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Organoleptic validation of a color masking system specified for green and black tea (Camellia sinensis L.) brews

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1. SUMMARY

Numerous studies focusing on organoleptic tests have shown that the visual characteristics of the product under study cause a preconception (expectation error) in the judge, which distorts the perception of the other sensory characteristics to varying degrees. In cases where the rating is not based on visual judgment, it is advisable to ensure test conditions where it can be ruled out that the color stimulus of the product does not influence the decision of the judges [1]. Consequently, it is necessary to reduce the intensity of color sensation or the quality of the sensation, but most of all to mask them. The methods widely used in practice (blindfolding, colored vessels, colored lenses, etc.) are subject to distortions, therefore, a spectrally adjustable lighting system specified for the types of the given product can provide a solution to eliminate these by optimizing the parameters of the observation and by the sensory validation of them. The said spectrally adjustable LED measuring system with a homogeneous light distribution is controlled by arduino (an open-source electronic prototyping platform enabling users to create interactive electronic objects – ed.).

In our study, the organoleptic validation of a color masking system specified for green and black tea (Camellia sinensis L.) brews is presented. Participants of the experiment were tested according to international standards [2, 3]; based on our test results, they had normal vision in all respects. The results showed that, by color masking the smallest detectable threshold value and by determining the spectral characteristics, differences in visual perception between sample pairs with a certain difference in color stimulus can be partially or completely masked. As a result, under perfectly masking illumination, expectation errors due to perception do not distort the judgment of the other organoleptic characteristics (such as smell, taste, texture and mouth coating) of tea brews. Partial masking eliminates color differences in many cases, increases judgment time 4 to 8-fold, however, differences due to brightness remain observable.

2. Introduction and literature review

From a taxonomy point of view, the tea plant was first described by Carl von Linné in his work titled *Species Plantarum* in 1753. The scientific name of the tea plant is *Camellia sinensis* (L.) O. Kuntze. In a taxonomic sense, the most important varieties of the tea species (*Camellia sinensis* (L.) O. Kuntze) from

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a cultivation point of view are *Camellia sinensis var. sinensis* (Chinese tea, origin: Yunnan province, China) and *Camellia sinensis var. assamica* (J. W. Masters) Kitamura (Assam tea, origin: Brahmaputra Valley, India). Commercial teas are typically made from variants of these two species. The other two varieties of the tea plant are less significant: *Camellia sinensis var. dehungensis* and *Camellia sinensis var. pubilimba* **[4]**. *Camellia sinensis var. assamica subspecies lasiocalyx* (Planchon ex Watt.) is a subspecies of Assam tea: the Cambodian or southern type. They can be distinguished based on their leaf size: the leaves of Assam tea are the largest, followed in size by the leaves of Cambodian tea, and the leaves of Chinese tea are the smallest **[5]**. Initiallly, the taxonomic classification of tea plants focused on their morhpological features, primarily on their externally appearing characteristics (plant size, leaf shape, its hairiness, the number of flower petals, the nature of the fruit, etc.). This was followed later by classification based on internal structures (cellular and histological structure), while nowadays relationships are determined using genetic and DNA tests.

The tea species (*Camellia sinensis* (L.) O. Kuntze) is a perennial, evergreen woody plant. It is a plant of the subtropical regions and tropical highlands, originating in Southeast Asia. It prefers tropical and subtropical climates, and is cultivated in China, India, Sri Lanka and Japan, as well as in several African and South American areas. Its leaves are simple, typically ovoid in shape, with pointed, scattered tips. The leaves are leathery, shiny and hairy when young. The leaves at the apex are light green, those below are darker green. The leaves have a serrated edge, they are 2 to 5 cm wide and 4 to 15 cm long. The veins are clearly visible on the back side, the stalks of the leaves are short. The leaves of the Chinese version of tea are smaller, thicker, coarser-veined, while the leaves of the Assam version are thinner, with finer veins **[6]**. The flowers of the tea plant develop from the petiole, typically singly or in pairs. The petals of the flower are white with a pinkish tinge, the stamens are yellow and are arranged in two circles. Those in the outer circle are partially fused with the petals. The stamens in the inner circle are smaller, with the stigma located in the middle. Flowering typically occurs from October to February, with fruit production taking place between August and October **[7]**. The tea shrubs take 5 to 6 years to begin producing. The fruits are initially small and green in color, the trilocular capsules have 2 or 3 seeds. The brown seeds are 10 to 16 mm in diameter, they are round, hard and germinate slowly (usually within 4 to 6 weeks). Seeds can be extruded to obtain tea tree oil **[5]**.

The Chinese variaty (*Camellia sinensis var. sinensis*) is grown in China and Japan; it exhibits good resistance to cold environemnt. The tea shrub, which is typically 2.7 to 4.5 m tall, bears 4 to 6 cm long leaves for up to 80-100 years. The Assam variety (*Camellia sinensis var. assamica*) is grown in tropical regions; its shoots grow for 40-50 years. Its structure is more robust, with a height of 14 to 18 m its size is similar to that of a smaller tree, and its leaves are also larger: they are 15 to 35 cm long. The southern subspecies of the Assam variety (*Camellia sinensis var. assamica subspecies lasiocalyx*) is predominantly grown in tropical Cambodia, it is typically 4 to 6 m in height **[8]**. Some plantations may have tea shrubs that are up to 30 to 40 years old. The oldest tea tree is found in China, it is 32 meters tall and is estimated to be 1,700 years old **[9]**.

Tea plants are typically grown in tropical areas near the equator, where the temperature is between 10 and 35 °C, the annual rainfall is 1200 to 2400 mm and the altitude is between 300 and 2100 meters **[10]**. The established plantation is typically harvested 4-5 times a year, and all parts of the plant (bud, leaf, stem) are utilized. The most valuable parts are the buds and the top two fresh leaves. In practice, at plantations with intensive cultivation technologies, harvesting frequency is 15 days, while at plantations with extensive cultivation technologies it is 45 days. More frequent picking requires more work and energy, but results in better quality and higher yields. Less frequent picking requires less organizational work, but ore conducive to the spread of pests and pathogens. In most cases, yields are influenced by the weather (amount and evenness of rainfall, sunlight, ground frost). Harvesting can be performed manually or by machine. Harvesting of high quality teas can only be achieved by hand picking **[9, 11]**.

The FAO (*Food and Agriculture Organization of the United Nations*), which collects the most important statistics on agricultural production and foodstuffs (FAOSTAT), has set up the *Intergovermental Group on Tea* (IGGT), the task of which is intergovernmental consultation, as well as the evaluation of the production, consumption, trade, and the current and future market trends of tea. The Intergovernmental Group on Tea organizes its biennial meetings at major tea-producing centers; the last (twenty-third) session was held between May 17 and 20, 2018, in China, in the city of Hangzhou.

Tea is one of the most frequently consumed drinks all over the world, and according to certain estimations, it is the most commonly consumed liquid after water. World tea production is divided into four main categories: black, green, instant and other. Over the last decade, tea production has been increasing by an average of 4.4% per year, reaching 5.73 million tonnes in 2016. The world's two largest tea-producing countries are China (2.41 million tonnes) and India (1.25 million tonnes), accounting for more than half of world tea production. The largest tea-producing countries are China (2.41 million tonnes), India (1.25 million tonnes), Kenya (0.47 million tonnes), Sri Lanka (0.34 million tonnes), Turkey (0.24 million tonnes) and Vietnam (0.24 million tonnes). China is primarily responsible for the increase in global tea production:

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the production of the country has more than doubled over the past decade (2007: 1.17 million tonnes, 2016: 2.41 million tonnes). This is due to the growth of domestic demand, as well as other reasons such as health awareness and the development of herbal drinks. The largest areas of cultivation are typically found in the countries that are the largest producers: China, India, Sri Lanka, Kenya, Vietnam, Indonesia, Myanmar, Turkey **[12]**.

With stable prices and the health benefits of green tea, global black tea production increased by 3.0% and that of green tea by 5.4% over the last decade, both globally and annually. The largest black tea producing countries are India (1,260,000 tonnes), Kenya (439,850 tonnes), Turkey (310,500 tonnes), China (310,000 tonnes) and Sri Lanka/Ceylon (305,000 tonnes). The largest green tea producing countries are China (1,527,437 tonnes), Vietnam (94,200 tonnes), Japan (76,667 tonnes) and Indonesia (34,013 tonnes). Today's tea-growing areas are well defined, and the distribution of tea-producing areas is characterized by a territorial concentration (FAO, 2018). Over the past decade, world exports of tea have increased by 1.4% annually, reaching 1.75 million tonnes in 2016. The two largest exporters are Kenya (2016: 475,300 tonnes) and Sri Lanka (2016: 295,300 tonnes). While Kenya's export increased by 18%, the export of Sri Lanka fell by 11% due to weather conditions and state restrictions on fertilizers. Exports by India and China increased only slightly due to the increase in domestic demand. The FAO International Weighted Average Price Index for black tea was 2.57 USD/kg in 2016, but rose by 22.6% to 3.15 USD/kg in 2017. At the largest tea auctions (in Calcutta, Cochin, Colombo and Mombasa) prices have risen steeply for tea produced by both the orthodox and the CTC method. Of course, international tea prices are influenced by numerous factors (crop quantity and quality, pests, diseases, weather conditions, retailers, wholesalers, multinational companies, etc.). The demand side can also be shaped by many factors, such as price, income, demographics, education, occupation, cultural background, health awareness, substitute products, etc. Demand has started to increase significantly in the case of Asian, African and Latin American tea-producing countries. The countries of the European Union are traditionally importing countries **[12]**.

With forecasts based on dynamic time series models, world black tea production is projected to reach 4.42 million tonnes by 2027, with an expected average annual growth rate of 2.2%, resulting in significant growth in China, Kenya and Sri Lanka. In the case of green tea, the 1.53 million tonnes in 2016 is expected to increase to 3.31 million tonnes in 2027, with an average growth rate of 7.5%. This growth rate is expected to be due to increased productivity (higher yield varieties, the spreading of better agricultural practices, etc.). By 2027, black tea consumption is expected to grow by 2.5% annually to 4.17 million tonnes. While higher consumption growth (2-9%) is expected in African countries, only a slight consumption growth (0.2-1.4%) is expected in Western countries. The main factors contributing to increased consumption in tea-processing countries are as follows: increase in per capita income, increased awareness of the health benefits of tea consumption and XXX, widening of the product range. Black tea exports are expected to reach 1.66 million tonnes by 2027, while trade figures for major exporting countries may remain unchanged. World green tea exports are expected to reach 605,455 tonnes by 2027, with an annual growth rate of 5.0%. China will continue to dominate the export market (416,350 tonnes), followed by Vietnam (148,493 tonnes), Indonesia (12,889 tonnes) and Japan (10,445 tonnes). Most dynamically will grow the green tea exports of Japan (9.3%) and Vietnam (9%), as opposed to the 4% growth of China. Since the tea plant (*Camellia sinensis*) is very sensitive to changing growing conditions, therefore, the local effects of global warming greatly influence production. In light of this, the growing demand in the forecasts will be increasingly difficult to meet. When considering tea development strategies, the consequences of climate change should also be considered **[12]**.

Although several methods have been developed to assess the quality and market value of tea, but there are normative internationally standardized methods in terms of food safety, nutritional physiology and organoleptic testing. For the qualification of teas, based partly on instrumental and partly on organoleptic characteristics, it is advisable to seek the assistance of accredited testing laboratories. Organoleptic testing often includes the judging of the quality of the tea leaf, the beverage made from it and the soaked tea leaves, and the three attributes together give the quality classification of the finished product.

Tea-related standards are produced by the Subcommittee on Tea (SC 8) of the Technical Committee for Food Products (TC 34) of the International Organization for Standardization (ISO), with its international acronym being ISO/TC 34/SC 8. The Subcommittee on Tea was established in 1981, its secretariat is headed jointly by the *British Standards Institution* (BSI, 389 Chiswick High Road, London, United Kingdom) and the *Standardization Administration of China* (SAC, No. 9 Madian Donglu, Haidian District, Beijing 100088, China). The field of the Subcommittee on Tea (SC 8) is standardization related to tea (*Camellia sinensis*), which includes, inter alia, the standardization of the various types of tea, testing methods of composition and organoleptic quality, as well as good manufacturing and transport practices. Standardization is aimed at the clarification of the quality of tea in international trade in order to meet consumer expectations for tea quality. The Subcommittee on Tea (SC 8) assigned different subfields to different *working groups* (WG): WG 4 *White tea*, WG 6 *Tea classification*, WG 7 *Oolong tea*, WG 10 *Green tea – Vocabulary*, etc. The Subcommittee on Tea currently has 18 members (national standardization bodies) and 24 observers (national standardization bodies). To date, the Subcommittee on Tea has published 30 ISO standards and two other standards are under development (***Table 1***).

From an organoleptic point of view, the quality of the tea is determined by its color, freshness and aroma components and their intensities. In general, the younger the certain part of the tea plant is, the more valuable it is. Accordingly, the individual parts of the plant may be arranged in a series. The order, starting with the most valuable part is: closed leaf bud, opening leaf bud, top young pair of leaves, lower leaves, even lower leaves, stem. Overall it can be stated that the higher the rank number of the leaf, the lower the quality of the tea is **[9]**. Of course, the integrity of the leaves is also important for classification purposes. There are three main categories: 1. whole leaves; 2. broken leaves; 3. leaf debris and/or dust. The method of preparation is influenced by the size of the particles. The smaller the particles, the shorter the time recommended for soaking/extraction, because fragrance and aroma components dissolve more rapidly through a higher specific surface area **[13]**. Tea beverages are typically made using leaf buds, leaves and shoots, but certain types of tea are made only from plant stem parts. The Japanese green tea made from the stem parts separated during the harvest is the *kukicha* (*boucha*: stem tea, *shiraore*: white flock). Thus, the aroma profile of kukicha is not characterized by the sweet taste and floral, sour notes typical of green teas, but the nutty and creamy texture of the aromas released from the stem parts **[14]**.

The tea plant has previously been the focus of many international and domestic studies, however, research has been aimed primarily at the bioactive components and their effects on health, and possibly at the food safety risks of teas. Because of the enjoyment value of the tea consumed as food, it is crucial to characterize the organoleptic quality of dried tea leaves and the tea beverage. Factors that influence the components found in tea beverages and, through them, the organoleptic parameters are as follows: starting material (species/variant/variety, growing area, technology of cultivation, age of the tea shrub); harvesting (method, time, location of the harvested parts on the plant); processing (time, particle size, oxidation state); storage conditions (temperature, humidity, time, light exclusion); water used for the preparation of the beverage (chemical properties, temperature); beverage preparation processes (extraction time, solution concentration) **[14, 15]**.

The biological potential of tea leaves is determined by the genetic characteristics of the tea plant (tea species/subspecies/variant/variety). However, environmental conditions may influence the quality of the tea shrub that grows from the genetic possibilities. Similarly to foods, it is also true for tea beverages that high quality tea can only be made from high quality ingredients. The two most important ingredients of the tea beverage are tea and water. Factors influencing the organoleptic properties of tea are as follows: geographical location; weather conditions (temperature, precipitation, amount and distribution of sunlight); soil/growing medium; altitude; tea species/subspecies/variant/variety; cultivation type (greenhouse, plastic greenhouse, open field, shading length, humidification, air exchange, etc.); agricultural practices; harvest time; age of the tea plant; location of the collected tea leaves on the plant; morphology and bioactivity of the tea leaves; method and time of harvest; method of processing (type and degree of fermentation: white, green, yellow, black, oolong, dark); storage conditions (temperature, humidity, time, light exclusion) **[16, 17]**. The most important properties of the water used to make a tea beverage are as follows: type of water (hardness, pH, mineral content, etc.); water temperature (initial soaking temperature, rate of temperature decrease); soaking, leaching, extraction time; concentration (amount of tea/water used); tea beverage/brew preparation procedures. In the case of beverages made using soft (≤8 °dH) water, the aroma components usually dissolve from the tea leaves well, so the features and the character of the tea can be properly emphasized. The recommended initial temperature of the water/soaking is typically between 60 and 80 °C. When using hot water with a temperature of 100 °C, the tannic acids in the tea dissolve immediately, and the bitter substances will dominate the beverage. Very high temperatures also damage the phytonutrients of the tea (vitamins, nutrients, antioxidants, etc.). The optimal temperature of the brewing water is therefore around 80 °C. By increasing the soaking time (30 mp - 150 mp), the proportions of the flavor and aroma components can also be adjusted. The rate of decrease in water temperature is determined by the external temperature, that is, the temperature of the air in direct contact with the beverage and the temperature of the vessel. The larger the surface of the vessel, the more important it is for the vessel to have the same temperature as the initial temperature of the water. In most cases this is accomplished by preheating and heat retention.

In their research **[18]**, Lee and Chambers investigated the brewing methods that influence the taste of green tea. The purpose of their study was to describe the change in the taste of green tea when it is made with different water temperatures and brewing times. Green tea samples were brewed at three different temperature levels (50, 70 and 90 °C), where the extraction time was systematically varied between 1, 2, 5 and 20 minutes. A total of twelve brewing temperature and time combinations were investigated using three different green teas from Korea. Trained judges participated in a descriptive sensory analysis using a previously developed green tea lexicon. In the course of the experiment, investigating teas at twelve dif-

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ferent brewing temperature and time combinations, the researchers found that as the brewing time and temperature increased, brown and brownish properties (ash/sooty, burnt/scorched), as well as bitterness and astringency increased, while green and greenish properties (green beans, spinach) decreased. The flavor of green tea is formed by the substances it contains, but the amount of water-soluble components can be significantly influenced by the extraction temperature and the extraction time. Ingredients that contribute primarily to the taste of green tea include catechins, which are responsible for 70 to 75% of bitterness and astringency **[19, 20]**.

Caffeine in tea is bitter **[21]**, while tannins produce a strongly astringent or pungent taste **[22]**. Amino acids are responsible for juicy taste, while free sugars contribute to sweet taste **[23]**. With increasing water temperature and brewing time, the amount of tannin, free sugar and total nitrogen all increase in green tea **[24]**. As the water temperature increases, the caffeine content of green tea, together with its bitterness, also increases **[25]**. However, it should be emphasized that water temperature and extraction time also strongly influence the nutritional properties of green tea. The amount of catechins, responsible for the antioxidant effect of tea, depends on the brewing method. Therefore, from a nutritional point of view, it is recommended that green teas are brewed in hot water for 3 to 5 minutes, resulting in a bitter and sour green tea **[16, 26]**.

Some researchers have previously sought to determine the optimal brewing conditions using green tea bags and green tea leaves. When using tea bags, it was found that the amount of soluble solids (phenols and flavonoids) in green tea increased with increasing water temperature and brewing time. Based on the physico-chemical and acceptability data,it was concluded that the optimal brewing method can be achieved with water at 73-83 °C and a brewing time of 5.3-6.3 minutes **[27, 28]**. Methods with different water temperatures and brewing times result in green tea beverages with different flavors. If consumers brew the given green tea in water with a temperature of 50-70 °C for 1-5 minutes, then its green, not brown taste will be dominant, and bitterness will be low to moderate. When brewing green tea for more than 5 minutes and/or using water with a temperature of 95 °C, the beverage will have a stronger, brown aroma and a bitter, sour taste. Some green teas produce a moldy (“new leather”) when brewed at 95 °C or for more than 5 minutes, and an unpleasant, drug-like taste is produced when boiled at 95 °C for 20 minutes. It follows from these experiences that it is advisable for consumers to make green tea by soaking at 70 °C for 1 or 2 minutes, or brewing at a temperature of 50 °C for 2 to 5 minutes. Based on the results it can be stated that both bitterness and astringency increases with increasing water temperature, brown flavors appear at high temperatures, as well as moldy notes when combined with long soaking times. When making green tea, it is usually advisable to use water with a temperature of 50-70 °C and a soaking time of 1-5 minutes, which can be adjusted depending on the taste properties of the tea we would like to highlight **[18]**.

During the various organoleptic tests, the organoleptic properties of tea and tea beverages are evaluated and classified by the judging teams, typically with the help of their sense organs. In the process of perception, first the stimuli-specific receptors of the individual sense organs (eyes, ears, nose, tongue, skin) register the stimuli coming from the products or samples. The stimuli then activate the receptors, so that information is now being transmitted to the central nervous system, the spinal cord and the brain, in the from of a signal. Perception is actually the observation of the effects of sensory stimuli **[29]**. According to light engineering terminology, color exemplifies the triad of stimulus-signal-sensation because, in the physical sense, it is a light stimulus of a certain wavelength (380-780 nm) that can be detected by the human eye, in a physiological sense, it is a signal caused by one or more rays of light in the eye, the organ for color vision, whereas in a psychological sense, it is a sensation of color in the cerebral cortex induced by signals transmitted through the neural pathways of the organ of sight **[30]**.

The reliability of organoleptic results is determined by three key factors: the adequacy of the judges, the experimental design and the circumstances of the organoleptic method or experiment, and the implementation of the organoleptic tests. The adequacy of the judges is ensured by their selection and training, and by tracking their performance, their inadequacies and areas of personal development can be identified **[2, 31]**. In organoleptic testing, the adequacy of the judges’ organs is crucial. For this reason, screening for color blindness of the judges is also an important consideration, since both color discrimination and color identification are much less pronounced in color blind subjects than in people with normal sight. Organoleptic tests generally use pseudo-isochromatic tests to measure color blindness (Ishihara, Stilling, Velhagen), while instrumental anomaloscopic examinations are more accurate, giving accurate and quantitative measurement results on the degree and type of color blindness **[3]**. In all cases, the selection of the experimental desgin and the appropriate organoleptic method is based on the research question, taking into account the given possibilities.

Numerous organoleptic studies report that the visual characteristics of the product under investigation cause a preconception (expectation error) in the judges, because they distort the perception of other sensory characteristics to varying degrees. Judges assume, even before starting the tests, that darker red wine is more full-bodied, that darker chocolate is more bitter, that beer with a darker shade is more aromatic, that yellowish ice cream is more creamy; the above-mentioned characteristics can significantly influence the objective perception of taste, smell and texture **[32]**. In cases where rating is not based on visual judgment, it is advisable to provide test conditions where it can be ruled out that the color stimulus of the product affects the decision of the judges. For this reason, the intensity of the perception of the color stimulus or the quality of sensation must be reduced, or even masked.

One solution to this may be for the judges to perform testing blindfolded, and each of the judges is assisted by a support staff. In our previous experiment, however, we have seen that people with normal sight make inconsistent judgments as a result of blindfolding **[33]**. This method is rarely used not only for this reason, but also because of its excessive human resource requirement. A solution to this problem may be to hide the color stimulus differences between the products using glasses with color filter lenses, but the weakness of this method is human curiosity: judges can rarely help not to look under the under the glasses or remove them, so this method does not prove to be an appropriate means of masking color differences either **[34].** (Because of this, and due to technical and production difficulties, this method is not widespread in practice.) The third possible solution is to present the samples dark, opaque, typically colored glass cups with a narrow mouth and a tulip shape, which are used in testing beverages and can concentrate aroma components. For example, cobalt-colored (bluish) or, in certain cases, red glasses are used for the testing of olive oils. The samples are covered with a transparent glass lid prepared for the tasting cup, so that the aromas can be enriched in the headspace. The international standard states in particular that the test cup is not for the analysis of the color or the texture of the olive oils **[35]**. The biggest fault of this solution is that the judges almost invariably look into the glass and detect the original visual characteristics of the product, leading to a distorted judgment. For the above reasons, this method can only be used for the strictly controlled examination of a specific foodstuff, and in no way in a general sense. For many product categories (roasted meats, bakery products, chocolates, etc.) it is impossible and unrealistic to judge through colored glass.

Some researchers have raised the issue of of mixing samples with wet coloring substances. However, the use of this method is limited, since in the case of complex food matrices, the added coloring substances may affect different organoleptic properties, thus rendering the organoleptic examination itself meaningless. At the same time, organoleptic laboratories typically test finished products to which they cannot add any food colorings **[34]**. According to the international standard describing the methodology and general principles of organoleptic examinations, the effect of color differences can be partially obscured by illumination that minimizes color difference **[1]**. Illumination may hide color differences and other appearance factors, so that judges can focus on other organoleptic features or the reception of the characteristics of the particular test sample without visual cues **[36]**. Most often, the masking effect of red light is emphasized, which can effectively mask, for example, the differences in shade of cooked meats, the crust of baked goods or the color of some fruits and vegetables **[37]**. Unfortunately, the spectral characteristics of the recommended fluorescent lamps do not allow for the masking of the differences in the color range of food samples of different colors and brightness. The color (spectral composition), luminous intensity and color temperature of the colored fluorescent lamps used in practice cannot be adjusted.

Based on the results found in the literature it can be stated that in the case of organoleptic tests there is no suitable method for the effective masking of visual differences. To eliminate the problems listed above, a complete solution can be provided by a spectrally adjustable lighting system specified for the types of the given product by optimizing the parameters of the observation (visual geometry, photometric and spectral character of the light source, eye adaptation state) and by the sensory validation of them.

Objectives of the research:

1. Testing the color vision of sensory judges: color vision correctness, hue test, contrast sensitivity, color discrimination test;

2. Determination of the spectral properties of green and black tea (*Camellia sinensis* L.) brews;

3. Testing the effect of masking; determination of the color discrimination ability (minimum detectable threshold) of judges with respect to the reference color points associated with the product groups, with or without masking light.

3. Materials and methods

Regarding the samples included in the study, our goal was to represent each tea-producing country and tea-producing area according to their importance (***Tables 2 and 3***).

Transmission values of the tea samples were determined by spectrophotometric measurements (UV-1600/VIS, AOE Instruments). Transmission measurements were carried out in the visible range between wavelengths 360 and 760 nm, with a resolution of 5 nm. Tea infusions were prepared in accordance with international standards **[38]**. After the preparation of the tea infusions, tea samples were pipetted into 5 ml cuvettes, and then they were covered cuvette lids. For the spectrophotometric measurements, five replicates were prepared from each sample, and these were also used for the organoleptic tests.

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When testing the color vision of the judges, the requirements of the relevant international standards were used as a guidance **[2, 3]**. Corresponding to these, serial dilution color test, pseudo-isochromatic color recognition test (Ishihara),hue discrimination test, instrumental color vision test (OCULUS 47700 Heidelberg MultiColor anomaloscope), as well as contrast sensitivity and general color discrimination tests (Cambridge Research System, Visage system) were performed.

The spectrally adjustable measuring station, containing five different wavelength LED sources (red (640 nm), green (530 nm), blue (460 nm), amber (590 nm) and neutral white), was built at the Department of Mechatronics, Optics and Mechanical Engineering Informatics of the Budapest University of Technology and Economics. The intensity value of each LED channel is adjustable from 0 to 255, so virtually any number of illuminations can be tested. The 1.5 x 1 x 1 meter installation has five types of power LEDs mounted on four fixed panels. The box is made of 1 cm thick diffuse wood furniture board ensuring high reflection. The panels are rotatable and are accessible via two doors. In the box there are also two baffles, which obscure the light sources when viewed and improve the homogeneity of the bottom plate. The schematic structure of the system is shown in **Figure 1** below.

The light sources are located in each corner of the measuring station, and after multiple reflections, the emitted light enters the work area from the white walls. Because of the homogeneity, the angle between the panels and the walls is 45°. Viewed from the front, there is a large opening on the front surface of the installation, providing access to the working space inside the device. Due to the positioning of the panels in the spacious working space, the distribution of the light density is uniform on both the horizontal bottom plate and the rear wall. It can comfortably accommodate the tea samples and their colors can be examined with proper illumination. Control is performed using two Arduino Uno microcontrollers. In the program, the LEDs can be set from 0 to 255, which is achieved by the microcontroller by pulse width modulation, i.e., the brightness of the LEDs is adjusted by changing the fill factor. The implemented LED measurement system is arduino-controlled, has a homogeneous light distribution and can be spectrally tuned **[40]**. Regarding the perception of the color of foods, several research groups have emphasized the need for a multispectral approach **[41]**, as well as relevance of hyperspectral imaging techniques **[42, 43, 44]**.

Judges were selected from among the students of the Budapest University of Technology and Economics and Szent István University who had good sight. For the sensory examinations, a triangle test was used, which is one of the most sensitive methods of difference analysis; it is suitable for the detection of small differences and requires moderate use of the sense organs of the judges. The logic of the triangle test follows the shell game principle to determine the difference or similarity between two samples (A and B), where the judges are given three samples in each case. The task is to identify the different samples.

During the study, certain tea beverages were compared. Under different illuminations, the tea samples in the cuvettes were tested by the judges separately, with the cuvettes spaced 6 cm apart. The results were recorded in Microsoft Excel and evaluated according to the relevant standard. The binomial theorem and the sequential procedure were used for the evaluation **[38, 39]**. In the first step, the tea samples were tested under illumination with a color temperature corresponding to artificial sunlight (D65), as recommended by the international standard describing the methodology and general principles of organoleptic tests **[1]**. In the second step, different masking illuminations were assembled and tested for effectiveness. Of course, during the organoleptic tests, only those pairs of samples were examined under masking light that differed under the standard („artificial sunlight") light source (D65).

4. Results and conclusions

The mean transmission values of the tea infusions are plotted for both green teas and black teas. The characteristics of the spectra of green teas were very similar: light was transmitted primarily at higher wavelengths, while less or no light was transmitted at lower wavelengths. The different types were grouped by maximum transmission. Some samples had a maximum transmission between 80 and 90%, while for others it was between 30 and 50%. The tea samples generally differed in the extent of transmission. The Matcha Jikagise tea (Sample 6) from Uji Province, Japan, was made from a ground material, resulting in a significant difference in color and texture compared to infusions made from tea leaves: it was opaque and bright light green (***Figure 2***).

In the case of black teas, the transmission spectra also had a higher light transmission at longer wavelengths, while their transmittance gradually decreased at shorter wavelengths. The nature of the curves was similar for each sample. However, it can be seen that, in the case of black teas, there are a number of variations in color stimuli and the spectral lines intersect (***Figure 3***).

The judges participating in the experiment had normal vision, so all participants could perform any further sensory examination.

In the case of green teas, all sample pairs (5-14, 14-11, 4-7, 3-9, 1-10) showed differences under D65 illumination (***Tables 4 and 5***). Based on the sequential (graphical) evaluation, the number of all correct answers fell above the rejection line. According to the results of the binomial procedure, the calculated probability value was below the specified 0.05, therefore rejecting the H0 (null hypothesis) we can state with 95% probability that in the case of judges with normal vision, there was a statistically verifiable sensory difference between the two samples. During the triangle test, at the 95% significance level, for the acceptability of the masking settings, 14 incorrect answers in 27 trials are required (which in this case means that the judge incorrectly chooses the differing sample(s)).

Perfect masking means that the differences between the samples are masked both in terms of hue and brightness. This was achieved with setting 2 for sample pair 5-14. Based on the sequential evaluation, the number of all correct answers fell below the acceptance line. According to the result of the binomial procedure, the calculated probability value was above the specified 0.05, so the H0 was accepted, i.e., it can be stated with a 95% probability that, in the case of judges with normal vision, there was no statistically verifiable sensory difference between the two tea samples. For sample pairs 5-14 and 14-11, settings 1 and 3 partially masked the differences.

For black teas, a logic similar to that of green tea tests was used. Triangle tests of the sample pairs were performed first with illumination D65 and then with the different masking illuminations (***Tables 6 and 7***). While in the case of green teas multiple LED channels were used to create the illumination, for black teas, it seemed sufficient to use a single spectrum, so only the red, green, blue and amber LEDs were used for masking. For black teas, each sample pair (11-15, 3-4, 2-12, 1-9, 7-19, 14-20) showed a difference under illumination D65. Based on the seuential (graphical) evaluation, the number of all correct answers fell above the rejection line. According to the result of the binomial procedure, the calculated probability value was below the specified 0.05, therefore, rejecting H0, it can be stated with a 95% probability that, in the case of judges with normal vision, there was a statistically verifiable sensory difference between the two samples. During the triangle test, at the 95% significance level, for the acceptability of the masking settings, 14 incorrect answers in 27 trials are required (which in this case means that the judge incorrectly chooses the differing sample(s)).

Perfect masking was achieved for sample pair 14-20 under blue illumination, while in the case of sample pair 3-4 under red illumination; this fact was confirmed by the sequential evaluation and the evaluation of the binomial theorem. It was instructive that the 14-20 tea infusion pair was close to each other in color stimulus, as mistakes were made in each color environment for this pair.

In several cases, masking eliminated the color differences, while increasing the decision time of the judges 4- to 8-fold. Differences due to brightness remained noticeable. The research results have shown that if the color stimulus difference between the samples is significant, then the masking effect cannot be realized. Partial masking may result from the fact that not only the masking of color, but also the masking of brightness is necessary; this should be tested in the future using different levels of illumination.

A masking light meeting all needs could not be created for green and black tea samples, because the difference between the samples was not in color or saturation, but in brightness. This difference could not be eliminated simply by modifying the illumination. Characteristically, the spectra of the green teas were a set of curves more alike than the transmittance curves of the black teas. Generally, the transmission curves of the green teas differed in the extent of light transmission, but they were almost parallel. However, in the case of black teas, there were several variations in terms of color stimuli, the spectra crossed each other. Instrumental color measurements have also confirmed the assumption that the color parameters of teas change relatively quickly, so it is advisable to carry out the tests as soon as possible after the preparation of the tea infusion.

5. Summary

In summary, it is possible, in the case of beverages prepared from tea plants of different origin (*Camellia sinensis* L.), to partially or completely hide the visual perception differences between sample pairs with certain color stimulus differences by color masking the minimum detectable threshold specified for judges with normal vision and by determining the spectral characteristics. As a result, under perfect masking illumination, expectation errors due to perception do not distort the judging of other organoleptic properties of tea beverages (smell, taste and mouth coating). Partial masking eliminates color differences in many cases and increases the decision time of the judges 4- to 8-fold, but differences in brightness are still noticeable. Based on the results of the research, it is recommended that the instrument is further developed by splitting its test area into parts. In the individual spaces thus formed, the luminous intensity of the LED types can be adjusted from the software in order to achieve the same color stimulus effect at each relative control value.

The results can be immediately utilized in international, domestic and accredited food testing practices of organoleptic tests, as they help to ensure that other organoleptic characteristics of the food under examination are not influenced by its visual properties. By the color masking of the spectrally adjustable measuring station and the application of the sensory judging panel, spectral characteristics can be determined in a product-specific way for other food and product types (ketchups, barbecue sauces, mustards, yogurts, white, rosé and red wines, beers, milk chocolates, liquid eggs, etc.).

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