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APPLICATION OF FTIR SPECTROSCOPY AND DIFFERENT METHODS TO DETECT ADULTERATION IN MANGO DRINKS

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ABSTRACT

The increasing popularity of fruit drinks in meals, diets, school lunchboxes, and restaurants has raised concerns about the authenticity and quality of these products due to potential adulteration. Efficient and reliable analytical techniques are crucial for the detection of such adulteration. In this study, random samples of mango drink brands accepted by school students sold in Egyptian markets were evaluated for adulteration using Fourier transform infrared (FTIR) spectroscopy, fruit juice percentage, sugars, and preservatives. Findings revealed that brands C, D, E, and F exhibit significant levels of adulteration, as evidenced by fruit percentages that are lower than the assigned value. Brands C and D contained higher concentrations of preservatives and sucrose levels, respectively, than the standard specification, as indicated by high-performance liquid chromatography (HPLC). FTIR spectroscopy of drinks free from adulteration showed that the main functional groups detected were in the molecular structure of brand A, which contained abundant hydroxyl groups, polysaccharide, and phenols at 1330–1340 and 3449–3620cm^{-1}, followed by brand B. Brands D and F had an amide 111-band aromatic ester at 1253–1255cm^{-1} with transmittance percentages of 50.38 and 21.11, respectively, potentially indicating the addition of water, polymer, and plasticizer. Accurate labeling of fruit drinks is essential for protecting consumers from potential health risks associated with adulterated fruit drinks.

1.Introduction

The fruit drink industry constantly introduces new drinks to attract consumers, making them a popular component of meals, diets, school lunchboxes, and restaurants. However, the adulteration of fruit drinks remains a serious health risk, with risks ranging from poisoning, hypertension, cancer, paralysis, and mental retardation (Tomar & Alka, 2022). To increase profits, some fruit drink manufacturers adulterate their products and deceive customers by adding low-cost or inappropriate materials, such as water and cheap fruit juices, and removing valuable nutrients from their products. These products are often advertised as 100% fruit juice but frequently include chemical substances such as colorants, synthetic flavor enhancers, preservatives, or texture improvers, which cause health hazards such as tremors, headaches, and allergies (Maireva et al., 2013; Uddin et al., 2017). Mango, orange, and apple drinks are among the top seven fruit drinks susceptible to adulteration, requiring the use of traditional and contemporary anti-adulteration methods to effectively combat fraudulent activity (Pithava & Pandey, 2018). Therefore, fruit drink manufacturers must strictly adhere to quality

control measures to guarantee pure and safe fruit drinks, while ensuring authenticity and preventing adulteration, for healthy consumption.

Various methods have been developed for detecting adulteration of fruit drinks, and research studies have revealed that fruit content, dilution with water, mineral content, and sugar content are important parameters in the detection of adulteration. For example, Maireva et al. (2013) found that the levels of calcium, magnesium, and potassium in fruit drinks can be used to identify adulteration, with higher levels suggesting the presence of added water or other non-fruit additives. Detecting adulteration requires the consideration of other parameters in addition to fruit drink composition, such as fractionated sugars, preservatives content by high performance liquid chromatography (HPLC), ash, and minerals content. In particular, high levels of added sugar can mask the taste of fruit, making it more difficult to identify adulteration (Richardson et al., 2019). It is crucial to highlight the adulteration of certain fruit drinks to increase awareness about the issue of fruit drink adulteration and guide industry initiatives aimed at addressing this problem.

Mango juice is a beloved and nutrition-packed drink that is a favorite during the summer months due to its numerous health advantages. A study by Reddy et al. (2020) indicates that mango juice contains carotene, which has anti-cancer properties, and it is rich in various nutrients such as vitamins A, C, B1, B2, and B3, calcium, iron, phosphorus, and potassium. However, commercial mango drinks are frequently considered adulterated. The process of detecting adulteration of mango products may include chemical, sensory, microscopic, DNA-based, HPLC, and Fourier transform infrared (FTIR) spectroscopy analysis (Jha & Gunasekaran, 2010; Uddin et al., 2017). Based on the detection of adulteration, utilizing these methods can verify the integrity of mango juice, preserving its nutrient density and potential health advantages.

Research conducted in Egypt has identified several points for an investigation into the adulteration of fruit drinks, including mango drink (Maireva et al., 2013). An effective method for detecting adulteration in food products are FTIR and HPLC. These methods have been widely employed in quality control and process control applications due to their rapidity, noninvasiveness, and minimal preparation required for detection. However, to date, no FTIR spectroscopic or chemometric studies have been carried out to determine whether Egyptian mango drinks are adulterated or safe with an excess of simple sugars (Uddin et al., 2017). Additionally, FTIR technology has emerged as a promising technique for the detection of food adulterants and their legitimacy since it is a less time-consuming method that is more effective at eradicating the problems experienced by industrial members.

To combat the deficiencies in adulteration detection, this study was conducted to assess the likelihood of adulteration in six popular commercial mango drink brands frequently consumed by school students, purchased from Egyptian markets via traditional anti-adulteration methods (physicochemical tests) and contemporary anti-adulteration techniques (HPLC and FTIR spectroscopy techniques).

2. Materials and methods

2.1. Materials and chemicals

Commercial mango drinks coded as A, B, C, D, E, and F were purchased from local Egyptian markets (cardboard containers).

Food Technology Research Institute in Egypt and Sigma-Aldrich Company, cat. no. (AA8887) provided sodium hydroxide, phenol, potassium sorbate, sodium benzoate, hydrochloric acid, methanol, potassium dihydrogen phosphate, and sulphoric acid phosphoric acid.

2.2. Physicochemical tests

The total ash, Brix value (TSS%), were determined using the methods prescribed by the Association of Official Analytical Chemists (AOAC) (AOAC, 2019). The total carbohydrate content was determined using the phenol-sulfuric acid method (DuBois et al., 1956).

2.3. Determination of fruit content in the drinks

In total, 10ml of each fruit drink sample were diluted with 0.25N sodium hydroxide solution at pH 8.1, as described by Pithava and Pandey (2018). Equal amounts of formaldehyde solution were then added. After one minute, the solution was potentiometrically titrated at pH 8.1 with 0.25N NaOH. The percentage of fruit content was calculated according to the following Equation 1.

$$\%\ \boldsymbol{fruit\ content} = \frac{\mathbf{1.05\ F}}{\mathbf{1.4}} \quad (1)$$

*where F refers to the formol number (formol index)

2.4. Viscosity

A Brookfield AMETEK RV viscometer was used to directly measure the flow properties (shear rate, shear stress, and apparent viscosity) of all tested mango drinks. Samples were placed in small sample adapters, and the SC4-18 spindle was utilized to measure each sample. The viscosity of the mango drinks was measured at room temperature with shear rates ranging from 13.2 to 79.2s^{-1}, and the results were presented as centipoise (cP).

2.5. Turbidity

Turbidity measurements were carried out using a PC Compact Turbidimeter (Aqualitic Germany) (Turb 430T, serial no. 19430784) as a Nephelometric Turbidity Unit (NTU). Each mango drink was placed in a 15ml cell, capped, and gently inverted twice to ensure even mixing.

2.6. Preparation of standards and samples for sugar profile analysis and determination of preservatives by HPLC

The HPLC analysis was conducted using an Agilent Technologies 1100 series liquid chromatograph equipped with an autosampler and a refractive index detector (RID). A Shim-pack SCR-101N analytical column was utilized. The mobile phase consisted of ultrapure water, and the flow rate was kept at 0.7ml/min for a total run time of 20 minutes with isocratic elution.

A sugar profile analysis of mango drinks was conducted using an official method described by the AOAC (AOAC, 1995), with minor modifications. A 10µL portion of each prepared sample was injected into an HPLC equipped with RI detection (Shimadzu refractive index, RID-10A). A ShimpackSCR-101N separation column (250mm L × 4.6mm I.D., 10µm) was used, and the column temperature was maintained at 30°C. The mobile phase was a mixture of water/acetonitrile (80:20v/v), and the flow rate was 1.3ml/min. Sugars were identified by comparing their retention times with appropriate sugar standards. Quantitation was done using the external standard method on peak areas or peak heights (Al-Mahasneh et al., 2021).

HPLC was used to determine sodium benzoate and potassium sorbate preservatives in all tested mango drinks. To prepare a stock solution of 1000ppm, 0.01g of each standard (sodium benzoate and potassium sorbate) was weighed and dissolved in 10ml of deionized water. A series of dilutions was prepared, and the peak area was plotted against each concentration. As part of the HPLC method, samples were prepared after concentration, and the mobile phase was diluted prior to analysis. These preservatives were determined according to Burana-osot et al. (2014). The results were expressed as benzoic and sorbic acid equivalents by equations 2 and 3.

$$\boldsymbol{Benzoic\ acid} \times \mathbf{1.18} = \boldsymbol{sodium\ benzoate} \quad (2)$$

$$\boldsymbol{Sorbic\ acid} \times \mathbf{1.2} = \boldsymbol{potassium\ sorbate} \quad (3)$$

2.7. Detecting adulteration by FTIR spectroscopy

FTIR spectroscopy was used to detect adulteration by Thermo Nicolet Nexus 670 instrument equipped with a mercury cadmium telluride A (MCTA) detector, XT-KBr beam-splitter, and OMNIC software. Drink samples were analyzed by placing a 0.5ml aliquot of each on a multi-bounce ZnSe crystal. The spectra

were measured by taking 128 scans at a resolution of 4cm-1, which were then averaged over the 4000–650cm-1 region. Prior to each analysis, a background was collected and then automatically subtracted from the sample spectra (Vardin et al., 2008).

2.8. Statistical analysis

For statistical analysis, a one-way analysis of variance (ANOVA) assessment was conducted at a significant rate of 0.05 for the entire results using Co-Stat (Ver. 6.400) according to (Steel et al., 1997). Prediction performance was quantified using a correlation coefficient (R). The least significant difference (LSD) test was used to assess the significance of the results among the drinks. All experiments were conducted in triplicate.

3. Results and discussions

The six commercial brands of mango drinks A to F were tested for adulteration using traditional and modern methods, including physicochemical tests, qualitative and quantitative fractionated sugars and preservative materials of the drink were determined using the HPLC method, while functional groups were analyzed using FTIR spectroscopy.

3.1. Physicochemical analysis

Table 1 shows the results of the physicochemical analysis, including ash, TSS, total carbohydrates, fruits percent of mango drinks (denoted as A, B, C, D, E, and F).

3.1.1. Ash

The total ash content is an important traditional indicator for detecting adulteration in fruit drink products. In Table 1, commercial mango drink brands C and F exhibited significantly higher total ash content (0.154 and 0.124%, respectively) than brand A (0.007%), indicating the presence of adulterants. The findings are consistent with previous studies by Usman et al. (2018). Total ash content in adulterated fruit drinks often arise from several sources, including the addition of non-fruit ingredients like fillers and sweeteners, the use of low-quality raw materials or cheaper fruit, and the deliberate incorporation of mineral salts for flavor enhancement. Impurities introduced during manufacturing (Ammari et al., 2015; Pasha et al., 1994).

3.1.2. Total soluble solids

TSS% is the simplest and most economical way to determine fruit drink adulteration. Table 1 shows that the TSS values varied between 11 and 15% for all tested mango drinks. The highest TSS values were obtained for brands C and D, 15 and 14.7%, respectively, which may be attributable to the addition of sucrose during processing (adulteration). The increase in TSS is related to the greater degree of tissue breakdown, where more compounds such as sugars are released (Nath et al., 2015). Brands E and F had slightly lower values (11 and 12%) than brands A and B (13.5%), suggesting water dilution (adulteration). These values are comparable with those of (Dżugan et al., 2018).

Table 1 also shows that the TSS recorded on the drinks' label descriptions as "no less than 8, average between 8 and 9, and similar or different numbers than actual" differed for all tested commercial mango drinks, which is considered adulteration and misleading to consumers (Jha et al., 2016). The TSS label was lower than the obtained results for brands C, D, and E. This finding indicates that adulteration in fruit drinks occurs by manipulating the TSS levels from those stated on drink labels.

3.1.3. Total carbohydrates

Detection of adulteration in fruit drinks, where the inclusion of sugars is a frequent occurrence, is often accomplished by detecting the presence of carbohydrates. In examining correlations between fruit content and total carbohydrates within various mango drinks, a strong correlation between these metrics was observed (r=0.982), as shown in Table 1, because mangoes are known to possess a high level of carbohydrates throughout the process of maturation. Analysis of the carbohydrates presented in Table 1 indicated that brands D and E possessed the highest carbohydrate levels of all the tested brands (18.14 and 18.13%, respectively), which exceeded the values stated

on their packaging label (17.12 and 14%, respectively).

With respect to the other tested drinks, brands A and B showed the lowest levels of carbohydrates (14.59 and 13.55%, respectively), although the value of brand B was closer to that stated on its label. Incorrectly stated carbohydrate levels on drink labels may be indicative of adulteration (Martínez Montero et al., 2004).

Table 1. Physicochemical properties of mango drink brands.

Mango drinks	Ash (%)	Laboratory test	Label claim	Fruit content (%)	Sucrose (%)	Sucrose (%) Quantitative HPLC	Laboratory test	Label claim
		TSS (°Brix)			Label claim	Laboratory test	Total carbohydrates (%)	
A	0.007^{b}±0.00	13.5^{b}±0	14.0	14.68^{a}±0.27	13.0	10.03	14.59^{c}±0.37	14
B	0.062^{ab}±0.05	13.5^{b}±0	14.5	11.53^{b}±0.33	15.00	9.39	13.55^{d}±0.29	14
C	0.154^{a}±0.14	15.0^{a}±0	8	7.84^{e}±00	13.90	12.33	16.89^{b}±0.98	13.4
D	0.091^{ab}±0.017	14.7^{a}±0	Not less than 8	5.31^{f}±0.27	13.45	12.62	18.14^{a}±0.32	17.12
E	0.070^{ab}±0.035	11.0^{d}±0	Average 8-9	7.09^{e}±00	14.00	11.37	18.13^{a}±0.33	14
F	0.124^{a}±0.02	12.0^{d}±0	15	7.03^{e}±00	15.00	11.31	16.89^{b}±0.11	16

Means in the same column with different superscripts (a, b, c …) are significantly different ($p \leq 0.05$).

3.1.4. Fruit and sucrose content in drinks

Fruit content is a valuable indicator

of adulteration. As shown in Table 1, the fruit content of mango drink brands A and B were 14.68 and 11.53%, respectively which are slightly lower than the general standards (15-25%) (CODEX-STAN247, 2005; EOSQ, 2017). In contrast, brands C, D, E, and F were significantly below standards 7.84, 5.31, 7.09, and 7.03%, respectively. The low fruit content indicates that minimal mango was added, contributing to economic gains in the mango concentrate and, therefore, indicating adulteration and misleading consumers (Jha et al., 2016).

The results in Table 1 shows a negative correlation between the fruit constituents in drink and the sucrose content in brand A and B. Specifically, the mango-based A demonstrated a strong and negative correlation, denoted by a correlation coefficient of -0.98. This observation indicates that an increase in fruit composition results in a concomitant decrease in sucrose quantity, which conforms to the predominate fruit-derived sugar, according to the extant literature (Duarte et al., 2002). Brands A and B mango drinks used fruit as a natural sweetener rather than heavily relying on added sugars (Kumar et al., 2020). Conversely, the brand D mango drink displayed a comparatively weaker negative correlation between the fruit constituents in drink (5.31%) and the sucrose content (12.62%). This finding suggests that although there is still a tendency for the fruit content to be a natural sweetener in this product, it is not as pronounced as in brands A and B mango drink. It is possible that the brands C and D mango drink may rely more on added sugars or may use a different method for sweetening the product that is not as closely related to the fruit content (Richardson et al., 2019).

According to current classification conventions, fruit drinks with less than 10% fruit content are typified as artificial fruit drinks (Rajauria & Tiwari, 2017). Overall, the present study offers valuable insight into the correlation between the fruit constituents and the sucrose content in mango drinks, underscoring the importance of understanding fruit drink product attributes for those seeking healthier dietary options.

3.1.5. Viscosity

Viscosity has been employed as an indicator of the quality of fruit drinks and, particularly, to determine the degree of their adulteration. In Table 2, viscosity of mango drink brands C, D, E and F increased with adulteration by 48.4, 45.8, 44.8 and 46.0cP, respectively. The low viscosity of brands A and B (22.4 and 25cP, respectively) may be attributed to its degree of methylation, pH imbalances, and TSS of the drink (Giap, 2010). Conversely, the highest viscosity in all tested brands may be attributable to the presence of pectin, pulp juice, stabilizer, and gum which enhance the consistency of drinks and create highly viscous media. All tested brands showed higher viscosity than brands A and B as expected due to adulteration.

3.1.6. Turbidity

Turbidity is the level of cloudiness or haziness caused by the dispersed matter in fruit juices, primarily composed of comminuted cellular tissues. In Table 2, turbidity can be a desirable attribute (cloudy), as shown in all tested mango drinks. The turbidity value of brands A and B were significantly lower (493 and 442NTU) than the values of all tested drinks C, D, E, and F, which were gradually increased by 897, 680, 636, and 657NTU, respectively providing brand drinks with higher turbidity. The rise in turbidity levels of drink brands compared to brands A and B may be a result of mature mango usage, insoluble pulp tissue fragments, or undissolved components such as pectin, cellulose, hemicellulose, starch, protein, and lignin released during enzymatic prepress maceration (Rai et al., 2022). Brands A and B however, exhibited a negative attribute (lack of apparent turbidity) may be due to the filtration process used to reduce turbidity and eliminate impurities, which was preferred by consumers (Calle et al., 2022). It might be concluded that brands C, D, E, and F have markedly higher adulteration levels.

Table 2. Viscosity and turbidity in brands of the mango drinks.

Mango drinks	Viscosity	Turbidity
	cP	NTU
A	6.4	493
B	35.0	742
C	38.4	897
D	44.8	680
E	44.8	636
F	32.0	657

3.2. HPLC analysis of sugars in mango drinks

The most abundant sugars in fruit drinks, particularly mango, are sucrose, glucose, and fructose (Duarte et al., 2002). However, sugars are commonly added to neutralize acidity or to provide sweetness (Hammond, 2016). Consequently, an analysis of sugar in tested mango drinks was conducted using HPLC analysis to detect adulterants, quantify and qualify added sugars, and provide valuable insight into a drink's purity. Three sugars were analyzed using HPLC, namely, sucrose, glucose, and fructose (Table 3 and Figure 1). The results indicated that all tested mango drinks containing sucrose levels ranged from 10.03 to 12.62%. For all drink brands, there are

noticeable changes in glucose concentrations (1.69 – 3.6%) and fructose concentrations (1.49 – 5.60%) in comparison with brands A and B which shows a slight decrease in sucrose (10.03 and 9.39%, respectively) and an increase in both glucose (3.6 and 2.66%) and fructose (5.6 and 4.27%) compared with other drinks.

As shown in Table 3 and Figure 1, the recorded sucrose levels on the label packages of brands A, B, C, D, E, and F were 13, 15, 13.9, 13.45, 14, and 15%, respectively. The labeled values indicate poor agreement with laboratory values. Due to mango maturity, processing, and storage conditions, sugar degradation may occur in mango drinks. In the case of brands A and B, on the label packages, sucrose levels were high, when compared with the same brands laboratory test which may be attributable to the addition of sucrose during processing. It is possible that the brands C and D mango drink may rely more on added sugars or may use a different method for sweetening the product that is not as closely related to the fruit content (Richardson et al., 2019). The low or high sugars content of mango drinks are likely caused by the addition of fruit juice (peach or grape) or the use of cane sugar as a sugar substitute.

Table 3. Quantitative sugars of mango drink brands, as determined by HPLC.

Mango drinks	Sucrose		Glucose	Fructose
	%			
	Label claim	Laboratory test		
A	13	10.03	3.6	5.6
B	15	9.39	2.66	4.27
C	13.9	12.33	1.69	1.49
D	13.45	12.62	1.82	1.68
E	14	11.37	2.14	1.76
F	15	11.31	2.49	2.25

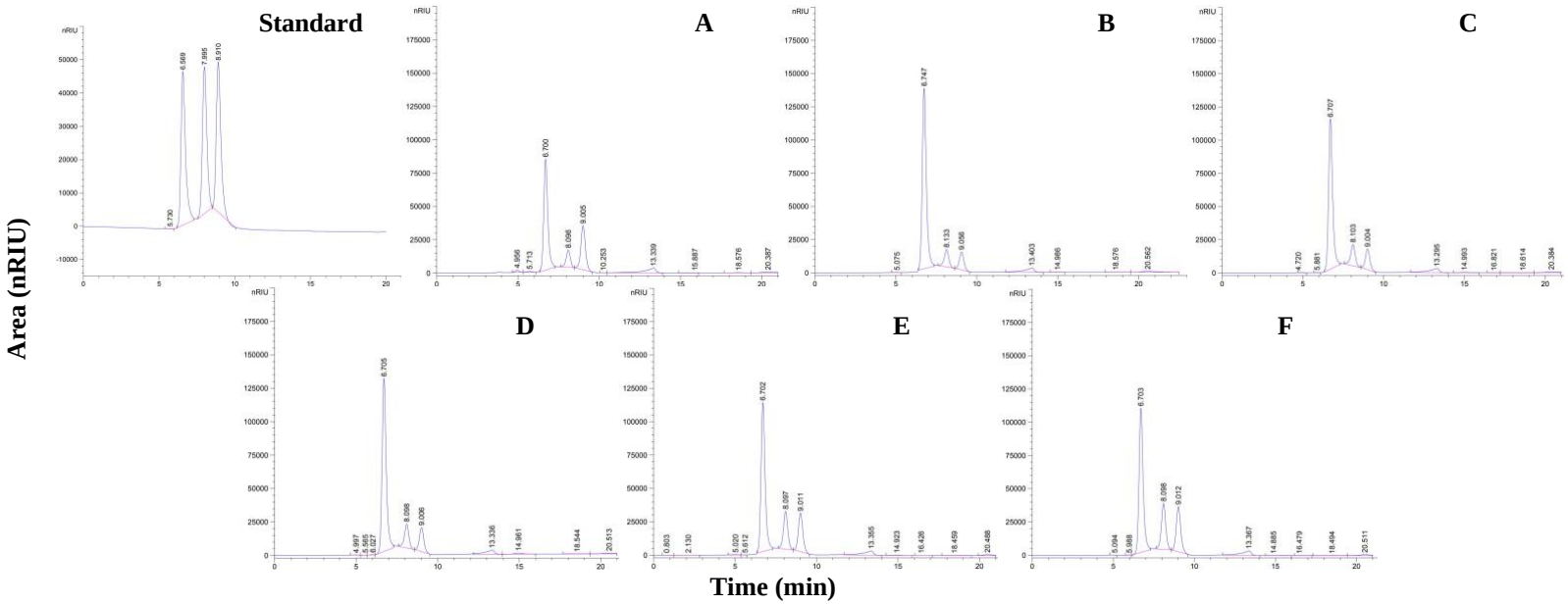

Figure 1. Qualitative HPLC analysis of standard sugar solutions, mango drink brands (A to F).

3.3. HPLC analysis of preservative determination in mango drinks

The use of preservatives such as sodium benzoate (E211) and potassium sorbate (E202) in fruit drinks is vital in modern food and drink technology for shelf-life extension and maintaining quality. However, excessive consumption and adulteration of these preservatives pose significant health risks (Ahmed et al., 2013; Aslam et al., 2020). Using the HPLC technique, as standards g/100g (%), this study analyzed six mango drink brands to detect the presence and amounts of sodium benzoate and potassium sorbate (Table 3 and Figure 2). The results revealed that sodium benzoate was the prevailing preservative utilized, while potassium sorbate was absent in all tested drinks. A similar indication has been reported in the literature (Ahmed et al., 2013). According to the U.S. Food and Drug Administration (U.S. FDA) (FDA, 1999), brands C and D contained high levels of sodium benzoate (0.804 and 1.442%, respectively), and the values differ from those on their package labels, indicating significant adulteration. The remaining mango drink brands were free of these preservatives. Accordingly, sodium benzoate should not exceed 0.1%, whereas potassium sorbate is permitted at 0.1 to 0.2% (100mg/100ml), respectively. As allowable food additives, both analyzed preservatives must not exceed recognized limits to ensure consumer safety (Aslam et al., 2020). Additionally, the results indicate that commercial mango drinks (A and B) with a shelf life comparable to that of brands E and F, were produced without preservatives by using appropriate processing and storage techniques, with the exception of brand C and D. According to the package label, during processing, for example, citric acid and ascorbic acid were added to brand C, while ascorbic acid and stabilizers E415 were added to brand D. However, where required, potassium sorbate and sodium benzoate or their combination at prescribed concentrations can be effectively used to preserve mango drinks' quality (Ahmed et al., 2013).

To ensure consumer safety, it is crucial to verify both the names and specific quantities of preservatives used in fruit drinks, which can now be more easily identified with the latest advancements in analytical chemistry and instrumentation (Calle et al., 2022).

Table 3. HPLC-based quantitative preservatives according to standards g/100g (%) in the mango drinks brands.

Mango drinks	Label Claim	Sodium Benzoate	Potassium Sorbate
A	No preservatives	ND	ND
B	No preservatives	ND	ND
C	Permitted preservative (citric acid+ascorbic acid)	0.804	ND
D	Permitted preservative (ascorbic acid+E415)	1.442	ND
E	No preservatives	ND	ND
F	Permitted preservative (citric acid+potassium citrate)	ND	ND

ND: not detected.

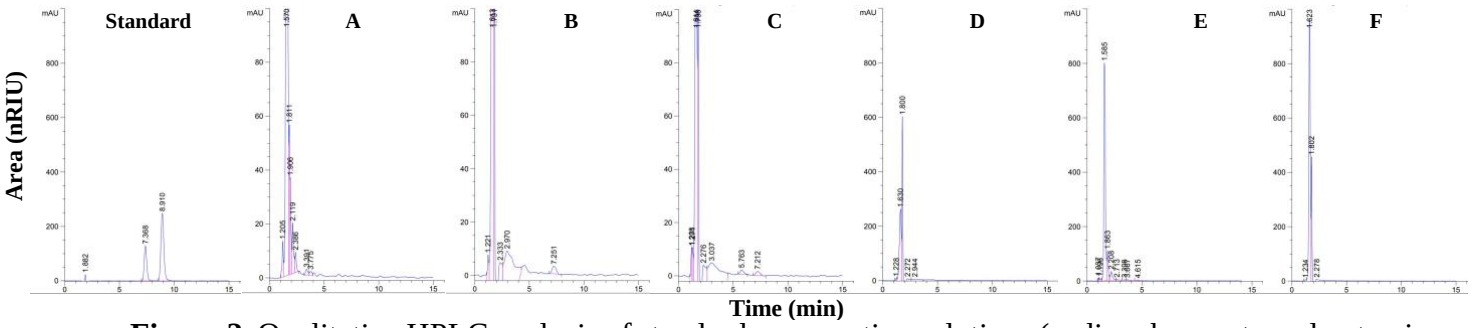

Figure 2. Qualitative HPLC analysis of standard preservative solutions (sodium benzoate and potassium sorbate), mango drinks brands (A to F).

3.4. FTIR spectroscopy analysis of functional groups in mango drinks

Adulteration of fruit drinks such as mango with cheaper ingredients has become a serious concern in the food and drink industry. FTIR spectroscopy has been identified as a reliable method for identifying the presence of adulterants by detecting changes in the functional groups of the drink. The study investigated the functional groups present in commercial mango drink brands (A to F) using FTIR spectroscopy. The spectra of all types of drink brands were found to be nearly identical, with absorption bands at 3449, 2387, 2059, 1636, 1416, 1330, 1253, 1106, 1054, 996, 485, and 550cm^{-1}, respectively (Table 4). The hydroxyl groups (O-H) at 1330–1340 and 3449–3620cm^{-1} were the most prominent functional groups detected in mango drinks brand A and B, followed by other commercial brands. The bands at 1045–1340cm^{-1} (polysaccharide and phenols) were observed, with the asymmetric CH stretching vibration causing these bands.

Table 4 shows the bands of the major functional groups, wavenumbers, and transmittance percentages of mango drinks. The bands at 1045, 1106, and 1253cm^{-1} were characterized by (C-O) stretching vibrations in the furanose ring. The strong bands at 996, 1636, and 2378cm^{-1} were allocated to an α-D-glcopyranosyl deposit in the carbohydrate conjugated chain (C\\C). These findings are consistent with previous reports of the FTIR spectra of mango juice (Uddin et al., 2017). The band at 1106–1107cm^{-1} was not specific for mango drink brands C, D, E, and F. Additionally, the band at 1253–1255cm^{-1} (amide 111 band and aromatic ester) for brand C (zero transmittance percentage) could be attributable to dilution with water, which is an adulteration method, indicating the hygroscopic properties of this homo polysaccharide.

Additionally, the same table shows that the bands at 1416 and 1417cm^{-1} in mango drinks spectra confirmed C-H ring vibration in the presence of 2-ketofuranose. Polyphenols, carbohydrates (intermolecular bonded O-H), and hydroxyl bonds were detected at 3449–3620cm^{-1} in brand A drink. The mango drink spectra confirmed strong N=C=S rings between 2059 and 2068cm^{-1}, suggesting that the functional group isothiocyanate is present where the drink brands A and B have a high transmittance. The percentage of transmission was higher in brand A followed by brand B, which could be attributed to the absence of adulteration. The bands at 2387cm^{-1} in the mango brand's F spectra confirmed C=C conjugated ring vibration in the presence of amino perfluoro alkyl sulfonate (polymer additives and plasticizers), as shown in Table 4 and Figure 3.

Amide 111-band aromatic ester was observed at 1253–1255cm^{-1} and 2387cm^{-1} for brands D and F with a transmittance percentage of 50.38 and 21.11, respectively. This finding could be attributed to the addition of polymer and plasticizer. The study found that brands A and B were free of adulterants and contained the main functional hydroxyl groups (O-H) and

polysaccharides, as well as phenols. These results demonstrate the potential of FTIR spectrometry, coupled with chemometrics, in detecting the adulteration of mango drinks (Jha & Gunasekaran, 2010). Thus, the advances in analytical chemistry and instrumentation have simplified the detection of fruit drink adulteration (Calle et al., 2022)

Table 4. Summary of the band assignments used for the FTIR spectra of the major functional groups, wavenumbers, and % transmittances for mango drink brands.

Functional groups	**Wavenumber** cm^{-1}	**Transmittance** %					
		A	**B**	**C**	**D**	**E**	**F**
CH out of plane aromatic band	485-550	27.115	3.754	-0.773	10.637	0.800	10.012
C=C, strong-bending-alkene-monosubstituted	996-997	68.245	42.434	-	39.26	-	24.022
C-O, strong-stretching-carbohydrate-polysaccharide	1045-1057	66.210	34.893	2.097	32.906	4.168	21.110
C-O, strong-stretching-polysaccharide	1106-1107	79.700	50.448	-	-	-	-
C-O, strong-stretching-aromatic ester, C-N, Amide 111band	1253-1255	10.371	12.032	-	50.380	9.982	21.110
OH, medium, bending, phenol	1330-1340	92.246	70.155	18.258	50.986	9.133	28.326
C-H, bending, alkane-methyl group, stretching C=O, inorganic carbonate	1416-1417	92.748	70.941	18.302	50.728	8.997	28.258
C=C, medium, stretching, alkene (disubstituted Cis), C=O amide 1 band	1636-1651	34.536	5.909	-0.256	9.747	0.611	9.953
N=C=S, strong, stretching, isothiocyanate	2059-2068	115.147	101.019	50.932	66.961	14.706	32.502
C=C, conjugated	2387	-	-	-	-	-	37.202
O-H, stretching, carbohydrate, polyphenols (intermolecular bonded OH), N-H, medium stretching, primary amine	3449-3620	6.912	-1.020	-1.440	1.586	-0.248	1.400

* Mango drink brands D and F contained polymer additives and plasticizers (amine perfluorealkylesulfonate) only. Mango drink brands C and E contained polymer additives and plasticizers, and dyes, nitro, and azo compounds such as polyetherinide and N,N-BIS(salicylidene)-1,3-propanediamine.

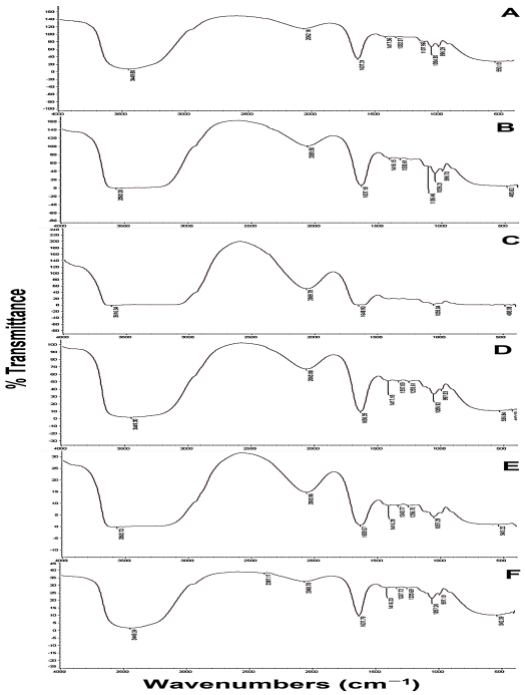

Figure 3. Qualitative FTIR spectra characterization of brands (A to F) of mango drinks.

4. Conclusions

The extensive use of fruit drinks in various settings highlights the significant health hazards associated with the adulteration of this industry. As a result, there is an urgent need for accurate and prompt analytical techniques to guarantee the authenticity and quality of these drinks. This study has effectively demonstrated that conventional and contemporary anti-adulteration methods, namely, physicochemical tests, HPLC, and FTIR spectroscopy, can efficiently identify adulteration in commercial mango drink brands. According to HPLC analysis, brands C and D have been adulterated with sucrose, and preservative materials. The potential of FTIR spectrometry, coupled with chemometrics, in detecting the adulteration of mango drinks. Brands D and F had an amide 111-band aromatic ester at 1253–1255cm^{-1} with transmittance percentages of 50.38 and 21.11, respectively, potentially indicating the addition of water, polymer, and plasticizer. Furthermore, the findings of this study reveal that brands C, D, E, and F have markedly higher adulteration levels and lower fruit content, suggesting water dilution. Therefore, fruit drink manufacturers must ensure accurate product labeling to mitigate health hazards related to adulterated fruit drinks. In addition, it is possible to eliminate the need for preservatives in commercial mango drinks or to use acceptable levels of preservatives by employing appropriate processing and storage techniques to provide safer and healthier drinks. Regulatory limits on food additives must also be enforced, accompanied by accurate food product labeling to ensure consumer safety.

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