NFSU JOURNAL OF FORENSIC SCIENCE
ISSN: 3049-2408 (Online)
Journal Homepage: https://jfs.nfsu.ac.in/

A Compendious Review of Adulteration and Forensic Analysis of Non-Alcoholic Beverages

Lovlish Gupta[1], Vijendra Kumar[2], Neha Tomar[1,*] and Rajendra Kumar Sarin[1]
[1]School of Forensic Sciences, National Forensic Sciences University, Delhi, India
[2]Regional Centre for Biotechnology, Faridabad, India
[neha.tomar_dc@nfsu.ac.in] (Corresponding Author) *

Abstract

Non-alcoholic beverages (NABs) are incumbent part of our life. Humans around the globe have integrated the consumption of NABs as a lifestyle routine. In such a scenario, the adulteration of such commonly used beverages is of great concern. The present paper reviews and presents the extensive literature on adulterants of commonly used NABs such as tea, coffee, milk, juices, soda water, carbonated drinks, etc. The paper also presents extensive review on the forensic chemical analysis and instrumental analysis of such NABs. Various instruments used in the forensic analysis include Gas Chromatography- Mass Spectroscopy (GC-MS), Liquid Chromatography Mass Spectrometry (LC-MS), High-Performance Liquid Chromatography (HPLC), (Ultraviolet-Visible) UV-vis Spectroscopy, and isotopic dilution, etc. The routine analysis of these NABs is based on the margin of exposure approach made by the European Food Safety Authority (EFSA). This review synthesizes data from three prominent databases - Web of Science, Scopus, and Google Scholar - to investigate patterns of adulteration and forensic analysis in NABs.

Keywords: *Non-Alcoholic, Beverages, Adulterants, Forensic analysis.*

1. Introduction

Non-alcoholic beverages (NABs) have evolved from being a mere choice to an indispensable part of daily life, integral to human consumption and well-being. NABs comprise a diverse range of drinks that are inherently alcohol-free or have undergone processing to eliminate or prevent alcohol content. These beverages include naturally alcohol-free options such as water, fresh fruit juices, teas, coffee, and infused drinks. Additionally, de-alcoholised beverages like de-alcoholised beer and wine, as well as low-alcohol versions of traditional spirits, are also available. Soft drinks, energy drinks, sports drinks, flavoured sparkling water, and mocktails are formulated to avoid alcohol formation during production. Specialized beverages like kombucha, kefir, vegetable juices, and plant-based milks also fall under this category. These NABs cater to diverse consumer preferences, including health-conscious individuals, those with dietary restrictions, and individuals seeking alternatives to traditional alcoholic drinks. NABs, which

comprise soft drinks, fruit juices, tea, coffee, milk, and water, are vulnerable to adulteration. Table 1 analyses the major segments branching of NABs.

Table 1. Different categories of NABs.

Different alcoholic Beverages	Examples
Naturally Alcohol-Free Beverages	Water, fruit, juices, teas, coffee, infused drinks
De-alcoholised beverages	Dealcoholized Beer, Wine, Low-Alcohol Spirits.
Formulated beverages	Soft Drinks, Energy Drinks, Sports Drinks, Mocktails, Flavoured Sparkling Water
Specialized beverages	Kombucha, Kefir, Vegetable Juices, Plant-Based Milks.

The contamination with harmful substances, microorganism contamination, unapproved additives, and mislabelling defines adulteration. Forensic significance of such beverages is substantial and can lead to several foodborne illnesses, fraud, and legal consequences [1]. Daily consumption of NABs such as tea, coffee, soft drinks, and mocktails has become ubiquitous, driven by their stimulating effects, nutritional value, and versatility in meeting various consumer needs, from energy boosts to health-conscious choices [2]. To combat this, forensic scientists employ various techniques, including physical examination, microbiological testing and chemical analysis, as depicted in Table 2. samples.

Table 2. Forensic investigative techniques.

Techniques employed	Description	Methodology
Physical Examination	Inspection for packaging defects, tampering	Odour, physical appearance, texture
Microbiological testing	Identifying harmful microbes	Compound microscope, stereomicroscope, Scanning electron microscope, transmission electron microscope
Chemical analysis	Detection of toxins and preservatives, illegal additives	Colour test, flame test, Thin Layer Chromatography (TLC)
Instrumental analysis	Traceability and ingredient authenticity	UV-vis spectroscopy, Raman spectroscopy, NMR spectroscopy, FT-IR, Gas Chromatography, Liquid

		Chromatography, Mass spectroscopy, etc.

Investigating and prosecuting cases of adulteration ensures the safety and authenticity of these beverages for consumers. Through rigorous examination and analysis, the integrity of NABs can be maintained. The public would be able to trust the quality of products that they are consuming [3]. have no relation with tea consumption.

1.1 Common Non-alcoholic Beverages (NABs): NABs majorly include carbonated drinks, cereal beverages, various fruit drinks such as punches, energy or protein drinks, non-alcoholic beer, milk products, smoothies, sparkling, reduced water beverages [4], [5]. There are various criteria included for the consumption of NABs, some of which are dependent upon the market criteria such as consumer acceptance, cost, quality, consumer satisfaction, and associated health measures. For this cause, routine quality checks and inspections are to be kept on a priority by manufacturers. These quality checks are maintained by both intra and inter-laboratory specifications involving internal calibration, assessment of physical and chemical properties, and third-party inspections, etc. [6], [7]. Another aspect of the analysis of such beverages is concerned with traditional forensic practices. Howbeit, traditional methods for analysing NABs continue to pose significant challenges in routine forensic analysis. Despite advancements, the field still lacks profound and validated techniques, hindering efficient examination. Consequently, forensic experts face substantial difficulties in conducting thorough evaluations. Therefore, this area necessitates urgent attention and ongoing development to establish reliable and robust analytical protocols, ensuring accurate and reliable results in forensic investigations [8]– [10]. Table 3 highlights the quality checks criteria for NABs and forensic analysis.

Table 3. Quality control checks for analysis of NABs.

Major aspects	Criteria	Methodology	Consideration	Ref.
Market criteria	Consumer acceptance and quality, health measures, and consumer satisfaction	Sales data analysis, market surveys, and feedback from consumers	Variations in regional preferences, cost constraints, and health trends	[6], [5]
Routine Quality Checks	Regular calibration, physical and chemical analysis, third-party assessment	Laboratory testing, periodic audits, and industrial standards	Maintenance of calibration, external audits	[7]

1.2 Tea: Tea is the most popular beverage consumed worldwide. It contains caffeine, which stimulates our nervous system. A study was conducted on elemental analysis of tea using neutron activation analysis on different parts of India (Assam, Darjeeling, Munnar, Kangra). It was found that tea is a good source of potassium, manganese, sodium, and iron. The degree of variation was different for different area [11]. There have been certain studies conducted which established a relation between tea consumption and cancer. Excessive consumption of tea increases the possibility of esophageal cancer [11], [12]. Howbeit, certain studies also established that tea consumption reduces the possibility of esophageal cancer in women [13]. In 2020, Lin et al. conducted a study among 942 patient of esophageal squamous cell carcinoma. He concluded that drinking very hot (>65° C) is

significantly related with risk of esophageal cancer. Consumption of black tea was also associated with greater risk of cancer of kidney, colon and rectal, lungs, pancreas and stomach [14]–[17]. Hot tea consumption followed by alcohol or smoking also increases the risk manifolds [18]. However, literatures have reported that uterus and prostate cancer have no relation with tea consumption.

1.3 Coffee: Coffee belongs to genus *Coffea*, which further belongs to the family Rubiaceae. However, family is composed of various genera such as *Gardenia*, *Ixora*, *Cinhona*, and *Rubia*. The entire world is known for the two major species of coffee tree, i.e., *Coffea arabica* and *Coffea canephora* var. *robusta* [19]. Like tea, coffee have enormous health benefits. Studies have found that consumption of 3 to 4 cups of coffee a day reduces the risk of colorectal cancer by 7%. Coffee contains antioxidants and stimulates central nervous system, cardiovascular system respiratory system [20], [21]. Coffee is diuretic and delays fatigue [22]. Regular consumption of coffee also reduces the risk of liver disease [23]. Table 4 represents several health benefits of coffee consumption.

Table 4. Health benefits of coffee consumption.

Health Benefits	Description	Ref.
Reduced Colorectal cancer risk	Coffee consumption reduces the risk of 7% with 3-4 cups of coffee per day	[19]
Antioxidant properties	Coffee is rich in antioxidants; help fight oxidative stress	
CNS stimulation	Stimulates brain activity, increasing alertness and reducing fatigue	
Improves Cardiovascular system	Improves heart health, increases circulation, and may reduce the risk of heart disease	
Improves Respiratory system	Opens airways, supports respiratory function.	
Liver Disease risk	Regular consumption may lower the risk of liver disease	[23]
Diuretic effect	Promotes urination, helps balancing fluid balance	

On the other hand, coffee consumption also increases the probability of premature death. Consuming around 28 cups of coffee per week increases the probability of premature death by 21% [24]. Heavy coffee consumption causes increased heart rate, blood pressure, and peripheral arterial stiffness [25]. High dose consumption can cause miscarriage in pregnant women [26]. Coffee consumption causes insomnia and restlessness in both young and adult [27]. Salari-Moghaddam, A.,

et al., 2019 have demonstrated that different coffee has shown several effects after the risk of ovarian cancer on regular consumption. However, no significant study was conducted evaluating the risk associated with caffeine consumption. However, significant dose-response relationships were established stating that an extra cup in daily intake of coffee may cause ovarian cancer [28]. Coffee consumption causes indigestion [29]. Coffee consumption is beneficial when we have it in moderation i.e., 2-4 cups per day. Overconsumption can have a considerable negative effect on our health [30]. Table 5 represents the negative health consequences of excessive coffee consumption.

Table 5. Negative health effects of coffee consumption.

Health Benefits	Description	Ref.
Premature Death Risk	Consuming 28 cups per week increases the risk of premature death by 21%	[24]
Cardiovascular effects	Increased heart rate, blood pressure, and peripheral arterial stiffness	[25]
Miscarriage Risk	High caffeine intake may increase the risk of miscarriage in pregnant women	[26]
Insomnia and restlessness	Causes sleep disturbances and restlessness in young and adults	[27]
Ovarian Cancer Risk	Possible link with ovarian cancer, though conclusive evidence is lacking	[28]
Indigestion	Causes digestive issues like indigestion, gastroesophageal reflux disorder	[29]

1.4 Soft drinks: Consumption of soft drinks, such as cold drinks containing caffeine, is popular all around the world. Regular/ excessive consumption of this carbonated drink is directly related to obesity and reduced bone mineral density [31]. Caffeine from coffee and tea seems to have no effect on semen parameters, but caffeine from cold drinks or caffeinated drinks can reduce semen volume, count and mobility. It is also associated with aneuploidy. Readymade/ packed fruit juices are marketed as 'healthy' but most of them contain added sugar, preservative and artificial colour, which can cause obesity and cancer. Certain brand market their product as free from sugar but they contain artificial sweeteners, which is even more dangerous. According to US food and Drug Administration (USFDA) has a prone the use of five artificial sweeteners namely saccharin, sucralose, aspartame, neotame and cyclamate [32]. Carbonated soft drinks (CSDs) are undergoing notable transformations in their sugar composition, driven by the growing consumer demand for low-sugar and healthier alternatives [33]. Table 6 represents various artificial sweeteners added in NABs.

Table 6. Health effects of Artificial sweeteners in Beverages.

Artificial Sweeteners	Health concerns	Regulation Status
Saccharin	Potential link to cancer, especially in high doses (may cause bladder cancer).	Banned in some countries, allowed in others with caution
Sucralose	Linked to metabolic syndrome and gut health disruption.	Generally recognized as safe by the FDA (low doses).
Aspartame	May cause headaches, mood disorders, and other neurological issues in sensitive individuals.	FDA-approved but controversial due to health concerns.
Neotame	Like aspartame, may cause adverse neurological effects	Allowed for use in many countries but restricted in some.
Cyclamate	Banned in some countries due to concerns over cancer risk.	Banned in the U.S. but allowed in many other countries.

A study conducted by Sewwandi et al in Sri Lanka on total sugar and artificial colour in packed fruit juices. They used two analytical methods Lane and Eynon titration and UV Visible spectroscopy and the total sugar content was on an average found to be 18.38g/100ml and 18.31g/100ml respectively. Based on analysis using TLC of natural and synthetic colour about 57.14% contained natural colorant and 42.86% contained artificial colorant [34].

This review aims to critically focus on various types of NABs, including their chemical constituents, nutrient profile, their labelling, shelf life, and safety from microorganisms. There are various practices such as fermentation and bioreactors, used for their production [35]. Various literature studies have also revealed that many of the NABs are found to be contaminated with heavy metals [36]. The review also highlights the impact of use of such beverages by different age group people, especially upon children and senescent people [37]. Analysis of various drinks such as tea, coffee, cereal based drinks, smoothies, sparkling water, reduced water, etc. using various chemical and instrumental techniques such as GC-MS, HPLC, UV-vis spectroscopy are of great importance [38]–[40]. Table 7 Contaminants and safety concerns in NABs.

Table 7. Contaminants and safety concerns in NABs.

Contaminant	Beverages Affected	Health Risks	Ref.
Heavy metals	Found in various NABs (e.g., tea, coffee, juices)	Long-term exposure can lead to toxic accumulation, affecting organs like the liver and kidneys	[36]
Microbial Contamination	Can occur in improperly stored or handled beverages,	Cause foodborne illnesses, especially in children and elderly	[37]

	particularly fruit juices and smoothies	people	
Chemical contaminants	Soft drinks, packed juices, cereal-based drinks	Preservatives and additives like artificial colours may contribute to cancer risk and allergic reactions	

2. Industrial Survey to Production and Consumption of NABs

The demand of NABs are increasing day by day by people of almost all age groups. NABs like green tea, black tea, coffee and derivatives, fruit juices, vegetable juices, carbonated drinks are highly consumed all over the world. Hence, the regulatory measures for the presence of adulteration by various quality check measures in these beverages is one of the most important aspects. As per the various available literatures, NAB industry tends to be the one of largest industry on entire globe, with a market size of 531.3 billion dollars as per the records available in 2013. The estimates declare that the global volume of these NABs is between 0.1 trillion units, from 2023 to coming 2027 [41]. Estimated volume for their consumption is 0.94 trillion in 2027. The United States has the leading estimates of revenue for non-alcoholic drinks to be 447.4 billion U.S. dollars. India tends to be a large explorer of various beverage industries, as the demand is increasing amongst middle class people, young consumers, and people belonging to other age groups as well [42]. Table 8 presents global overview for production of NABs.

Table 8. Year-wise Global Market Overview of NABs [46].

Year	Global aspects	Details
2013	Global market size	$531.3 billion (NAB industry)
2023-2027	Projected Global Volume	0.1 trillion units in 2023, reaching 0.94 trillion by 2027
2026	Projected Market Size	$2175 billion
2024	Leading Revenue Country	United States: $447.4 billion
-	Key Market segments	Carbonated Soft Drinks (CSDs) Mineral water Tea, coffee, fruit and vegetable juices

The scenario of global market production has held around USD 1180 billion, in year 2020. According to projection the global NABs market is anticipated to reach staggering USD 2175 billion by the beginning of 2026, representing a significant industrial expansion in terms of economy. Out of which, 60% percent market is subjected only towards the production of carbonated soft drinks (CSD), including

drinks like sports drink and energy drinks. These CSDs are produced on large scale in India, when compared to other Asian countries. Apart from CSDs, India also possesses the large segment production, sale and consumption of mineral water, including both packaged drinking water, and natural mineral water [43]. In India, production of tea estimated to be of 1.2 billion kilograms in 2022 [44] and 1.37 billion kilograms, in year 2023, and the majorly contributing states to this production tea production is Assam and West Bengal [45]. The total production of tea from various financial years from 2013-2023 is depicted in figure 1.

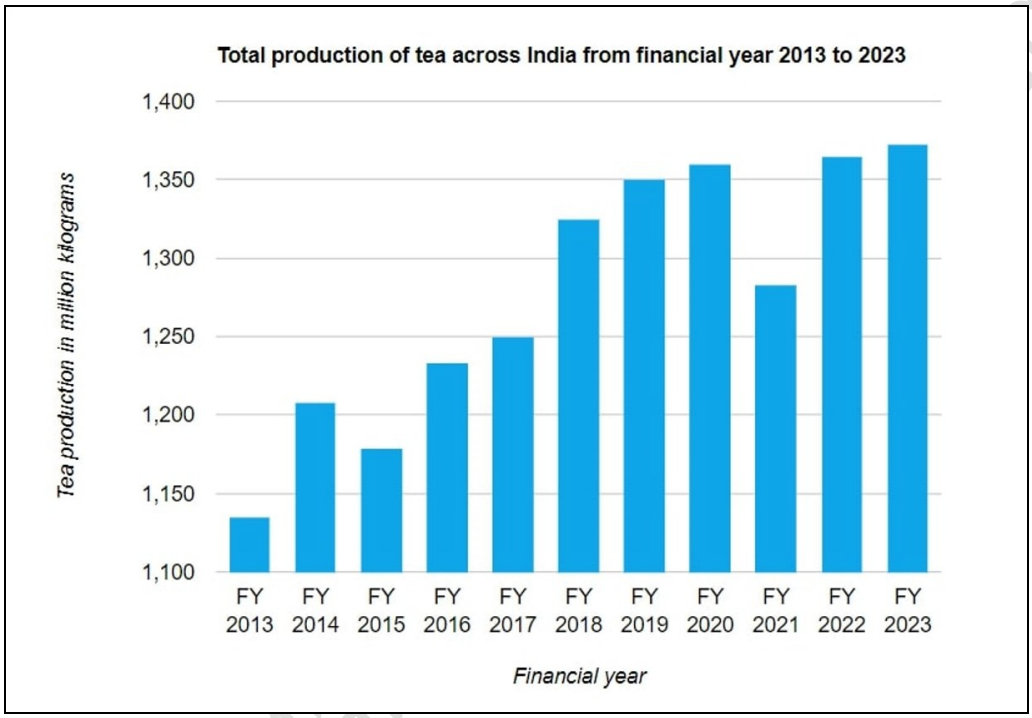

Figure 1. Production of tea in India in respective years.

Approximately, 80% of the tea being produced in India is for domestic consumption, majorly involved in 'in-home' consumption [47]–[49]. This highlights the significance of tea in Indian culture and daily life, with India being one of the largest tea consumers globally. Similarly, when talking in terms of soft drinks, the estimated revenue in India soft drink market is projected to be 8.885 billion US dollar in 2023 and is expected to increase 5.39% annually. Additionally, the estimated mean volume for per capita consumption of soft drinks per person is 4.89L in 2023 [50]. This growth is driven by factors such as changing lifestyles, increasing disposable incomes, and a rising demand for convenience beverages. The records of market share for carbonated beverages are significantly larger when compared to non-carbonated drinks, as illustrated in figure 2. This dominance is attributed to popular brands and flavours, as well as effective marketing strategies. Whereas, statistical estimations reveal that the global market volume of soft drinks is growing at compound annual growth rate (CAGR) of 5.33% from 2024 to 2028. The Indian carbonated soft drink (CSD) market is expanding at a markedly accelerated pace, significantly outstripping the global growth trajectory. Table 9 presents the market overview of Indian soft drinks. NABs.

Table 9. Year-wise Market overview of Indian Soft drinks [33].

Year	Global aspects	Details
2020	Global market Volume	Lowest global market volume for soft drinks
2021	Global market Volume	Highest global market volume for soft drinks. Economic recovery post-pandemic.
2023	Estimated Market Revenue	$8.885 billion USD
-	Annual Growth Rate	Projected at 5.39% annually
2023	Per Capita Consumption	4.89 litres per person
-	Factors driving Growth	Changing lifestyles Increasing disposable incomes Rising demand for convenience beverages
-	Market share	Carbonated beverages hold a significantly larger share than non-carbonated drinks

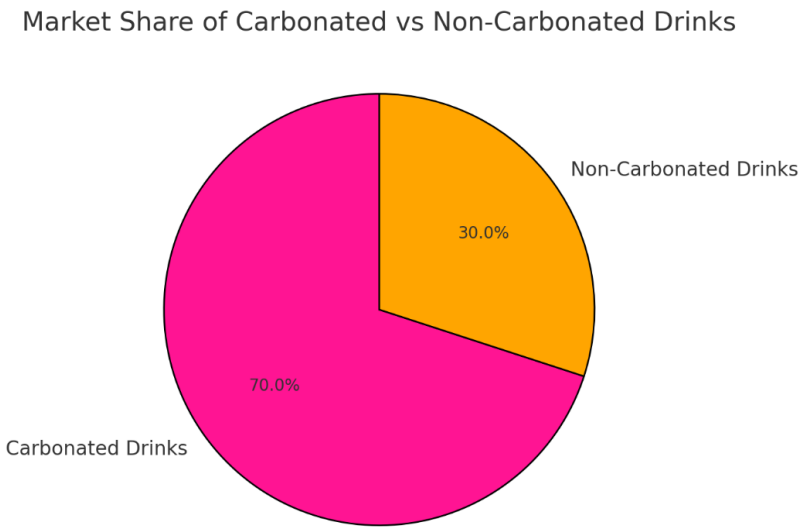

Figure 2. Global share of carbonated and non-carbonated drinks, as per 2021 records.

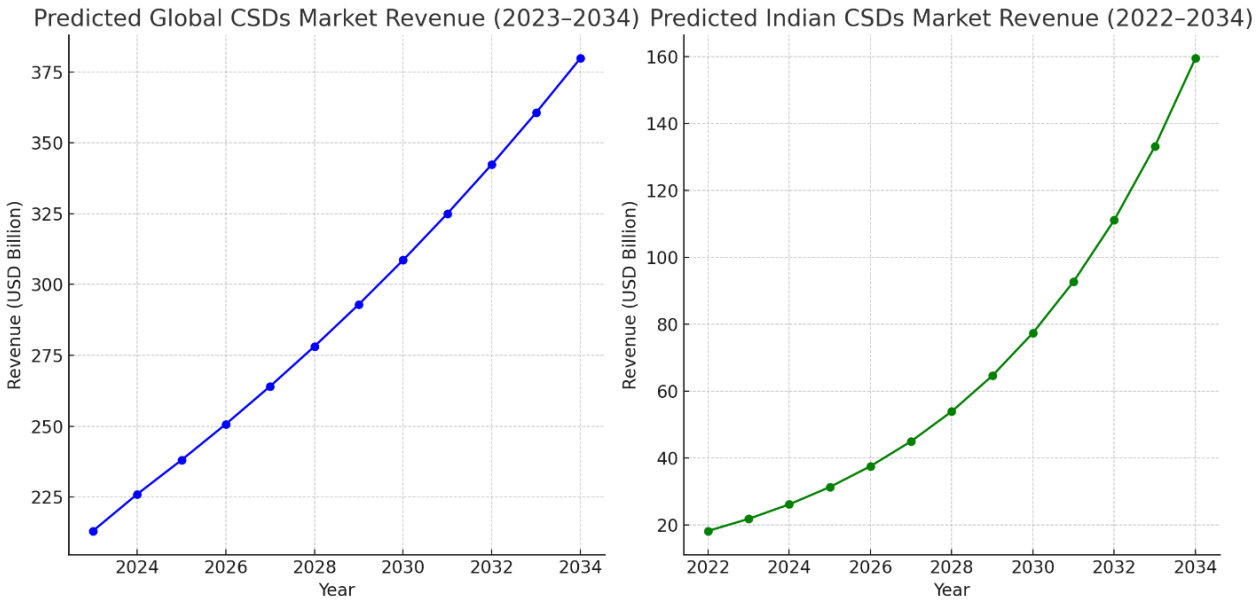

Figure 3. Global and Indian carbonated soft drink (CSDs) market, from 2023-2034.

Additionally, statistical records reveal that global coffee consumption for 2022-2023 reached 167 million bags, each of 60 kgs, valued at approximately USD 45.6 billion. Whereas, average coffee consumption in India across 2023 is subjected to be 1,23,5000 kg bags [51], [52]. Cultivation of coffee in large quantities is mandated by various countries because of its large demand. Recent studies revealed Brazil as the highest production of coffee, and India also stands under the top 10 countries having the market shares for coffee production. Figure 4 summarises the production of coffee by various counties with the percentage of their market shares in year 2021.

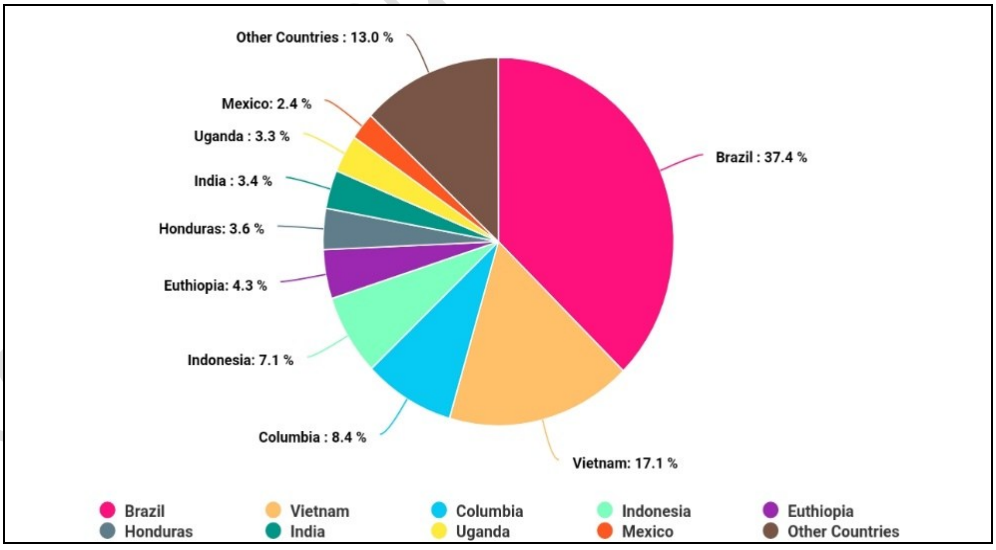

Figure 4. Market share for coffee production & sale amongst top 9 countries in world in year 2021-22.

As the consumption of these NABs is one of the fundamental components of the invariable number of populations in various countries. Hence, these NABs are supposed to be subjected to routine analysis to check for the adulterants, contaminants and toxic metals etc. These types of analysis are thereby is one of the most required aspects of forensic sciences.

3. Forensic Analysis

An adulterant is a substance which is being added to a substance to increase its bulk, appearance and to make it more valuable than it existed. Howbeit, the major purpose of the adulteration is to increase the quantity and enhance its appearance, making it more appealing to the consumers. Several adulterants in tea, coffee and various soft drinks have been reported in literatures and are associated with various health effects [53]. The purpose of the adulteration has been becoming rampant not just to reduce the cost of manufacturing but ultimately to earn higher profits.

3.1 Adulteration in Tea: Tea (Camellia sinensis) is reported to be the second most consumed NABs worldwide, preceded only by water. Adulterations in the tea is not only intentional but also accidental during the manufacturing, harvesting, storage, processing, transportation and commercialisation. This tends to degrade the quality, its nutritional quantification and other properties [54]. Tea samples have been determined to have several phenolic compositions and antioxidant activity [55]. Karori, S.M., et al 2007 has also demonstrated that green tea has higher catechins, polyphenol and total antioxidant properties [56]. On the other hand, black tea contains higher level of theaflavins and thearubigins. For antioxidant activities in black tea, gallic acid is being induced in the tea. Reverse phase HPLC and several spectroscopic techniques have been used for analysis of internal composition of tea. As demonstrated by several researches, various types of tea have been found incorporated with several adulterants [56], [57]. Table 10 highlights phenolic composition and antioxidant properties in various tea samples.

Table 10. Comparison of Phenolic composition and antioxidant properties in different tea samples.

Tea Type	Key phenolic components	Key Antioxidant properties	Example of major phenolic compounds	Antioxidant activity indicator	Ref.
Green tea	Catechins, polyphenols	Higher antioxidant properties, rich in catechins and polyphenols	Epigallocatechin gallate (EGCG)	Strong antioxidant activity due to higher catechin content.	[56]
Black Tea	Theaflavins, Thearubigins	Moderate antioxidant properties, rich in theaflavins and	Theaflavin, thearubigins	Moderate antioxidant activity. Gallic acid contributes significantly to antioxidant	[55]

		thearubigins		activity in black tea	

Furthermore, Pekal, A., et al., 2013 has also demonstrated that tea samples such as premium black tea, flavoured black tea, fruit tea, as well as green tea, from several brands are incorporated with disparate trace elements and flavonoids [58]. Metals such as Iron, copper, cobalt, manganese, nickel, etc. are usually present in such teas. Whereas, flavonoids such as Rutin, naringin and hesperidin are incorporated in tea infusions [58]. Table 11 draws the most common adulterants present in the tea, their adaptability as tea adulterants and several Health effects. NABs.

Table 11. Common tea adulterants in different tea samples, their utility and health effect.

Tea	Common Adulterants	Use	Health Effects	Forensic Analysis
Black Tea	Sugar	Enhance colour, quality &brew characteristics	Increases blood sugar levels, diabetes, obesity, high blood pressure, etc.	Anthrone method for UV-Vis Spectrophotometer λmax= 630 nm
				Phenol sulphuric acid for UV-Vis spectrometric detection. λmax= 490 nm
Black Tea and Green Tea	Dried Exhausted/ Consumed leaves	add bulk to tea, Enhances colour	Neurogenesis.	--
Black Tea	Ferrous Sulphate	Enhances colour.	Gastrointestinal effects	--
Black Tea	Potassium Permanganate		Methemoglobinemia, acute respiratory distress syndrome	HPLC with chemiluminescence detection Sensitivity= 10^{-5} M
Black Tea	Sodium Hydroxide		Eye, skin and mucosa irritation, skin	--

			burns &hair loss.	
Black Tea, and Darjeeling Black tea	Artificial Colour	Enhances colour	Hyperreactivity, Skin irritation, behavioural changes, increases chronic diseases as well.	Friedman Test, ANOVA for absorbance value
				NIR Spectroscopy with (PLS-DA) & Soft independent Modelling of Class Analogies O-H, N-H & C-O bands= 4250 cm^{-1}. C=O overtone zone= 5350 cm^{-1} CH_2& CH_3 overtone zone= 5775& 5920 cm^{-1}, respectively. C-H & O-H stretching= 7150 cm^{-1}
Black Tea	Coal Tar dye		Carcinogenic	Chloroform method Antioxidant activity= 3.29±1.03 to 15.96±1.2
				Sulphuric acid & Hydrochloric acid test Pink/ crimson colour produced.
Black Tea	Azo colours		Carcinogenic	--
Black Tea Brewed Black tea	Azo dyes such as Tartrazine, sunset Yellow, lemon yellow, erythrosine, Carmoisine and Ponceau	Enhances colour	Carcinogenic	FT-IR, Chemometrics: Least-squares support vector machines (LS-SVM) & PLS-DA Predicted results has high Regression coefficient > 0.89
				FT-IR with PLS, LS-SVM & Real Coded Genetic Algorithm

				(RCGA)-LS-SVM Regression coefficient (RC) = 0.9989 and 0.9979
Black Tea	Sodium Bicarbonate	Enhances colour	Diarrhoea, vomiting, dehydration, kidney diseases	--
Black and Green tea	Leather Flakes	Extra glace to tea	Allergic reactions, diabetes (mild-to-severe)	Burnt paper test: Specific odour of leather flakes
Black and Green tea	Sand	Adds Bulk	Damages digestive tract, causes ulcers	Mass spectrometry, ICP-MS, XRF Spectrometry, Energy Dispersive Polarized XRF Spectrometry (EDP-XRFS)
Black and Green tea	Cereal starch	Adds extra starch and glace	Nausea, Vomiting, Gastric pain and burning sensation.	Starch-Iodine Test: Blue colour
Black and Green tea	Powder of scorched persimmon stone	Hinders the caffeine concentration	Reduction of harmful fats.	Blotting paper test: Red colour
Black Tea	Prussian Blue	Enhances colour	Upset stomach and constipation	--
Black Tea	Turmeric		Allergies, sinuses, heavy breathing, nausea, diarrhoea,	Liquid phase micro-extraction LOD= 9.0×10^{-5} mg/L Standard Deviation= 1.4-42.2%

Black Tea	Indigo		Irritability, sleep issues, weak memory hyperactivity,	--
Black Tea	Plumbago (Black lead)		Anaemia, paralysis, stomach disorders.	--
Black Tea and green tea	*Dendrocalamus hamiltonii* (Bamboo)	Enhances fragrance and colour	Oxidative stress, lipotoxicity, and CVD.	--
Black Tea	Foreign vegetables	Substitutes original tea for financial profits	--	--
Black Tea	Stones	Adds Bulk	--	Microscopic Tests: Structure characterisation
Black Tea	Black gram husk	Enhances shine and appearance and bulk	--	Multispectral imaging
Black Tea	Cashew Husk		--	High Resolution Melting (HRM) Analysis LOD= 1% v/v cashew
Diff. teas	Chicory, roots of *Cychorium intybus*	Enhances aroma	Sedative effects on CNS.	Potassium ferrocyanide test: dark green to Brown and murky liquid
Black Tea and other teas	Iron filling	Adds Bulk	Enhances possibility of tetanus, carcinogenic, cause liver disorders.	Magnet test: to attract iron fillings
Black Tea	Catechu	Induce slight sweetness	Lowers blood pressure. Causes skin diseases.	Ferric chloride test: Green ppt
Black Tea	Carmine	Synthetic	Allergies,	HPLC

		colourant to enhance colour	dermatitis, conjunctivitis.	RC= 0.988 and 0.972 for black tea
Green Tea & Mixed herbal Tea	Sibutramine	For weight loss	Diabetes, hypertension, cardiovascular diseases.	ATR-FTIR Principal Component Analysis (PCA) Spectral range=2746-2656 cm^{-1}

3.2 Adulterations in Coffee: One of the most important beverages consumed globally by people of different age groups, coffee is an important element for industrial and economic growth. Economic growth of various countries such as Brazil, Vietnam, etc. are sum inclusive of the abundance of production and exportation of coffee throughout the globe [80]. However, the producers are implying several ways for the adulterating coffee in different forms such as ground and roasted coffee [81]. Several methods have been applied so far for the detection of these adulterations, such as Thin Layer Chromatography [82], HPLC [81], NMR, IR spectroscopy [83] etc. Table 12 represents different organic compounds found in coffee samples. One of the most important beverages consumed globally by people of different age groups, coffee is an important element for industrial and economic growth. Economic growth of various countries such as Brazil, Vietnam, etc. are sum inclusive of the abundance of production and exportation of coffee throughout the globe [80]. However, the producers are implying several ways for the adulterating coffee in different forms such as ground and roasted coffee [81]. Several methods have been applied so far for the detection of these adulterations, such as Thin Layer Chromatography [82], HPLC [81], NMR, IR spectroscopy [83] etc. Table 12 represents different organic compounds found in coffee samples.

Table 12. Organic compounds and contaminants in coffee samples.

Coffee samples	Adulterants detected	Analytical methods	Ref.
Green Coffee	Polycyclic aromatic hydrocarbons (PAHs)	HPLC, GC-ECD	[84]
Roasted Coffee Beans	Similar PAHs and pesticides as green beans	HPLC, GC-ECD	[81], [85]
Ground Coffee	Pesticides, PAHs, heavy metals	HPLC, NMR	[81], [85]
Coffee Granules	Organic contaminants including pesticides	Gas Chromatography, HPLC	[84], [85]

Stanciu, G., et al., 2008 analysed various organic compounds from different coffee samples using HPLC with fluorescence detector, Gas Chromatography with Electron Capture Detector (GC-ECD). It

was determined that several polycyclic aromatic hydrocarbons and several organochloride pesticides found amalgamated within the coffee samples. Samples from green coffee bean, roasted coffee beans, various coffee granules, etc. have been analysed for several organic components [84], [85]. Whereas, Hudakova, J., et al., 2016 have demonstrated several antioxidant effects with radical scavenging assay in Coffee beans [86]. It was reported that green *Arabica* coffee has 89.55% antioxidant activity and unroasted ground extracts contains 100% antioxidant activities. On the other hand, high levels of phenols and flavonoids have been reported in 100% green coffee, *Arabica* [86], [87]. Significant research also describes the utility of Flame Atomic Absorption Spectrometry (FASS) to account the concentration of minerals such as Ca, K, Fe, Zn, Co, Pb, etc. in several types of coffees. It has been estimated that 5 brands of coffees such as Jacobs-Aroma, Jacobs-Kronung, Doncafe elite, Nova Brasilia and Fort-Strong Coffee shows 99.96% of macro elements from total mineral concentration [88]. Table 13 demonstrates several adulterants being incorporated coffee samples, their use, health effects and analytical techniques reported in various literatures.

Table 13. Different Coffee adulterants, their uses, health effects & analytical techniques.

Coffee Samples	Common Adulterants	Use	Health Effects	Forensic Analysis
Robusta Coffee beans	Glucose	Enhance colour and glace masks undesirable flavours, reduces bitterness.	Increases blood sugar level	ATR-FTIR Spectral Region of 970-1470 cm^{-1} [89]
Robusta Coffee beans	Starch	Enhances volume, reduces bitterness. Added to ground coffee to increase weight.	Hazardous to people with diabetes and congenital sucrase-isomaltase deficiency (CSID). Also causes gastro-intestinal discomfort	Thin layer chromatography, ATR-FTIR and Diffused Reflectance FTIR Spectral range: 1000-1200cm^{-1} [89]
Robusta Coffee beans	Chicory	Enhances glace & flavour, reduces bitterness.	Maintains gut health. Long consumption is cytotoxic	Diffused Reflectance FTIR Spectral range: 1600-1700 cm^{-1} [89]

Arabica and Robusta: green coffee	Sugar	Taste modification, Simulated a premium brand	Increases blood sugar level, diabetes and CVDs.	High-resolution-magic-angle spinning nuclear magnetic resonance spectroscopy (HR-MAS NMR) Spectral region= b/w 3.3 and 5.0 ppm [90]
Arabica and Robusta: green coffee	Pyrazines	Enhances intense aroma.	--	HR-MAS NMR Spectral region singlet= at 8.4 ppm [83]
Roasted ground coffee	Brown Sugar	Enhance glace, texture & colour	May increases the blood sugar level.	Charged Coupled Device (CCD) Camera with Stereo microscope & Image processing software [91]
Roast and ground Coffee beans	Husks/ Coffee Husks	Enhances bulk and imparts colour	Contains tannins and polyphenols, cause toxic effects, cause respiratory issues, eye irritations,	Mid-Infrared Spectroscopy (MIRS) Spectral Range= 2800-3000 cm^{-1} Diffuse Reflectance FTIR Spectroscopy Significant peak= 2925 and 2848 cm^{-1} [92]
Roasted ground coffee	Straw		--	CCD Camera with Stereo microscope and Image processing software (IPS). Correlation

				Coefficients= 0.972 [93]
Roasted coffee bean (Arabica)	Maize/ Corn	Reduces Caffeine content	Prevents cancer, rich in antioxidants, Reduces risks of oxidative stress, heart diseases and colon cancer	CCD camera, Stereo microscope & IPS. Correlation Coefficients= 0.972 CCD camera, Stereo microscope & IPS. Correlation coefficients= 0.991 [94], [95]
Roasted Grounded coffee				Photoacoustic Spectroscopy wavelengths 4579, 4880, 5145, & 6471Å. [96]
Roasted ground (Arabica)	Chickpea			Laser induced breakdown spectroscopy (LIBS) Coefficient of determination (CoD)= 0.995 & LOD= 0.52% [94]
Roasted ground (Arabica)	Wheat			LIBS CoD= 0.996 & LOD= 0.56% [94]
Roasted ground (Arabica)	Oat			LIBS CoD= 0.995 & LOD= 0.45% [94]
Coffea arabica	Rice			FT-MIS Spectroscopy Coupled, with Partial Least Squares (PLS) model CoD= 0.9985 & Standard

				error of calibration (SEC)= 0.99 FT-MIS Spectroscopy Coupled, with PLS model CoD= 0.9989 & SEC= 0.99 [95]
Roasted Grounded coffee	Barley	Enhances nutritional content	Prevents hair loss, improves digestion, gall bladder stones	Photoacoustic Spectroscopy λ=4579, 4880, 5145, and 6471 Å. [96]
Roasted Grounded coffee	Coffee Parchment	To enhance overall aroma of coffee.	Causes obesity related disorders	Photoacoustic Spectroscopy λ=4579, 4880, 5145, and 6471 Å. [96]
Arabica coffee	Soybean	Accidental addition. Also used as filler in ground coffee	Diarrhoea, nausea, allergic reactions	IR spectrometry, HPLC, CCD Camera, Stereo microscope & IPS Correlation coefficients= 0.94 [95]
Green Arabica Coffee beans	Soybean and spent grounded coffee	Accidently Added, lowers coffee quality.	May cause CVDs, blood pressure problems	HPLC Based-Chemometric [Principal component Analysis- PCA] analysis Sensitivity= 0.875, Specificity= 0.938, Reliable Rate= 0.813, Positive likelihood= 14.1, Negative likelihood= 0.133

				[97]
Brazilian brewed and roasted coffee	Defective, immature, sour and black seed	Enhances bulk, alters flavour	--	SPME- Headspace gas chromatography Nitrogenated and volatile compounds such as Pyrazines, pyrroles and pyridines were obtained. [98]

3.3 Adulterations in Soft Drinks: One more essential accolade of the NABs are soft drinks. It majorly constituted using concentrated fruit juices. The quality of water used is one of the important estimates to be checked before commercialising such drinks [99]. Various elements such as sugars, artificial sweeteners have been reported as one of the components of soft drinks, fruit drinks, cold drinks, etc. Commonly available soft drinks are fruit juices, carbonated drinks, cold drinks, packaged fruit juices, etc [100]. Various types of are tested in day-to-day life and significant cases have been reported for their adulterations. Various routine forensic analysis includes analysis of sweeteners, artificial or synthetic colourants, neutral pigments, caffeine, etc [101], [102]. Different components and key components present in soft drinks, are highlighted in table 14.

Table 14. Common soft drinks and their components.

Soft drinks	Common ingredients	Key components
Fruit Juices	Concentrated fruit juice, water, sugar, natural flavours	High in sugars, vitamin C (depending on the fruit), sometimes preservatives
Carbonated drinks	Carbonated water, sugar, artificial sweeteners, caffeine, flavouring	High sugar content, caffeine (in some), artificial flavourings and sweeteners.
Cold Drinks	Carbonated water, high-fructose corn syrup, artificial flavouring	Often high in sugar or artificial sweeteners, sometimes with caffeine
Packed Fruit Juices	Concentrated fruit juice, sugar, preservatives, water	High sugar content, vitamins, artificial sweeteners or preservatives
Sodas/Colas	Carbonated water, sugar, caffeine, artificial colorants, flavouring	High sugar content, caffeine, artificial colorants (e.g., caramel color).

The consumption of soft drinks has increased exponentially including rural India. This is because of availability and affordability. Some of the basic components present can cause serious health issues if consumed on regular basis. However, now a days adulteration of these beverages has made the situation worse. Table 15 contains a list of adulterants, their detection, incorporated results, uses and health effects in soft drinks.

Table 15. Different soft drink adulterants, their purposeful uses, health effects and analytical techniques.

Soft Drinks	Common Adulterants	Use	Health Effects	Forensic Analysis
Cola	Cadmium	Nil	Itai-Itai (ouch-ouch) disease, Increased salivation, acute gastritis, liver & kidney damage, prostate cancer [103], [104].	Atomic Absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICPMS) AAS- 228.8-228.9 nm and ICP-MS
Orange Carbonated water	Cadmium	Nil		AAS- 228.8-228.9 nm and ICP-MS [103]
Cola and Orange carbonated water	Pesticides & insecticides: lindane, DDT, malathion &chlorpyrifos	Nil	Skin and eye irritation, headaches, dizziness, and nausea, cancer, asthma, and diabetes [105].	Raman spectroscopy, ATR-FTIR, NMR R-2,4'-DDT, IR bands 1400 & 1200 cm^{-1}, R-2,4'-DDT, Raman bands 1000 cm^{-1}. For Malathion, IR peaks is 1737 cm^{-1}, Raman shift corrected using a baseline defined at 1900 cm^{-1}, FTIR bands1017 cm^{-1}. For chlorpyrifos, FTIR bands are 990-2830 and 1259-1227cm^{-1}, Raman bands1278cm^{-1}& 1571cm^{-1} [106]–[110]
Fruit drinks	Brominated vegetable oils	Stabilizer	Anaemia, enlargement of heart [111]	GC-MS
Packed Fruit Juice	Cadmium	Nil	Same as above [103]	AAS- 228.8-228.9 nm and ICP-MS
Packed	Water and low-	Dilution of fruit	Type II diabetes, heart disease	--

Fruit Juice	quality Sugar	juice	[112].	
Packed Fruit Juice	Saccharin	Artificial sweetener	Cancer [113].	UV Visible spectroscopy, FTIR, FT Raman spectroscopy, NMR UV-vis spectroscopy, λmax= 269 nm. Raman spectroscopy-701.5(Skeleton deformation), 1032.0 (Aryl ring deformation), 1132.2 (Aryl ring deformation and C-H bending), 1300.0 (C-N stretching and C–H bending) [114]
Packed Fruit Juice	Calcium Carbide	Ripening of fruits	Headache, dizziness, sleepiness, confusion, memory loss, cerebral edema, seizures & cancer [115], [116].	NIR and FTIR spectroscopy
Drinking water	Fluoride	Nil	Causes fluorosis (mottling of teeth, skeletal& neurological disorders) [117], [118]	GC-microwave-induced plasma mass (685.6 nm) spectrometry (GC- MIP), ion selective electrode, INAA
Water	Lead	Nil	foot drop, insomnia, anaemia, constipation [119].	AAS (most sensitive lines for Pb are 217.001 nm and 283.306 nm) & ICPMS

4. Forensic Analysis

NABs are the most savoured beverage along the world. So far, several adulterants have been aired in various beverages such as tea, coffee, fruit juices, cold drinks, etc. Adulterants such as Glucose, chicory, heavy metals, soybean, husks, maize, barley, carmine, artificial colourants, chicory, azo dyes, ferrous sulphate, etc. are unfailingly used in NAB via industries, subsequently [120]. The pretension behind using such adulterants is the economic profound. Howbeit, reported literatures have also communicated that beaucoup adulterants are also being added unintentionally or accidently. The market size globally has impacted the economic excrescency [121].

Hence, a subsequent need for the analysis of such beverages is indispensable and mandate. Both, chemical and instrumental analysis has been stupendously used for the analysis. The divulged methods like ATR-FTIR, Diffused Reflectance FTIR, UV-Vis spectrometry, HPLC with chemiluminescence detection, NIR Spectroscopy, Headspace SPME GC-MS, etc. have been insignificantly studied for the analysis of organic and inorganic adulterants such as sugar, glucose, artificial colourants, dyes, starch, chicory [109], [122]–[125]. In lieu, techniques such as ICP-MS, ICP-OES, AAS has also been reported for the quantising the metallic composition [126]–[128]. Several advanced techniques such as CCD camera with stereo microscope, LIBS, photoacoustic spectroscopy, FT-MIS, described to be used for the identification of chickpea, wheat, grains, straw, etc. from NAB samples [129]. Alongside, XRF, ICP-MS have also implemented their applications in the analysis of sand particles, iron fillings along with microscopic analysis [130]–[133]. Table 16 describes various analytical methods used to detect adulterants in NABs. It lists the techniques, the adulterants they detect, and their advantages, such as non-destructive analysis or high sensitivity. Techniques like Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy (ATR-FTIR), Ultraviolet- Visible (UV-Vis) spectroscopy, and Gas Chromatography- Mass Spectrometry (GC-MS are commonly employed for detecting organic and inorganic adulterants.

Table 16. Different analytical techniques for detecting organic adulterants in NABs.

Analytical technique	**Purpose of Use**	**Adulterants detected**	**Efficiency/ Advantages**	**Ref.**
ATR-FTIR Spectroscopy	Detection of organic compounds in beverages	Sugars, glucose, artificial colorants, starch, chicory	Non-destructive, quick, and effective for organic adulterants	[109], [122]
UV-Vis Spectrometry	Identification of chemical composition	Artificial colorants, sugars, glucose	Simple, widely used for detecting colorants and sugars	[123], [124]
HPLC	Separation and quantification of compounds	Glucose, sugar, starch, artificial sweeteners, dyes	High sensitivity, allows separation of complex mixtures	[125]
NIR Spectroscopy	Quantification of organic and inorganic compounds	Sugars, starch, artificial sweeteners	Rapid and non-destructive, used for both organic and inorganic components	[122]
GC-MS	Identification and quantification of volatile compounds	Artificial flavourings, dyes, pesticides	Highly sensitive and accurate for volatile compounds	[109], [123]
ICP-MS	Quantification of metallic elements	Heavy metals (Pb, Hg, Cd, Fe)	High sensitivity for trace metal detection	[126], [128]

AAS	Detection of Metallic elements	Heavy metals	Widely used for metal analysis, high precision	[126], [127]
XRF Spectroscopy	Detection of inorganic elements	Sand particles, iron fillings	Non-destructive, good for elemental analysis	[130], [132]

Furthermore, literatures have proposed several chemometric tools such as PLS-DA, RCGA-LS-SVM, PCA, for their extensive use in the quantification of adulterants [134], [135]. Table 17 highlights major chemometric tools for quantification of adulterants.

Table 17. Chemometric tools for quantification of adulterants.

Chemometric tool	**Purpose of Use**	**Adulterants detected**	**Efficiency/ Advantages**	**Ref.**
PLS-DA (Partial Least Squares Discriminant Analysis)	Classification and quantification of adulterants	Artificial sweeteners, colorants, preservatives	Effective for complex data, multivariate analysis	[135]
RCGA-LS-SVM (Radial Basis Function-Genetic Algorithm-Linear Support Vector Machine	Optimization and quantification of adulterants	Artificial colorants, glucose, sugars, preservatives	High classification accuracy, reduces data complexity	[135]
PCA (Principal Component Analysis)	Reduction of dimensionality for analysis	Sugars, glucose, artificial sweeteners, colorants	Simplifies complex data, enhances pattern recognition	[134], [135]

5. Conclusion

Adulteration is the persistent global menace to all the food products, primarily for monetary benefits. Several severe health issues and potentially debilitating perils are prominently linked to this issue. Human health and quality of life ultimately face multiple vulnerabilities and substantial threats due to this. Several incidents are documented in routine life scenarios. This persistent issue has become a blotch over the modernization era today. Extensive practices lead to several issues accommodated by various

stakeholders. This poses a significant challenge to forensic analysts. NABs forensic analysis decodes the intention behind the adulteration processes, i.e., whether the adulteration is unintentional accidental such as metallic contamination, or the adulterants have been added with financial motives. They also recount the toxic effects and adverse health consequences of such adulterers. NABs are thereby one of most widely consumed beverages worldwide. Even, India being the second-highest producer of tea and has been known for the largest consumer of tea worldwide. This paper has critically reviewed significatory aspects of NABs, their adulteration, health hazards, which are presented with forensic insights and analytical protocols. The manuscript also highlighted several qualitative and quantitative analytical protocols for detection of adulterants in NABs, highlighting the need of development of validated routine methodologies in forensic laboratory. Control approaches by relevant regulatory authorities can lead to help government, industries, forensic analysts, as well as the scientific communities, raise consumer awareness.

Adulteration in NABs poses a significant threat to public health and safety, primarily driven by monetary gains. The widespread nature of adulteration necessitates stringent quality control measures, forensic analysis, and collaborative efforts among regulatory authorities, industries, and scientific communities. Implementing validated methodologies and raising consumer awareness are critical steps in combating adulteration. By addressing this issue, we can ensure the safety and integrity of NABs, protecting the health and well-being of consumers worldwide.

6. Acknowledgement

The authors gratefully acknowledge the administrative support and facilities provided by the National Forensic Sciences University, Delhi Campus. Authors appreciate the conducive research environment and assistance extended, which greatly facilitated the preparation of this manuscript.

References

[1] T. Suzan, "A review on packed non-alcoholic beverages: Ingredients, Production, trends and future opportunities for functional product development," Trends Food Sci. Technol., vol. 112, pp. 442-454, 2021.

[2] T. Tada, T. Nishimura, M. Yoshida, and H. Iijima, "Nonalcoholic fatty liver disease and nonalcoholic steatohepatitis: new trends and role of ultrasonography," J. Med. Ultrason., vol. 47, pp. 511-520, 2020.

[3] C. M. Glanakis, Trends in Non-Alcoholic Beverages. 2019.

[4] K. Bansal, S. R. Acharya, and V. Saraswathi, "Effect of alcoholic and non-alcoholic beverages on color stability and surface roughness of resin composites: An in vitro study," J. Conserv. Dent., vol. 15, no. 3, p. 283, 2012.

[5] C. N. Mhurchu et al., "Monitoring the availability of healthy and unhealthy foods and non-alcoholic beverages in community and consumer retail food environments globally," Obes. Rev., vol. 14, pp. 108-119, 2013.

[6] M. D. Garcia, M. R. Castellar, and J. M. Obon, "Juices and Non-Alcoholic Beverages," in Comprehensive Analytical Chemistry, vol. 60, M. d. l. Guardia and A. Gonzalvez, Eds. Elsevier, 2013, pp. 4539-4459.

[7] B. Osuntogun and O. O. Aboaba, "Microbial and Physico-chemical evaluation of some non alcoholic beverages," Pak. J. Nutr., vol. 3, no. 3, pp. 188-192, 2004.

[8] A. Behl, A. Mishra, G. P. Sharma, and V. Mishra, "Detection and determination of the levels of physiologically active substances in non-alcoholic beverages," Int. J. Med. Toxicol. Leg. Med., vol. 24, pp. 164-174, 2021.

[9] A. G. d. C. Netro, M. M. A. Costa, M. S. V. Schuler, and E. P. d. P. Azevedo, "Study of The Main Types of Beverages Adulteration Seized in Recife City – Brazil," Braz. J. Forensic Sci. Med. Law Bioeth., vol. 5, no. 2, pp. 133-145, 2016.

[10] M. F. Yohannes and T. Matsuda, "Demand Analysis of Non-Alcoholic Beverages in Japan," J. Agric. Sci., vol. 7, no. 10, pp. 143-153, 2015.

[11] G. J. Kapadia, S. Rao, and J. F. Morton, "Herbal tea consumption and esophageal cancer," in Carcinogens and Mutagens in the Environment, Boca Raton, FL: CRC Press, 1983, pp. 3-12.

[12] J. F. Morton, "The potential carcinogenicity of herbal tea," J. Environ. Sci. Health C, vol. 4, no. 2, pp. 203-223, 1986.

[13] Y. T. Gao, J. K. McLaughlin, W. J. Blot, B. T. Ji, Q. Dai, and J. F. Fraumeni, "Reduced Risk of Esophageal Cancer Associated With Green Tea Consumption," J. Natl. Cancer Inst., vol. 86, no. 11, pp. 855-858, 1994.

[14] S. Lin et al., "Tea drinking and the risk of esophageal cancer: focus on tea type and drinking temperature," Eur. J. Cancer Prev., vol. 29, no. 5, pp. 382-387, 2020.

[15] L. Kinlen, A. Willows, P. Goldblatt, and J. Yudkin, "Tea consumption and cancer," Br. J. Cancer, vol. 58, no. 3, pp. 397-401, 1988.

[16] P. Stocks, "Cancer Mortality in Relation to National Consumption of Cigarettes, Solid Fuel, Tea and Coffee," Br. J. Cancer, vol. 24, no. 2, pp. 215-225, 1970.

[17] L. J. Kinlen and K. McPherson, "Pancreas cancer and coffee and tea consumption: A case-control study," Br. J. Cancer, vol. 41, no. 1, pp. 93-96, 1984.

[18] C. Yu et al., "Hot Tea Consumption and Its Interactions With Alcohol and Tobacco Use on the Risk for Esophageal Cancer," Ann. Intern. Med., vol. 168, no. 7, p. 489, 2018.

[19] C. Rodrigues et al., "Coffee," in Comprehensive Analytical Chemistry, vol. 60, Elsevier, 2013, pp. 573-598.

[20] A. Onatibia-Astibia, R. Franco, and E. Martinez-Pinilla, "Health benefits of methylxanthines in neurodegenerative diseases," Mol. Nutr. Food Res., vol. 61, no. 6, 2017.

[21] E. Harpaz, S. Tamir, A. Weinstein, and Y. Weinstein, "The effect of caffeine on energy balance," J. Basic Clin. Physiol. Pharmacol., vol. 28, no. 1, pp. 1-10, 2017.

[22] Y. Gan et al., "Association of coffee consumption with risk of colorectal cancer: a meta-analysis of prospective cohort studies," Oncotarget, vol. 8, no. 12, pp. 18699-18711, 2017.

[23] S. Saab, D. Mallam, G. A. Cox, and M. J. Tong, "Impact of coffee on liver diseases: a systematic review," Liver Int., vol. 34, no. 4, pp. 495-504, 2014.

[24] K. E. D'Anci and R. B. Kanarek, "Caffeine, the Methylxanthines and Behavior," in Nutrition and Behaviour: A Multidisciplinary Approach, 2006, pp. 179-194.

[25] D. Echeverri, A. Pizano, F. R. Montes, and P. Forcada, "Acute effect of coffee consumption on arterial stiffness, evaluated using an oscillometric method," Artery Res., vol. 17, p. 17, 2017.

[26] X. Weng, R. Odouli, and D. K. Li, "Maternal caffeine consumption during pregnancy and the risk of miscarriage: a prospective cohort study," Am. J. Obstet. Gynecol., vol. 198, no. 3, pp. 279.e1-279.e8, 2008.

[27] V. Bhojaraja, H. Janardhan, N. Hameed, F. R, and M. Ali, "Knowledge, attitude and practices towards

consumption of caffeine containing drinks among the student population of Ras al-Khaimah medical and health sciences university, UAE," Int. J. Res. Med. Sci., vol. 4, no. 9, pp. 3537-3541, 2016.

[28] A. Salari-Moghaddam, A. Milajerdi, P. J. Surkan, B. Larijani, and A. Esmaillzadeh, "Caffeine, type of Coffee, and Risk of Ovarian Cancer: A Dose-Response Meta-Analysis of Prospective Studies," J. Clin. Endocrinol. Metab., vol. 104, no. 11, pp. 5349-5359, 2019.

[29] M. J. Shirlow and C. D. Mathers, "A Study of Caffeine Consumption and Symptoms: Indigestion, Palpitations, Tremor, Headache and Insomnia," Int. J. Epidemiol., vol. 14, no. 2, pp. 239-248, 1985.

[30] J. V. Higdon and B. Frei, "Coffee and Health: A Review of Recent Human Research," Crit. Rev. Food Sci. Nutr., vol. 46, no. 2, pp. 101-123, 2006.

[31] R. Ogur et al., "Evaluation of the Effect of Cola Drinks on Bone Mineral Density and Associated Factors," Basic Clin. Pharmacol. Toxicol., vol. 100, no. 5, pp. 334-338, 2007.

[32] T. A. More, Z. Shaikh, and A. Ali, "Artificial Sweeteners and their Health Implications: A Review," Biosci. Biotechnol. Res. Asia, vol. 18, no. 1, pp. 227-237, 2021.

[33] Indian Council for Research on International Economic Relations (ICRIER), "Policy brief on Indian beverage industry," 2024. [Online]. Available: https://icrier.org/pdf/ppt_IBA_Policy_Brief.pdf

[34] S. D. Sewwandi, P. C. Arampath, A. G. Silva, and R. Jayatissa, "Determination and Comparative Study of Sugars and Synthetic Colorants in Commercial Branded Fruit Juice Products," J. Food Qual., vol. 2020, pp. 1-11, 2020.

[35] F. Altay, F. K. Guler, C. D. Dikmen, and D. Heperkan, "A review on traditional Turkish fermented non-alcoholic beverages: Microbiota, fermentation process and quality characteristics," Int. J. Food Microbiol., vol. 167, no. 1, pp. 44-56, 2013.

[36] G. N. Abdel-Rahman, M. B. Ahmed, B. A. Sabry, and S. S. Ali, "Heavy metals content in some non-alcoholic beverages (carbonated drinks, flavored yogurt drinks, and juice drinks) of the Egyptian markets," Toxicol. Rep., vol. 6, pp. 210-214, 2019.

[37] B. Kelly et al., "Monitoring food and non-alcoholic beverage Promotions to Children," Obes. Rev., vol. 14, pp. 59-69, 2013.

[38] V. Prakash et al., "Structural insight on thiourea doped graphene: An efficient electrochemical sensor for voltammetric detection of morphine in alcoholic and non-alcoholic beverages," Curr. Res. Green Sustain. Chem., vol. 5, p. 100277, 2022.

[39] C. E. Cagnasso, L. B. Lopez, V. G. Rodriguez, and M. E. Valencia, "Development and validation of a method for the determination of EDTA in non-alcoholic drinks by HPLC," J. Food Compos. Anal., vol. 20, no. 3-4, pp. 248-251, 2007.

[40] M. Acikkol, S. Mercan, and S. Karadayi, "Simultaneous Determination of Benzodiazepines and Ketamine from Alcoholic and Nonalcoholic Beverages by GC-MS in Drug Facilitated Crimes," Chromatographia, vol. 70, no. 9-10, pp. 1295-1298, 2009.

[41] S. R. Department, "Global market value of non-alcoholic beverages 2016 to 2027," Statista, 2023.

[42] L. C. Salantă et al., "Non-Alcoholic and Craft Beer Production and Challenges," Processes, vol. 8, no. 11, p. 1382, 2020.

[43] A. Mukherjee, E. Mukherjee, and V. Menon, "Contribution of Non-alcoholic beverage Sector to Indian

Economic Growth and Atmanirbhar Bharat," AF Press, 2022.

[44] A. Minhas, "Consumption volume of tea in India FY 2015-2022," Statista, 2023.

[45] S. Keelery, "Production of tea in India FY 2013-2023," Statista, 2023.

[46] Technavio, "Soft drinks and non-alcoholic beverages industry analysis," 2025. [Online]. Available: https://www.technavio.com/industries/soft-drinks-non-alcoholic-beverages

[47] I. Tea Board, "Executive Summary of Study on Domestic Consumption of Tea in India," 2010.

[48] V. N. Asopa, "Tea industry in India," Indian Institute of Management, 2007.

[49] A. Nirza, "Indian tea scenario," J. Sci. Res. Publ., vol. 3, no. 9, pp. 1-10, 2013.

[50] "Soft Drinks - India," Statista, 2023.

[51] A. Minhas, "Coffee consumption in India 2016/2017-2022/2023," Statista, 2023.

[52] B. Suseela, S. Bhalke, and A. V. Kumar, "Daily intake of trace metals through coffee consumption in India," Food Addit. Contam., vol. 18, no. 2, pp. 115-120, 2001.

[53] S. Singh, "A Study of the extent of adulteration in the most commonly used beverage-tea in four major cities of Uttar Pradesh," Voice of Intellectual Man-An International Journal, vol. 2, pp. 129-138, 2013.

[54] E. Rappaport, "Packaging China: Foreign Articles and Dangerous Tastes in the Mid-Victorian Tea Party," in The Making of the Consumer: Knowledge, Power and Identity in the Modern World, F. Trentmann, Ed. New York: Berg, 2006, pp. 125-146.

[55] J. Yang and R. H. Liu, "The phenolic profiles and antioxidant activity in different types of tea," Int. J. Food Sci. Technol., vol. 48, no. 1, pp. 163-171, 2013.

[56] S. M. Karori, F. N. Wachira, J. K. Wanyoko, and R. M. Ngure, "Antioxidant capacity of different types of tea products," Afr. J. Biotechnol., vol. 6, no. 19, pp. 2287-2296, 2007.

[57] S.-D. Lin, P. Udompornmongkol, J.-H. Yang, S.-Y. Chen, and J.-I. Mau, "Quality and Antioxidant Property of Three Types of Tea Infusions," J. Food Process. Preserv., vol. 38, no. 3, pp. 1401-1408, 2014.

[58] A. Pekal, M. Biesaga, and K. Pyrzynska, "Trace Metals and Flavonoids in Different Types of Tea," Food Sci. Biotechnol., vol. 22, no. 4, pp. 925-930, 2013.

[59] S. D. Jayawardhane et al., "Development of a method for the detection of sugar adulteration in black tea," in Proc. 6th Plantation crop research symposium, BMICH, 2016.

[60] H. Wedagedara, W. Wanigasuriya, S. Nissanka, B. Mendis, and W. Botheju, "Detecting of Sugar Adulteration in Black Tea and its Impact on Quality Parameters," in Proc. Peradeniya University International Research Session, Sri Lanka, 2019.

[61] A. D. Pal and T. Das, "Analysis of adulteration in black tea," Int. J. Biol. Res., vol. 3, no. 3, pp. 253-257, 2018.

[62] S. M. Eteiwi et al., "Potassium Permanganate Poisoning: A Nonfatal Outcome," Oman Med. J., vol. 30, no. 4, pp. 291-294, 2015.

[63] G. McDermott, X. A. Conlan, L. K. Koonan, and J. W. Costin, "Screening for antioxidants in complex matrices using high performance liquid chromatography with acidic potassium permanganate chemiluminescence

detection," Anal. Chim. Acta, vol. 684, no. 1-2, pp. 134-141, 2011.

[64] "Chemical Safety, Sodium Hydroxide Safe Handling Guideline," Environment, Safety, Health and Quality Division, 2023.

[65] D. N. Gunathilaka and W. R. Warnasooriya, "Adulteration and Quality of Black Tea in Sri Lanka," in The 2nd Faculty Annual Research Session, Faculty of Applied Science, University of Vavuniya, Sri Lanka, 2021.

[66] P. Firmani, S. De Luca, R. Bucci, and F. Marini, "Near infrared (NIR) spectroscopy-based classification for the authentication of Darjeeling Black Tea," Food Control, vol. 100, pp. 292-299, 2019.

[67] R. Amsaraj and S. Mutturi, "Rapid detection of sunset yellow adulteration in tea powder with variable selection coupled to machine learning tools using spectral data," J. Food Sci. Technol., vol. 60, pp. 1530-1540, 2023.

[68] Z. Tolkien, L. Stecher, A. P. Mander, D. I. Pereira, and J. J. Powell, "Gastrointestinal Side-Effects in Adults: A Systematic Review and Meta-Analysis," PLoS One, vol. 10, no. 5, p. e0126785, 2015.

[69] C. Wettasinghe, "Taint threatens to stain Ceylon Tea," Daily Mirror, Mar. 14, 2018. [Online]. Available: http://www.dailymirror.lk/147233/Taint-threatens-to-stain-Ceylon-Tea

[70] I. Rehan et al., "Determination of nutritional and toxic metals in black tea leaves using calibration free LIBS and ICP: AES technique," Arab. J. Sci. Eng., pp. 1-9, 2022.

[71] T. Taylor, "Microscopic investigations relating to tea and its adulterations," in Proc. Am. Soc. Microsc., 1889.

[72] L.-y. Xie et al., "Simultaneous determination of curcuminoids in Curcumae Longae Rhizoma and turmeric tea using liquid-phase microextraction based on solidification of floating deep eutectic solvent drop," Microchem. J., vol. 159, p. 105436, 2020.

[73] J. Panee, "Potential Medicinal Application and Toxicity Evaluation of Extracts from Bamboo Plants," J. Med. Plant Res., vol. 9, no. 23, pp. 681-692, 2015.

[74] A. Sagaya, A. Alanamu, A. Rahaman, and A. Adewumi, "Authentication of some commercial teas in Ilorin, North-Central, Nigeria," Plant Biol. (Buchar), vol. 68, no. 1-2, pp. 41-49, 2023.

[75] G. Lagiotis et al., "Detection and quantification of cashew in commercial tea products using High Resolution Melting (HRM) analysis," J. Food Sci., vol. 85, no. 6, pp. 1629-1634, 2020.

[76] P. K. Sharma, A. Mohammad, and D. K. Yadav, "Physicochemical and Phytochemical evaluation of different black tea brands," J. Appl. Pharm. Sci., vol. 1, no. 8, pp. 121-124, 2011.

[77] R. Varghese and S. Ramamoorthy, "Status of food colorants in India: conflicts and prospects," J. Verbrauch. Lebensm., vol. 18, pp. 107-118, 2023.

[78] L. Wei, Y. Yang, and D. Sun, "Rapid Detection of Carmine in Black tea with Spectrophotometry coupled predictive modelling," Food Chem., vol. 329, p. 127170, 2020.

[79] N. Cebi, M. T. Yilmaz, and O. Sagdic, "A rapid ATR-FTIR spectroscopic method for the detection of sibutramine adulteration in tea and coffee based hierarchial cluster and Principle Component Analysis," Food Chem., vol. 229, pp. 517-526, 2017.

[80] E. D. Assad, E. E. Sano, S. A. Cunha, T. s. Correa, and H. R. Rodrigues, "Identifying Adulteration in Coffee Powders by Spectral Signatures and Digital Analyses," Pesqui. Agropecu. Bras., vol. 37, no. 2, pp. 211-216, 2002.

[81] D. S. Domingues et al., "Detection of Roasted and Ground Coffee Adulteration by HPLC by Amperometric and by Post-Column Derivatization UV-Vis Detection," Food Chem., vol. 146, pp. 353-362, 2014.

[82] G. E. Davis et al., "Chromatographic Profile of Carbohydrates in Commercial Coffees. 2. Identification of Mannitol," J. Agric. Food Chem., vol. 38, no. 6, pp. 1347-1350, 1990.

[83] R. Briandet, E. K. Kemsley, and R. H. Wilson, "Approaches to Adulteration Detection in Instant Coffees Using Infrared Spectroscopy and Chemometrics," J. Sci. Food Agric., vol. 71, no. 3, pp. 359-366, 1996.

[84] G. Stanciu, S. Dobrinas, S. Birghila, and M. Poescu, "Determination of Organic Compounds From Different Types of Coffee by HPLC and GC-ECD Analysis," Environ. Eng. Manag. J., vol. 7, no. 5, pp. 661-666, 2008.

[85] S. Spaniolas, M. Tsachaki, M. J. Bennett, and G. A. Tucker, "Evaluation of DNA Extraction methods from Green and Roasted Coffee Beans," Food Control, vol. 19, no. 3, pp. 257-262, 2008.

[86] J. Hudakova, D. Marcincakova, and J. Legath, "Study of Antioxidant Effects of Selected Types of Coffee," Folia Vet., vol. 60, no. 3, pp. 34-38, 2016.

[87] A. S. Fontes et al., "Thermal Lens Evaluation of the Presence of Adulterants in Brewed Coffee," Anal. Sci., vol. 17, supplement, pp. 526-529, 2001.

[88] I. Gogoasa et al., "The Mineral Content of Different Coffee Brands," J. Hortic. For. Biotechnol., vol. 17, no. 1, pp. 68-71, 2013.

[89] M. M. Paradkar and J. Irudayaraj, "Rapid determination of caffeine content in soft drinks using FTIR-ATR Spectroscopy," Food Chem., vol. 78, no. 2, pp. 261-266, 2002.

[90] A. Ciampa, G. Renzi, A. Taglienti, P. Sequi, and M. Valentini, "Coffee Roasting Process by Means of Nuclear Magnetic Resonance Spectroscopy," J. Food Qual., vol. 33, no. S1, pp. 199-211, 2010.

[91] E. E. Sano et al., "Quantifying Adulteration in Roast Coffee Powders by Digital Image Processing," J. Food Qual., vol. 26, no. 2, pp. 123-134, 2003.

[92] K. M. Tavares et al., "Mid-infrared Spectroscopy and Sensory Analysis Applied to Detection of Adulteration in Roasted Coffee by Addition of Coffee Husks," Quim. Nova, vol. 35, no. 6, pp. 1164-1168, 2012.

[93] E. B. Goncalves et al., "Intralaboratory validation of an imaging method for detection and quantification of impurities in roasted and ground coffee: husks and sticks as an example," Braz. J. Food Technol., vol. 10, no. 2, pp. 144-150, 2007.

[94] B. Sezer, H. Apaydin, G. Bilge, and I. H. Boyaci, "Coffee arabica Adulteration: Detection of Wheat, Corn and Chickpea," Food Chem., vol. 240, pp. 839-846, 2018.

[95] F.-V. Mauricio, O. G. Meza-Marquez, G. Osorio-Revilla, and T. Gallardo-Velazquez, "Identification and quantification of adulterants in coffee (Coffea arabica L.) using FT-MIR spectroscopy coupled with chemometrics," Foods, vol. 9, no. 7, p. 851, 2020.

[96] C. L. Cesar, H. Vargas, C. S. Lima, F. J. Mendes, and L. M. Miranda, "On the Use of Photoacoustic Spectroscopy for Investigating Adulterated or Altered Powdered Coffee Samples," J. Agric. Food Chem., vol. 32, no. 6, pp. 1355-1358, 1984.

[97] W. L. Cheah and M. Fang, "HPLC-Based Chemometric Analysis for Coffee Adulteration," Foods, vol. 9, no. 7, p. 880, 2020.

[98] A. T. Toci and A. Farah, "Volatile Fingerprint of Brazilian Defective Coffee Seeds: Corroboration of Potential Marker Compounds and Identification of New Low Quality Indicators," Food Chem., vol. 153, pp. 298-314, 2014.

[99] W. S. Tsang, M. A. Clarke, and F. W. Parrish, "Detection and determination of aspartame and its breakdown products in soft drinks by RP-HPLC with UV detection," J. Agric. Food Chem., vol. 33, no. 4, pp. 734-738, 1985.

[100] D. A. Hammond, "Analysis of soft drinks and fruit juices," in Chemistry and technology of soft drinks and fruit juices, 2004, pp. 236-278.

[101] D. A. Hammond, "Methods to detect the adulteration of fruit juice and purees," in Food Authenticity, London: Blackie, Academic & Professional, Chapman & Hall, 1996.

[102] G. Wadds, "Analysis of synthetic food colours," in Developments in Food Colours, London: Elsevier Applied Science, 1984, pp. 23-74.

[103] D. Karunasagar and J. Arunachalam, "Determination of cadmium by inductively coupled plasma mass spectrometry-reduction of molybdenum oxide interferences by addition of acetonitrile," Anal. Chim. Acta, vol. 441, no. 2, pp. 291-296, 2001.

[104] Y. K. Kim, "Better Wavelength for Cadmium Analysis between 228.8 Nanometer and 228.9 Nanometer in Atomic Absorption Spectrophotometry," South Asian Res. J. Biol. Appl. Biosci., vol. 2, no. 3, pp. 106-108, 2020.

[105] K. H. Kim, E. Kabir, and S. A. Jahan, "Exposure to pesticides and the associated human health effects," Sci. Total Environ., vol. 575, pp. 525-535, 2017.

[106] D. K. Sahu et al., "Detection of Flonicamid insecticide in vegetable samples by UV-Visible spectrophotometer and FTIR," Results Chem., vol. 2, p. 100059, 2020.

[107] "Lindane," SpectraBase. [Online]. Available: https://spectrabase.com/compound/5PMob7aIdKz

[108] M. V. Castillo, M. A. Iramain, L. Davies, M. E. Manzur, and S. A. Brandan, "Structural Study and vibrational assignments of FTIR and FT-Raman spectra powerful pesticide 2,4'-DDT. Its Comparison with 4,4'-DDT," J. Mol. Struct., vol. 1228, p. 129486, 2021.

[109] G. Quintas et al., "Fourier transform infrared spectrometric determination of Malathion in pesticide formulations," Anal. Chim. Acta, vol. 502, no. 2, pp. 213-220, 2004.

[110] G. Xiao et al., "Detection of pesticide ((Chlorpyrifos) Residues on Fruit Peels through Spectra of Volatiles by FTIR," Food Anal. Methods, vol. 8, no. 6, pp. 1341-1346, 2015.

[111] P. Bendig, L. Maier, and W. Vetter, "Brominated vegetable oil in soft drinks- an underrated source of human organobromine intake," Food Chem., vol. 133, no. 3, pp. 678-682, 2012.

[112] S. Das, V. J. Nandeshwar, and G. S. Phadke, "Discrimination of adulteration orange juice by Linear Discriminant Analysis (LDA)," in IEEE Int. WIE Conf. Electr. Comput. Eng. (WIECON-ECE), 2015.

[113] R. Jackson, "Non-Alcoholic Beverages Adulteration Analysis," NIR-For-Food, 2023.

[114] A. G. Mignani et al., "Characterization of Artificial Sweeteners Using Raman Spectroscopy," Ref. Ser. Phytochem., pp. 1-14, 2016.

[115] H. Per et al., "Calcium carbide poisoning via food in childhood," J. Emerg. Med., vol. 32, no. 2, pp. 179-180,

2007.

[116] R. Ramanathan, "BMC Crackdown on chemicals in lassi, soft drinks and carbide in fruits," Times of India, May 21, 2023. [Online]. Available: https://timesofindia.indiatimes.com/city/bhubaneswar/bmc-crackdown-on-chemicals-in-lassi-soft-drinks-carbide-in-fruits/articleshow/100390005.cms

[117] K. Chiba et al., "Determination of ultratrace levels of fluorine in water and urine samples by a gas chromatographic/atmospheric pressure helium microwave induced plasma emission spectrometric system," Anal. Chem., vol. 54, no. 4, pp. 761-764, 1982.

[118] H. G. Knight, A. K. Furr, and T. F. Parkinson, "Determination of fluorine by neutron activation analysis," Anal. Chem., vol. 49, no. 11, pp. 1507-1510, 1977.

[119] M. Resano et al., "Simultaneous determination of Co, Fe, Ni and Pb in carbon nanotubes by means of solid sampling high-resolution continuum source graphite furnace atomic absorption spectrometry," J. Anal. At. Spectrom., vol. 28, no. 5, p. 657, 2013.

[120] S. Pardeshi, "Food adulteration: its implications and control approaches in India," Int. J. Trend Sci. Res. Dev., vol. 5, no. 5, pp. 1117-1123, 2021.

[121] L. B. Dogarawa, "Overview of the Socio-economic Implications and Management of Product Faking and Adulteration," Greener J. Bus. Manag. Stud., vol. 3, no. 5, pp. 119-125, 2013.

[122] V. L. McDevitt, A. Rodriguez, and K. R. Williams, "Analysis of soft drinks: UV spectrophotometry, liquid chromatography, and capillary electrophoresis," J. Chem. Educ., vol. 75, no. 5, p. 625, 1998.

[123] H.-H. Lim and H.-S. Shim, "Simple Determination of 4-Methylimidazole in Soft Drinks by Headspace SPME GC-MS," Chromatographia, vol. 76, no. 1-2, pp. 97-101, 2013.

[124] X. Li, Y. He, C. Wu, and D. W. Sun, "Nondestructive measurement and fingerprint analysis of soluble solid content of tea soft drink based on Vis/NIR spectroscopy," J. Food Eng., vol. 83, no. 3, pp. 316-323, 2007.

[125] V. Armoogum and K. Boodhoo, "Full optimization and validation of an HPLC method for the quantitative analysis of total sugars in a soft drink," Bull. Chem. Soc. Ethiop., vol. 34, no. 3, pp. 419-426, 2020.

[126] R. E. Froes et al., "Exploratory analysis and inductively coupled plasma optical emission spectrometry (ICP OES) applied in the determination of metals in soft drinks," Microchem. J., vol. 92, no. 1, pp. 68-72, 2009.

[127] M. M. Ghunieum, M. A. Khorshed, and E. R. Souaya, "Method validation for direct determination of some trace and toxic elements in soft drinks by inductively coupled plasma mass spectrometry," Int. J. Environ. Anal. Chem., vol. 99, no. 6, pp. 515-540, 2019.

[128] S. J. Bunu et al., "Atomic absorption spectroscopic (AAS) analysis of heavy metals and health risks assessment of some common energy drinks," Pharmacol. Toxicol. Nat. Med., vol. 3, no. 1, pp. 1-10, 2023.

[129] R. Preti, "Progress in beverages authentication by the application of analytical techniques and chemometrics," Qual. Control Bev. Ind., pp. 85-121, 2019.

[130] O. L. Zucchi, S. Moreira, M. J. Salvador, and L. L. Santos, "Multielement analysis of soft drinks by X-ray fluorescence spectrometry," J. Agric. Food Chem., vol. 53, no. 20, pp. 7863-7869, 2005.

[131] G. Quintas, S. Garrigues, and G. M. de la, "FT-Raman Spectrometry determination of Malathion in pesticide formulations," Talanta, vol. 63, no. 2, pp. 345-350, 2004.

[132] Y. Liu et al., "Detection of Phosmet Residues on Navel Orange Skin by Surface-Enhanced Raman

Spectroscopy," Intell. Autom. Soft Comput., vol. 21, no. 4, pp. 23-432, 2015.

[133] I. A. Potarniche et al., "Classification of Food Additives Using UV Spectroscopy and One-Dimensional Convolutional Neural Network," Sensors, vol. 23, no. 10, p. 4880, 2023.

[134] R. Preti, "Progress in beverages authentication by the application of analytical techniques and chemometrics," in Quality control in the beverage industry, 2019, pp. 85-121.

[135] H. K. Khurana, I. K. Cho, J. Y. Shim, Q. X. Li, and S. Jun, "Application of Multibounce attenuated total reflectance fourier transform infrared spectroscopy and chemometrics for determination of aspartame in soft drinks," J. Agric. Food Chem., vol. 56, no. 3, pp. 778-783, 2008.