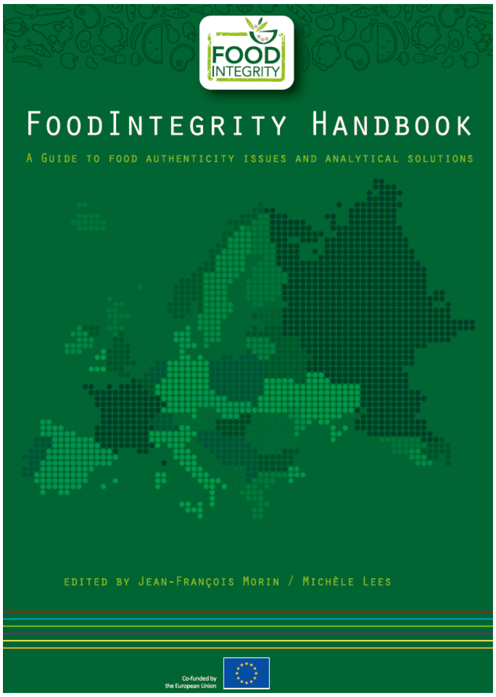
FOODINTEGRITY HANDBOOK

A GUIDE TO FOOD AUTHENTICITY ISSUES AND ANALYTICAL SOLUTIONS

Editors: Jean-François Morin & Michèle Lees, Eurofins Analytics France



ISBN *print version* *978-2-9566303-0-2*
electronic version *978-2-9566303-1-9*

https://doi.org/10.32741/fihb

Tea and flavoured tea

Stephanie Heaney*, Tassos Koidis
Institute for Global Food Security, Queen's University Belfast, United Kingdom
**E-mail corresponding author: sheaney16@qub.ac.uk*

Jean-François Morin
Eurofins Analytics France, Nantes, France

General overview of the product

Tea *(Camellia sinensis)* is an important agricultural crop that is grown in the tropical and sub-tropical regions of the world. The tender shoots and leaves of the plant are processed in factories and used to prepare an aromatic infusion which is consumed globally as a beverage. Tea is known to be one of the most popular beverages in the world and it is thought to be the most widely consumed non-alcoholic drink after water [1].

Tea is a global market which was worth EUR 34 billion in 2017 [2]. It is produced in more than 40 countries; mainly in Asia, Africa and Latin America. China, India, Sri Lanka, Kenya and Indonesia account for 80 % of worldwide production. China is the largest tea producer in the world which produces 2 230 000 tonnes per year. India is second with 1 191 100 tonnes and Kenya positions third with 399 210 tonnes. The Republic of Ireland, followed by Britain, is the largest per capita tea drinking nation [3]. Tea is not commercially grown in the EU and therefore, EU countries need to import all their tea for consumption. Tea has been imported into Europe for over 200 years with few, reported safety concerns and has consequently been deemed to be 'low' risk in terms of food safety. In 2016, a total of 238 224.30 tonnes of tea were imported into the EU, breaking down to 13.86 % green tea and 86.14 % black tea [4].

The tea value chain is represented in Figure 1 from producing countries to the European consumption market. A high level of vertical integration characterises this chain: few major companies control various production stages upstream and downstream, including the ownership of plantations and manufacturing operations.

Around 85 % of global tea production is sold by a few multinational companies owning plantations and buying production of smallholders [6]. Many of the larger tea companies have their own buyers based in the major tea buying centres of the world or they employ trading companies to make purchases on their behalf. Tea is exported in bulk whereby blending and packaging takes place in the importing country. Consumer markets in the EU are dominated by popular blended brands. These blends can contain 35 different types of tea that are blended in the consuming country [7]. Blending and packaging are highly added value operations and represent 80 % of the retail price.

https://doi.org/10.32741/fihb.17.tea

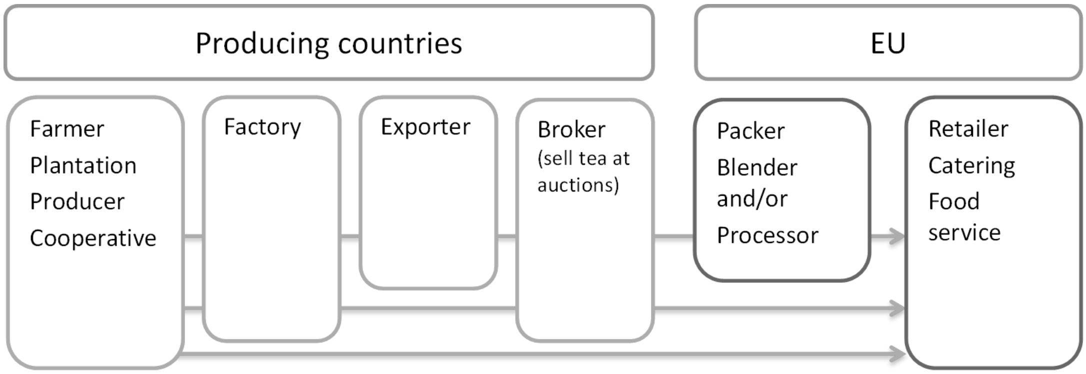


Figure 1: Tea value chain [5]

In Europe, tea is mainly sold by supermarkets and convenience stores which may sell their own-label tea as well as the major brands from tea companies. Some retailers specialise in upper-end tea blends and also pack their own products.

1. Product Identity

1.1. Definition of the product and manufacturing process

Tea is derived solely from the leaves of the plant species *Camellia sinensis*. There are many stages in tea processing which transforms the fresh shoots and leaves of the tea plant into dried leaves for brewing an infusion. Immediately after harvesting the leaves are brought to the factory for processing. It is the processing procedure that determines the type of tea produced. The main types of tea produced are; white, black, oolong and green. The manufacturing process for these types mainly differ in the degree of enzymatic oxidation or interchangeably known as the 'fermentation' process. In the processing of green and black teas, the fresh leaves are left to wither until the moisture content is reduced to a degree which depends of the type of variety of the tea [8]. The loss of water results in the concentration of polyphenols compounds and a deterioration of the leaf structural integrity. Withering is important for aroma development [9] and to prepare the leaf for rolling and/or maceration. If the leaf is still turgid when it is rolled or macerated this prevents efficient mixing of the cellular components important for initiation of oxidation or generation of aroma. The withered leaves are rolled and crushed to initiate the oxidation of tea polyphenols. Green tea leaves are dried after rolling to prevent further chemical changes. Tea leaves which have been macerated are known as 'dhool.' The preparation of the brew is simple, and involves adding hot water over the processed, dry tea leaves.

1.1.1. Major tea products

Black tea: it is produced by withering, rolling or cutting, oxidation and drying. During black tea processing, the leaves are oxidised for up to two hours to ensure they are fully oxidised. Black tea has two main process types, these are orthodox rolling and CTC (cut tear curl). India and Sri Lanka are considered the major growing regions for black tea. A brewed black tea can range in colour from amber to red to dark brown depending on the duration of oxidation, particle size, temperature and degree of aeration [10].

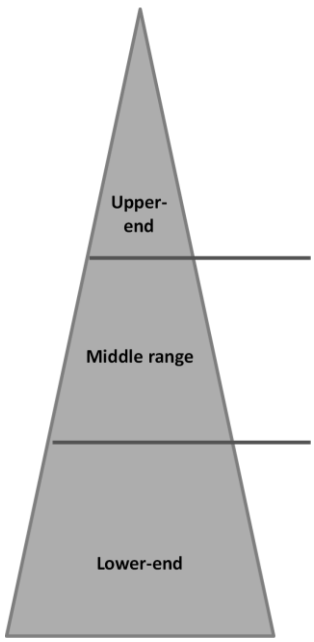
Oolong tea: traditionally from China's Fujian province and Taiwan, oolong tea is produced by withering, then partial aeration or tumbling [11]. During the tumbling process, the edges of leaf become bruised and partially oxidised. The drying process is called roasting and sometimes the tea is heated and dried repeatedly until the process is completed. The degree of fermentation, which varies according to the chosen oxidation duration, can range from 8–85 %, depending on the variety and production style. The name oolong tea came into the English language from the Chinese name which means black dragon tea or dark green teas.

Green tea: for its manufacture, the withered leaf is steamed (Japanese style) or pan fired (Chinese style) and rolled before drying. This is done to prevent the veins in the leaf breaking and thus preventing oxidation of the leaf [11]. In green tea processing, once the leaves have been dried, they can also undergo orthodox rolling or CTC. A brewed green tea is typically green, yellow or light brown in colour. Most green tea is quite light in colour and only mildly astringent.

White tea: this tea was originally established in Fujian Province, China. Authentic white tea is produced on a very limited scale, picked for only a few weeks each year in Fujian. It is made from the unopened buds of *Camellia sinensis*, which contain fine white filaments on the surface. The name is associated with these silvery white hairs on the unopened buds. For optimum quality of white tea, it is essential that shoots and leaves are gently plucked to minimise damage. The buds plucked are usually shielded from sunlight during growth which results in a reduction of chlorophyll from sunlight. The brew of white tea is usually very pale in colour. This type of tea is not as popular as black or green tea. White tea processing involves rapid drying of the freshly harvested leaves to inactivate the enzymatic reactions [12].

Pu-erh (or Pu'er) tea: it is a variety of aged dark tea which is produced in the Yunnan province of China. The tea leaves undergo microbial fermentation and oxidation after they are dried and rolled. The quality of this tea improves with maturation and time [12].

Tea products can be segmented into three different groups according to the quality of the tea. They are described in more detail in Figure 2.



Excellent quality, premium teas, handpicked, long-leaved teas. With a special story behind it or products with a sustainability label.

- Special origins such as Darjeeling, Oolong and Ceylon-Uva have the highest prices.
- Sold either by large blending and packing companies and specialty shops
- Typical retail price: € 50-55 per kg

Good quality, sold in supermarkets.

- Sustainability certification is increasingly required
- Innovation mainly in material and shape of teabags.
- Sold mainly by large blending and packing companies, to a lesser extent by specialty shops
- Typical retail price: € 10-20 per kg

Regular black tea. Low quality bulk products sold in auctions

- Extensive blending deliberately reduces differences in quality
- Many tea qualities have become interchangeable and are bought where they are cheapest
- Sold uniquely by large blending and packing companies
- Typical retail price: € 5 per kg

Figure 2: Tea products segmentation according to quality [5]

1.1.2. Other tea products

The increasing knowledge of the health benefits of tea along with the gradual increase in tea consumption has encouraged the development of other tea products on the market. Instant, ready-to-drink (RTD), flavoured, herbal and decaffeinated teas are becoming more popular in many countries.

Instant teas*:* these are sold as powders which require water to become reconstituted into a tea beverage. Instant teas are made using fully oxidised, partially oxidised and unoxidised dried leaves. The most common types of instant teas which are sold include green, black or jasmine tea. Other instant teas available to customers include teas which contain milk or fruit additives.

Ready-to-drink (RTD) teas*:* many RTD products are made from tea extract powders, similar to instant teas. The amount of tea solids is usually quite low and due to the sugar content it is difficult to make any nutritional or health benefit claims.

Flavoured teas*:* these are created by adding flavourings or food ingredients with flavouring properties to white, black, green and oolong teas [13]. Other food ingredients which do not lend to a specific flavour may also be added (e.g. vitamins, minerals and rice). Flavoured tea can be produced and sold as loose tea leaves, tea bags, and RTD products or as instant tea. Some of the most common flavoured teas include Jasmine and Earl Grey tea.

Herbal and fruit infusions: these are amongst the world's most popular and widely enjoyed beverages as a result of their unlimited variety and convenience. There are many types of varieties produced including, fruit, mint, sweet, and spicy. Up to 300 different plants and 400 parts of plants are used for making herbal and fruit infusions [14]. These infusions are prepared by brewing with hot water.

Decaffeinated tea: decaffeinated or decaf tea is made by processes which reduce the natural caffeine content in tea. There is no harmonised legislation in place for the maximum level caffeine content remaining in the decaffeinated product however; there is a maximum threshold of 4 mg/g in Germany, Austria and Slovakia and in some countries such as Belgium, France, Italy and Switzerland it is as low as 1 mg/g [13].

1.1.3. Health benefits

Tea is recognised for its enjoyable flavour, health benefits and stimulating effects on the human body. The growing popularity of tea coupled with the increased awareness of the potential health benefits associated with tea consumption has influenced tea chemistry to become a vibrant, developing field. Tea is composed of a range of phytochemicals that demonstrate significant physiological properties and health promoting benefits, including polyphenols, amino acids, vitamins, carbohydrates and purine alkaloids. The polyphenols determine up to 30 % of the dry weight of the leaf [15] and these compounds offer various benefits for human health, nutrition, and physiology [16,17]. Caffeine is principally valued due to its stimulatory effects [18]. It occurs naturally in the tea plant and is a central nervous system stimulant which increases alertness, stimulates metabolism and contributes to an increase in dopamine levels in the blood which improves mood. There is a considerable amount of evidence which suggests that moderate consumption of tea may protect against several forms of cancer, cardiovascular diseases, the formation of kidney stones, bacterial infections, and dental cavities [19]. Substantial studies worldwide have interpreted the role of tea in nutrition and disease [20–25].

1.2. Current standards of identity or related legislation

1.2.1. International Organization for Standardization (ISO)

ISO is a worldwide federation of national standards bodies (ISO member bodies) which has produced several standards relating to tea. The standards are produced to provide world-class specifications for tea products, services and systems, to ensure quality, safety and efficiency. The ISO methods produced mainly compromise of definition and basic requirements of black, green, white and instant tea [26–29]. ISO has also developed a range of standard methods of determining quantities of important chemical parameters of tea which include: total ash [30], water-soluble ash and water-insoluble ash [31], acid-insoluble ash [32], alkalinity of water-soluble ash [33], total polyphenols [34], catechins [35], theanine [36] and crude fibre [37].

1.2.2. European Union (EU) legislation

There is no specific regulation on tea and tea products in the European Union. All these products fall under general food regulations, such as regulation (EC) No 178/2002, regulation (EU) No 1169/2011 for labelling, regulations (EC) No 1829/2003 and No 1830/2003 for GMOs, regulation (EU) No 1169/2011 for allergens, regulation (EC) No 1334/2008 for flavourings, regulation (EC) No 1333/2008 for food additives and regulation (EC) No 1925/2006 for vitamins and minerals [13].

One protected designation of origin (PDO) and one protected geographical indication (PGI) have been granted by the European Union:

- Longjing Cha tea (PDO) in Commission Implementing Regulation (EU) No 449/2011;
- Darjeeling tea (PGI) in Commission Implementing Regulation (EU) No 1050/2011.

2. Authenticity issues

2.1. Identification of current authenticity issues

2.1.1. Adulteration of tea by dilution and substitution

Historically, tea has been prone to adulteration. The adulteration of tea was common in the 19th century to maximise profits through mixing genuine tea with leaves from other plants, or with tea leaves that had been already brewed. The most common tea adulterants are leaves of other species including bilberry, willow, elder, sloe, hawthorn and beech leaves as well as tea leaves which have already been brewed, dried and mixed with authentic tea leaves. Sometimes the resulting colour was not similar enough to tea, so anything from sheep's dung to poisonous copper carbonate was added to make it look more authentic [38]. The issue of tea adulteration with other herbs is now a less common matter as this fraudulent act can be easily detected using visual and macroscopic techniques. Tea leaves which have been already brewed can be identified by reduced quantities of extract compounds and tannins. The results from quantifying individual catechins, polyphenols, fibre, ash contents from tea extracts using ISO standards would confirm if the tea has been adulterated (cf. Section 3.1.3).

2.1.2. Geographic origin

There has been an increase in consumer interest in geographical origin of tea, which is driven by the reputation of the country or specific cultivation area [39]. The higher demand for specific regions, allows the producer to ask for significantly higher than average prices. The higher value product therefore, can become a target for food criminals. Tea which originates from the Darjeeling district in West Bengal, India has been a victim of fraudulent activities. The favourable geo-agro-climatic situation, specific soil characteristics, plantation conditions and traditional human practices results in Darjeeling tea possessing a specific flavour and a very high quality. This quality distinguishes it from tea grown elsewhere in the world. Tea products have been sold which were falsely labelled as 'Darjeeling.' This fraudulent activity is harmful to its potential market and misleading to consumers. To combat this situation, the Tea Board of India has administered the Darjeeling certification mark and logo so consumers can be assured they are purchasing an authentic Darjeeling tea.

2.1.3. Tea categories

Higher value products such as upper-end tea blends are potential targets for food criminals. The higher price of these teas attracts criminals and encourages them to falsely label and sell cheaper tea products to mislead consumers. Teas which are targets of fraud are usually less available on the market. The most widespread issues are:

- **Mislabelling of the main types of tea**: Green, oolong and black tea, and the mislabelling between white and green teas, as white tea is more expensive as it is produced on a limited scale and picked for only a few weeks each year in Fujian.
- **Mislabelling within the same tea category**: Sencha Japanese green teas processed by steaming, and Chinese green teas processed by drying.
- **Mislabelling of teas undergoing a specific process:** Smoked teas or roasted teas such as Hojicha or Matcha. Authentic Matcha tea is very expensive and there is a high risk of adulteration with teas not grown or processed in the traditional way or with other high chlorophyll containing materials. Currently there is no ISO standard for Matcha.

2.1.4. Tea grade

Tea leaf grading is a significant process required for evaluating products based on the quality and condition of the leaves. The highest grades are referred to as "orange pekoe" and the lowest as "fannings" or "dust". The characteristics which are considered in tea leaf grading mainly include, age, size and quality. Younger, smaller leaves are more valuable than larger, older leaves. The presence of buds is associated with a higher grade. The condition of the leaves, for example, ground or chopped and broken or full leaves are considered during the grading process. Like any up market product, quality grade teas face fraudulent threats.

2.1.5. Tea liquor

The current process for determining tea liquor quality is typically based on experience and subjective judgment. Human panel tests for assessing quality are carried out by trained 'tea tasters' who assess appearance, aroma and taste. Characteristics which are evaluated during this assessment include colour, physical appearance, clarity, aroma, flavour and mouth feel. Sensory scores are recorded for each batch which determines the price range. These results could be fabricated to make the buyer believe that the tea is a better quality.

2.1.6. Tea cultivar

Teas made from original cultivars tend to be of higher prices. Cultivars are made from selection and breeding of tea plants which have desired characteristics. The choice between cultivars is an important decision for tea farmers as they consider properties according to their specific needs and the demands of the market. Different cultivars produce a variety of flavour profiles and unique characteristics. Some of the most popular tea cultivars include; Yabukita (Japan), Qing Xin (Taiwan), Jin Xuan (Taiwan), Ruby #18 (Taiwan), Tie Guanyin (China) and Qi Dan (China).

2.2. Impact of climate change on authenticity

Tea cultivation depends on weather conditions for optimal growth. Global climate change therefore has a great impact on the growth of tea, quality and final tea prices. This issue could increase risk of adulteration of high value origin teas with cheaper products.

Furthermore, the increase in temperature and extreme weather events are posing a significant threat to the resilience of tea production systems, inducing social problems in impacted producing countries as well as authenticity and quality issues. Within the last few decades, the major tea producing countries (China, India, Sir Lanka and Kenya) have witnessed a significant change in climate [40]. Many growing regions may become unsuitable for tea cultivation in the future. Optimum growing regions will gradually shift to higher latitudes. Tea production and quality could benefit from the increase in temperature and CO_2 elevation. However it could be negatively affected by drought, heavy rains, and frosts, proliferation of pests and diseases and soil degradation.

2.2.1. Effects of climate change on tea production yields

The incidence and proliferation of pests and disease in tea plantations is expected to increase with climate change [41]. Warmer weather conditions will help many insects and pathogens to survive in winter, which is usually a critical time for their reduction. A higher survival rate will result in an increased rate of reproduction and will therefore increase the number of annual generations in some species. For example, one of the most threatening pests to tea plants is the Tea Geometrid *(Ectropis obliqua)* which usually has six generations per year in Hangzhou, China in normal weather conditions. This is expected to increase to seven generations, if the mean temperature rises [42]. Some studies have demonstrated that during periods of increased rainfall, yields can increase, however the overall quality of the leaves is negatively affected [43].

2.2.2. Effects of climate change on tea quality

A study [43] has shown that during the summer Monsoon in China, tea leaves grow twice as quickly than in the dry season, however the overall quality of the leaves was found to decrease. During the Monsoon, yields were 50 % higher whilst concentrations of catechin and methylxanthine secondary metabolites, major compounds that determine tea functional quality, were 50 % lower. Ultimately, this resulted in a decline of up to 50 % in household income from tea sales [44].

The formation and stability of polyphenol compounds in tea shoots depend on nitrogen and carbon metabolism and their balance in tea plants which is significantly affected by climate change. A study which has investigated the increase of CO_2 levels on tea quality found that levels of polyphenols, free amino acids and theanine concentrations increased, while the caffeine concentration decreased [45]. Another study found that in elevated CO_2 conditions there was a decrease in caffeine, free amino acids and an increase in the concentration of the polyphenol compounds in the tea plant [46]. The gradual change in the ratio of free amino acids to polyphenols in shoots will ultimately cause deterioration of black tea quality [47]. Research has demonstrated that higher levels of amino acids can contribute to higher quality green tea and higher quantities of polyphenol compounds are positively associated with black tea quality [46].

3. Analytical methods used to test for authenticity

3.1. Officially recognised methods

Visual assessment and tea tasting are the initial quality control methods completed internationally. Further analysis is carried out on tea if any issues are identified during initial assessments. Sensorial, visual and analytical controls of the tea are done both by the vender and purchaser.

3.1.1. Macroscopic analyses

Macroscopic or visual examination is used for the identification of undeclared products or unwanted substances including non-vegetable materials, non-tea materials and moulds. An evaluation of the overall general appearance of the leaves is carried out using this method. Sieves can also be used to separate any foreign bodies which are amongst the tea leaves.

3.1.2. Sensory testing

The acceptability of the tea leaves processed in the factory is generally assessed by sensory evaluation and human panel tests. Skilled and fully trained personnel carry out these sensory assessments to judge the overall tea quality. These expert 'tea tasters' organoleptically determine the market value of the final product by considering the size and shape of leaf, colour and flavour. Teas are tasted after processing, on arrival at the auctions and after blending. Sensory analyses represent a high cost for the tea industry. It has been argued that this practical evaluation of tea quality is entirely subjective and may lead to inaccurate results owing to adaptation, fatigue and state of mind [48]. However, this testing method is still widely used throughout the whole tea supply chain. It is still the most efficient and cost effective way to assess tea acceptability. ISO 3110 [49] can be used for the preparation of liquor for use in sensory tests, however there is currently no ISO standard for tea sensory analyses.

3.1.3. Determination of compounds

The determination of many compounds in tea can provide information about the variety, category and geographical origin of the tea. For instance low levels of caffeine and polyphenol values will reveal substitution of tea by other material or the inclusion of already used tea leaves.

ISO 14502-1 [34] was developed for the determination of total polyphenol content of leaf tea and instant tea in a colorimetric *in vitro* assay using Folin-Ciocalteu reagent. It is applicable to both green and black tea products.

Chromatographic techniques can provide accurate, reproducible results although they are sample destructive and time consuming. High performance liquid chromatography (HPLC) has shown good separations of tea phenolic compounds [50]. HPLC is widely used for the quantification of compounds including: tea catechins, gallic acid, purine alkaloids, theanine in tea because of its high efficiency and high resolution [51]. The quantification of catechins using HPLC has been used to detect geographical origin of tea [52–54].

ISO 14502-2 [35] specifies a HPLC method for the determination of the total catechin content of tea from the summation of 9 individual catechins. It is applicable to both leaf and instant green tea and has precision limitations to black tea. Gallic acid, theogallin and caffeine can also be determined by this method. ISO 19563 [36] specifies a HPLC method for the determination of total theanine in tea. There is currently no standard method for the quantification of theaflavins however this is under development by ISO.

3.2. Other commonly used methods

3.2.1. DNA-based methods

Molecular markers and genetic fingerprints have been studied by several research groups worldwide whose results have differentiated tea cultivars. Several sets of simple sequence repeats (SSRs) have been identified, for instance, in a recent publication using 6 SSRs markers, with a probability of identity between two random cultivars for the whole set of 6 SSR markers was estimated to be 2.22×10^{-5}, enabled full identification of 66 tested tea cultivars [75]. In another study using SNP (single nucleotide polymorphism) markers in combination with a high-throughput genotyping protocol, authors have established and verified specific DNA fingerprints using 60 SNPs for 40 tea varieties from China [76]. DNA-based methods are useful for variety authentication and quality control of premium teas for the industry as well as the management of tea genetic resources and breeding, where accurate and efficient genotype identification is essential.

3.2.2. Spectroscopic methods

During the past decades, spectroscopic methods had been investigated for their effectiveness in the quality control of teas. The most studied techniques include near-infrared spectroscopy (NIR), nuclear magnetic resonance spectroscopy (NMR) and atomic spectroscopy, such as isotope ratio mass spectrometry (IRMS). These techniques are highly repeatable, reproducible and environmentally friendly. In tea authentication, several studies have demonstrated their potential which still has to be translated in routine testing laboratories for a wide use by tea industrial organisations.

3.2.2.1. IRMS

Mass spectrometry is one of the most sensitive techniques that can be used for identification of compounds. IRMS is a rapid, reproducible technique. Stable isotope signatures of both tea leaves and tea infusions have been investigated to identify the geographical origin in several studies. Results have demonstrated the potential for IRMS to determine geographical origin in tea samples [68,69].

3.2.2.2. NMR

NMR has been widely used for metabolic profiling in medicinal plants. It provides a very fast and detailed analysis of the biomolecular composition of crude extracts. NMR spectrum is a physical characteristic of a compound and thus highly reproducible. NMR has demonstrated the ability to identify authenticity issues associated with tea including quality and geographical origin [67].

3.2.2.3. NIR

NIR spectroscopy is a fast, accurate and non-destructive analytical tool. Many studies have demonstrated the ability for NIR spectroscopy and multivariate calibration to quantify the chemical composition of teas and classify tea products into different categories [55,56], varieties [57–63], age [64] and geographical origin [39,57,65,66]. The NIR applications in tea studies show great potential for the instrument to be applied in the industry to detect authenticity parameters. Handheld portable NIR spectrometers could also be implemented online during tea production or used at tea auctions to verify authentication.

3.2.3. Other chromatographic techniques

Other chromatography methods such as high performance thin-layer chromatography (HPTLC) [70], ultra-high performance liquid chromatography (UHPLC), capillary electrophoresis (CE) [71,72] and gas chromatography (GC) with their combination with mass spectrometry (MS) have been used to determine the internal components in tea [73,74]. They usually involve expensive instrumentation and time-consuming sample preparation using solvents as well as analysis. They are therefore not suitable for quality assurance during processing for rapid analysis or online monitoring of chemical composition.

3.3. Future analytical perspectives

In order to enable food industries to rapidly respond to food adulteration, fraud and unauthentic tea products, new analytical tools are continuously being developed for instantly determining chemical composition. These techniques include computer vision technologies and electronic sensors which are easy-to-use and could potentially be used in the future if they can be developed to provide the relevant information associated with authenticity parameters.

3.3.1. Electronic sensors

The imitation of human senses using sensor arrays and pattern recognition systems has been investigated. This technique is known as electronic sensing. Within the last two decades, a considerable amount of research has focused on investigating the use of electronic sensing techniques, such as electronic nose (E-nose) and electronic tongue (E-tongue) to detect quality parameters in tea powder and infusions.

3.3.1.1. E-nose

The E-nose is designed to mimic the mammalian sense of smell by producing a composite response unique to each odorant. As an important quality factor of tea, aroma depends upon the amount of volatile organic compounds and their ratios. Compared with the conventional methods, it is an increasingly reliable, fast, and robust technology. Over the last decade, numerous applications of E-nose in tea quality detection have been reported and many studies have been dedicated to improve the capability. Preliminary results from studies have demonstrated the ability of the E-nose to be a valuable method for targeting potential and future tea authenticity issues including; tea grades [77,78], types [79], varieties [80,81], categories [82], geographical origin [80,83] and storage times [84].

3.3.1.2. E-tongue

The E-tongue is an analytical instrument that artificially reproduces the taste sensation [85]. The taste of tea infusions is the influential attribute of sensory information. It is an important factor in both assessing tea quality and classifying tea grades. E-tongue instruments have shown good precision, accuracy and reliability, but they are time-consuming, destructive and unsuitable for online monitoring. Thus, this technique opens up new avenues in taste sensing and could be successfully implemented in the near future for tea analysis. Studies have demonstrated the ability of the E-tongue to discriminate tea varieties [86,87], geographical origin [88], grades [88–94]and fermentation degree [95]. The benefits are still unclear over traditional tea tasters as it is time consuming, not practical and does not give the same resolution as a human taster.

3.3.2. Computer vision applications

Computer vision systems are becoming increasingly popular within the food industry. Computer vision provides an automated, non-destructive and cost-effective technique to analyse products. This approach is based on image analysis and has provided a great potential in tea quality assessment. Multi-spectral, hyperspectral and normal camera imaging are the most commonly studied computer vision tools. It is expected that computer vision will become an emerging platform technology in the future.

3.3.2.1. Multi-spectral imaging

Multi-spectral imaging is a technique which captures images using specific wavelength regions which are usually separated by filters. The multi-spectral imaging system applied to assess tea quality typically consists of a three-channel common aperture camera, a frame grabber, numerous tungsten halogen lights and a computer [96]. Multi-spectral imaging is developed based on hyperspectral imaging using the selected wavelengths, thus it is advantageous than hyperspectral imaging as it accumulates less data. Multi-spectral imaging techniques have been able to identify tea categories [97–99], grades [100] and brands [101].

3.3.2.2. Hyperspectral imaging

Hyperspectral imaging is a developing technique that integrates conventional spectroscopy and digital imaging to gather chemical information and visualise spatial distribution of chemical constituents within a matrix. The device system typically contains the following components: objective lens, spectrograph, camera, acquisition system, translation stage, illumination, and computer [96]. Hyperspectral images which are known as hypercubes are three-dimensional blocks of data, comprising of two spatial and one wavelength dimension. After hyperspectral image acquisition, spectral pre-processing, variables selection, image extraction and processing are completed for analysis. Some research has demonstrated that tea grade [102,103], quality [104] can be determined using this technology.

3.3.2.3. Normal camera imaging

Normal camera imaging is another commonly used computer vision tool. Tea classification studies have demonstrated the ability for normal camera imaging to discriminate; tea grades [105], varieties [106,107] and colour [108].

4. Overview of methods for authenticity testing

The following table provides a summary of the methods and the authenticity issues they address.

Analytical technique	Indicative data or analyte	Authenticity issue / information
Sensory analysis	Visual, olfactory and taste scores	Tea grades, adulteration
Macroscopic observation	Visual assessment	Adulteration
Sieving	Foreign bodies	Adulteration
HPLC	Catechins and theaflavins	Geographical origin
HPTLC	Catechin compounds	Geographical origin
CE	Catechins, caffeine, theanine and other amino acids	Geographical origin
IRMS	Catechin and theaflavins	Geographical origin
NIR	Catechin compounds	Tea categories, geographical origin, varieties, age
NMR	Amino acids, organic acids, caffeine and catechins	Geographical origin and quality
SSR fingerprinting	Genome	Varietal identification
SNP fingerprinting	Genome EST transcriptome	Varietal identification
E-Nose	Volatile organic compounds	Tea grades, types, varieties, categories, geographical origin, storage times
E-Tongue	Catechins, amino acids and caffeine	Tea varieties, geographical origin, grades, fermentation degree
Multi-spectral imaging	Image analysis	Tea categories, grades, brands
Hyperspectral Imaging	Image analysis	Tea grades, quality
Normal Camera Imaging	Image analysis	Tea grades, varieties, colour

5. Conclusion

Tea is recognised as one of the world's most popular beverages and the authenticity of tea relies on many factors linked to the chemical composition of the final product. Global and EU legislation and standards have been developed to ensure quality and safety of tea products. The most problematic authenticity issues discovered in the industry to-date include mislabelling of tea grades and geographical origin.

Wet chemical analysis is currently used for the determination of the main quality parameters of tea, however, it would be more efficient to use alternative methods which are rapid, non-destructive and not labour intense. Looking into the future, spectroscopic, electronic or computer vision sensors would be ideal for detecting authenticity in tea products. Portable sensors could be utilised in tea factories or by purchasers to determine the chemical composition of the product. They would be beneficial at auctions to verify the tea leaf grading process and the quality of the product. The studies which investigate the use of these rapid techniques have demonstrated early evidence that these recently developed technologies have been equally reliable as chromatographic methods which are standard methods used to test for authenticity by regulatory bodies.

It is significant that enhanced detection methods are developed and utilised in industry to ensure tea authentication. Food NIR or NMR fingerprinting approaches are expected to become very effective methods in authentication verification aiming at products with complex compositions such as teas. These approaches aim to capture as many compounds or features as possible to gain a comprehensive insight into the composition of the sample. A comparison of authentic samples may allow revealing mislabelled or adulterated products.

Global climate change will have a great impact on the growth of tea, its end quality and finally on tea prices. The increase in temperature and extreme weather events pose a major threat to the resilience of tea production systems. Significant change in climate may result in the major tea producing countries becoming less suitable for tea cultivation in the future. Therefore there is an increased risk of adulteration of high value origin teas being blended with cheaper teas.

6. Bibliographic references

1. Preedy V.R. (2013). – *Tea in health and disease prevention*. Elsevier.
2. Statista. Size of the global tea beverage market 2013-2021 (2018). Available at: https://www.statista.com/statistics/326384/global-tea-beverage-market-size/.
3. UK Tea and Infusions Association. – Tea Glossary and FAQ's. Available at: https://www.tea.co.uk/tea-faqs.
4. Tea and Herbal Infusions Europe – Tea market data. Available at: http://www.thie-online.eu/tea/market-data/.
5. Ministry of Foreign Affairs (2016). – *CBI Market channels and segments: Tea*. Netherlands.
6. Potts J., Lynch M., Wilkings A., Huppe G., Cunningham M. & Voora V. (2014). – Tea Market. . In *The State of Sustainability Initiatives Review 2014: Standards and the Green Economy*. pp 297–322
7. UK Tea and Infusions Association. – Tea Processing and Blending. Available at: https://www.tea.co.uk/tea-processing-and-blending.
8. Balentine D.A., Wiseman S.A. & Bouwens L.C. (1997). – The chemistry of tea flavonoids. *Crit. Rev. Food Sci. Nutr.*, **37** (8), 693–704.
9. Harbowy M.E., Balentine D.A., Davies A.P. & Cai Y. (1997). – Tea Chemistry. *CRC. Crit. Rev. Plant Sci.*, **16** (5), 415–480.
10. Obanda M., Okinda Owuor P. & Mang'oka R. (2001). – Changes in the chemical and sensory quality parameters of black tea due to variations of fermentation time and temperature. *Food Chem.*, **75** (4), 395–404.
11. Tea and Herbal Infusions Europe – Types of tea. Available at: http://www.thie-online.eu/tea/types-of-tea/.
12. UK Tea and Infusions Accociation. – Teas from China. Available at: http://www.tea.co.uk/teas-from-china.
13. Tea and Herbal Infusions Europe (2016). – Compendium of Guidelines for Tea (Camellia sinensis). (4), 1–13.
14. Tea and Herbal Infusions Europe – Herbal materials. Available at: http://www.thie-online.eu/herbal-infusions/herbal-materials/.
15. Senthil Kumar R.S., Murugesan S., Kottur G. & Gyamfi D. (2013). – Black Tea: The Plants, Processing/Manufacturing and Production. *Tea Heal. Dis. Prev.*, , 41–57.
16. Khan N. & Mukhtar H. (2007). – Tea polyphenols for health promotion. **81**, 519–533.
17. Sharma R. (2014). – Polyphenols in Health and Disease: Practice and Mechanisms of Benefits. *Polyphenols Hum. Heal. Dis.*, , 757–778.
18. Spiller G. (1997). – *Caffeine*. CRC Press.
19. Trevisanato S.I. & Kim Y.I. (2009). – Tea and Health. *Nutr. Rev.*, **58** (1), 1–10.

20. Bhoo Pathy N., Peeters P., Gils C. van, Beulens J.W.J., Graaf Y. van der, Bueno-de-Mesquita B., Bulgiba A. & Uiterwaal C.S.P.M. (2010). – Coffee and tea intake and risk of breast cancer. *Breast Cancer Res. Treat.*, **121** (2), 461–467.

21. Deka A. & Vita J.A. (2011). – Tea and cardiovascular disease. *Pharmacol. Res.*, **64** (2), 136–145.

22. Dominguez-Perles R., Moreno D.A., Carvajal M. & Garcia-Viguera C. (2011). – Composition and antioxidant capacity of a novel beverage produced with green tea and minimally-processed byproducts of broccoli. *Innov. Food Sci. Emerg. Technol.*, **12** (3), 361–368.

23. Hsu S. (2005). – Green tea and the skin. *J. Am. Acad. Dermatol.*, **52** (6), 1049–1059.

24. Mukhtar H. & Ahmad N. (2000). – Tea polyphenols: prevention of cancer and optimizing health1–3. *Am. Soc. Clin. Nutr.*, **71** (6), 1698–1702.

25. Setiawan V.W., Zhang Z.F., Yu G.P., Lu Q.Y., Li Y.L., Lu M.L., Wang M.R., Guo C.H., Yu S.Z., Kurtz R.C. & Hsieh C.C. (2001). – Protective effect of green tea on the risks of chronic gastritis and stomach cancer. *Int. J. Cancer*, **92** (4), 600–604.

26. ISO Standard (2011). – Black tea - Definition and basic requirements. **IS0 3720**. Available at: https://www.iso.org/standard/51541.html.

27. ISO Standard (2011). – Green tea - Definition and basic requirements. **ISO 11287**. Available at: https://www.iso.org/standard/51540.html.

28. ISO Standard (2013). – White tea - Definition. **ISO 12591**. Available at: https://www.iso.org/standard/51542.html.

29. ISO Standard (1990). – Instant tea in solid form - Specification. **ISO 6079**. Available at: https://www.iso.org/standard/12280.html.

30. ISO Standard (1987). – Tea - Determination of total ash. **ISO 1575**. Available at: https://www.iso.org/standard/6170.html.

31. ISO Standard (1988). – Tea - Determination of water-soluble ash and water-insoluble ash. **ISO 1576**. Available at: https://www.iso.org/standard/6172.html.

32. ISO Standard (1987). – Tea - Determination of acid-insoluble ash. **ISO 1577**. Available at: https://www.iso.org/standard/6174.html.

33. ISO Standard (1975). – Tea - Determination of alkalinity of water-soluble ash. **ISO 1578**. Available at: https://www.iso.org/standard/6175.html.

34. ISO Standard (2005). – Characteristic of green and black tea —Part 1: Content of total polyphenols in tea — Colorimetric method using FolinCiocalteu reagent. **ISO 14502**. Available at: https://www.iso.org/standard/31356.html.

35. ISO Standard (2005). – Determination of substances characteristic of green and black tea — Part 2: Content of catechins in green tea — Method using high-performance liquid chromatography. **ISO 14502**. Available at: https://www.iso.org/standard/31357.html.

36. ISO Standard (2017). – Determination of theanine in tea and instant tea in solid form using high-performance liquid chromatography. **ISO 19563**. Available at: https://www.iso.org/standard/65341.html.

37. ISO Standard (1999). – Tea - Determination of crude fibre content. **ISO 15598**. Available at: https://www.iso.org/standard/28336.html.

38. UK Tea and Infusions Association. – Tea - A Brief History of the Nation’s Favourite Beverage. Available at: https://www.tea.co.uk/tea-a-brief-history.

39. Diniz P.H.G.D., Gomes A.A., Pistonesi M.F., Band B.S.F. & Araújo M.C.U. de (2014). – Simultaneous Classification of Teas According to Their Varieties and Geographical Origins by Using NIR Spectroscopy and SPA-LDA. *Food Anal. Methods*.

40. Han W., Li X., Yan P., Zhang L. & Jalal G. (2017). – Tea cultivation under changing climate conditions. . In *Global tea science: Current status and future needs*

41. Lal R. (2005). – *Climate change and global food security*. Taylor & Francis.

42. Wang S.. & Jin Z.F. (2010). – Climate and tea cultivation with high yield and better quality. , China Meteorological Press, Beijing

43. Ahmed S., Stepp J.R., Orians C., Griffin T. & Matyas C. (2014). – Effects of Extreme Climate Events on Tea (Camellia sinensis) Functional Quality Validate Indigenous Farmer Knowledge and Sensory Preferences in Tropical China. *PLoS One*, **9** (10), 109–126.

44. Larson C. (2015). – Reading the tea leaves for effects of climate change. **348**, 953–954. Available at: www.sciencemag.org.

45. Li X., Zhang L., Ahammed G.J., Li Z.X., Wei J.P., Shen C., Yan P., Zhang L.P. & Han W.Y. (2017). – Stimulation in primary and secondary metabolism by elevated carbon dioxide alters green tea quality in Camellia sinensis L. *Sci. Rep.*, **7** (1), 7937.

46. Jiang, Y.L., Zhang, Q.G., Zhang S.. (2006). – Effects of atmospheric CO2 concentration on tea quality. *J. Tea Sci.*, **26**, 299–304.

47. Sharma V.S., Gunasekare K., Barman T.S., Chen L. & Wang X.C. (2018). – *Global Tea Science Current Status and Future Needs*.

48. J. Yang, Fu, Z.G. Lou, L.Y. Wang, G. Li W.. (2006). – Tea classification based on artificial olfaction using bionic olfactory neural network. *Free. Adv. Neural Networks*, **3972**, 343–348.

49. ISO Standard (1980). – Tea - Preparation of liquor for use in sensory tests. **ISO 3103**. Available at: https://www.iso.org/standard/8250.html.

50. Dalluge J. & Nelson B. (2000). – Determination of tea catechins. *J. Chromatogr. A*, **881**, 411–424.

51. Peng L., Song X., Shi X., Li J. & Ye C. (2008). – An improved HPLC method for simultaneous determination of phenolic compounds, purine alkaloids and theanine in Camellia species. *J. Food Compos. Anal.*, **21** (7), 559–563. Available at: www.elsevier.com/locate/jfca.

52. Wang L., Wei K., Cheng H., He W., Li X. & Gong W. (2014). – Geographical tracing of Xihu Longjing tea using high performance liquid chromatography. *Food Chem.*, **146**, 98–103.

53. He X., Li J., Zhao W., Liu R., Zhang L. & Kong X. (2015). – Chemical fingerprint analysis for quality control and identification of Ziyang green tea by HPLC. *Food Chem.*, **171**, 405–411.

54. Pedro L. Fernández, Fernando Pablos, Martín M.J. & González A.G. (2002). – Study of Catechin and Xanthine Tea Profiles as Geographical Tracers. *J. Agric. Food Chem.*, **50** (7), 1833–1839.

55. Chen Q.S., Zhao J.W., Fang C.H. & Wang D.M. (2007). – Feasibility study on identification of green, black and Oolong teas using near-infrared reflectance spectroscopy based on support vector machine (SVM). *Spectrochim. Acta Part a-Molecular Biomol. Spectrosc.*, **66**, 568–574.

56. Zhao J.W., Chen Q.S., Huang X.Y. & Fang C.H. (2006). – Qualitative identification of tea categories by near infrared spectroscopy and support vector machine. *J. Pharm. Biomed. Anal.* , **41**, 1198–1204.

57. Liu S.L., Tsai Y.S. & Ou A.S.M. (2010). – Classifying the variety, production area and season of Taiwan partially fermented tea by near infrared spectroscopy. *J. Food Drug Anal.*, **18**, 34–43.

58. Tan S.M., Luo R.M., Zhou Y.P., Xu H., Song D.D., Ze T. & et al. (2012). – Boosting partial least-squares discriminant analysis with application application to near infrared spectroscopic tea variety discrimination. *J. Chemom.*, **26**, 34–39.

59. Chen Q., Zhao J., Zhang H. & Wang X. (2006). – Feasibility study on qualitative and quantitative analysis in tea by near infrared spectroscopy with multivariate calibration. *Anal. Chim. Acta*, **572** (1), 77–84.

60. He Y., Li X.L. & Deng X.F. (2007). – Discrimination of varieties of tea using near infrared spectroscopy by principal component analysis and BP model. *J. Food Eng.*, **79**, 1238–1242.

61. Li X.L., He Y. & Qiu Z.J. (2007). – Application PCA-ANN method to fast discrimination of tea varieties using visible/near infrared spectroscopy. *Spectrosc. Spectr. Anal.*, **27**, 279–282.

62. Chen Q.S., Zhao J.W., Zhang H.D., Liu M.H. & Fang M. (2005). – Qualitative identification of tea by near infrared spectroscopy based on soft independent modelling of class analogy pattern recognition. *J. near Infrared Spectrosc.*, **13**, 327–332.

63. Chen Q.S., Zhao J.W., Liu M.H. & Cai J.R. (2008). – Nondestructive identification of Tea (Camellia sinensis L.) varieties using FT-NIR spectroscopy and pattern recognition. *Czech J. Food Sci.*, **26**, 360–367.

64. Schulz H., Engelhardt U.H., Wegent A., Drews H.H. & Lapczynski S. (1999). – Application of near-infrared reflectance spectroscopy to the simultaneous prediction of alkaloids and phenolic substances in green tea leaves. *J. Agric. Food Chem.*, **47**, 5064–5067.

65. Chen Q.S., Zhao J.W. & Lin H. (2009). – Study on discrimination of Roast green tea (Camellia sinensis L.) according to geographical origin by FT-NIR spectroscopy and supervised pattern recognition. *Spectrochim. Acta Part A e Mol. Biomol. Spectrosc.*, **72**, 845–850.

66. Zhou J., Cheng H., He W., Wang L.Y., Liu X. & Lu W.Y. (2009). – Short communication: identification of geographical indication tea with Fisher's discriminant classification and principal components analysis. *J. near Infrared Spectrosc.*, **17**, 159–164.

67. Gwénaëlle Le Gall, Ian J. Colquhoun A. & Defernez M. (2004). – Metabolite Profiling Using 1H NMR Spectroscopy for Quality Assessment of Green Tea, Camellia sinensis (L.). *J. Agric. Food Chem.*, **52** (4), 692–700.

68. Pilgrim T.S., Watling R.J. & Grice K. (2010). – Application of trace element and stable isotope signatures to determine the provenance of tea (Camellia sinensis) samples. *Food Chem.*, **118** (4), 921–926.

69. Cengiz M.F., Turan O., Ozdemir D., Albayrak Y., Perincek F. & Kocabas H. (2017). – Geographical origin of imported and domestic teas (Camellia sinensis) from Turkey as determined by stable isotope signatures. *Int. J. Food Prop.*, **20** (12), 3234–3243.

70. Reich E., Schibli A., Widmer V., Jorns R., Wolfram E. & DeBatt A. (2006). – HPTLC Methods for Identification of Green Tea and Green Tea Extract. *J. Liq. Chromatogr. Relat. Technol.*, **29** (14), 2141–2151.

71. Gotti R., Furlanetto S., Lanteri S., Olmo S., Ragaini A. & Cavrini V. (2009). – Differentiation of green tea samples by chiral CD-MEKC analysis of catechins content. *Electrophoresis*, **30** (16), 2922–2930.

72. Kodama S., Ito Y., Nagase H., Yamashita T., Kemmei T., Yamamoto A. & Hayakawa K. (2007). – Usefulness of Catechins and Caffeine Profiles to Determine Growing Areas of Green Tea Leaves of a Single Variety, Yabukita, in Japan. *J. Heal. Sci.*, **53** (4), 491–495.

73. Rio D. Del, Stewart A.J., Mullen W., Burns J., Lean M.E.J., Brighenti F. & Crozier A. (2004). – HPLC-MSn Analysis of Phenolic Compounds and Purine Alkaloids in Green and Black Tea. *J. Agric. Food Chem.*, **52** (10), 2807–2815.

74. Pongsuwan W., Bamba T., Yonetani T., Kobayashi A. & Fukusaki E. (2008). – Quality Prediction of Japanese Green Tea Using Pyrolyzer Coupled GC/MS Based Metabolic Fingerprinting. *J. Agric. Food Chem.*, **56** (3), 744–750.

75. Wang R.J., Feng Gao X., Kong X.R. & Yang J. (2016). – An efficient identification strategy of clonal tea cultivars using long-core motif SSR markers. *J. Agric. Food Chem.*, **52** (10), 2807–2815.

76. Fang W.P., Meinhardt L.W., Tan H.W., Zhou L., Mischke S. & Zhang D. (2014). – Varietal identification of tea (Camellia sinensis) using nanofluidic array of single nucleotide polymorphism (SNP) markers. *Hortic. Res.*, **1** (1), 1–8.

77. Chen Q., Zhao J., Chen Z., Lin H. & Zhao D.A. (2011). – Discrimination of green tea quality using the electronic nose technique and the human panel test, comparison of linear and nonlinear classification tools. *Sensors Actuators B Chem.*, **159** (1), 294–300.

78. Qin Z., Pang X., Chen D., Cheng H., Hu X. & Wu J. (2013). – Evaluation of Chinese tea by the electronic nose and gas chromatography–mass spectrometry: Correlation with sensory properties and classification according to grade level. *Food Res. Int.*, **53** (2), 864–874.

79. Nouretdinov I., Li G., Gammerman A. & Luo Z. (2010). – Application of Conformal Predictors to Tea Classification Based on Electronic Nose. . In *Artificial Intelligence Applications and Innovations*, Springer, Berlin, Heidelberg. pp 303–310

80. Bhattacharyya N., Bandyopadhyay R. & Bhuyan M. (2008). – Electronic nose for black tea classification and correlation of measurements with tea taste marks. *IEEE Trans. Instrum. Meas.*, **57**, 1313–1321.

81. Li X.L., He Y. & Qui Z.J. (2007). – Application PCA-ANN method tofast discrimination of tea varieties using visible/near infrared spectroscopy. *Spectrosc. Spectr. Anal.*, **27**, 279–282.

82. Chen Q., Liu A., Zhao J. & Ouyang Q. (2013). – Classification of tea category using a portable electronic nose based on an odor imaging sensor array. *J. Pharm. Biomed. Anal.*, **84**, 77–83.

83. Tudu B., Bhattacharyya N. & Bikram K. (2008). – Comparison of multivariate normalization techniques as applied to electronic nose based pattern classification for black tea. . In *Proceedings ofthe Third International Conference on Sensing Technology*. pp 254–258

84. Yu H.C., Wang Y.W. & Wang J. (2009). – Identification of Tea storage times by linear discrimination analysis and back-propagation neural network techniques based on the eigenvalues of principal components analysis of E-nose sensor signals. *Sensors*, **9**, 8073–8082.

85. Escuder-Gilabert L. & Peris M. (2010). – Review: Highlights in recent applications of electronic tongues in food analysis. *Anal. Chim. Acta*, **665**, 15–25.

86. Ivarsson P., Holmin S., Höjer N.E., Krantz-Rülcker C. & Winquist F. (2001). – Discrimination of tea by means of a voltammetric electronic tongue and different applied waveforms. *Sensors Actuators B Chem.*, **76** (1–3), 449–454.

87. Tian S.Y., Deng S.P. & Chen Z.X. (2007). – Multifrequency large amplitude pulse voltammetry: A novel electrochemical method for electronic tongue. *Sensors Actuators B Chem.*, **123** (2), 1049–1056.

88. He W., Hu X., Zhao L., Liao X., Zhang Y., Zhang M. & Wu J. (2009). – Evaluation of Chinese tea by the electronic tongue: Correlation with sensory properties and classification according to geographical origin and grade level. *Food Res. Int.*, **42** (10), 1462–1467.

89. Bhattacharyya R., Tudu B., Das S.C., Bhattacharyya N., Bandyopadhyay R. & Pramanik P. (2012). – Classification of black tea liquor using cyclic voltammetry. *J. Food Eng.*, **109**, 120–126.

90. Palit M., Bhattacharyya N., Sarkar S., Dutta A., Dutta P.K., Tudu B. & Bandyopadhyay R. (2008). – Virtual Instrumentation Based Voltammetric Electronic Tongue for Classification of Black Tea. . In *2008 IEEE Region 10 and the Third international Conference on Industrial and Information Systems*, IEEE. pp 1–6

91. Palit M., Tudu B., Bhattacharyya N., Dutta A., Dutta P.K., Jana A., Bandyopadhyay R. & Chatterjee A. (2010). – Comparison of multivariate preprocessing techniques as applied to electronic tongue based pattern classification for black tea. *Anal. Chim. Acta*, **675** (1), 8–15.

92. Palit M., Tudu B., Dutta P.K., Dutta A., Jana A., Roy J.K., Bhattacharyya N., Bandyopadhyay R. & Chatterjee A. (2010). – Classification of Black Tea Taste and Correlation With Tea Taster's Mark Using Voltammetric Electronic Tongue. *IEEE Trans. Instrum. Meas.*, **59** (8), 2230–2239.

93. Chen Q., Zhao J. & Vittayapadung S. (2008). – Identification of the green tea grade level using electronic tongue and pattern recognition. *Food Res. Int.*, **41** (5), 500–504.

94. Xiao H. & Wang J. (2009). – Discrimination of Xihulongjing tea grade using an electronic tongue. *African J. Biotechnol.*, **8** (24), 6985–6992.

95. Nieh C.H., Hsieh B.C., Chen P.C., Hsiao H.Y., Cheng T.J. & Chen R.L.C. (2009). – Potentiometric flow-injection estimation of tea fermentation degree. *Sensors Actuators B Chem.*, **136** (2), 541–545.

96. Chen Q., Zhang D., Pan W., Ouyang Q., Li H., Urmila K. & Zhao J. (2015). – Recent developments of green analytical techniques in analysis of tea's quality and nutrition. *Trends Food Sci. Technol.*, **43** (1), 63–82.

97. Chen X.J., Di W., He Y., Li X.L. & Liu S. (2008). – Study on discrimination of tea based on color of multispectral image. *Spectrosc. Spectr. Anal.*, **28** (11), 2527–30.

98. Wu D., Chen X.J. & He Y. (2009). – Application of multispectral image texture to discriminating tea categories based on DCT and LS-SVM. *Spectrosc. Spectr. Anal.*, **29**, 1382–1385.

99. Li X.L., He Y., Qui J. z, Bao Y., Qiu Z.J. & Bao Y. (2008). – Tea category classification using morphological characteristics and support vector machines. . In *28th International Congress on High-Speed Imaging and Photonic*, International Society for Optics and Photonics, Canberra, Australia.

100. Li X.L. & He Y. (2009). – Classification of tea grades by multi-spectral images and combined features. *Trans. Chinese Soc. Agric. Mach.*, **40**, 113–118.

101. Li X.L., He Y. & Qiu Z.J. (2008). – Textural feature extraction and optimization in wavelet sub-bands for discrimination of green tea brands. . In *International Conference on Machine Learning and Cybernetics*, IEEE. pp 1461–1466

102. Jiang F., Qiao X., Zheng H. & Yang Q. (2011). – Grade discrimination of machine-fried Longjing tea based on hyperspectral technology. *Trans. Chinese Soc. Agric. Mach.*, **27**, 343–348.

103. Zhao J.W., Chen Q.S., Cai J.R. & Ouyang Q. (2009). – Automated tea quality classification by hyperspectral imaging. *Appl. Opt.*, **48**, 3557–3564.

104. Zhao J.W., Wang K.L., Ouyang Q. & Chen Q.S. (2011). – Measurement of chlorophyll content and distribution in tea plant's leaf using hyperspectral imaging technique. *Spectrosc. Spectr. Anal.*, **31** (2), 512–5.

105. Wang J., Zeng X.Y. & Du S.P. (2010). – Identification and grading of tea using computer vision. *Appl. Eng. Agric.*, **26**, 639–645.

106. Chen Q.S., Zhao J.W. & Cai J.R. (2008). – Identification of tea color by using computer vision. *Trans. ASABE*, **51**, 623–628.

107. Chen Q.S., Zhao J.W., Cai J.R. & Wang X.Y. (2006). – Study on identification of tea using computer vision based on support vector machine. *Chinese J. Sci. Instrum.*, **12**, 031.

108. Chen Q.S., Zhao J.W. & Cai J. (2008). – Identification of tea varieties using computer vision. *Trans. ASABE*, **51** (2), 623–628.