Journal of Agriculture and Rural Development Studies
Volume 2 – Issue 3 – 2025
ISSN Online 3061-2756
www.imadr.jards.ugal.ro

DOI https://doi.org/10.35219/jards.2025.3.02

Characterization of Red, Orange, and Tomato Iraqi cultivars using FTIR and HPLC

Hamid Shlakah Mugheir Al-Delfi *, Hadi Hoobi Shallal**, Raghad S. Mouhamad***, Raghdan H. Mohsin****

ARTICLE INFO

Article history:
Received: June 26, 2025
Accepted: August 10, 2025
Published: August 25, 2025

Keywords:
Red via Orange tomatoes, bioactive compounds, HPLC, breeding, FTIR spectroscopy

ABSTRACT

This study aimed to compare three orange tomato cultivars and three red tomato cultivars in terms of their biochemical composition and sensory quality in order to support breeding programs and applications in the food and industrial sectors. The results clearly distinguished the two groups. The orange tomatoes had an ascorbic acid content of 12.8 to 22.6 mg/100 g, while the red tomatoes had higher values, ranging from 16.2 to 24.5 mg/100 g, indicating their superior potential as a vitamin C source. Orange tomatoes had higher total soluble solids (Brix) values (5.2–7.3° Brix) than red tomatoes (4.8–6.7° Brix), indicating greater sugar accumulation during ripening. The orange tomatoes' fructose and glucose levels, which ranged from 4.3 to 5.4 g/100 g and 4.3 to 5.5 g/100 g, respectively, also reflected these trends. These sugars were slightly lower in the red tomatoes, with fructose ranging from 3.8 to 5.1 g/100 g and glucose ranging from 3.9 to 5.3 g/100 g. Additionally, the orange cultivars had higher pH values (4.2–4.68 vs. 3.95–4.4) and a higher citric acid content (1.7–2.0 g/100 g) than the red cultivars (1.4–1.8 g/100 g), suggesting a profile with a more evenly distributed balance between sweetness and acidity. For a more comprehensive characterisation, Fourier-transform infrared (FTIR) spectroscopy was used to identify non-destructive biochemical differences between the samples. The higher absorbance of the red tomato juices at 1745 and 1620 cm1 suggests that they contain more lycopene and phenolic compounds. Orange tomatoes, on the other hand, had distinct absorption peaks at 2920 and 2850 cm1, indicating higher concentrations of lipid- and beta-carotene-associated compounds. Each cultivar's genetic focus on increasing beta-carotene in orange varieties and lycopene in red varieties is reflected in these spectral characteristics. The spectrum traits of each cultivar reflect its genetic emphasis on enhancing beta-carotene in orange variants and lycopene in red ones; also, this study was emphasised the need of integrating HPLC and FTIR approaches for accurate and speedy tomato freshness evaluation. FTIR, may help with breeding programs, the development of healthier meals, the identification of different types and their vegetable quality, and the calculation of fruit and vegetable nutritional content.

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1. Introduction

Orange tomatoes, vibrant colour and rich flavour make them most than just suitable for cooking, a good source of bioactive compounds, that significant health benefits. The compounds such as Carotenoids, flavonoids, and phenolic are abundant in these fruits, and their antioxidant, anti-inflammatory, and

* Ministry of Higher Education and Scientific Research, Baghdad, Iraq, ** Middle Technical University, College of Applied Arts, Baghdad, Iraq, *** Scientific Research Commission, Baghdad, Iraq, **** Department of Animal Production, College of Agriculture, University of Basrah, Iraq. Email addresses: HamidAl-Delfi@mohesr.gov.iq (H. S. M. Al-Delfi), hadi.hoobi@mtu.edu.iq (H. H. Shallal), RaghadSMouhamad@SRC.edu.iq (Corresponding author – R. S. Mouhamad), raghdan.mohsin@uobasrah.edu.iq (R. H. Mohsin).

disease-preventive properties have been extensively investigated (Anjum et al., 2020; Scarano et al., 2018). Kondratyeva & Golubkina (2016) and Khachik et al., shown that the pigments have given tomatoes their bright color and are known to improve vision and boost immunity, carotenoids like beta-carotene and lutein, are particularly abundant in orange tomato varieties. (2002).

Pphytochemical content of tomatoes have enhanced because of plant breeding and biotechnology and genetic diversity (Bai & Lindhout, 2007; Gascuel et al., 2017). The biochemical composition of tomatoes is influenced by postharvest treatments, environmental conditions, and genetics, including the concentration and stability of carotenes (Da Silva-Souza et al., 2020; Ili et al., 2009). modern analysis and extraction techniques has been revolutionized the separation and characterization of these valuable compounds. Environmentally friendly techniques include enzyme-assisted extraction, ultrasound-assisted extraction, and supercritical CO2 extraction; These techniques have gotten the most out of tomato byproducts, also help keep food safe and make functional foods and nutraceuticals (Romano et al., 2020; Duan et al., 2021; Chutia & Mahanta, 2021).

FT-IR spectroscopy and HPLC techniques has been gotten the most out of tomato byproducts, also help keep food safe and make functional foods and nutraceuticals, Therefore, optimizing detection procedures and gaining a deeper understanding of the phytochemical profiles of various tomato genotypes are becoming increasingly important in light of the growing consumer interest in natural antioxidants and health-promoting ingredients (Fact, 2023; Wang et al., 2023).

The orange type of tomato has been appeared to be a source of essential bioactive compounds; too Through innovative sustainable extraction methods, biotechnological developments, and advanced breeding, the research aims to enhance their health-promoting potential. The biochemical composition of a few orange tomato varieties is the primary focus of this study.

2. Materials and Methods

The preparing and obtaining samples when fully ripe, with six distinct tomato cultivars of the three red-fleshed and three of the orange-fleshed varieties; were obtained from Iraqi locally agricultural markets (Figure 1). All the fruit was picked because it was the same size, colour, and didn't have any physical flaws. After harvest, the samples were transported to the laboratory in cool conditions and stored at 4 °C. Within a 24-hour period, each analysis was carried out (Ilić et al., 2009). The edible parts of the fruits were blended using a stainless-steel sterile blender after being air-dried and rinsed in distilled water. To obtain clear juice for analysis, the homogenate was filtered through a double-layered muslin cloth. For each one, three measurements were taken. In accordance with Klein and Perry's (1982) method, the amount of ascorbic acid was measured using high-performance liquid chromatography (HPLC).

Prior to analysis, juice samples were filtered through 0.45 m syringe filters. A UV detector with a wavelength of 254 nm and a C18 reversed-phase column were part of the HPLC system. At 1.0 mL/min, the mobile phase was 3% metaphosphoric acid (Anjum et al., 2020; Wang et al., 2023). The measurement was carried out using a standard L-ascorbic acid external calibration curve. Milligrams of ascorbic acid per 100 grams of fresh weight (mg/100 g) were used to represent the outcomes.

Total Soluble Solids The digital refractometer (ATAGO PAL-1, Japan) was used to measure the soluble solids content (°Brix). The refractometer was calibrated with distilled water prior to measurement. After placing a drop of filtered juice on the surface of the prism, three readings were taken. Analyses of sugar (glucose and fructose) Using an HPLC and a refractive index detector, the concentrations of glucose and fructose were determined. Juice samples were filtered after being centrifuged for ten minutes at 10,000 rpm. The mobile phase in the carbohydrate analysis column (Waters Sugar-Pak I) was distilled water at 85 °C and 0.5 mL/min. In order to create calibration curves, glucose and fructose were used as standards. The sugar content was expressed in grams per 100 grams of fresh weight (g/100 g), in accordance with Duarte et al. (2002).

Quantification of Citric Acid The trictrac acid content was analysed by HPLC using a UV detector at 210 nm in accordance with the instructions provided by Nunes et al. (2011). A C18 column with a mobile phase of 0.01 M sulfuric acid and a flow rate of 0.6 mL/min was used for the separation. The pH was measured using a Mettler Toledo Seven Compact, a digital pH meter from Switzerland. The measurements were given in grams per 100 grams of fresh juice. Before each use, the meter was calibrated with standard buffer solutions of 4.0 and 7.0 pH. Triplicate measurements were taken, and the mean pH was recorded. FTIR spectroscopy the juice samples' Fourier-transform infrared (FTIR) spectra were recorded using an attenuated total reflectance (ATR) module on a Bruker Alpha FTIR spectrometer. After the juice, which was approximately one millilitre, was applied directly to the ATR crystal, 32 scans were taken from each sample to collect spectra with a resolution of 4 cm-1 over the 4000–400 cm-1 range. therefore, comparing spectral peaks to standard FTIR absorption bands, functional groups that correspond to sugars, acids, and phenolic compounds were identified (Dufour, 2009).

Statistics Analyses Each experiment's mean minus the standard deviation (SD) is shown. Three times were used to replicate each experiment. One-way analysis of variance (ANOVA) was used to look for significant differences between the tomato cultivars for each parameter. For pairwise comparison, Tukey's Honest Significant Difference (HSD) test was utilized when significance was established (p 0.05). Pearson correlation analysis was also used to examine the connections between the variables (ascorbic acid, sugars, acids, and pH). IBM SPSS Statistics v25.0 was used for all of the statistical analyses.

Figure 1. Tomato cultivars

Source: Mouhamad et al., 2025

3. Results and Discussion

The HPLC analysis

Biochemical Composition of Orange and Red tomatoes the HPLC analysis revealed notable differences in the biochemical profiles of the orange and red tomato samples (Figure 2). the red cultivars were exhibited a broader range of ascorbic acid concentrations ranged (11.9–25.1 mg/100 g) compared to the orange tomato cultivars (12.5–23.8 mg/100 g). This wider variability suggests a greater genetic potential for vitamin C enrichment among orange tomatoes, making them attractive candidates for biofortification and breeding programs. Similar results were reported by Ilahy et al. (2011) regarding the influence of tomato varieties and maturity on ascorbic acid content in pigmented tomatoes.

The ascorbic acid content of the studied cultivars (10–30 mg/100 g) falls within the typical range for commercial tomato varieties, making them nutritionally valuable (Dumas et al., 2003). The total soluble solids content, represented by Brix values, was higher in orange tomatoes (5.1–7.7) than in red ones (4.4–6.8). Elevated Brix values suggest improved sugar accumulation and taste quality. Consistent with Georgé et al. (2011), our results suggest that carotenoid-rich tomato cultivars exhibit increased sugar levels due to linked biosynthetic pathways, a desirable trait for high-Brix tomato products in the food processing industry.

Orange cultivars have most fructose (4.12–5.50 g/100 g) and glucose (4.15–5.62 g/100 g) levels among to red tomatoes (fructose: 3.89–5.70 g/100 g; glucose: 4.03–4.40 g/100 g). This sweeter profile in orange cultivars aligns with previous studies findings that sugar accumulation is cultivar-dependent and influenced by environmental factors (Cebolla-Cornejo et al., 2011). While tomato sugar profiles vary globally, these results suggest a favourable balance for improved flavour and consumer acceptance in orange cultivars.

Orange tomato cultivars (1.67–2.02 g/100 g citric acid) exhibited higher citric acid content than red cultivars (1.49–1.92 g/100 g), resulting in a more pronounced sweet-acid balance. Orange cultivars might offer improved benefiting, flavour complexity, both fresh consumption and processing, which aligns with plays the roles of organic acids in tomato flavour and citric acid in fruit acidity and buffering capacity. While orange tomatoes exhibited slightly higher pH values (4.10–4.76) than red tomatoes (3.90–4.60), they also displayed greater titratable acidity, suggesting differences in acid composition and buffering that could influence shelf-life and sensory traits.

Analysis of the FTIR Spectral Characteristics

The FTIR analysis further confirmed these findings, highlighting important differences in polyphenols; carotenoids, and lipids (Figure 3). Orange tomato juices displayed higher absorption (~2920 and ~2850 cm^{-1}), corresponding to aliphatic C–H stretching from lipid-soluble compounds such as β-carotene. These results agree with Da Silva-Souza et al. (2020) and Anjum et al. (2020), who reported alike patterns in orange tomatoes selected for provitamin A enhancement. also, the weaker signals (900–700 cm^{-1}) suggest lower polyphenolic diversity in orange tomatoes, a conclusion also drawn by Duarte et al. (2002). Conversely, Red tomatoes showed stronger absorbance (~1745 and ~1620 cm^{-1}), linked to ester carbonyls and aromatic compounds, indicative of higher lycopene and polyphenol levels. This alike findings by Scarano et al. (2018) and Wang et al. (2023), they confirming that red cultivars are metabolically enriched in antioxidant pigments. Cultivar-Specific Signatures. The FTIR spectra confirmed the expected biochemical differences based on cultivar breeding goals. Red tomatoes like 'Roma' and 'Heinz' are optimized for lycopene and antioxidant traits, while orange types such as 'Jubilee' and 'Orange Banana' are designed for higher β-carotene and milder taste profiles (Bai & Lindhout, 2007; Gascuel et al., 2017).

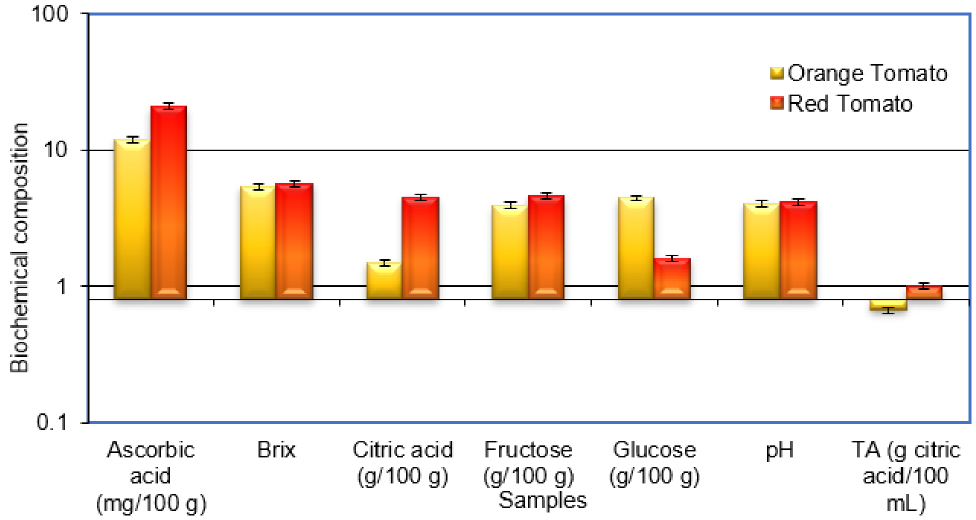

Figure 2. HPLC analysis of tomatoes

Source: Mouhamad et al., 2025.

FTIR is increasingly used in food quality control and variety authentication, complementing traditional chromatographic techniques; also aid locally breeding strategies amid on sensory attributes diversifying and nutritional. the FTIR enhances on-destructive method and a rapid, for distinguishing cultivars depended on revealing clear spectral markers, biochemical composition, for lycopene and β-carotene content. As highlighted by Dufour (2009) and Pike Technologies (2011) and Mouhamad et al. (2020).

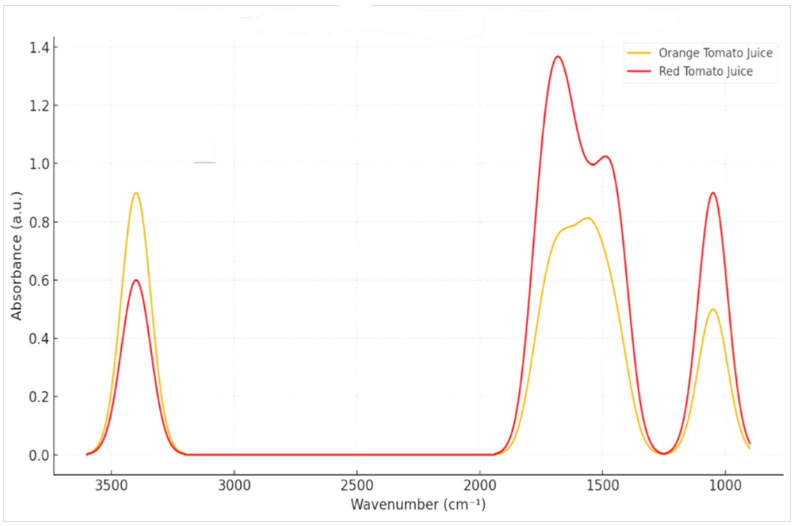

Figure 3. FTIR spectrometers of tomato cultivars

Source: Mouhamad et al., 2025.

4. Conclusions

This study set out to evaluate the biochemical characteristics and sensory qualities of three orange tomato varieties against three red tomato varieties. The goal was to support breeding efforts and their utilization in both food and industrial applications. The results pointed to some clear differences between the two types of tomatoes. Through high-performance liquid chromatography (HPLC) and FTIR spectroscopy, we identified significant variations in the biochemical composition of the red and orange tomatoes. In particular, the orange tomatoes showed higher amounts of ascorbic acid and sugar, along with increased acidity, which makes them particularly suitable for specific processing purposes. therefore, these results underscore the value of combining traditional biochemical methods with modern spectroscopic techniques to achieve a deeper understanding of tomato cultivars, which is crucial for breeding, industrial technologies, and nutritional research.

Acknowledgements

This research was supported by the **Scientific Research Commission, Baghdad, Iraq**. The author expresses sincere gratitude to the Commission for providing essential support, guidance, and the necessary equipment that made this study possible.

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