Comparative Study of Natural and Commercial Lemon Beverages Based on Physicochemical Properties and FT-IR Spectral Analysis

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Abstract
Lemon juice is widely consumed because of its content of vitamin C, phenolic compounds, and aromatic substances. During extraction, transportation, storage, and packaging, the physicochemical properties of the juice play an important role in maintaining product quality and stability. Physicochemical analyses are an important component of food quality control. In the food industry, product quality is not limited to organoleptic characteristics such as taste, aroma, and texture; it is also assessed using physicochemical parameters such as pH, density, and soluble solids content. The physical properties of liquids, including viscosity and surface tension, influence fluid behavior and can affect pulp stability, homogenization, foaming, and sensory characteristics. The study of these parameters contributes to the characterization of lemon-based beverages and provides information relevant to their technological properties. In this study, two commercially available lemon beverages were analyzed and compared with freshly squeezed natural lemon juice. The study highlights the relevance of physicochemical characterization for comparing natural and commercial lemon beverages, particularly with respect to acidity and soluble solids content.
FT-IR spectroscopy was also employed to characterize the dried lemon pulp used to obtain the natural juice, and the characteristic spectrum was recorded and interpreted.

Keywords: physicochemical analysis, lemon juice, density, refractive index, FT-IR spectroscopy

1. Introduction

Lemon (*Citrus limon L.*) is a citrus fruit belonging to the Rutaceae family and is widely cultivated in subtropical and Mediterranean regions. Owing to its nutritional value, bioactive compounds, and numerous industrial applications, lemon is important in both human nutrition and the food industry.

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Lemons are recognized for their high content of citric acid and vitamin C (ascorbic acid). They also contain flavonoids, phenolic compounds, dietary fiber, potassium, and small amounts of B-complex vitamins [1]. These constituents contribute to the nutritional and antioxidant properties of the fruit.
Numerous studies have investigated the composition and potential health-related properties of citrus fruits and their bioactive compounds.
Lemon consumption contributes to dietary intake of vitamin C and other bioactive compounds. Vitamin C is involved in collagen synthesis and normal immune function, while citrus phenolic

compounds contribute to the antioxidant potential of the fruit.

Furthermore, the antioxidant compounds present in lemons may contribute to reducing oxidative stress, although their effects depend on the amount consumed and the overall dietary context [2].

Lemon is widely used in the food industry for the production of juices, soft drinks, bakery products, and preserved foods. Essential oils extracted from the peel are used in the cosmetics, perfumery, and pharmaceutical industries, while citric acid is widely used as an acidity regulator and preservative.

Through its nutritional value, bioactive composition, and versatility, lemon is an important fruit for both human consumption and various industrial applications.

Lemon juice is frequently consumed both at household level and in the food industry. Because of its content of citric acid, vitamin C, and other bioactive compounds, it is valued for its characteristic sensory and functional properties. Freshly squeezed juice and commercially processed lemon beverages can differ substantially in chemical composition, nutritional characteristics, and technological properties.

The composition of lemon beverages varies depending on the raw material, formulation, processing, and storage conditions. Differences between freshly squeezed juice and commercial products may affect parameters such as organic acids, sugars, soluble solids, and other dissolved compounds.

Freshly squeezed juice may retain a substantial proportion of the fruit's bioactive compounds; however, it has a relatively short shelf life because vitamin C can undergo oxidation during exposure to air, light, and unfavorable storage conditions. Vitamin C losses during postharvest handling and storage have been reported in the literature [3].

Commercial beverages are generally subjected to controlled processing and microbiological quality procedures. Processing and preservation treatments can reduce the risk of microbial contamination and extend shelf life.

Therefore, natural and commercial products involve a balance between freshness, composition, stability, and shelf life. A direct comparison of physicochemical parameters can provide useful information about their characteristics.

Given the increasing interest in food quality and authenticity, rapid and non-destructive analytical methods are valuable for characterizing food products.

Fourier-transform infrared spectroscopy (FT-IR) is a rapid and efficient technique for characterizing the chemical composition of food samples. It provides information about functional groups and molecular structures and, when combined with complementary analytical methods, can contribute to a more comprehensive evaluation of differences among sample types [4–7].

FT-IR spectroscopy is a rapid and non-destructive technique widely used in food and plant analysis to identify functional groups and characterize chemical composition [8, 9]. It provides a characteristic spectral fingerprint for each sample type and was therefore applied to the analysis of dried lemon pulp. Integrating FT-IR spectroscopy with complementary physicochemical determinations allows a more comprehensive characterization of the analyzed material.

The aim of this study was to compare natural lemon juice with commercially available lemon beverages using complementary physicochemical measurements and to characterize dried lemon pulp by FT-IR spectroscopy. The study evaluated pH, soluble solids content, refractive index, and density and interpreted the main FT-IR absorption bands of the lemon pulp.

2. Materials and methods

Biological material

The study material consisted of freshly squeezed natural lemon juice and two commercially available lemon beverages (Fanta and Frutti Fresh).

Natural lemon juice was obtained by directly squeezing fresh lemons, without industrial stabilization or the addition of additives. For each type of beverage, two 100 mL samples were prepared: one sample was used for density determination, while the second was used for the other physicochemical analyses.

All samples were analyzed at a room temperature of 20 °C. The samples were not refrigerated and were kept uncovered during the measurements.

FT-IR spectroscopy

Dried lemon pulp was prepared from fresh lemon fruit and dried at room temperature. For FT-IR analysis, 0.005 g of dried sample was used

without further purification. FT-IR spectra were recorded in absorbance mode using a Jasco FT-IR-4100 spectrophotometer and the KBr pellet technique. The sample was mixed with potassium bromide (KBr) at a ratio of 3 mg sample to 200 mg KBr. Measurements were performed over the 350–4000 cm^{-1} range at a spectral resolution of 4 cm^{-1}, and 256 scans were acquired for each spectrum.

The spectral data were analyzed using Origin 6.0 software (Fig. 1). The observed absorption bands were interpreted by comparison with reported vibrational assignments for similar functional groups in the literature.

3. Results and discussion

FT-IR analysis

Figure 1 presents the FT-IR spectrum of the dried lemon pulp sample.

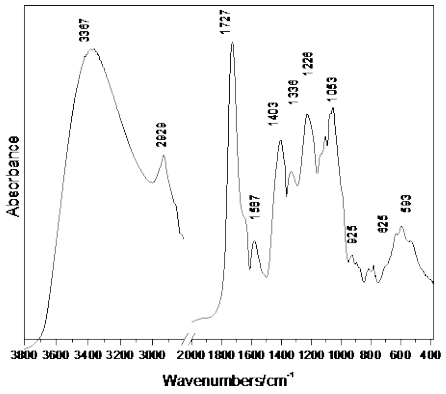

Figure 1. FT-IR spectrum of dried lemon pulp

The FT-IR spectrum indicates that dried lemon pulp contains hydroxyl-containing compounds, carbohydrates, fibers, and organic acids, which are characteristic components of citrus plant biomass.

In the 3200–3600 cm^{-1} region, a broad and intense band is observed, corresponding mainly to O–H stretching vibrations. This band may originate from residual moisture as well as hydroxyl groups in cellulose, pectin, and phenolic compounds.

The weak band observed at approximately 2929 cm^{-1} corresponds to C–H stretching vibrations of aliphatic CH_2 and CH_3 groups, which can be associated with lipids, sugars, and other organic constituents of lemon pulp.

In the 1700–1750 cm^{-1} region, a characteristic carbonyl (C=O) absorption band is observed. This band can be associated with organic acids, esters, and pectic components present in citrus tissues.

A strong band is observed at 1727 cm^{-1} in the spectrum shown in Figure 1, consistent with carbonyl-containing compounds present in lemon pulp.

The band at 1587 cm^{-1} can be attributed to vibrations involving C=C bonds and may be associated with aromatic or other conjugated compounds.

The medium-intensity band observed at approximately 1403 cm^{-1} can be attributed to deformation vibrations of aliphatic C–H groups and/or symmetric vibrations of carboxylate groups ($–COO^–$). Its presence is consistent with carboxylic compounds and polysaccharide-containing plant material.

The band at approximately 1336 cm^{-1} can be mainly associated with O–H deformation and C–O stretching vibrations in phenolic compounds, carbohydrates, and pectins. This band is consistent with the presence of polysaccharide- and fiber-related structures in dried lemon pulp.

The medium-intensity bands at 1226 and 1053 cm^{-1} correspond mainly to C–O and C–O–C vibrations characteristic of polysaccharides, cellulose, and pectins [10]. These bands support the carbohydrate- and fiber-rich character of dried lemon pulp [11].

The bands observed in the low-wavenumber region, at approximately 925, 625, and 593 cm^{-1}, may be associated with vibrations of polysaccharide structures and other components of plant biomass.

The band at 925 cm^{-1} can be attributed to bending and stretching vibrations involving C–O–C and C–H groups in polysaccharides, including cellulose and pectin. This assignment is consistent with carbohydrate structures characteristic of plant fibers [10].

The band at 625 cm^{-1} may be associated with bending vibrations involving inorganic components and/or structural vibrations of the plant matrix. In plant-derived materials, this region may include contributions from lignocellulosic and mineral components [12].

The band at 593 cm^{-1} may be associated with bending vibrations of C–H bonds and/or mineral components present in the plant residue. Its assignment should be considered tentative because several molecular contributions can occur in this low-wavenumber region.

Physicochemical analyses

Determination of pH in lemon beverages

Natural lemon juice had the lowest pH (approximately 2.2), indicating high acidity. This acidity is primarily associated with the high concentration of citric acid and contributes to the characteristic sour taste of lemon juice.

The acidic pH may also contribute to inhibiting the growth of some microorganisms; however, pH alone does not ensure microbiological preservation.Fanta had a slightly higher pH (approximately 2.9) but remained strongly acidic. Its acidity is influenced by the acids present in the formulation, while the higher soluble solids content contributes to a sweeter sensory profile.

Frutti Fresh had a pH of approximately 4.0, indicating lower acidity than the other two analyzed beverages.

Table 1 presents the pH values of the studied lemon juices.

Table 1. pH Values

Lemon beverages	pH values of juice
Natural lemon juice	2.2
Fanta	2.9
Frutti Fresh	4

Determination of soluble solids content in lemon beverages

The soluble solids content, expressed in degrees Brix (°Brix), was determined using a portable refractometer, and the obtained values are presented in Table 2. Natural lemon juice had the lowest °Brix value (3), whereas Fanta had the highest value (10), consistent with its higher soluble solids content. Frutti Fresh showed an intermediate value of 7 °Brix.

Table 2. The values of the sugar concentration

Lemon beverages	Sugar contents (°Brix)
Natural lemon juice	3
Fanta	10
Frutti Fresh	7

Determination of the refractive index of lemon beverages of lemon juices

The refractive index was determined using an Abbe refractometer, with water (n = 1.333 at 20 °C) used as the reference. The refractive index (n) depends on the concentration of dissolved substances, including sugars and organic acids. In general, an increase in °Brix is accompanied by an increase in refractive index.

Table 3 presents the refractive index values for the three analyzed beverages. Natural lemon juice showed n ≈ 1.335, close to that of water but slightly higher because of dissolved sugars, organic acids, and other compounds. Fanta showed the highest value (n ≈ 1.348), consistent with its higher soluble solids content. Frutti Fresh showed an intermediate value (n ≈ 1.341).

All analyzed beverages showed refractive index values higher than that of water because they contain dissolved sugars, acids, and other soluble substances.

Table 3. The values of the refractive index

Lemon beverages	Refractive index
Natural lemon juice	1.335
Fanta	1.348
Frutti Fresh	1.341

The differences in refractive index are consistent with the differences in °Brix: beverages with higher soluble solids content generally have higher refractive indices. Refractive index measurements therefore provide useful information about the concentration of dissolved substances and can complement °Brix measurements in quality control and product characterization. The method is rapid and non-destructive and can also be useful for detecting substantial dilution or compositional differences.

Determination of the density of lemon beverages

The data presented in Table 4 show that the lowest density was recorded for Frutti Fresh (1028 kg/m³).

The lower density is consistent with the lower concentration of dissolved substances compared with the other analyzed beverages.

The highest density was recorded for Fanta (1057 kg/m³).

This higher density is consistent with its higher soluble solids content and the presence of other dissolved components in the beverage.

Table 4. The values of density

Lemon beverages	Density (kg/m^3)
Natural lemon juice	1045
Fanta	1057
Frutti Fresh	1028

4. Conclusions

The pH, soluble solids content, refractive index, and density values revealed clear physicochemical differences among the analyzed lemon beverages. Natural lemon juice showed the lowest pH and °Brix values, whereas Fanta showed the highest °Brix, refractive index, and density values. Frutti Fresh presented intermediate values for most parameters, with a pH of approximately 4.0. Overall, the results demonstrate that the measured physicochemical parameters can be used to differentiate natural and commercial lemon beverages and to describe their acidity and concentration of dissolved substances.

The FT-IR analysis of dried lemon pulp revealed characteristic absorption bands associated mainly with hydroxyl-containing compounds, carbohydrates, pectins, organic acids, and other components of plant biomass. The combination of FT-IR spectroscopy with physicochemical measurements provides complementary information for the characterization of lemon-derived products. However, the present results are based on the analyzed samples and should not be generalized to all commercial formulations or lemon cultivars.

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