] of Green Tea

Attributes	Leaf form			Tea bag			LSD[d]
	Chinese	Japanese	Korean	Chinese	Japanese	Korean	
Green	2.64 bc	4.12 a	4.29 a	1.86 c	3.31 ab	3.65 ab	1.19
Asparagus	0.00	0.00	1.76	0.00	0.00	0.50	
Celery	0.00 b	0.00 b	0.00 b	0.00 b	1.00 a	0.00 b	0.75
Green beans	0.00	0.00	0.00	0.00	0.00	0.79	
Green herb-like	0.00	0.00	0.00	0.00	0.62	0.00	
Parsley	0.55 b	1.74 a	1.26 ab	0.81 ab	1.21 ab	0.71 ab	1.05
Spinach	1.10 ab	2.31 a	2.33 a	0.00 c	0.00 c	1.79 ab	1.65
Brown	3.19 b	1.90 c	1.67 cd	4.00 a	1.14 de	0.98 e	0.69
Ashy/sooty	3.33 b	0.00 c	0.00 c	4.05 a	0.00 c	0.00 c	0.57
Burnt/scorched	1.71 a	1.33 a	0.81 ab	1.64 a	0.00 b	0.00 b	1.11
Tobacco	0.71 b	0.00 b	0.00 b	2.21 a	0.00 b	0.00 b	0.94
Animalic	0.64 a	0.00 b	0.52 a	0.00 b	0.00 b	0.00 b	0.48
Musty/new leather	1.60 a	0.00 b	0.00 b	0.79 ab	0.00 b	0.00 b	1.15
Seaweed	0.00 b	1.48 a	0.00 b	0.00 b	0.00 b	0.00 b	1.11
Straw-like	1.76	1.14	1.24	1.64	1.29	0.88	
Bitter	5.76 ab	6.33 a	5.02 bc	5.52 abc	3.74 d	4.62 cd	0.98
Astringent	2.00 a	2.14 a	1.71 ab	1.79 ab	1.10 c	1.50 bc	
Toothetch	0.83 ab	1.02 a	0.55 b	0.83 ab	0.00 c	0.00 c	0.41

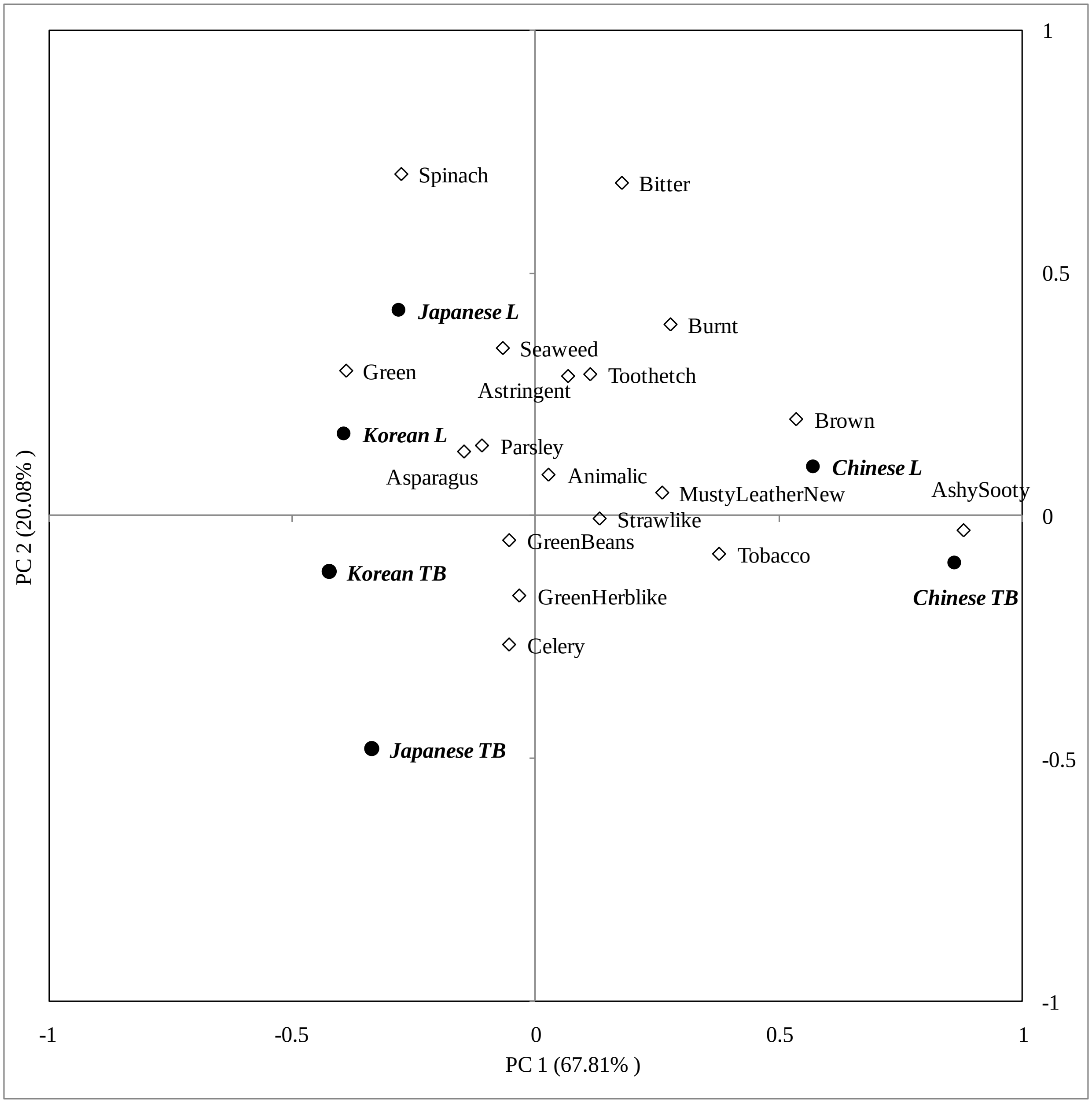
[a] Ratings used a 15-point numerical scale with 0.5-point increments, where 0 = not and 15 = extreme.

[b] Means with the same latter designation in the same row are not statistically significantly different (alpha = 0.05).

[c] All means below 0.5 were listed as zero, as they probably represented random effects.

[d] Least significant difference

Figure 9.1 Principal Component Analysis of 6 Green Tea Samples from Three Different Countries[a]



[a] Sample name includes country of origin and their form. L stands for loose leaf form and TB stands for tea bag.

The principal component analysis of 6 green tea samples from 3 different countries is shown in Figure 9.1. Principal component (PC) 1 explained 67.81% of data variability and PC 2 explained 20.08% of data variability. *Chinese L* is in the first quadrant and *Chinese TB* is in the fourth quadrant. However, they are located close to each other because they are similar in their flavor characteristics. As mentioned above, both have flavor characteristics such as brown, ashy/sooty, burnt/scorched, and musty/new leather, and tobacco in common. In the second quadrant, *Japanese L* and *Korean L* are placed near spinach and green flavor attributes. Both have green and spinach flavor at higher intensity than the other samples evaluated. *Korean TB* and *Japanese TB* are located in the third quadrant. They have similar flavor characteristics to those of *Korean L* and *Japanese L* except that both were the least bitter green teas in the study. In general, the loose leaf teas had slightly higher green vegetable notes.

Consumer Hedonic Test

Generally consumers preferred green tea made using bags rather than loose leaves (Table 9.3), perhaps because they perceived the flavor intensity as slightly lower (Table 9.3). Consumers perceived intensity of bitterness in tea bag teas as lower than loose leaf teas. These findings corroborate with the findings of an acceptability test of canned black tea products, in which Korean consumers liked the tea that had the lowest bitterness (Cho and others 2005).

Chinese TB and *Japanese TB* were the most liked green tea samples among United States consumers. Consumers' ratings for *Korean TB* were not statistically different from the most liked samples for flavor intensity and bitterness perceived by consumers (Table 9.3); however, consumers were neutral to the *Korean TB* and the overall liking score was lower than *Chinese TB* and *Japanese TB.* Consumers disliked *Korean L* and *Japanese L (Sencha)* slightly. *Chinese L* was rated the lowest among samples and was disliked moderately to slightly.

Interestingly, Chinese samples were the most and the least liked samples (Table 9.3). Consumers' evaluation of overall flavor intensity and bitterness intensity for *Chinese L* was approximately one and two points higher (9-point scale), respectively, than *Chinese TB*, may explain the difference in liking scores. Japanese samples differed less in overall flavor intensity and bitterness intensity perceived by consumers (around 0.5 and 1.4 higher, respectively, in Japanese L), thus resulting a smaller difference in the overall liking score. Korean green tea samples showed even smaller differences between *Korean L* and *Korean TB* in overall flavor intensity (0.35) and bitterness intensity (1) perceived by consumers, which may have contributed the smallest difference in overall liking score of 0.6. Yet, the difference was significant and *Korean TB* was liked better.

Table 9.3 Consumers' Rating[a,b,c] of Green Tea

Questions	Leaf form			Tea bag			LSD[d]
	Chinese	Japanese	Korean	Chinese	Japanese	Korean	
Overall liking[a]	3.80 d	4.47 c	4.49 c	5.99 a	5.74 a	5.08 b	0.42
Liking of flavor strength[a]	4.28 c	4.61 c	4.64 c	5.73 a	5.57 ab	5.16 b	0.45
Overall flavor intensity[b]	5.71 a	5.47 ab	5.25 bc	4.79 d	4.96 cd	4.90 cd	0.39
Bitter intensity[b]	5.55 a	5.01 b	4.89 b	3.58 c	3.64 c	3.90 c	0.45
Number of consumers	144	129	128	141	141	137	

[a] Ratings used a 9-point box scale with 1-point increments, where 1 = dislike extremely, 5=neither like nor dislike, and 9 = like extremely.

[b] Ratings used a 9-point numerical scale to measure intensity with 1-point increments, where 1 = none and 9 = extreme

[c] Means with the same latter designation in the same column are not statistically significantly different ($\alpha = 0.05$)

[d] Least significant difference

The current findings may have been differed if brewing direction for green teas in the tea bag had been followed. All the tea bag samples were brewed with 240 mL of 70°C water for 2 minutes to reflect how the green teas are normally brewed in Asia where green tea is common beverage (Kim 1996) and to provide a independent comparison where brewing methods was not confounded with teas. However, the directions for tea bags varied. The *Chinese TB* directions recommended brewing a tea bag in 6 oz. (180 mL) of boiling water for 3 minutes. The *Japanese TB* directions recommended brewing a tea bag in 8 oz. (240 mL) of boiling water for 5-10 minutes. Following package directions could have resulted in higher bitterness and may have affected the consumers' preference because brewing green tea in higher temperature increased caffeine content in the liquor (Kwon and others 1990).

Consumers were further divided into sub groups to investigate if there were any differences based on their consumption of green tea.

Overall liking scores of consumers who never drink green tea and those consumers who drink green tea at least occasionally were compared (Table 9.4). For the consumer group who never drank green tea, *Chinese TB* scored the highest liking followed by *Japanese TB*. All three green teas in loose leaf form were equally disliked. Contrarily, consumers who consume green tea at some degree gave generally higher score than consumers who never drank green tea. This group also liked *Chinese TB* and *Japanese TB* however they were neutral to *Korean TB, Korean L*, and *Japanese L*, and only disliked *Chinese L*.

Consumers who participated in the current study appear to be similar to green tea consumers in the United States. When consumers were asked to select all beverages that they drink at least once a week, 22% of consumers marked green tea as a beverage that they drink at

Table 9.4 Overall Liking Ratings[a,b] of Green Tea by Consumers Grouped Based on Consumption of Green Tea

Questions	Leaf form			Tea bag			LSD[c]
	Chinese	Japanese	Korean	Chinese	Japanese	Korean	
Never (n=161)	3.85 c (59)	3.96 c (55)	3.90 c (51)	5.55 a (56)	5.19 ab (47)	4.84 b (56)	0.64
Drink green tea (occasionally to heavily) (n=242)	3.75 c (81)	4.84 b (74)	4.90 b (74)	6.27 a (85)	6.00 a (91)	5.22 b (79)	0.57

[a] Ratings used a 9-point hedonic scale with 1-point increments, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.

[b] Means with the same latter designation in the same column are not statistically significantly different (alpha = 0.05)

[c] Least significant difference

[d] (Number of consumers)

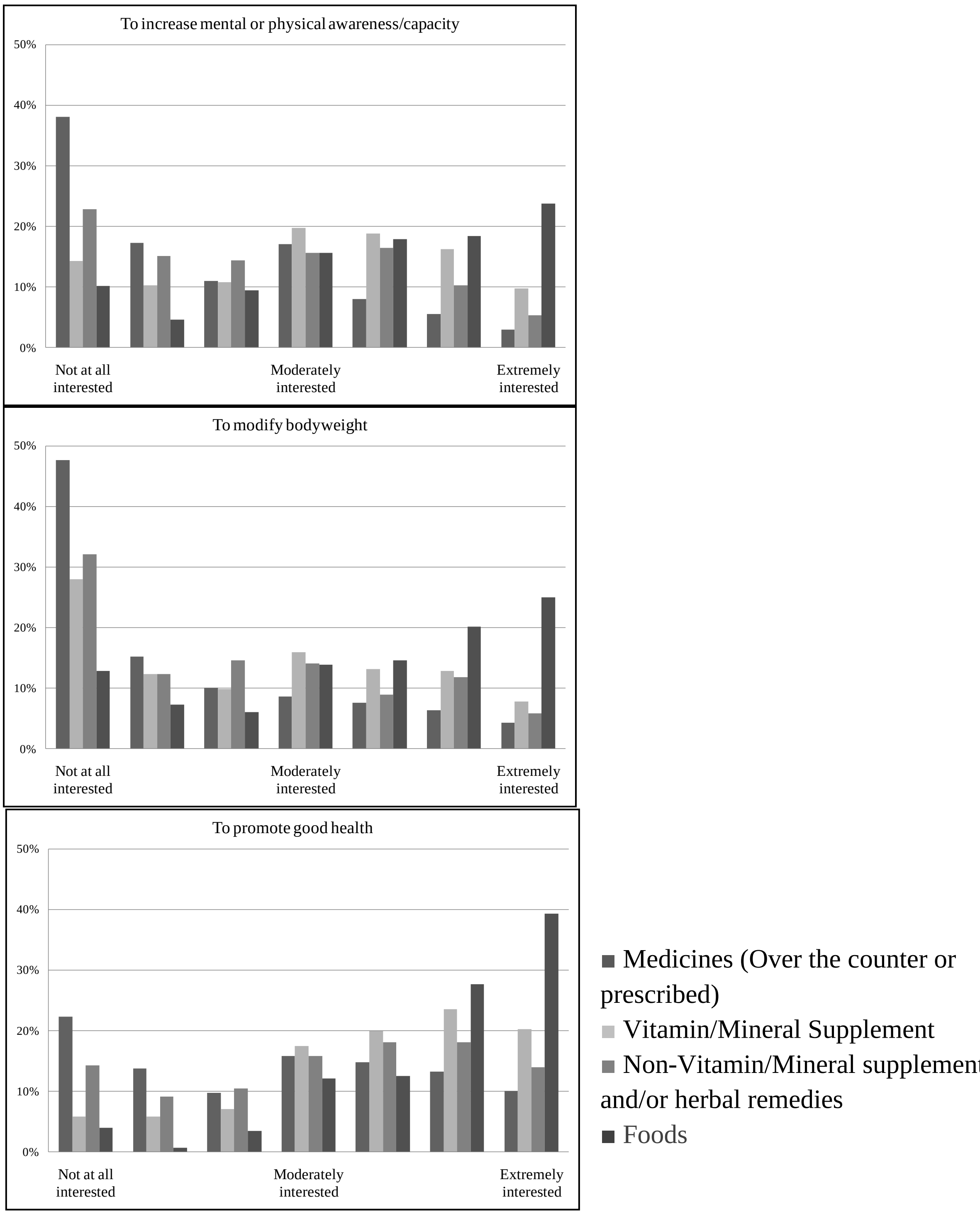
least once a week. This is similar to the level found by the American Institute for Cancer Research (AICR 2005) in their green tea consumption frequency survey. The summation of consumers who answered that they either drank green tea 5 or more times a week, 3-4 times a week or once or twice a week was 22.1% for the AICR (2005) survey. Approximately 40% of consumers who participated in this study indicated that they never drank green tea. This is slightly lower than what AICR (2005) found in their data, but their lowest frequency consumption choice was ‘rarely/never’, which was a broader choice than ‘never.’

Our consumers’ purchase interest of medicines, vitamin/mineral supplements, non-vitamin/mineral supplements and/or herbal remedies, or food to increase mental or physical awareness/capacity, to modify one’s bodyweight, or to promote good health are given in Figure 9.2. For all the questions, consumers were most interested in using food and least interested in using medicine (over the counter or prescribed), vitamin/mineral supplements. Green tea is a beverage that may meet this criterion. It has been shown that L-theanine, green tea amino acid, has a relaxation effect on humans (Juneja and others 1999) and L-theanine and caffeine in combination can improve behavioral performance (Kelly and others 2008). Epigallocatechin-3-gallate, the major tea catechins, showed fat oxidation and therefore green tea might have anti-obesity consequences (Boschmann and Thielecke 2007). High green tea consumption (equal to or more than 6 cups per day) reduced the risk of type 2 diabetes by 33% in Japanese adults (Iso and others 2006). In the epidemiological evidence review, Arts (2008) concluded that research on tea, flavonoids, and lung cancer showed positive relation by and large. In the review of breast cancer risk and tea relationship, Sun and others (2006) saw about 20% decreases in breast cancer risk within a high green tea consumption group (equal to or more than 5 cups per day). Green tea is a potential choice for consumers who are interested in using foods to increase mental or physical awareness/capacity, to modify their bodyweight, or to promote good health. If the flavor of green teas is acceptable to consumers, more consumers will choose green tea as their beverage choice.

Correlation of Descriptive Analysis and Consumer Evaluation of Green Teas

Consumers’ overall liking score was negatively correlated with animalic (-0.75), spinach (-0.68), astringent (-0.62) and bitter (-0.52) measurements of descriptive analysis of the same green tea. The correlation between descriptive analysis and consumer acceptability of green teas

Figure 9.2 Consumers Purchase Interest Distribution of Medicines, Vitamin/Mineral Supplements, Non-vitamin/Mineral Supplements and/or Herbal Remedies, or Food to Increase Mental or Physical Awareness/Capacity, to Modify One's Bodyweight, or to Promote Good Health



are only moderate, but that suggests that the relationship between liking and flavor is more complicated than single attribute correlations can describe, an expected finding. Larger numbers of green tea samples with diverse flavor profile will need to be evaluated to further investigate the relationship between consumer liking and descriptive evaluation of green tea.

Correlation between bitter measured by descriptive panel and consumers was only moderate with a correlation coefficient of 0.63. Both the descriptive panel and consumers agreed that *Japanese TB* has the lowest bitterness. However consumers also rated bitterness of *Chinese TB* as similar to *Japanese TB* when the descriptive panel rated *Chinese TB* having higher bitterness than *Japanese TB*. This most likely is because the consumers used bitter as a surrogate for disliking as opposed to actually measuring bitterness. The correlation of consumer perception of bitter and liking was -0.97, which suggests that the consumers simply used bitter to describe samples they did not like. Another possibility is that consumers may be confused between astringency and bitterness or used bitterness to describe a combination of those flavors because astringency evaluated by descriptive panel shows higher correlation with the bitter intensity measured by consumers (r=0.71).

Conclusion

US consumers preferred green tea with lower flavor and bitterness intensity in their perception. Correlation between US consumers' preference of green tea and flavor characteristics described by the trained panel were moderate, but the correlation suggested that green flavor related to spinach, bitterness, astringency and off-flavor such as animalic had negative influence on the US consumers' liking of green tea. Further investigation may help understand the relationship between green tea flavor and consumers' liking of green tea.

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CHAPTER 10 - Consumer Acceptance for Green Tea by Consumers in Three Countries and its Relationship to Flavor Characteristics

Green tea consumption has been common in some countries for centuries but in others it is just finding popularity. The objectives of this study were to 1) determine the liking of green tea by consumers in three countries: Korea, where green tea commonly is consumed; Thailand, an Asian country where green tea is generally consumed in a cold form; and the United States, a country where green tea is not commonly consumed and 2) identify the attributes which appear to influence consumers' liking. The liking of green tea varied depending on the country and the consumer segment. Korean consumers generally liked the green tea samples with various green flavors and moderate bitterness, although a few of the Korean consumer segments liked samples with other flavor profiles. Most of the US consumers liked the tea samples that had brown, fruity, or sweet aromatic flavors with little or no green flavors. Thai consumers preferred tea samples with fruity flavors and no green flavor but were not as discriminating among samples as the Korean or US consumers were. Regardless of the consumers' origin, the green tea samples with the highest bitterness were disliked.

The current research suggests that familiarity plays a role in tea acceptance. However, various flavor profiles may be acceptable to consumers who are from different countries and are familiar with other flavors of tea. This suggests that, although familiarity plays a role in consumers' acceptance of green tea flavors, other factors also contribute to liking. This study has particular implications for the selection of mass marketed green teas.

Introduction

Worldwide, tea is one of the most popular beverages (Chen 2002) and is a part of many Asian countries' cultures (Ukers 1935; Kim 1996; Choi 2002; Ellis 2002). However, in 1996 in the US only 4% of the national tea consumption was green tea, while black tea held around 95% of the market (Segal 1996). Recently, green tea has become more popular in Western countries, including the US, because consumers are becoming more aware of the possible health benefits of green tea (Nutraingredients.com 2005; Buss 2006), which have been studied and reviewed by many researchers (Chen 2002; Iso and others 2006; Kuriyama and others 2006; Binns and others 2008; Hakim and others 2008; Kuriyama 2008; Kumar and others 2009; Naganuma and others 2009). Currently there are various green tea products in Western markets and one can easily purchase green teas from grocery stores, tea specialty stores, and on-line retailers. Many national and international chain restaurants serve green tea in various forms.

The sensory characteristics, such as taste, texture, aroma, and appearance, have different importance among individual consumers, although taste is the most important sensory characteristic for foods and beverages (Rabino and others 2007). Ukers stated as early as 1935 that, although consumers drink green tea for a variety of reasons, including aroma, flavor, appearance, functionality, health benefits, and other factors, flavor is the most important. Recently, 68.2% of Korean tea consumers said that they consider flavor to be the most important aspect of green tea, followed by aroma (28.1%), and then color (3.4%) (Yang and others 2004).

Consumer acceptance of green tea has been examined in several different studies that attempted to define how flavor characteristics influence acceptability (Cho and others 2005; O. H. Lee and others 2008; S. M. Lee and others 2008; Lee and others 2009). In one study Korean consumers evaluated teas prepared from tea bags and found that the green teas with burnt leaf and roasted barley flavors were the most preferable (O. H. Lee and others 2008). One study included 29 green tea samples from China, Japan, and Korea, finding that Korean consumers prefer roast-processed green tea samples over steam-processed or steam-roast-processed samples (Yang and others 2004). In a study evaluating Korean consumers' acceptability of four decaffeinated green teas, the authors found that consumers who drank any type of green tea products regularly preferred the tea samples with lower flavor intensities and bitterness, while consumers who drank only green teas brewed from a loose leaf form regularly preferred green tea with higher flavor intensities, bitterness, and astringency (Lee and others 2009). Previous research suggests that Korean consumers may have particular preferences for certain green teas flavors and tastes, probably because they consume green tea so regularly (Jung 2002).

It is well established that cultural patterns of eating are different among different cultures. Acceptability for specific foods or types of foods can be different among countries and cultures but it also can vary within a culture. For example, the preferences of consumers from different countries differed for beef (Thompson and others 2008), lamb meat (Font i Furnols and others 2006), and pork patties with Shiitake mushroom powder (Chun and others 2005). Consumers also were affected differently by the color of sugar solutions (Strugnell 2002) and consumers from six countries chose differently among organic, ordinary, or spray-free genetically modified fruits (Knight and others 2007). Consumers from three countries had different preferences for genetically modified (GM) food (Costa-Font and Gil 2009) and German and Greek consumers differed in their acceptance and willingness to purchase GM food (Tsakiridou and others 2007). In addition, some consumer studies have shown differences in acceptance among consumers within a country or culture for particular products (Font i Furnols and others 2006; Rabino and others 2007). However, it is also shown that interactions between different cultures may reduce the differences in textural acceptance of novel snacks (Murray and others 2001) and consumption trends (Smith and Mitry 2007).

Studies of cross-cultural acceptance for green tea were not found even though this beverage has received increased attention in recent years. It is reasonable that green tea consumers from different countries may have different preferences for green tea flavors based on their respective cultures, expectations, exposures, tastes, and other differences (Zajonc 1968; Yeh and others 1998; Strugnell 2002; Wansink and others 2002; Tsakiridou and others 2007). Wansink and others (2002) suggest that introducing unfamiliar foods to different countries with different contexts requires different introduction approaches.

A study where consumers from different countries with different experiences in drinking tea evaluated green teas with varying sensory characteristics, could provide a foundation for understanding consumer acceptance of the flavor of green teas.

The objectives of this study were 1) to determine consumers' liking of green tea with various flavor characteristics in consumer groups from three different countries that represent different consumption habits of tea: a group from a country familiar with drinking standard loose-leaf green tea (Korea), a group from a country familiar with drinking cold green tea and many flavors of hot tea (Thailand), and a group from a country where green tea consumption is relatively new (U.S.A), and 2) to identify the attributes from the descriptive sensory analysis that appear to affect consumers' liking.

Materials and Methods

Tea Samples

A total of 12 tea samples were included in this study (Table 10.1). They were produced in China, Japan, Korea, Sri Lanka, Taiwan, Tanzania, Thailand and two of unknown origin. The samples were selected to represent different countries of origin, manufacturing methods, prices (range from USD 3.88/100g to USD 52.13/100 g), and sensory qualities. The two samples of

Table 10.1 Green Tea Sample[a]

Label	Product Name	Country of origin	Purchased from	Price (USD/100g)
Chinese	*Alvita* Chinese Green Tea (in tea bags)	China	Local health food store, Manhattan, KS, US	6.75[b]
Gunpowder	*Formosa Gunpowder* Tea	Taiwan	CulinaryTeas.com	3.88
Gyokuro	Moonlight *Gyokuro*	Japan	AdagioTeas.com	
Irish	Irish Breakfast Green Tea	Unknown	CulinaryTeas.com	4.25
Lipton	*Lipton* Green Tea 100% Natural (in tea bags)	Unknown	Dillon's, local grocery store, Manhattan, KS, US	4.99[c]
Mulberry	Mulberry Tea Beverage	Thailand	Emporium, gourmet store, Bangkok, Thailand	1.47[d]
Ouksujin	Sulloccha Ouksujin	Korea	Amorepacific Co., Korea	30.74[e]
Sejac	Sulloccha Premium Tea Sejac	Korea	Amorepacific Co., Korea	52.13[f]
Sencha 1	Ito En Okumidori Sencha	Japan	ItoEn.com	31.75
Sencha 2	YamaMotoYama Sencha	Japan	Amazon.com	2.75
Tanzania	Green Tea	Tanzania	Janesteas.com	9.99
White	Adam's White Tea	Sri Lanka	ImperialTeaGarden.com	32.50

[a]Green tea samples were in loose leaf form except *Chinese* and *Lipton* samples.

[b]One tea bag contains 2.37g of green tea leaves and price for a tea bag is USD 0.16.

[c]One tea bag contains 2.25g of green tea leaves and price for a tea bag is USD 0.10.

[d]Price was THB 49 for 100g. The price was converted to USD based on average exchange rate of testing period, which was USD 1.00 equal THB 33.41.

[e]Market price was KRW 23,000 for 80g. The price was converted to USD based on average exchange rate of testing period, which was USD 1.00 equal KRW 935.18.

[f]Market price was KRW 39,000 for 80g. The price was converted to USD based on average exchange rate of testing period, which was USD 1.00 equal KRW 935.18.

unknown origin were *Lipton* green tea bags and an *Irish* green tea. The classification of the *Irish* sample is not clear. At the time of purchase and testing, the origin was listed as unknown. Currently the retailer's website lists Kenya, China, and Japan as its origins. It is likely that the Irish sample is a blend of teas grown and processed in Kenya, China, and Japan.

Of the 12 tea samples, nine were selected to represent various flavor profiles from teas used in the development of a green tea lexicon (Lee and Chambers 2007). These samples were *Gunpowder*, *Gyokuro*, *Irish*, *Ouksujin*, *Sencha 1*, *Sencha 2*, *Sejac*, *Tanzania*, and *White*. In addition to the nine samples, *Lipton Green Tea* in tea bags was added to the samples in order to represent an easily available and common green tea product in the United States. *Alvita Chinese Green Tea* (China) in tea bags also was added because it represented a flavor known to be accepted by US consumers based on preliminary research. Lastly, *Mulberry green* tea, a common type of green tea from Thailand, was added. *Mulberry green* tea is the one product included in the study that is not green tea from the Camelia Sinesis plant. All the tea samples were stored at 4℃ for less than four months before the evaluation.

Tea Preparation

For brewing, the package directions regarding the tea amount versus the water amount, temperature of water, and length of brewing were followed when possible. When the brewing directions were not available, we used 10 grams of green tea in 500 mL of 70℃ water for 2 min, a brewing method modified from Lee and Chambers (2007). In this study we used glassware to brew the teas because using porcelain tea pots was not practical for brewing tea in the large quantities needed for the consumer tests. Package directions and actual brewing methods are available in Table 10.2. Reverse osmosis, deionized, carbon filtered water; Jeju Samdasu (2L Bottled; Nongsim, Korea); and Nestlé® Pure Life® (6L Bottled; Nestle, Thailand) were used for brewing in the US, Korea, and Thailand, respectively.

For the loose tea leaf samples, the appropriate amount of water was poured into Pyrex® Laboratory glassware (Corning Inc., New York) and the pre-measured tea samples were added. The glassware was left undisturbed during the brewing except for the *White* sample, which was very light and did not submerge. To help the *White* tea leaves submerge they were pushed down gently until all the leaves were drenched. When the green tea reached the brewing time, it was poured into new glassware through a porcelain strainer.

Table 10.2 Brewing Methods of 12 Tea Samples

Tea Samples	Tea leaves amount (gram)	Amount of water (mL)	Temperature of water (℃)	Length of brew (min'sec")
Chinese[a]	4.74 (2 tea bags)	360	95	3'
Gunpowder[b]	5	500	80	3'
Gyokuro[c]	10	500	80	3'
Irish[d]	5	500	95	5'
Lipton[e]	4.5 (2 tea bags)	360	95	1'30"
Mulberry[f]	4.5	500	90	3'
Ouksujin	5.8	500	70	2'
Sejac	5.8	500	70	2'
Sencha 1[g]	6.7	500	80	1'30"
Sencha 2	6.7	500	80	2'
Tanzania[h]	5	500	90	5'
White	10	500	70	2'

[a-f]Brewing direction on the package.

[a]The best way to make a good cup of tea is by the infusion method. Place one tea bag in a cup and add no more than 6 oz. of boiling water. Let steep for 3 minutes. Press the bag before removing to enhance flavor. Add honey to sweeten.

[b]1 tsp per cup 180℉, 2-3 min, 2-3 infusions

[c]180℉, 3min

[d]1 tsp per cup, 212℉, 3-5 min

[e]For a Delicious Cup of Hot Green Tea, bring fresh cold water to a rolling boil and pour over tea bag. Brew 1 to 1-1/2 minutes or to desired strength. Remove tea bag. Sweeten to taste with honey or sugar.

[f]Use 80-90℃ water with 1 tablespoon of tea: 250 cc water and let it warm in 3 minutes.

[g]Tea: 1tsp, Water: 176F (80C) / 6 oz, Steeping: 1-1.5 min

[h]To make a great cup of tea: Bring cold water to the boil. Just before boiling point, warm the teapot by adding a little of the water and then pouring it away. Add one teaspoon of tea per person and one for the pot, according to your taste. Just beofre the water has reached boiling

point, pour the water over the tea leaves, stir and allow to brew for four to five minutes. Pour the tea into the cup through a tea strainer.

The two tea bag samples were brewed following the package instructions. For the *Chinese* sample, the tea bags were gently pressed with a spoon before they were removed as directed. This was not done for the *Lipton* sample.

No additives, such as sugar, lemon, or milk, were added to any of the samples.

Countries Selected

Three countries were selected for this test. Korea was selected because it has over 1,000 years of green tea history and it has been estimated that Korean consumers consumed 40 grams of green tea per capita in 2000 (Jung 2002). Thailand was selected because it is another Asian country, but one where green tea consumption is much lower. Although green tea was one of the three most common herbal teas consumed in Thailand (Nookabkaew and othes 2006), black tea, chrysanthemum tea, and jasmine tea are more common. In addition, green tea, when consumed in Thailand, often is drunk cold. The United States was selected because in that country black tea is consumed much more often and by more consumers than green tea (AICR 2005). However, green tea has grown in popularity in the U.S. as its potential health benefits have become more widely known.

Consumer Acceptability Test

One hundred and twenty Korean consumers (Sunchon, Korea), 239 Thai consumers (Bangkok, Thailand), and 100 US consumers (Manhattan, KS, USA) participated in the acceptability tests. The Korean and US consumers visited the test location twice and evaluated six samples each day following a Latin square design for the serving order. The Thai consumers visited the test location once and evaluated six samples based on a balanced incomplete block design. Thus, each green tea sample was evaluated by 100-120 consumers in each country. Approximately 45 mL of brewed green tea was poured into 120 mL Styrofoam cups (James River Corp., Dixie Products, Easton, NJ, USA). All of the samples were prepared at the time of testing so they would be fresh. The green tea samples were served at 60℃±2℃ labeled with random 3-digit numbers. The consumers rated each tea for overall liking and liking of flavor strength, using a 9-point box scale anchored from dislike extremely to like extremely. The consumers also rated the flavor intensity and bitter intensity using a 9-point intensity scale anchored from none to extreme. The consumers were encouraged to write comments about their likes and/or dislikes for each sample to aid in the researcher's better understanding of their liking scores. The Korean consumers used crackers (Charm Cracker, Crown Confectionery, Seoul, Korea) and bottled water (Jeju Samdasu, NongShim, Korea) to refresh their palates between samples. The Thai consumers used crackers (Plain Crackers, Meiji, Singapore) and bottled water (Nestlé® Pure Life®, Thailand) to cleanse their palates. The US consumers ate unsalted-top crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon filtered water as palate cleansers between the green tea samples.

Descriptive Sensory Analysis

Six highly trained descriptive panelists from the Sensory Analysis Center at Kansas State University (Manhattan, KS, USA) participated in this study. The panelists had completed 120 hours of general training and had a minimum of 1000 hours of general sensory testing including beverages, vegetables, and other food products with descriptors similar to those that might be found in green tea. This panel had participated in the development of the green tea lexicon (Lee and Chambers 2007) and had evaluated more than 100 green tea samples. As they were already familiar with the lexicon, only a 3hr orientation was needed. Other researchers have used similar panels and testing procedures for other products such as UHT milk (Oupadissakoon and others 2009), tomatoes (Hongsoongnern and Chambers 2008), cheese (Talavera-Bianchi and Chambers 2008), and ice cream (Thompson and others 2009).

For the descriptive analysis, approximately 45 mL of brewed tea was poured into 120 mL Styrofoam cups (James River Corp., Dixie Products, Easton, PA). The green tea samples were served at 60℃. Each sample was assigned a 3-digit random code and served in a random order, one at a time. The same sample was prepared again 10 minutes later to provide a second, warm sample for the panelists to examine. The panelists tasted in 90 min sessions, spending a total of 9 hours after the orientation evaluating the green tea samples. The panelists used unsalted-top crackers (Unsalted tops premium saltine crackers, Nabisco, East Hanover, NJ, USA) and reverse osmosis, deionized, carbon-filtered water to cleanse their palates between the evaluations. The

Sensory Analysis Center uses Compusense *five* (Compusense Inc., Guelph, Ontario, Canada) for data collection.

Data Analysis

Analysis of variance was conducted using PROC GLM of the SAS® system, version 9.1 (SAS Institute Inc., Cary, NC, USA) for the consumer and descriptive data. For the consumer data, the frequency of liking rating for each green tea sample was counted and the percentages were calculated for each country so that the trend of liking for each sample could be recorded (Table 10.5). Additionally, cluster analyses were conducted within each country to determine if there were differences in the consumers' preferences for certain green teas. For the cluster analysis of the Korean and US consumers, the liking scores were used in a PROC CLUSTER procedure. For the cluster analysis of the Thai consumers, the liking scores were predicted using PROC MIXED and were used in the PROC CLUSTER procedure because each consumer did not evaluate every sample and cluster analysis cannot be conducted with missing values.

To determine the linear relationships between the descriptive and the consumer data, correlation analysis was conducted using the mean scores and PROC CORR of the SAS® system. External preference mapping was conducted in order to gain a better understanding of what flavor characteristics of the green tea samples influenced the consumers' liking.

The mean scores of the consumer clusters were regressed onto the principal components of descriptive sensory analysis data. The mean scores of each country were also included to identify the overall tendency of preference. The Unscrambler® (version 9.7, Camo Software Inc., Woodbridge, NJ, USA) program was used for the external preference mapping.

Results and Discussion

The consumers' demographic information is shown in Table 10.3 and includes gender, age, ethnicity, level of education, teas consumed more than once a week, and the consumption frequency of various teas. As expected, consumers from different countries differed in their tea consumption markedly. Almost 80% of Korean consumers answered that they drank unsweetened green tea more than once a week whereas only 31.7% of the Thai consumers and 33.0% of the US consumers drank unsweetened green tea more than once a week. In addition, the Korean consumers drank green tea more often than the Thai or US consumers when

Table 10.3 Demographic Information of Consumers Participated

	Korean Consumers (n = 114)		Thai Consumers (n = 240)		US Consumers (n = 103)	
Gender						
Female	65	57.0%	146	61.1%	66	70.2%
Male	49	43.0%	93	38.9%	28	29.8%
Age						
Under 18	1	0.8%	2	0.8%	0	0.0%
18-25	46	40.4%	120	50.2%	29	28.2%
26-35	19	16.7%	51	21.4%	16	15.5%
36-45	12	10.5%	33	13.8%	17	16.5%
46-60	30	26.3%	32	13.4%	39	37.9%
61 and older	6	5.3%	1	0.4%	2	1.9%
Ethnicity						
White, Non-Hispanic	0	0.0%	0	0.0%	85	83.4%
Hispanic or Latino	0	0.0%	0	0.0%	5	4.9%
African American	0	0.0%	0	0.0%	6	5.9%
Asian or Pacific Islander	114	100.0%	240	100.0%	3	2.9%
American Indian	0	0.0%	0	0.0%	0	0.0%
Multiple from previous categories	0	0.0%	0	0.0%	3	2.9%
Other	0	0.0%	0	0.0%	0	0.0%
Education						
Some high school or less	15	13.2%	65	27.2%	0	0.0%
High school graduated or GED	15	13.2%	6	2.5%	15	14.6%
Completed some college courses, associated degree (2-year), or technical school	43	37.7%	27	11.3%	38	36.9%
College graduate (bachelor degree)	23	20.2%	123	51.5%	31	30.1%
Post-graduate degree	18	15.7%	18	7.5%	19	18.4%
Beverages drink more than once a week						
Black tea, unsweetened	9	7.9%	20	8.3%	28	27.2%
Black tea, sweetened	7	6.1%	56	23.3%	24	23.3%
Green tea, unsweetened	89	78.1%	76	31.7%	34	33.0%
Green tea, sweetened	9	7.9%	87	36.3%	25	24.3%
Mulberry tea, unsweetened	13	11.4%	33	13.8%	4	3.9%
Mulberry tea, sweetened	0	0.0%	15	6.3%	3	2.9%
Iced Tea, unsweetened	5	4.4%	43	17.9%	41	39.8%
Iced tea, sweetened	32	28.1%	105	43.8%	32	31.1%
Bottled tea, unsweetened	18	15.8%	56	23.3%	19	18.4%
Bottled tea, sweetened	25	21.9%	71	29.6%	13	12.6%

Ice/Hot regular tea consumption frequency						
Never	29	25.9%	0	0.0%	0	0.0%
Once a month or less	46	41.1%	23	9.6%	11	10.7%
2-4 times a month	15	13.4%	90	37.7%	15	14.6%
1-5 times a week	16	14.3%	109	45.6%	58	56.3%
More than 5 times a week	6	5.4%	17	7.1%	19	18.4%
Iced/Hot green tea consumption frequency						
Never	2	1.8%	9	3.8%	12	11.7%
Once a month or less	8	7.1%	36	15.2%	26	25.2%
2-4 times a month	25	22.1%	94	39.6%	21	20.4%
1-5 times a week	44	38.9%	90	38.0%	33	32.0%
More than 5 times a week	34	30.1%	8	3.4%	11	10.7%
Iced/Hot mulberry tea consumption frequency						
Never	60	54.1%	91	38.1%	82	79.6%
Once a month or less	27	24.3%	73	30.5%	12	11.6%
2-4 times a month	10	9.0%	43	18.00%	5	4.9%
1-5 times a week	9	8.1%	19	8.0%	4	3.9%
More than 5 times a week	5	4.5%	13	5.4%	0	0.0%

questioned about their consumption frequency of green tea in detail. Less than 30% of the Korean consumers drank the other beverages listed (black tea, mulberry tea, iced tea, sweetened green tea, and bottled tea, both unsweetened and sweetened) more than once a week.

The Thai and the US consumers differed in their beverage selections. Thai consumers drank sweetened iced teas (43.8%), sweetened green teas (36.3%), unsweetened green teas (31.7%), and sweetened bottled teas (29.6%) while the US consumers drank unsweetened iced teas (39.8%), unsweetened green teas (33.0%), and sweetened iced teas (31.1%) more than once a week.

Overall Consumer Acceptability of Green Tea Samples

The consumers' ratings on overall liking, liking of flavor strength, strength of flavor, and strength of bitterness are shown on Table 10.4. Not surprisingly, consumers from different countries liked different samples. The Korean consumers liked *Ouksujin, Sejac, Sencha 1,* and *Sencha 2* the most, all of which had green, spinach, brown, seaweed, straw-like, bitter, astringent, and toothetch flavors. Also, all of those samples were produced either in Korea or Japan. Although the green tea samples were served with 3-digit random number and the consumers

Table 10.4 Consumers' Average Rating of Tea Samples

Consumers	*Chinese*	*Gunpowder*	*Gyokuro*	*Irish*	*Lipton*	*Mulberry*	*Ouksujin*	*Sejac*	*Sencha 1*	*Sencha 2*	*Tanzania*	*White*	LSD[1]
***Overall Liking*[2]**													
Korean	3.97f	4.55de	4.47e	4.90cde	4.82cde	5.03cd	6.32a	6.20a	6.03ab	6.22a	5.09c	5.59b	0.48
Thai	4.38h	5.65abcde	5.00g	5.59bcdef	5.68abcd	5.41cdefg	5.12fg	5.24defg	5.13efg	5.97ab	5.88abc	6.12a	0.52
US	4.28cd	4.78bc	3.96d	5.33ab	5.69a	5.80a	4.69c	4.48cd	4.24cd	4.48cd	4.80bc	5.90a	0.58
***Liking of Flavor Intensity*[2]**													
Korean	3.97e	4.34de	4.65cd	4.88c	5.01bc	4.84c	6.02a	5.91a	5.93a	6.02a	5.01bc	5.41b	0.48
Thai	4.97	5.62abc	5.02de	5.82ab	5.90ab	5.49bcd	4.90e	4.81e	5.19cde	6.11a	5.90ab	6.04a	0.52
US	4.42de	5.03bc	4.32e	5.59ab	5.65a	6.13a	5.03bc	4.72cde	4.52cde	4.51cde	4.97cd	5.72a	0.57
***Flavor Intensity*[3]**													
Korean	6.75a	5.37cde	6.46a	5.88b	5.62bc	5.79b	5.11ef	4.97ef	5.51bcd	5.19def	5.62bc	4.93f	0.39
Thai	6.66a	5.45e	6.05bcd	6.36ab	5.70cde	6.38ab	4.82f	4.53f	4.92f	5.64de	6.14bc	4.81f	0.45
US	6.37a	4.94de	5.76b	5.53bc	4.95de	5.27cd	4.63ef	4.39f	5.20cd	5.25cd	4.44f	4.21f	0.46
***Bitter Intensity*[3]**													
Korean	6.90a	4.03cd	6.54a	5.57b	5.64b	3.26fg	3.69def	3.43efg	3.86de	4.35c	5.37b	3.01g	0.46
Thai	6.65a	3.84d	5.50b	5.73b	4.50c	3.52de	3.33ef	3.04fg	3.44def	4.40c	5.28b	2.76g	0.47
US	5.58a	3.58fg	5.51a	4.67bc	3.88def	3.22gh	3.60efg	3.57fg	4.16cde	4.84b	4.42bcd	2.93h	0.58

[1]LSD: Least significant difference at α=0.05.
[2]Scale: 9=like extremely, 1=dislike extremely.
[3]Scale: 9=extreme intensity, 1=none.
[a-h]Means followed by different letters are significantly different (α=0.05).

were not informed about the countries of origin of the samples, many of the Korean consumers commented that they were familiar with the flavor of these green tea samples. Korean and Japanese green teas are commonly sold in Korea.

The Thai consumers were the least discriminating among the three consumer groups. For example, they liked 5 tea of the samples and the liking scores of the most liked sample and the least liked sample differed only by 1.74 points on 9-point scale, whereas the Korean and US consumers' differed by 2.35 and 1.94, respectively. The Thai consumers liked the *Gunpowder*, *Lipton*, *Sencha 2*, *Tanzania*, and *White* samples most. Among these, the *White* sample was rated the highest in overall liking, although it was not significantly higher than the other four samples. The flavor characteristics of these 5 samples as determined by the descriptive sensory analysis varied (Table 10.5), making it hard to determine the green tea flavor characteristics that Thai consumers accept. The *Gunpowder*, *Lipton*, *Tanzania*, and *White* samples had no or low green flavors and slightly higher brown flavors. Characterizing flavor notes for these teas included ashy/sooty and musty/new leather for the *Gunpowder* sample, ashy/sooty, and nutty for the *Lipton* sample, ashy/sooty, fruity, tobacco, and sweet aromatics for the *Tanzania* sample, and brown spice, fruity, tobacco, sweet aromatics, and honey for the *White* sample. The *Sencha 2* sample had green flavors, with green beans and spinach as the characterizing green flavors, brown, ashy/sooty, and seaweed flavors. Bitterness ratings were low to moderate for these samples.

Overall, the US consumers liked the *Irish*, *Lipton*, *Mulberry*, and *White* samples in this study. Of those four samples, the *Irish* and the *Lipton* samples had similar flavor characteristics such as green, green beans, brown, ashy/sooty, musty/new leather, nutty, straw-like, tobacco, bitter, astringent, and toothetch (Table 10.5). The *Mulberry* sample had green flavors, including green beans and spinach, at higher intensities than the other samples liked most by the US consumers. Burnt/scorched, fruity, grain, and berry flavors were characteristics of these four samples that differed from most of the samples in the current study. The *White* sample had brown, brown spice, fruity, tobacco, sweet aromatics, and honey flavors in addition to the characteristics that all the green tea samples had: bitter, astringent, and toothetch.

The Korean and Thai consumers slightly disliked the *Chinese* sample, which was characterized with moderate brown, low musty/new leather, and moderate bitterness. The intensities of these attributes were the highest among tea samples in this study. The US

Table 10.5 Analysis of Variance for Sensory Attribute of Tea Samples[1]

Attribute	*Chinese*	*Gunpowder*	*Gyokuro*	*Irish*	*Lipton*	*Mulberry*	*Ouksujin*	*Sejac*	*Sencha 1*	*Sencha 2*	*Tanzania*	*White*	*LSD[2]*
Green	0.00f	0.00f	4.92a	0.53e	0.83e	4.53b	3.31d	2.97d	3.69c	3.08d	0.78e	0.00f	0.36
Celery	0.00b	0.00b	0.53a	0.00b	0.00b	0.78a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.26
Green beans	0.00e	0.00e	0.89bc	0.50d	0.63cd	1.78a	0.86bc	0.00e	1.00b	0.77bcd	0.00e	0.00e	0.31
Parsley	0.00c	0.00c	0.97a	0.00c	0.00c	0.00c	0.00c	0.00c	0.64b	0.00c	0.00c	0.00c	0.24
Spinach	0.00c	0.00c	2.69a	0.00c	0.00c	1.81b	1.83b	1.97b	2.47a	1.73b	0.00c	0.00c	0.34
Brown	5.97a	4.81b	1.72e	4.50b	3.44c	2.19d	0.97g	0.67g	1.08fg	1.52ef	3.33c	3.28c	0.45
Ashy/sooty	2.14b	2.90a	1.03c	2.14b	1.24c	0.00e	0.00e	0.00e	0.00e	0.58d	1.03c	0.00e	0.42
Brown spice	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.61b	1.08a	0.22
Burnt/scorched	1.11a	0.00b	0.94a	0.00b	0.00b	0.83a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.36
Fruity	0.00c	0.00c	0.00c	0.00c	0.00c	1.92b	0.00c	0.00c	0.00c	0.00c	1.58b	2.44a	0.34
Grain	0.97a	0.00c	0.69ab	0.58b	0.00c	0.53b	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.32
Musty/new leather	3.09a	1.40b	1.06bc	0.86c	0.73c	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.42
Nutty	1.39ab	0.00d	1.03c	1.56a	1.04bc	0.92c	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.35
Seaweed	0.00d	0.00d	2.00a	0.00d	0.00d	0.00d	1.75ab	1.67bc	1.36c	1.69ab	0.00d	0.00d	0.32
Straw-like	1.67abc	1.56bcd	1.72ab	1.94a	1.63bc	1.61bc	1.25ef	1.00f	1.28def	1.56bcd	1.39cde	1.28def	0.30
Tobacco	3.31a	2.38b	0.00e	1.86c	1.48cd	0.00e	0.00e	0.00e	0.00e	0.00e	1.47cd	1.11d	0.42
Bitter	7.19a	5.96c	7.14ab	6.72b	5.56cd	4.75fg	4.28h	4.36gh	4.86ef	5.29de	5.50cd	3.29i	0.46
Astringent	2.64a	2.10cd	2.39abc	2.53ab	2.31bc	1.50fg	1.42gh	1.72ef	1.75ef	1.81de	2.11c	1.17h	0.30
Toothetch	2.17b	1.85bcd	2.03bc	2.56a	1.96bc	1.28f	1.31f	1.42ef	1.58def	1.71cde	1.97bc	0.92g	0.32
Sweet aromatics	0.72de	0.50ef	0.00g	0.81d	0.00g	1.72b	0.00g	0.50ef	0.00g	0.00g	1.11c	2.17a	0.29
Honey	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	1.44a	0.17
Berry	0.00b	0.00b	0.00b	0.00b	0.00b	1.08a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.19

[1]Scale: 15=extreme, 0=none, 0.5 increment

[2]LSD: Least significant difference at α=0.05

[a-i]Means followed by different letters are significantly different

consumers slightly disliked the *Gyokuro* sample, which had moderate bitterness but green, spinach, and seaweed at the highest intensities among the 12 samples. The Korean and the US consumers both rated the *Chinese* and the *Gyokuro* samples as having the highest bitterness (Table 10.4). This is in agreement with the descriptive sensory results (Table 10.5). The Thai consumers rated only the *Chinese* sample as having the highest bitterness. We expected the bitterness perceived by consumers to affect the acceptability negatively, but the relationship between overall liking and the strength of bitterness perceived by consumers was weak, with negative correlations for the Korean and US consumers (r=-0.38, r=-0.46, respectively) and no correlation for the Thai consumers (r=-0.09). As stated, it was difficult to determine which flavor characteristics affected overall consumers' acceptability.

Segmentation of Consumers Based on Their Acceptability Ratings of Green Tea Samples

Segmentation of the consumers using cluster analyses were conducted to help better determine which flavor characteristics positively affected smaller groups of consumers from each country.

Based on patterns of liking for the tea samples, the Korean consumers were divided into eight clusters and the US consumers were split into eight clusters (Table 10.6). The Thai consumers remained as one cluster. The correlation analysis results also were considered in finding flavor characteristics that seem influencing the consumers' acceptability of green tea.

Of the eight clusters of Korean consumers, K1 (n=17) consisted of mostly female consumers who drank green tea one to five times a week or more (Table 10.3). Most Korean consumers in K1 answered that they drank regular black tea but less frequently than they drank green tea. The Korean consumers in K1 liked more than half of the green tea samples in the test. They liked the *White* sample the most, followed by the *Ouksujin* and the *Sejac* samples (Korean green teas), the *Tanzania* sample, the *Irish* sample, the *Sencha 1* and *Sencha 2* (Japanese samples), and the *Lipton* sample. The flavor characteristics of these seven green tea samples varied, however, they were all lacking burnt/scorched and grain flavors.

Approximately half of the Korean consumers in K2 (n=26) were male and approximately half were female. More than 75% of consumers in K2 consume green tea more than once a week

Table 10.6 Mean Overall Acceptability of Green Tea of Consumer Clusters[1]

Cluster	n	*Chinese*	*Gunpowder*	*Gyokuro*	*Irish*	*Lipton*	*Mulberry*	*Ouksujin*	*Sejac*	*Sencha 1*	*Sencha 2*	*Tanzania*	*White*	*LSD*
Korean Consumers														
K1	17	4.59e	5.71cd	5.24de	6.41abc	6.18bc	5.82cd	6.88ab	6.94ab	6.35abc	6.29abc	6.53abc	7.18a	0.92
K2	26	3.04c	4.69ab	4.12b	4.31b	4.76ab	4.42b	4.90ab	4.39b	4.12b	5.58a	5.35a	4.88ab	0.90
K3	14	3.86cde	2.86e	2.86e	4.86bc	4.43bc	4.29bcd	7.43a	7.71a	6.64a	5.29b	3.21de	4.79bc	1.13
K4	23	4.40cd	4.50bcd	6.78a	4.77bcd	5.27b	5.26bc	7.18a	6.90a	6.96a	6.78a	5.13bc	3.96d	0.85
K5	11	3.36ef	2.36f	2.91f	4.82bcde	4.91bcd	6.09abc	4.73cde	4.45de	6.27ab	6.73a	5.00bcd	7.45a	1.48
K6	9	6.67a	4.67bcd	2.33e	6.89a	3.56de	5.89abc	6.11ab	5.89abc	4.33cd	5.89abc	3.22de	5.56abc	1.65
K7	13	2.23h	5.85cd	4.38efg	3.31gh	3.92fg	4.92def	6.92abc	8.00a	7.69ab	6.92abc	5.69cde	6.46bc	1.37
K8	3	7.67ab	7.00abc	5.33bcd	4.00cde	3.67de	1.33e	8.00ab	5.00bcd	8.00ab	7.33ab	6.33abcd	8.67a	3.29
K Total	120	3.97f	4.55de	4.47e	4.90cde	4.82cde	5.03cd	6.32a	6.20a	6.03ab	6.22a	5.09c	5.59b	0.48
Thai Consumers														
T Total	239	4.38h	5.65abcde	5.00g	5.59bcdef	5.68abcd	5.41cdefg	5.12fg	5.24defg	5.13efg	5.97ab	5.88abc	6.12a	0.52
US Consumers														
US1	21	5.94abc	5.04cdef	5.47abcd	5.33bcde	6.11ab	6.44a	4.46efg	4.31fg	3.86g	4.44efg	4.56defg	5.36bcde	0.97
US2	14	5.06bcd	5.18abc	2.78e	6.14a	6.07ab	5.47abc	2.69e	2.86e	2.78e	4.09d	5.31abc	5.04cd	1.01
US3	12	2.69f	5.03bc	4.07cde	3.53def	5.70b	4.75bc	4.04cde	4.53bcd	4.94bc	4.40cd	3.20ef	6.99a	1.19
US4	13	3.91def	4.50cde	2.69g	6.23a	3.72efg	6.05ab	5.05bc	5.04bc	3.07fg	4.91cd	4.03cdef	6.36a	1.06
US5	20	4.71d	6.33ab	4.65d	5.52bcd	6.82a	6.18abc	6.57a	5.25cd	6.20abc	4.69d	6.21abc	7.03a	1.03
US6	10	2.23d	2.10d	2.40cd	2.73cd	4.77ab	5.58a	3.17cd	3.15cd	2.92cd	2.84cd	3.76bc	4.79ab	1.51
US7	7	3.71ef	2.57f	3.71ef	7.71a	7.00ab	4.14def	5.86abcd	6.29abc	4.43cdef	5.00cde	7.29ab	5.71bcd	1.94
US8	3	2.67c	5.00abc	5.33abc	5.33abc	2.00c	6.67ab	6.67ab	7.00ab	7.00ab	7.67a	2.00c	4.00bc	3.46
US Total	100	4.28cd	4.78bc	3.96d	5.33ab	5.69a	5.80a	4.69c	4.48cd	4.24cd	4.48cd	4.80bc	5.90a	0.58

However, they were either neutral or slightly disliked all the samples, disliking the *Chinese* sample the most (Table 10.6) probably because of musty/new leather note.

Around 60% of the consumers in K3 (n=14) drank green tea more than once a week. They liked the green teas with green vegetative flavors accompanied with seaweed, straw-like, bitter, astringent, and toothetch, which were the *Ouksujin, Sejac, Sencha 1*samples. The consumers in K3 were neutral to *Sencha 2* sample and disliked the rest of the samples.

More than 80% of the Korean consumers in K4 (n=23) drank green tea more than once a week. These consumers liked the *Gyokuro, Ouksujin, Sejac, Sencha 1*, and *Sencha 2* samples, all of which were either from Korea or Japan. Those green tea samples share green (with spinach as the characterizing green flavor), brown, seaweed, straw-like, bitter, astringent, and toothetch. The Gyokuro had the strongest green flavors and had one of the highest bitter intensities among the samples evaluated.

Around 50% of the consumers in K5 (n=11) consumed green tea regularly and they liked the *White* sample the most, followed by the *Sencha 1*, *Sencha 2*, and *Mulberry* samples, although the differences of the acceptability ratings were not significant. The *White* sample was quite different from the other three liked samples, having brown spice, fruity, tobacco, sweet aromatics, and honey attributes. The *Sencha 1* and *Sencha 2* samples had green, green beans, spinach, brown, seaweed, and straw-like flavors. The *Mulberry* sample had some similar flavor characteristics to both the *White* and the *Sencha* samples and also had green flavors, brown, fruity, nutty, straw-like, sweet aromatics, and berry.

More than 75% of the consumers in K6 (n=9) drank green tea more than once a week. The ratings of seven samples, which were the *Chinese, Irish, Mulberry, Ouksujin, Sejac, Sencha 2*, and *White* samples, were liked. Among the seven samples, the *Irish* and the *Chinese* samples had the highest acceptability ratings but they were not significantly higher than the others. This may be because of small number of consumers in this cluster. The flavor characteristics of those seven samples varied. Both the *Irish* and the *Chinese* samples had brown, ashy/sooty, grain, musty/new leather, nutty, straw-like, tobacco, and sweet aromatics. The *Ouksujin, Sejac*, and *Sencha 2* samples had green vegetative flavors. The *White* sample had brown, brown spice, fruity, tobacco, and honey flavors. The *Mulberry* sample had both green and brown related flavors and a berry flavor. The Korean consumers in K5 and K6 were quite different in their liking compared to the rest of the Korean consumers.

All of the consumers in K7 (n=13) drank green tea more than once a week and about 40% drank it more than five times a week. The consumers in K7 were similar to K3 in their liking of green tea because the Korean consumers in both groups liked the *Ouksujin, Sejac, Sencha 1,* and *Sencha 2* samples the most, which all had green, spinach, brown, seaweed, and straw-like flavors. However, the consumers in K7 also accepted the *White* sample with brown, fruity, tobacco, sweet aromatics, and honey flavors.

K8 was very small and had only three consumers who drank green tea two to four times a month. They liked the *White*, *Ouksujin*, *Sencha 1*, *Chinese*, *Sencha 2*, and *Gunpowder* samples. The consumers in K8 are similar to the consumers in K3 except for their acceptance for the *Gunpowder* sample. The *Gunpowder* sample had brown, ashy/sooty, musty/new leather, straw-like, and tobacco flavors and was accepted only by these three consumers in K8.

The cluster analysis of the Korean consumers' acceptability ratings of 12 green tea samples showed that, in addition to the samples liked the most overall (the *Ouksujin, Sejac*, *Sencha 1*, and *Sencha 2*), some Korean consumers moderately liked the *White* or the *Gyokuro* samples, 25% and 19%, respectively.

Initially, 6 clusters were found in Thai consumers data. However, the differences among the clusters were entirely related to how the consumers used the scale, for example using higher scores or lower scores. All of the green tea samples had the same rank order for all of the clusters. Therefore, we did not divide the Thai consumers into clusters. In the Thai consumers' rating distribution of the 12 tea samples it appears that the *Sencha 2* and the *White* samples, which had the highest liking scores, were liked by more than 60% of consumers to some degree. Other accepted samples (the *Irish, Lipton,* and *Tanzania*) also had more than 50% of the consumers who rated the samples positively. More than 30% of the Thai consumers liked the least liked *Chinese* sample. Furthermore, 20% to over 45% of the Thai consumers gave a liking score of seven or higher to all of the green tea samples indicating that all the green tea samples in the current study will meet certain groups of Thai consumers' palates.

The US consumers in US1 (n=21) rarely consumed green tea but they drank black tea more often. Around 20% drank green tea more than once a week. The consumers in US1 slightly liked the *Mulberry, Lipton,* and *Chinese* samples. Although the flavor characteristics of these three samples were different, they had a nutty flavor in common.

About 35% of the US consumers in US2 (n=14) consumed green tea more than once a week. In response to the frequency questions, the consumers in this cluster replied that they drank black tea and green tea at similar frequencies, the most common answer being 'consume one to five times a week.' The consumers in US2 liked the *Irish* and the *Lipton* samples, which have green, green beans, brown, ashy/sooty, musty/new leather, nutty, and straw-like flavors in common. They disliked the seaweed and spinach flavors commonly found in the *Ouksujin*, *Sejac, Gyokuro,* and *Sencha 1* samples, flavors that the Korean consumers tended to like.

US3 (n=12) was composed of the US consumers who consume more black teas than green teas. The consumers in US3 moderately liked the *White* sample and slightly liked the *Lipton* sample. Both the *White* and *Lipton* samples have brown, straw-like, and tobacco flavors in common.

The Consumers in US4 (n=13) drank black tea one to five times a week but only 15% drank green tea more than once a week. The US4 consumers slightly liked the *White, Irish,* and *Mulberry* samples. The only common flavor characteristics included brown, straw-like, and sweet aromatics.

Half of the consumers in US5 (n=20) drank green tea more than once a week. They moderately liked the *White* and *Lipton* samples and slightly liked the *Ouksujin, Sencha 1, Tanzania*, *Gunpowder*, and *Mulberry* samples, which have different flavor profiles. Thus, it is hard to find which flavor characteristics affected the consumers of US5's flavor acceptability of green tea.

Only 20% of the consumers in US6 (n=10) drank green tea more than once a week. Also, 20% of the consumers in US6 regularly consumed *Mulberry* tea. The consumers in this cluster only liked the *Mulberry* sample and disliked all of the other samples. The fruity flavor along with the berry flavor may be responsible for the preference.

Five of the consumers in US 7 (n=7) drank green tea more than once a week. The consumers moderately liked the *Irish, Lipton,* and *Tanzania* samples. The common flavor characteristics for these three green tea samples included green, brown, ashy/sooty, straw-like, and tobacco.

US8 (n=3) was composed of only three US consumers who all consumed green tea more than once a week. They slightly liked the *Mulberry*, *Ouksujin*, *Sejac*, *Sencha 1*, and *Sencha 2* samples.

Relationship between Descriptive Sensory Analysis and Consumer Acceptability

The external preference map is shown in Figure 10.1. With the first two principal components, 84% of descriptive data explained 41% of consumers' acceptability ratings. Although the rate of explanation is low, the map conveys what we found from the cluster analysis, the lack of specific characteristics that drove consumer liking across all groups.

The Korean consumers group was generally located in the second quadrant near the green tea samples with green vegetative and seaweed flavors. However, some Korean consumers also liked the *White, Irish,* or *Lipton* samples, which had sweet aromatics, honey, fruity, or brown flavors.

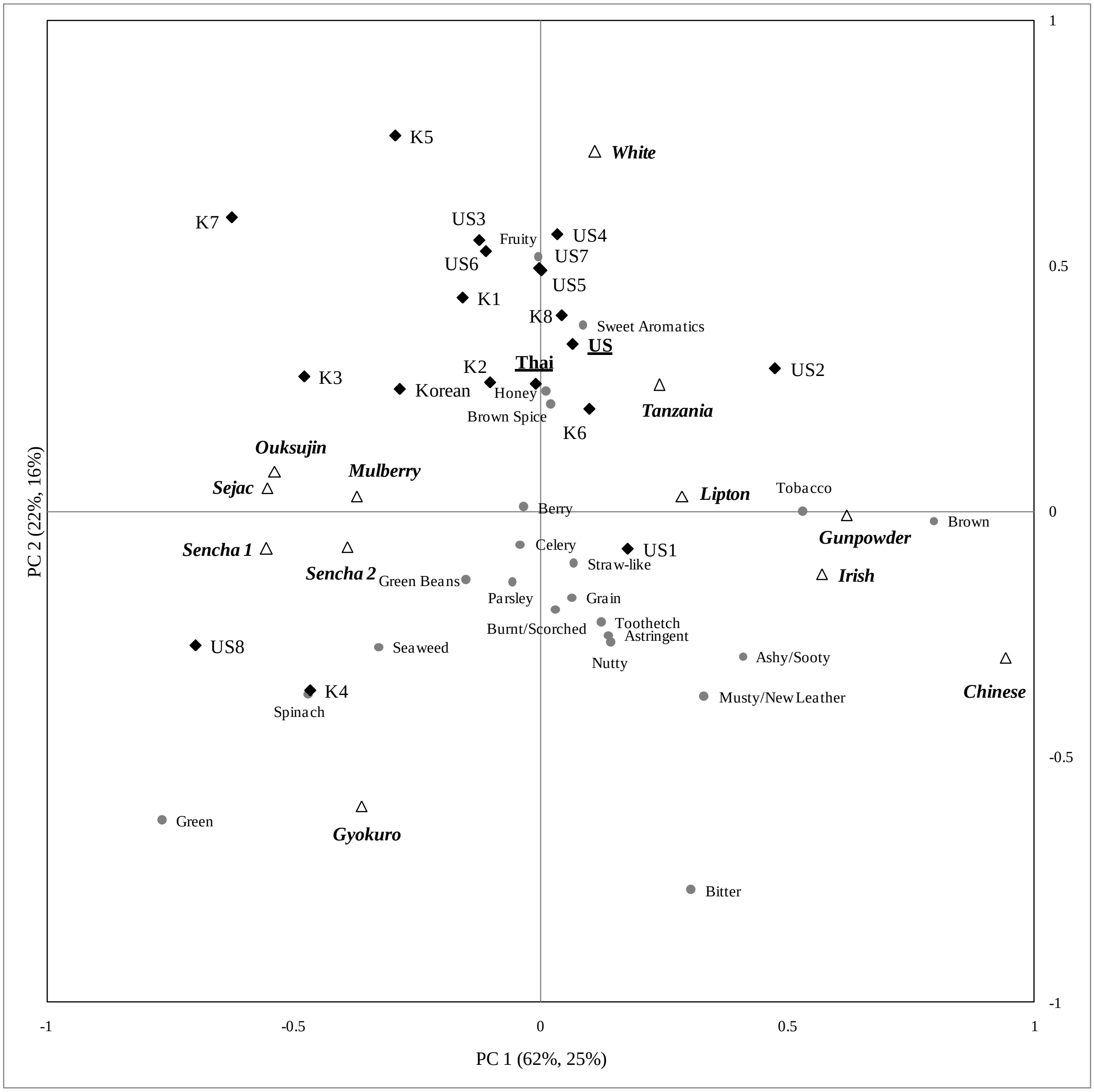
The Thai consumers were located in the middle of the green tea samples. Generally they liked many of the samples, but Thai consumers did not like green teas that include burnt/scorched and musty/new leather.

Five of the eight US clusters were located near the *White* sample, which was more naturally fruity, had sweet aromatics, and no green flavors. That is in contrast to the Korean consumers who liked the samples with green flavors most. Even though these five clusters (US3, US4, US5, US6, and US7) are almost overlapping on the map, they do differ in their liking of other green tea samples. US consumers who belong to the US2 cluster disliked seaweed and spinach flavors. On the other hand, a few of the US consumers (cluster US8) liked green and spinach flavors.

Overall, consumers from different countries generally liked different green tea samples bearing different flavor profiles. Overall, the green teas they liked most, tended to have flavors similar to those of other teas they are familiar with. However, within the groups of consumers from Korea and the United States it appears there are segments of consumers with preferences for different flavors in their green teas.

The acceptability ratings from the Thai consumers did not vary enough to determine their differences in liking of flavors in green teas for various consumer clusters, only finding a dislike for burnt/scorched and musty/new leather flavors. Perhaps this is because of how the Thai consumers characteristically rate their samples. In a study on mango gel snack optimization, Thai consumers' overall liking ratings for 15 samples varied only by 1 point on 9-point category scale (Ekpong and others 2006). In our study, the difference between the lowest and the highest liking scores was 1.74 on 9-point box scale.

Figure 10.1 External Preference Mapping of 12 Green Tea Samples Evaluated by Descriptive Sensory Panel and Consumers from Three Different Countries of Korea[a], Thailand[b], and the United States[c]



[a]Mean acceptability ratings of overall Korean consumers' (Korean) and eight clusters (K1 to K8) were used for the analysis.

[b]Mean acceptability ratings of overall Thai consumers'(Thai) was used for the analysis.

[c]Mean acceptability ratings of overall US consumers' (US) and eight clusters (US1 to US8) were used for the analysis.

Consumers' explanations for why they liked or disliked the green tea samples

Generally, the consumers were more detailed in explaining their reasons for disliking than their reasons for liking the green tea samples.

The Korean consumers used similar terms repeatedly to explain their opinions. It was obvious that the Korean consumers wanted some degree of bitterness from the green teas and, in some cases, it almost appeared as if many Korean consumers considered bitterness as separate from flavor when evaluating green tea. Both 'too bitter' and 'not too bitter' were reasons for disliking. When evaluating a sample with the lowest bitterness, the Korean consumers responded 'atypical green tea' because of low bitterness. Cigarette odor, burnt/scorched flavors, medicinal flavors, and aftertaste also were listed as reasons for disliking specific teas. A few times, fermented, floral, black-tea like flavors, and lacking typical green tea flavors were noted for reasons to dislike a tea. The Korean consumers also were influenced by the color of the liquor, feeling rejection when a brown colored tea was presented and expecting strong flavor from a darker green colored tea sample. For the Korean consumers, descriptions such as 'distinct' or 'different' often were associated with disliking, whereas 'familiar,' 'similar to what I normally consume,' or 'typical green tea flavor' were noted as reasons for liking.

In their comments, the Thai consumers were similar to the Korean consumers, except they did not use comments related to familiarity very often. As with the Korean consumers, the Thai consumers used cigarette odor or burnt smell as descriptions for disliking. In addition, 'too bitter,' 'unpleasant flavor,' 'seaweed flavors,' and 'too weak flavors (tasteless)' were listed as reason for dislike by the Thai consumers. In contrast to Koreans, the Thai consumers liked the 'mild flavor' and slight bitterness of the green tea samples.

The US consumers often used ashy, cigarette, smoky, tobacco, green/grassy, spinach flavor, fishy/seaweed-like aroma, odd odor, bad aftertaste, bitterness, or drying mouthfeel as reasons for disliking certain green tea samples. The US consumers liked some green tea samples for their mild flavor, no aftertaste, low bitterness, and flowery or fruity flavors. In addition, when the US consumers thought the flavor of the green tea sample was similar to black tea (e.g. brown flavor notes), they liked it because they are familiar with that sensory quality. The US consumers responded differently to the dark green color of one sample. Most of the US consumers commented that the dark green color seemed fake or induced by use of an artificial food coloring, however, some consumers found the dark green color appealing.

Certainly, reviewing the consumers' comments provided a different dimension to the findings drawn from the acceptability data. It was obvious that the consumers responded to familiar tastes more positively. For example, the Korean consumers recognized green tea flavors that they were used to and liked the samples that contained those flavors. The US consumers preferred the tea samples with the flavor characteristics of black tea, with which they were familiar. Other researchers have reported similar phenomenon where familiar food product was preferred over less familiar food product (Prescott 1998) such as lamb meats from animals with different weights (Font i Furnols and others 2006). Also, children preferred a product that looked familiar to them (Søndergaard and Edelenbos 2007) and children's preference of food were related to their consumption pattern (Cook 2007).

Cultural differences influenced how certain attributes were perceived by the consumers. An example is the seaweed flavor of green tea. While it was a positive attribute for the Korean consumers, the seaweed aroma reminded the US consumers of fishy foods and negatively affected their liking of the samples. Many of the US consumers found the light yellow or green colored liquor of some of the samples unappetizing because it reminded them of urine or lake water. If green tea consumption is to be increased in countries where consumption is not common, familiarity of flavors must be considered, perhaps by focusing on green teas that consumers might find similar to other products. After repeated exposure to increase acceptance (Zajonc 1968), retailers can expand the variety of their products to more traditional green tea flavors. A few of the US consumers noted that they were getting used to the flavor of various green tea samples by the end of the evaluation.

Conclusion

The liking of certain green tea flavors differs from one country to another. Overall, consumers in a country such as Korea, where green tea consumption has a long history, like teas with green vegetative characteristics the most. The consumers in countries such as Thailand or the US, where green tea consumption is a more recent phenomenon, teas that are brown, fruity, honey-like, and do not have strong green flavors are preferred. Further investigation with cluster analysis and reviewing scoring trends identified an opportunity for the tea samples that were not liked on average. These tea samples were liked by smaller groups of consumers and, thus, couldbe launched to target certain consumer groups.

The findings of this study have particular implications for the selection of green teas for mass marketing in countries with different consumption histories.

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Appendix A - Country or Origin, Region, Retail Company, Product Name, Price, and Other Information of 138 Green Tea Sample Evaluated in Chapter 2 and 3

Green Teas from China

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Anhui Province	The Fragrant Leaf	Wild Tree Huang Shan Mao Feng	$23.66	hand picked	902
Fuding, Fujian Province	The Fragrant Leaf	Fuding Da Hao	$19.64	hand picked	691
Fujian	Adagio Teas	Choral Pi Lo Chun	$8.93	Late March/Early April, hand-picked, hand-processed	258
Fujian	Enjoying Tea	White Silver Needle (Bai Hao Yinzhen)	$11.15	White tea	941
Fujian Province	Enjoying Tea	Jasmine Dragon Pearl (Imperial Long Chu)	$11.15		756
Fujian Province	Enjoying Tea	Longevity Brow (Shou Mei)	$4.01		156
Fujian Province	Enjoying Tea	Jasmine Silver Needle	$11.15		223

Fujian Province	The Fragrant Leaf	Mountain Spirit	$11.16	Hand roasted	917
Fujian Province	The Fragrant Leaf	Drum Mountain Clouds and Mist	$25.45		188
Guangdong	Adagio Teas	Li Zi Nutcracker	$7.14		144
Guangdong	XingHua Food Co., Ltd	Gosancha			413
Hunan	Adagio Teas	Jade Halfnotes	$22.60	Hand rolled	374
Hunan	Barkingside Co.	Sencha Decaff	$6.07		103
Lu An county, Anhui province	Enjoying Tea	Emerald Petals Green Tea (Lu An Gua Pian)	$6.69		983
Mt. Meng Ding, Sichuan	Seven Cups	Meng Ding Green Bamboo	$33.00		340
Mt. Meng Ding, Sichuan	Seven Cups	Meng Ding Sweet Dew	$36.00		642
Mt. Tianmu, Zhejian	Enjoying Tea	Organic Tianmy Yunding Green Tea	$6.69		475
Mt.Huangshan, Anhui Province	Enjoying Tea	Imperial Huangshan Maofeng	$8.47		480
Mt.Taimu	Adagio Teas	White Monkey	$10.70	Hand processed	801
Shanghai	Shanghai Tiantan Int'l trading Co., Ltd.	Special Gunpowder			735
West Lake of Hangzhou, Zhejian	Enjoying Tea	Superior West Lake Dragon Well (Superior Lung	$11.15		607

province		Ching)			
Yunnan	Upton Tea Imports	Yunnan Compressed Green Tuo Cha	$6.80		288
Yunnan	Upton Tea Imports	Yunnan Green Tuo Cha			803
Zhejian	Adagio Teas	Green Mu Dan	$16.10	Tied	875
Zhejian Province	The Fragrant Leaf	Organic Putuo Buddist Tea	$14.29		990
Zhejian Province	The Fragrant Leaf	Emerald Mist	$12.72	Harvested in early spring, oven-baked	267
Zhejian	Adagio Teas	Green Anji	$10.71		205
Zhejiang	Enjoying Tea	Wild Bitter Tea (Tianshan Lushui)	$6.69		179
Zhejiang Province	Culinary Teas	Lucky Dragon Hyson Tea	$3.83		342
Zhejiang Province	Seven Cups	Buddha's Eyebrow	$9.75		637
Zhejiang Province	Corporation Zhejiang tea branch	China Green Tea			128
		Kyoungsan Cha		Machine-roasted	791
		Chundohoeunchim		Machine-roasted	237
		Hwangsan Mao Feng		Machine-roasted	745
	Adagio Teas	Dragonwell	$9.00		954
	Adagio Teas	Green Pekoe	$7.14		723

	Adagio Teas	Gunpowder	$8.93	hand-rolled	849
		Chinese Green Tea			671
	Culinary Teas	Pearl Drop Morning Dew Tea	$26.81		409
	Culinary Teas	China Beauty Rings Tea	$8.43		493
	Enjoying Tea	Chun Mee Green Tea	$1.78	hand rolled, pan-fired	994
	Enjoying Tea	Mao Jian Green Tea	$5.79		672
	Enjoying Tea	White Peony (Bai Mudan)	$6.69	White	829
	Enjoying Tea	DragonWell Green Tea (Lung Ching)	$4.90		396C
	Enjoying Tea	Snow Water Green Cloud Tea	$8.47		166
	Imperial Tea Garden	Star of China	$50.00	White tea, hand tied	241

Green Teas from India

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Darjeeling	Imperial Tea Garden	Darjeeling White Tips White Tea	$50.00	White tea	934
Darjeeling	Simpson & Vail	Ambootia Green Organic Darjeeling	$11.14		341
Darjeeling	Simpson & Vail	Darjeeling Green - Arya Estate	$20.68		268
Sewpur Estate	Simpson & Vail	Assam (942)	$15.50		530

	Simpson & Vail	Nilgiri Korakunda			496
	The Fragrant Leaf	Organic Makaibari Darjeeling Silver Tips	$25.45	Second flush	119

Green Teas from Japan

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Kagoshima Prefecture	The Fragrant Leaf	Kagoshima Sencha	$26.79	First flush	509
Kumamoto Prefecture	The Fragrant Leaf	Kabuse Sencha	$33.93	Premium, shaded 2 weeks	921
Shizuoka	Adagio Teas	Hojicha Fugue	$8.93	Roasted Bancha	986
Shizuoka Prefecture	The Fragrant Leaf	Honyama Sencha	$16.07	Early spring	275
Shizuokaken	Yamama Masudaen Co. Ltd	Ara-cha			850
Uji	Harney & Sons	Tencha	$42.41		113
Uji	Japanese Green Tea Online	Kanro Gyokuro	$83.25	Highest quality Gyokuro	907
Uji district, Kyoto	Japanese Green Tea Online	Uji Gyokuro 100g	$27.00		638
Uji district, Kyoto		Premium Japanese Green Tea, TE8 Maccha			687

		Sencha			
Uji district, Kyoto		Premium Japanese Green Tea, Sencha			980
Uji district, Kyoto		Premium Japanese Green Tea, Konacha			422
Ujinotsuyu, Kyoto	Ujinotsuyuseicha Co. Ltd.	Japanese Green Tea (Sencha) Uji No Tsuyu			768
	Jeong-Gang-Cha	Jeong-Gang-Cha		Steamed	400
	Adagio Teas	Sencha Overture	$8.60	Second flush	536
	Adagio Teas	Sencha Premier	$18.60	First flush	325
	Adagio Teas	Moonlight Gyokuro			106
	Enjoying Tea	Hime Ban Cha Green Tea	$3.12		661
	Ito en	Uji Kabuse	$39.29		706
	Ito en	Iji Gyokuro	$55.36		309
	Ito en	Ureshino Tama Ryokucha	$14.29		210
	Ito en	Uji Mecha	$12.50		587
	Ito en	Okumidori Sencha	$37.50		784
	Ito en	Yame Gyokuro	$66.07		168
	Ito en	Megami Sencha	$19.64		388
	Ito en	Chiran Kanayamidori	$26.79		362
	Ito en	Kawane Sencha	$35.71		438
	Ito en	Umegashima	$21.42		718

		sencha			
	Ito en	Inakacha	$10.71		777
	Ito en	Karigane	$10.71		449
	Japanese Green Tea Online	Organic Fukamushi Cha	$17.75		404
	Japanese Green Tea online	Netto Gyokuro	$32.75		396J
	Maeda-en, Co., Ltd	Gold Hoji-cha			612
	Traditional Medicinal	Organic Bancha			417
	Upton Tea Imports	Kokei Cha	$5.12		678
	YamaMotoYama of America	Sen-Cha Green Tea			830
	YamaMotoYama of America	100% Organic Green Tea			685
	YamaMotoYama of America	Hoji-cha Roasted Green Tea			197
	YamaMotoYama of America	Roasted Green Tea			259
		Aso Premium tea		Machine-roasted	866
		Yabe-Cha		Steamed	126

Green Teas from Kenya

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Kericho district	Barkingside Co.	Kapchorua Green	$4.61		738

Kericho district	Culinary Teas	Kapchorua Kenya Green Tea	$3.66	fired green tea	311
	Upton Tea Imports	KTDA Cooperative Whole leaf green		$5.92	634

Green Teas from Korea

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Boseong	Boseong	JaksulMut			528
Bosung		Mongjunghocha			595
Hadong	HwagaeJeda	Chungmyungcha	$200.00	Hand-processed	390
Hadong	SSanggyeJeda	Okchun	$20.00	Late harvest, Roasted	196
Hadong	SsanggyeJeda	Jacsul			459
Hadong	Sunchon Nat'l Univ.	Sejac(Hadong, Mt. Jiri)			559
Hwagye, Hadong	SsanggyeJeda	Ujeon	$70.00		216
Suncheon	Snowy tea park	Jacsulcha		Third Flash, June 22. 2004	550
Suncheon	Snowy tea park	Jacsulcha		Second flash, 5/27/2004	263
Suncheon	Snowy tea park	Jacsulcha		First flash	542
Suncheon	Sunchon Nat'l Univ.	Sejac(SongGwangSa)			219
Suncheon	Tobu	Gok-u 3		Third flush	974
Suncheon	Tobu	Tobu Goku - 3		Third flush	491

Suncheon	Tobu	Tobu Superior Ujeon		Harvested earliest	905
Suncheon	Tobu	Tobu U-jeon		Second flush	765
Suncheon	Tobu	Tobu		Fourth flush	155
	AmorePacific	SullocCha Mansu		Roasted	473
	AmorePacific	Sulloc Premium Tea SeJac		2003.7.7	310
	AmorePacific	Sulloccha Soon		Roasted	692
	AmorePacific	Sulloccha Saeloktea			783
	AmorePacific	Sulloc Hallajin		Steamed, 2003.12.18	291
	AmorePacific	Sulloccha Hallajin			655
	AmorePacific	Sulloc Premium Tea SeJac	$48.00		320
	AmorePacific	Sulloccha Ouksujin	$48.00		249
	AmorePacific	Wolchulsunhyang	$217.00		680
	AmorePacific	2003 Sulloc OuksuJin		Steamed and Roasted	338
	AmorePacific	Wolchulsunhyang	$217.00		461
	AmorePacific	Illohyang			580
	AmorePacific	Wolchulsunhyang			620
	Boseong	Myoung Hyang		Late harvest, hand roasted	137
	Boseong	Jacsulcham			356

Green Teas from Sri Lanka

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Ceylon	Simpson & Vail	Ceylon Teardrop Green Tea	$3.50		418

Iddalgashinna Estate, Ceylon	Upton Tea Imports	Iddalgashinna Estate Ceylon OP1			269
	Barkingside Co.	Dumbara Curls	$8.04		563
	Imperial Tea Garden	White Tea Sri Lanka - Adams	$58.00	White tea	949

Green Teas from Taiwan

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Formosa	Simpson & Vail	Chin Cha, Taiwanese Green Tea	$12.93		658
Chi Lung	Culinary Teas	Formosa Gunpowder Tea	$3.75	Steamed	517
	Simpson & Vail	Pan Fried Green	$3.14		823
	Simpson & Vail	Chincha	$12.93		815

Green Teas from Tanzania

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Tanzania	Simpson & Vail	Tanzania Luponde Estate	$6.96		962

Green Teas from Vietnam

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number
Ha Giang Province	Thompsons	Ha Giang Green Tea			897

Green Teas – Countries of Origin Unknown

Region	Retail Company	Product Name	Price (100 g)	Other Information	Sample Number

Tanzania	Simpson & Vail	Tanzania Luponde Estate	$6.96		962
Unknown	Culinary Tea	Osmanthus Green Tea			957
Unknown	Culinary Teas	Irish Breakfast Green Tea	$7.59		522

Appendix B - SAS® Code used for Analyses in Chapter 3. A Comparison of Green Teas from around the World

Cluster Analysis – Wards Method using Raw Data

```
title ‘Chapter 3. A comparison of green teas from around the world, Cluster Analysis (Wards
Method) using raw data’;
data worldGT;
input ID $ country $ b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;
cards;
[DATA]
;
proc cluster method=ward s standard outtree=tree pseudo ccc outtree=tree;
var b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;
id ID;
run;
proc plot data=tree;
plot _ccc_*_ncl_=_ncl_/haxis=0 to 26 by 2;
run;
proc tree data=tree out=treeout nclusters=22;
copy b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;
id ID;
run;
proc sort data=treeout; by cluster;
proc print data=treeout;
id cluster;
run;
proc sort data=treeout; by id;
proc sort data=scores; by id;
```

Cluster Analysis – Wards Method using PC Scores

```
title 'Chapter 3. A comparison of green teas from around the world, Cluster Analysis (Wards Method) using PC Scores';
data worldGT;
input ID $ Country $ Prin1 Prin2 Prin3 Prin4 Prin5 Prin6 Prin7 Prin8 Prin9 Prin10 Prin11 Prin12 Prin13 Prin14;
cards;
[DATA]
;
proc cluster method=ward s standard outtree=tree pseudo ccc outtree=tree;
var Prin1 Prin2 Prin3 Prin4 Prin5 Prin6 Prin7 Prin8 Prin9 Prin10 Prin11 Prin12 Prin13 Prin14;
id ID;
run;
proc plot data=tree;
plot _ccc_*_ncl_=_ncl_/haxis=0 to 26 by 2;
run;
proc tree data=tree out=treeout nclusters=9;
copy Prin1 Prin2 Prin3 Prin4 Prin5 Prin6 Prin7 Prin8 Prin9 Prin10 Prin11 Prin12 Prin13 Prin14;
id ID;
run;
proc sort data=treeout; by cluster;
proc print data=treeout;
id cluster;
run;
proc sort data=treeout; by id;
proc sort data=scores; by id;
```

Cluster Analysis – K-Means

title ‘Chapter 3. A comparison of green teas from around the world, Cluster Analysis (K-Means)’;

data worldGT;

input ID $ country $ b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;

cards;

[DATA]

;

proc standard mean=**0** std=**1**;

var b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;

run;

proc princomp out=scrs;

var b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;

title2 'A PCA on the World of Green tea';

run;

proc plot;

plot prin2*prin1='*'/vaxis=**-4** to **4** by **2** haxis=**-4** to **4** by **2** vpos=**35** hpos=**60**;

title2 'A plot of the first two principal component scores';

run;

proc fastclus out=cluster maxclusters=**22**;

var b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;

title2 'K-Means clustering Raw data-World of green tea';

run;

proc plot;

plot prin2*prin1=cluster/vaxis=**-4** to **4** by **2** haxis=**-4** to **4** by **2** vpos=**35** hpos=**60**;

title3 'A plot of the clusters obtained';

run;

proc means uss; var distance;

title3 'Beale''s intracluster residual sum of squares';

run;

```
proc fastclus out=cluster maxclusters=22 random=2342901 drift maxiter=3;
var b c d e f g h I j k l m n o p q r s t u v w x y z aa ab ac ad ae af;
title2 'obtaining clusters with the data in a random order';
title3;
proc plot;
plot prin2*prin1=cluster/vaxis=-4 to 4 by 2 haxis=-4 to 4 by 2 vpos=35 hpos=60;
title3 'A plot of the clusters obtained - random data entry';
run;
proc means uss; var distance;
title3 'Beale''s Intracluster residual sum of squares';
run;
proc sort;
by cluster distance;
run;
proc print;
by cluster;
run;
```

Appendix C - SAS® Code used for Analyses in Chapter 5. Sensory Descriptive Evaluation: Brewing Methods Affect Flavor of Green Tea

ANOVA

```
title ‘ANOVA – Chapter 5.Sensory descriptive evaluation: Brewing methods affect flavor of
green tea';
data tea;
input Product $ Gcode $ Temperature  time  Panelist  Rep Brown  Green  Asparagus  Celery
GreenBeans  GrHerblike  Parsley  Spinach  AshySooty  BurntScorched  Citrus  Grain  Medicinal
MustyLeather  Nutty  Seaweed  Strawlike  Tobacco  Bitter  Astringent  Toothetch
SweetAromatics;
cards;
[DATA]
;
proc glm data=tea;
  class  temperature time;
  model Brown --SweetAromatics= temperature|time ;
  lsmeans temperature time temperature*time/stderr pdiff ;
title 'Interaction Temperature by Brewing Time-overall';
run;
proc sort data=tea;
by gcode;
run;
proc means data=tea;
var  Brown  Green  Asparagus  Celery  GreenBeans  GrHerblike  Parsley  Spinach  AshySooty
BurntScorched  Citrus  Grain  Medicinal  MustyLeather  Nutty  Seaweed  Strawlike  Tobacco
Bitter  Astringent  Toothetch  SweetAromatics;
by gcode;  run;
```

Canonical Analysis

```
title 'CVA using proc candisc – Chapter 5.Sensory descriptive evaluation: Brewing methods
affect flavor of green tea';
data CVA;
input Code $ Gcode $ Temperature Brewing Panelist Rep Brown Green Asparagus  Celery
GreenBeans GreenHerblike Parsley Spinach AshySooty BurntScorched  Citrus Grain Medicinal
MustyLeather Nutty Seaweed Strawlike Tobacco Bitter Astringent Toothetch SweetAromatics;
datalines;
[DATA]
;
proc candisc data=cva out=outcva anova;
class Gcode;
var Brown Green Asparagus Celery GreenBeans GreenHerblike Parsley Spinach AshySooty
BurntScorched Citrus Grain Medicinal MustyLeather Nutty Seaweed Strawlike Tobacco Bitter
Astringent Toothetch SweetAromatics;
run;
quit;
```

Appendix D - SAS® Code used for Analyses in Chapter 6. Sensory and Instrumental Flavor Changes in Green Tea Brewed Multiple Times

Repeated Measures ANOVA

```
title 'Repeated Measures ANOVA – Chapter 6. Sensory and Instrumental Flavor Chages in Green Tea Brewed Multiple Times';
data MultipleBrew;
input Panelist Product $ Brew Rep Brown Green Asparagus Beany Brussels Celery
GreenBeans GreenHerb Parsley Spinach Almond Animalic AshySooty BrownSpice Burnt
Citrus Fermented FloralPerfumy Fruity Grain Medicinal Mint MustyLeather Nutty
Seaweed Straw Sweaty Tobacco Bitter Astringent Toothetch SweetAromatics;
datalines;
[DATA]
;
run;
proc mixed;
class Panelist product brew;
model [ATTRIBUTE] = product brew product*brew/ddfm=satterth;
random Panelist(product);
repeated/type=cs sub=Panelist(product);
lsmeans product brew product*brew/pdiff;
by product;
run;
```

Principal Component Analysis

```
title ‘PCA – Chapter 6. Sensory and Instrumental Flavor Chages in Green Tea Brewed Multiple
Times';
data MultipleBrew;
input Panelist  Product $  Brew $  name $  Rep  Brown  Green  Asparagus  Beany  Brussels
Celery  GreenBeans  GreenHerb  Parsley  Spinach  Almond  Animalic  AshySooty  BrownSpice
Burnt  Citrus  Fermented  FloralPerfumy  Fruity  Grain  Medicinal  Mint  MustyLeather  Nutty
Seaweed  Straw  Sweaty  Tobacco  Bitter  Astringent  Toothetch  SweetAromatics ;
cards;
[DATA]
;
run;
proc sort;
by name;
run;
proc means;
by name;
var Brown  Green  Asparagus  Beany  Brussels  Celery  GreenBeans  GreenHerb  Parsley
Spinach  Almond  Animalic  AshySooty  BrownSpice  Burnt  Citrus  Fermented  FloralPerfumy
Fruity  Grain  Medicinal  Mint  MustyLeather  Nutty  Seaweed  Straw  Sweaty  Tobacco  Bitter
Astringent  Toothetch  SweetAromatics;
output out=means
mean = mBrown  mGreen  mAsparagus  mCelery  mGreenHerb  mParsley  mSpinach
mAshySooty  mBurnt  mTobacco  mCitrus  mFloralPerfumy  mFruity  mGrain  mMedicinal
mMustyLeather  mNutty  mSeaweed  mStraw  mBitter  mAstringent  mToothetch
mSweetAromatics;
run;
proc princomp data=means  covariance  out=pcScores;
var  mBrown  mGreen  mAsparagus  mCelery  mGreenHerb  mParsley  mSpinach  mAshySooty
mBurnt  mTobacco  mCitrus  mFloralPerfumy  mFruity  mGrain  mMedicinal
```

```
mMustyLeather mNutty mSeaweed mStraw mBitter mAstringent mToothetch
mSweetAromatics;
run;
proc print data=PcScores;
var name prin1-prin4;
run;
```

Appendix E - SAS® Code used for Analyses in Chapter 7. Flavor Characteristics of Green Tea Processed Using Steaming, Roasting, or Steam-Roasting

ANOVA

```
title 'ANOVA- Chapter 7. Flavor Characteristics of Green Tea Processed Using Steaming,
Roasting, or Steam-Roasting';
data Processing;
input Panelist  Product $  Rep  Code  Green  Asparagus  Beany  GreenBeans  Parsley  Spinach
Brown  BurntScorched  Tobacco  Grain  MustyNewLeather  Seaweed  Strawlike  Bitter
Astringent  Toothetch  SweetAromatics
;
datalines;
[DATA]
;
data Processing;
title2 'Analysis of Variance-product';
proc glm;
class  product  panelist;
model  Asparagus  Beany  GreenBeans  Parsley  Spinach  Brown  BurntScorched  Tobacco
Grain  MustyNewLeather  Seaweed  Strawlike  Bitter  Astringent  Toothetch  SweetAromatics  =
product  panelist;
means product/LSD lines;
run;
```

Appendix F - SAS® Code used for Analyses in Chapter 8. Flavors of Green Tea Change Little During Storage

Repeated Measures ANOVA

```
title 'Repeated Measures ANOVA- Chapter 8. Flavors of Green Tea Change Little During
Storage';
data Storage;
input product $  Storage $  Sample $  Amount  Panelist  Rep  Code $  Brown  Green
Asparagus  Beany  Celery  GreenBeans  GreenHerblike  Parsley  Spinach  Almond  AshySooty
BurntScorched  Citrus  FloralPerfumy  Fruity  Grain  Medicinal  Mint  MustyLeather  Nutty
Seaweed  Strawlike  Sweaty  Tobacco  Bitter  Astringent  Toothetch  SweetAromatics
;
datalines;
[DATA]
;
run;
proc mixed;
class panelist product storage;
model [ATTRIBUTE]  = product  storage  product*storage/ddfm=satterth;
random panelist(product);
repeated/type=cs sub=panelist(product);
lsmeans product storage product*storage/pdiff;
by product;
run;
```

Appendix G - SAS® Code used for Analyses in Chapter 9. Descriptive Analysis and US Consumer Acceptability of Six Green Tea Samples from China, Japan, and Korea

ANOVA – Consumer Liking Data

```
title ‘ANOVA, Consumer Liking Data - Chapter 9. Descriptive Analysis and US Consumer
Acceptability of Six Green Tea Samples from China, Japan, and Korea';
data Consumer;
input consumer  product $ Type $ Country $  OLiking  FSLiking  StrengthF  Bitter;
datalines;
[DATA]
proc glm;
class  consumer  product;
model OLiking  FSLiking  StrengthF  Bitter  =  consumer  product;
means product / lsd lines;
lsmeans product/pdiff;
run;
```

ANOVA – Descriptive Sensory Analysis Data

```
title ‘ANOVA, Descriptive Sensory Analysis Data - Chapter 9. Descriptive Analysis and US
Consumer Acceptability of Six Green Tea Samples from China, Japan, and Korea';
data Descriptive;
input Panelist  Product $  Rep  Sample  Brown  Green  Asparagus  Celery  GreenBeans
GreenHerblike  Parsley  Spinach  Animalic  AshySooty  Burnt  Seaweed  Grain
MustyLeatherNew  Mint  Strawlike  Tobacco  Bitter  Astringent  Toothetch  SweetAromatics;
datalines;
[DATA]
;
data Descriptive;
proc glm;
class rep product panelist;
model Brown  Green  Asparagus  Celery  GreenBeans  GreenHerblike  Parsley  Spinach
Animalic  AshySooty  Burnt  Seaweed  Grain  MustyLeatherNew  Mint  Strawlike  Tobacco
Bitter  Astringent  Toothetch  SweetAromatics = rep product rep*product panelist
product*panelist;
test h=product e=rep*product;
means product/lsd lines e=rep*product;
run;
```

Principal Component Analysis

```
title ‘PCA, Consumer Liking Data - Chapter 9. Descriptive Analysis and US Consumer
Acceptability of Six Green Tea Samples from China, Japan, and Korea';
data gt;
input Prod$ Brown Green Asparagus Celery GreenBeans GreenHerblike Parsley Spinach
Animalic AshySooty Burnt Seaweed MustyLeatherNew Strawlike Tobacco Bitter
Astringent Toothetch;
cards;
[DATA]
;
run;
proc princomp data=gt covariance out=pcScores;
var Brown Green Asparagus Celery GreenBeans GreenHerblike Parsley Spinach Animalic
AshySooty Burnt Seaweed MustyLeatherNew Strawlike Tobacco Bitter Astringent
Toothetch;
run;
proc print data=PcScores;
var Prod prin1-prin4;
run;
```

Correlation

```
title 'Correlation, Consumer Liking Data - Chapter 9. Descriptive Analysis and US Consumer
Acceptability of Six Green Tea Samples from China, Japan, and Korea';
data GreenTea;
input  Product $  Brown  Green  Asparagus  Celery  GreenBeans  GreenHerblike  Parsley
Spinach  Animalic  AshySooty  Burnt  Seaweed  MustyLeatherNew  Mint  Strawlike  Tobacco
Bitter  Astringent  Toothetch  Liking   LikingFS  FlavorI  BitterI;
datalines;
[DATA]
;
proc corr data=GreenTea;
var  Brown  Green  Asparagus  Celery  GreenBeans  GreenHerblike  Parsley  Spinach  Animalic
AshySooty  Burnt  Seaweed  MustyLeatherNew  Mint  Strawlike  Tobacco  Bitter  Astringent
Toothetch  Liking   LikingFS  FlavorI  BitterI;
run;
```

Appendix H - SAS® Code used for Analyses in Chapter 10. Consumer Acceptance for Green Tea by Consumers in Three Countries and its Relationship to Flavor Characteristics

ANOVA – Consumer Liking Data

```
title ‘ANOVA, Consumer Liking Data - Chapter 10. Consumer Acceptance for Green Tea by
Consumers in Three Countries and its Relationship to Flavor Characteristics';
data step1;
input Block  Consumer  Order  Product   OLiking  FSLiking  StrengthF  Bitter;
datalines;
[DATA]
;
proc glm;
class  consumer  product;
model OLiking FSLiking StrengthF Bitter  =  consumer  product;
means product / lsd lines;
lsmeans product/pdiff;
run;
proc corr ;
var OLiking FSLiking StrengthF Bitter;
run;
```

ANOVA – Descriptive Sensory Data

```
title ‘ANOVA, Descriptive Sensory Data - Chapter 10. Consumer Acceptance for Green Tea by
Consumers in Three Countries and its Relationship to Flavor Characteristics';
data Descriptive;
input Panelist  Product $  Rep  Sample  $  Green   Celery  GreenBeans   Parsley  Spinach
Brown  AshySooty  BrownSpice  BurntScorched  Fruity  Grain  MustyNewLeather  Nutty
Seaweed  Strawlike  Tobacco  Bitter  Astringent  Toothetch  SweetAromatics  Honey  Berry;
datalines;
[DATA]
;
data Descriptive;
proc glm;
class product panelist;
model  Green   Celery  GreenBeans   Parsley  Spinach   Brown  AshySooty  BrownSpice
BurntScorched  Fruity  Grain  MustyNewLeather  Nutty  Seaweed  Strawlike  Tobacco  Bitter
Astringent  Toothetch  SweetAromatics  Honey  Berry =  product  panelist ;
means product/lsd lines;
run;
```

Cluster Analysis, Wards Method - Consumer Liking Data

```
title ‘Cluster Analysis, Consumer Liking Data - Chapter 10. Consumer Acceptance for Green
Tea by Consumers in Three Countries and its Relationship to Flavor Characteristics';
data Consumer;
input ID $  Tea_a  Tea_b  Tea_c  Tea_d  Tea_e  Tea_f  Tea_g  Tea_h  Tea_i  Tea_j  Tea_k
Tea_l;
cards;
[DATA]
;
proc cluster method=ward outtree=tree pseudo ccc ;
var  Tea_a  Tea_b  Tea_c  Tea_d  Tea_e  Tea_f  Tea_g  Tea_h  Tea_i  Tea_j  Tea_k  Tea_l;
id ID;
run;
proc plot data=tree;
plot _ccc_*_ncl_=_ncl_/haxis=0 to 20 by 1;
run;
proc tree data=tree out=treeout nclusters=8;
copy  Tea_a  Tea_b  Tea_c  Tea_d  Tea_e  Tea_f  Tea_g  Tea_h  Tea_i  Tea_j  Tea_k  Tea_l;
id ID;
run;
proc sort data=treeout; by cluster;
proc print data=treeout;
id cluster;
run;
proc sort data=treeout; by id;
proc sort data=scores; by id;
run;
```

Correlation

title ‘Correlation - Chapter 10. Consumer Acceptance for Green Tea by Consumers in Three Countries and its Relationship to Flavor Characteristics';

data Consumer;

input Product $ Green Celery GreenBeans Parsley Spinach Brown Ashy BrownSpice Burnt Fruity Grain Musty Nutty Seaweed Straw Tobacco Bitter Astringent Toothetch SweetAroma Honey Berry Thai Korean K1 K2 K3 K4 K5 K6 K7 K8 US US1 US2 US3 US4 US5 US6 US7 US8;

datalines;

[DATA]

;

proc corr data=consumer;

var Green Celery GreenBeans Parsley Spinach Brown Ashy BrownSpice Burnt Fruity Grain Musty Nutty Seaweed Straw Tobacco Bitter Astringent Toothetch SweetAroma Honey Berry Thai Korean K1 K2 K3 K4 K5 K6 K7 K8 US US1 US2 US3 US4 US5 US6 US7 US8;

run;

Appendix I - Consumer Test Material in English, Korean, and Thai Used in Chapter 10

Questionnaire - English

Consumer # _____ Sample # ______

Instruction **A. You are evaluating GREEN TEA.**

Instruction **B. Please rinse your mouth with water and take a bite of the cracker between samples or as needed.**

Instruction ***C*** **. Take at least 3 sips of the GREEN TEA before answering any of the questions. Make sure that you drink the entire sample before completing the last question.**

Instruction ***D*** **. Check one box for each question to rate <u>your opinion</u> of the GREEN TEA from <u>Dislike extremely to Like extremely</u>.**

	Dislike extremely				Neither like nor dislike				Like extremely
1. How much do you like the Green Tea <u>OVERALL</u>?	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. How much do you like the <u>STRENGTH of the FLAVOR</u>?	☐	☐	☐	☐	☐	☐	☐	☐	☐

Instruction E **. Check one box to rate the <u>amount</u> you get from the GREEN TEA from <u>None to Extreme</u>.**

	None				Moderate				Extreme
3. How <u>STRONG is the Flavor</u>?	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. How <u>BITTER is the tea</u>?	☐	☐	☐	☐	☐	☐	☐	☐	☐

<u>5. Please comment on what you like or dislike about this GREEN TEA:</u>

Demographic Questionnaire - English

CONSUMER #________________

1. Are you? ☐ Female ☐ Male

2. Which age group are you in?
   ☐ Under 18 ☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-60 ☐ 61 and older

3. Which of the categories below best describes your ethnicity?
   ☐ White, Non-Hispanic ☐ Hispanic or Latino ☐ African American
   ☐ Asian or Pacific Islander ☐ American Indian ☐ Multiple from pervious categories
   ☐ Other, please describe ____.

4. Mark the highest level of education you have completed.
   ☐ some high school or less ☐ college graduate (bachelor degree)
   ☐ high school graduated or GED ☐ post-graduate degree
   ☐ completed some college courses, associated degree (2-year), or technical school

5. What kind of beverages do you usually drink more than once a week? Check all that apply.
   ☐ Black Tea, unsweetened ☐ Black Tea, sweetened
   ☐ Green Tea, unsweetened ☐ Green Tea, sweetened
   ☐ Mulberry Tea, unsweetened ☐ Mulberry Tea, sweetened
   ☐ Iced Tea, unsweetened ☐ Iced Tea, sweetened
   ☐ Bottled Tea, unsweetened ☐ Bottled Tea, sweetened

6. How often do you drink Iced/Hot regular Tea?
   ☐ Never ☐ Once a month or less ☐ 2-4 times a month
   ☐ 1 -5 times a week ☐ More than 5 times a week

7. How often do you drink Iced/Hot Green Tea?
   ☐ Never ☐ Once a month or less ☐ 2-4 times a month
   ☐ 1 -5 times a week ☐ More than 5 times a week

8. How often do you drink Iced/Hot Mulberry Tea?
   ☐ Never ☐ Once a month or less ☐ 2-4 times a month
   ☐ 1 -5 times a week ☐ More than 5 times a week

9. How interested are you in purchasing the products below for the following purposes?

General Purpose / Products (Circle an answer for each of the 8 questions)	Not at all interested		Moderately interested				Extremely interested
For increased mental or physical awareness / capacity?							
Medicine (over the counter or prescribed)	1	2	3	4	5	6	7
Vitamin/mineral supplements	1	2	3	4	5	6	7
Non-vitamin/mineral supplements and/or herbal remedies	1	2	3	4	5	6	7
Food	1	2	3	4	5	6	7
To modify your bodyweight?							
Medicine (over the counter or prescribed)	1	2	3	4	5	6	7
Vitamin/mineral supplements	1	2	3	4	5	6	7
Non-vitamin/mineral supplements and/or herbal remedies	1	2	3	4	5	6	7
Food	1	2	3	4	5	6	7
To promote good health?							
Medicine (over the counter or prescribed)	1	2	3	4	5	6	7
Vitamin/mineral supplements	1	2	3	4	5	6	7
Non-vitamin/mineral supplements and/or herbal remedies	1	2	3	4	5	6	7
Food	1	2	3	4	5	6	7

Questionnaire – Korean

소비자 번호: __________ 시료 번호: ______

지시사항 가. 평가하실 시료는 녹차입니다.

지시사항 나. 시료를 맛보시는 사이나 필요에 따라 물과 크래커로 입을 헹궈주십시오.

지시사항 다. 최소한 세모금 이상의 녹차를 맛보신 후에 아래 답을 하시고, 마지막 질문을 답하시기 전까지 시료를 다 마시셔야 합니다.

지시사항 라. 녹차에 대한 본인의 의견을 대답하실 때, 각 질문에 상자를 하나씩만 표시하여 주십시오. <u>의견은 굉장히 싫어한다 에서 굉장히 좋아한다 입니다.</u>

	굉장히 싫어한다				좋아하지도 싫어하지도 않는다.				굉장히 좋아한다.
1. 전반적으로 이 녹차시료를 얼마나 좋아하십니까?	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. 향미(맛과 냄새)의 강도는 얼마나 좋아하십니까?	☐	☐	☐	☐	☐	☐	☐	☐	☐

지시사항 마. 녹차 시료에서 나는 맛의 강도에 대한 의견을 대답하실 때, 각 질문에 상자를 하나씩만 표시하여 주십시오. <u>의견은 전혀 없음에서 강함입니다.</u>

	전혀 없음				중간 정도				강함
3. 향미(맛과 냄새)는 얼마나 강합니까?	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. 차가 얼마나 씁니까?	☐	☐	☐	☐	☐	☐	☐	☐	☐

<u>**5.** 이 녹차 시료의 좋은 점, 싫은 점을 써 주십시오.</u>

Demographic Questionnaire – Korean

소비자 번호:_______________

1. 본인의 성별은…   □ 여성   □ 남성

2. 해당하는 연령에 표시하십시오.
   □ 18 세 미만   □ 18-25 세   □ 26-35 세   □ 36-45 세   □ 46-60 세   □ 61 세 이상

3. 본인의 인종을 가장 잘 설명하는 것에 표시하십시오.
   □ 백인   □ 라틴아메리카 사람   □ 미국 흑인
   □ 동양인 또는 태평양 섬 주민   □ 미국 원주민   □ 혼혈
   □ 기타, 설명하여주십시오 ____.

4. 최종학력을 표시하여 주십시오.
   □ 고등학교 졸업 미만   □ 4 년제 대학교 졸업
   □ 고등학교 졸업 또는 검정고시 합격   □ 대학원 이상의 학력
   □ 전문대학졸업 또는 대학교 수업을 어느 정도 들었음

5. 일주일에 보통 한번 이상 마시는 음료수는 어떤 것이 있습니까? 해당하는 것은 다 표시하여 주십시오.
   □ 단맛이 가미되지 않은 홍차   □ 단맛이 가미된 홍차
   □ 단맛이 가미되지 않은 녹차   □ 단맛이 가미된 녹차
   □ 단맛이 가미되지 않은 뽕잎차   □ 단맛이 가미된 뽕잎차
   □ 단맛이 가미되지 않은 아이스티   □ 단맛이 가미된 아이스티
   □ 단맛이 가미되지 않은 유리병에 든 차   □ 단맛이 가미된 유리병에 든 차

6. 차거나 뜨거운 홍차를 얼마나 자주 마십니까?
   □ 전혀 마시지 않는다   □ 한달에 한번이나 그 이하   □ 한달에 2-4 번
   □ 일주일에 1-5 번   □ 일주일에 5 번 이상

7 차거나 뜨거운 녹차를 얼마나 자주 마십니까?
   □ 전혀 마시지 않는다   □ 한달에 한번이나 그 이하   □ 한달에 2-4 번
   □ 일주일에 1-5 번   □ 일주일에 5 번 이상

8. 차거나 뜨거운 뽕잎차를 얼마나 자주 마십니까?
   □ 전혀 마시지 않는다   □ 한달에 한번이나 그 이하   □ 한달에 2-4 번
   □ 일주일에 1-5 번   □ 일주일에 5 번 이상

9. 아래 나열된 목적을 위해 밑에 나열된 제품을 구매하는 것에 대해 얼마나 관심있으십니까?

일반적인 목적/제품 (아래 각 질문에 대답을 표시하십시오.)	전혀 관심 없다			다소 관심있다			굉장히 관심있다
심적 또는 육체적 자각/재능 향상을 위해서?							
약 (처방전이 필요없거나 필요한)	1	2	3	4	5	6	7
비타민/무기질 보충제	1	2	3	4	5	6	7
비타민/무기질 보충제가 아닌 영양제 그리고/또는 약초요법	1	2	3	4	5	6	7
음식	1	2	3	4	5	6	7
체중조절을 위해서?							
약 (처방전이 필요없거나 필요한)	1	2	3	4	5	6	7
비타민/무기질 보충제	1	2	3	4	5	6	7
비타민/무기질 보충제가 아닌 영양제 그리고/또는 약초요법	1	2	3	4	5	6	7
음식	1	2	3	4	5	6	7
건강 증진을 위해서?							
약 (처방전이 필요없거나 필요한)	1	2	3	4	5	6	7
비타민/무기질 보충제	1	2	3	4	5	6	7
비타민/무기질 보충제가 아닌 영양제 그리고/또는 약초요법	1	2	3	4	5	6	7
음식	1	2	3	4	5	6	7

Questionnaire – Thai

ผู้ทดสอบลำดับที่_____ รหัสตัวอย่าง______

คำชี้แจงที่ 1 ตัวอย่างที่ท่านทำการทดสอบคือชาเขียว

คำชี้แจงที่ 2 กรุณากลั้วปากด้วยน้ำเปล่าและรับประทานขนมปังกรอบระหว่างตัวอย่างหรือทุกครั้งที่ท่านต้องการ

คำชี้แจงที่ 3 กรุณาจิบตัวอย่างอย่างน้อยสามครั้งก่อนที่จะตอบคำถามแต่ละข้อ และดื่มตัวอย่างทั้งหมดก่อนตอบคำถามข้อสุดท้าย

คำชี้แจงที่ 4 กรุณาทำเครื่องหมาย X ลงในช่องสี่เหลี่ยมตามที่ท่านรู้สึกจาก ไม่ชอบมากที่สุด-ชอบมากที่สุด

	ไม่ชอบมากที่สุด				เฉยๆ				ชอบมากที่สุด
1. ท่านชอบผลิตภัณฑ์นี้โดยรวมมากเท่าใด	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. ท่านชอบความเข้มของกลิ่นรสมากเท่าใด	☐	☐	☐	☐	☐	☐	☐	☐	☐

คำชี้แจงที่ 5 กรุณาทำเครื่องหมาย X ลงในช่องสี่เหลี่ยมตามความรู้สึกที่ท่านได้จากตัวอย่าง

	ไม่มีเลย				ปานกลาง				มากที่สุด
3. ผลิตภัณฑ์มีความเข้มของกลิ่นรสมากเท่าใด	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. ผลิตภัณฑ์มีรสขมมากเท่าใด	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. กรุณาให้ความคิดเห็นเกี่ยวกับสิ่งที่คุณชอบหรือไม่ชอบในตัวอย่างชาเขียวนี้

____

____

Demographic Questionnaire – Thai

ผู้ทดสอบลำดับที่ ___________________

ข้อมูลผู้ทดสอบ

1. เพศ
   - ชาย
   - หญิง
2. อายุ
   - ต่ำกว่า 18 ปี
   - 18 – 25 ปี
   - 26 – 35 ปี
   - 36 – 45 ปี
   - 46 – 60 ปี
   - 61 ปี หรือมากกว่า
3. ท่านจัดเป็นคนเชื้อชาติใด
   - คนขาวที่ไม่ใช่ละตินอเมริกา
   - เชื้อสายละตินอเมริกา/สเปน
   - แอฟริกัน อเมริกัน
   - เอเชีย หรือ คนพื้นเมืองหมู่เกาะในมหาสมุทรแปซิฟิก
   - คนพื้นเมืองอเมริกา
   - หลายเชื้อชาติ
   - อื่นๆ โปรดระบุ
4. ท่านจบการศึกษาระดับใด
   - มัธยมศึกษาตอนปลาย หรือต่ำกว่า
   - ปริญญาตรี
   - จบการศึกษาระดับสามัญ (สอบเทียบ)
   - สูงกว่าปริญญาตรี
   - ปวช., ปวส., หรือ อนุปริญญา
5. เครื่องดื่มประเภทใดที่ท่านดื่มมากกว่าสัปดาห์ละหนึ่งครั้ง (สามารถเลือกได้มากกว่าหนึ่งข้อ)
   - ชาดำ (ไม่เจือน้ำตาล, ไม่หวาน)
   - ชาดำ (เจือน้ำตาล)
   - ชาเขียว (ไม่เจือน้ำตาล)
   - ชาเขียว (เจือน้ำตา)
   - ชาใบหม่อน (ไม่เจือน้ำตาล)
   - ชาใบหม่อน (แบบหวาน)
   - ชาเย็น (ไม่เจือน้ำตาล)
   - ชาเย็น (แบบหวาน)
   - ชาบรรจุขวด (ไม่เจือน้ำตาล)
   - ชาบรรจุขวด (แบบหวาน)
6. ท่านดื่มชาร้อน หรือ ชาเย็นบ่อยเท่าใด
   - ไม่เคยดื่ม
   - เดือนละหนึ่งครั้ง หรือน้อยกว่า
   - 2 – 4 ครั้งต่อเดือน
   - 1- 5 ครั้ง ต่อสัปดาห์
   - มากกว่า 5 สัปดาห์
7. ท่านดื่มชาเขียวร้อน หรือ เย็นบ่อยเท่าใด
   - ไม่เคยดื่ม
   - เดือนละหนึ่งครั้ง หรือน้อยกว่า
   - 2 – 4 ครั้งต่อเดือน
   - 1- 5 ครั้ง ต่อสัปดาห์
   - มากกว่า 5 สัปดาห์

8. ท่านดื่มชาใบหม่อน หรือ เย็นบ่อยเท่าใด

- ไม่เคยดื่ม
- เดือนละหนึ่งครั้ง หรือน้อยกว่า
- 2 – 4 ครั้งต่อเดือน
- 1- 5 ครั้ง ต่อสัปดาห์
- มากกว่า 5 สัปดาห์

9. ท่านมีความสนใจในการซื้อผลิตภัณฑ์ดังต่อไปนี้มากน้อยเพียงใด เพื่อให้ได้ตามวัตถุประสงค์ที่ต้องการ

<u>**วัตถุประสงค์/ ผลิตภัณฑ์**</u> กรุณาวงกลมตัวเลขที่ท่านเห็นว่าตรงกับความเห็นท่านมากที่สุด	ไม่มีความสนใจ		สนใจปานกลาง			สนใจมากที่สุด	
เพื่อเพิ่มประสิทธิภาพทางร่างกายหรือจิตใจ							
ยา (ตามร้านขายยา หรือ ตามใบสั่งแพทย์)	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารประเภทวิตามิน หรือ เกลือแร่	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารที่ไม่ใช่วิตามิน เกลือแร่ และสมุนไพร	1	2	3	4	5	6	7
อาหาร	1	2	3	4	5	6	7
เพื่อเปลี่ยนแปลงน้ำหนัก							
ยา (ตามร้านขายยา หรือ ตามใบสั่งแพทย์)	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารประเภทวิตามิน หรือ เกลือแร่	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารที่ไม่ใช่วิตามิน เกลือแร่ และสมุนไพร	1	2	3	4	5	6	7
อาหาร	1	2	3	4	5	6	7
เพื่อสร้างสุขภาพที่ดี							
ยา (ตามร้านขายยา หรือ ตามใบสั่งแพทย์)	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารประเภทวิตามิน หรือ เกลือแร่	1	2	3	4	5	6	7
ผลิตภัณฑ์เสริมอาหารที่ไม่ใช่วิตามิน เกลือแร่ และสมุนไพร	1	2	3	4	5	6	7
อาหาร	1	2	3	4	5	6	7

Appendix J - Consumers' Acceptability Rating Distribution of Tea Samples

Consumers (%)	*Chinese*	*Gunpowder*	*Gyokuro*	*Irish*	*Lipton*	*Mulberry*	*Ouksujin*	*Sejac*	*Sencha 1*	*Sencha 2*	*Tanzania*	*White*
Korean Consumers												
9: Like Extremely	2.6	1.7	3.5	2.6	1.8	5.2	10.5	12.3	11.2	8.6	4.3	7.8
8	2.6	2.6	7.0	4.3	2.6	6.1	21.9	16.7	17.2	18.1	4.3	6.9
7	7.0	11.3	9.6	10.4	12.3	12.2	18.4	21.1	19.0	15.5	13.0	22.4
6	9.6	16.5	13.9	23.5	18.4	19.1	14.0	10.5	14.7	20.7	15.7	17.2
5: Neither Like Nor Dislike	17.4	21.7	17.4	14.8	23.7	18.3	21.1	23.7	13.8	23.3	28.7	19.8
4	18.3	14.8	9.6	22.6	18.4	14.8	7.0	7.9	11.2	11.2	17.4	10.3
3	13.0	13.9	16.5	14.8	14.9	10.4	3.5	2.6	6.9	0.9	7.8	6.9
2	18.3	13.0	12.2	2.6	4.4	11.3	1.8	2.6	3.4	0.9	4.3	4.3
1: Dislike Extremely	11.3	4.3	10.4	4.3	3.5	2.6	1.8	2.6	2.6	0.9	4.3	4.3
Thai Consumers												
9: Like Extremely	4.2	10.9	17.5	10.2	11.8	17.5	8.8	6.8	9.6	10.3	14.2	15.3
8	5.9	9.2	5.8	8.5	7.6	11.7	4.8	7.6	4.4	10.3	10.0	14.4
7	10.9	17.6	9.2	17.8	15.1	9.2	16.0	11.9	14.0	17.9	17.5	16.9
6	11.8	13.4	8.3	16.1	19.3	14.2	12.8	16.1	14.9	27.4	15.0	16.1
5: Neither Like Nor Dislike	16.8	21.0	17.5	22.0	25.2	15.0	20.8	28.0	19.3	15.4	20.0	22.0
4	10.9	11.8	5.8	11.0	5.9	5.0	13.6	9.3	14.9	7.7	11.7	3.4
3	14.3	7.6	13.3	2.5	5.9	4.2	8.0	9.3	7.9	5.1	3.3	2.5
2	10.1	5.0	8.3	5.1	3.4	10.0	8.0	5.9	8.8	4.3	3.3	3.4
1: Dislike Extremely	15.1	3.4	14.2	6.8	5.9	13.3	7.2	5.1	6.1	1.7	5.0	5.9
US Consumers												
9: Like Extremely	2.3	1.1	0.0	5.9	8.0	6.0	0.0	2.3	2.4	1.3	2.5	9.9
8	2.3	6.7	1.2	9.4	10.2	15.7	9.3	5.7	4.9	5.0	5.1	11.1

7	11.6	21.1	9.5	18.8	22.7	14.5	10.5	8.0	13.4	15.0	13.9	25.9
6	20.9	15.6	17.9	23.5	20.5	24.1	18.6	12.5	13.4	16.3	21.5	21.0
5: Neither Like Nor Dislike	9.3	8.9	8.3	9.4	8.0	16.9	18.6	23.9	6.1	7.5	13.9	8.6
4	14.0	13.3	19.0	9.4	15.9	9.6	11.6	12.5	15.9	17.5	15.2	6.2
3	15.1	15.6	17.9	7.1	5.7	7.2	11.6	19.3	13.4	18.8	8.9	6.2
2	9.3	11.1	15.5	9.4	4.5	3.6	15.1	8.0	24.4	11.3	13.9	7.4
1: Dislike Extremely	15.1	6.7	10.7	7.1	4.5	2.4	4.7	8.0	6.1	7.5	5.1	3.7