

Quality control challenges in modern soft drinks: analytical strategies and case studies

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Abstract

The evolution of the global soft drink market towards functional, low-sugar, and low-alcohol formulations has significantly increased the analytical complexity required for industrial quality control. Traditional official methods, such as HPLC and gas chromatography, although representing the regulatory reference, are often time-consuming and costly for routine monitoring. This study presents an advanced analytical characterization conducted on a heterogeneous panel of commercial beverages (including energy drinks, citrus sodas, artisanal colas, and wine-based aperitifs) using the CDR DrinkLab enzymatic photometric system. The objective was to assess a simplified workflow for the determination of critical parameters such as caffeine, alcohol, sugars, and acidimetric profile. The results demonstrate the effectiveness of the method in accurately quantifying caffeine in complex matrices (detected range 65 - 249 mg/L) and in detecting traces of alcohol with a sensitivity of up to 0.002% vol, essential for ensuring the legal compliance of non-alcoholic products. Furthermore, the differential characterization of the acidimetric profile (citric vs. phosphoric) provided data consistent with sensory and stability expectations. In conclusion, the photometric approach proves to be a valid operational alternative to traditional methods, offering rapid execution and reduced sample handling, effectively supporting regulatory compliance and shelf-life management.

1. Introduction: The Market Scenario and the Evolution of the Sector

Soft drinks today represent a vast and heterogeneous category of non-alcoholic beverages, which has evolved significantly from the first historical mixtures of water and citrus juices in the 17th century.

Modern formulations are technologically sophisticated and are typically produced from mineral water with the addition of one or more of the following components:

- monosaccharides and disaccharides or intense sweeteners
- acidifiers and acidity regulators, mainly citric, phosphoric and malic acid
- natural or nature-identical flavours
- botanical extracts, fruit juices or purees
- carbon dioxide
- authorised functional ingredients such as caffeine up to 320 mg/L, taurine, vitamins
- possible residual or intentionally added alcohol content lower than 1.2% vol in low-alcohol ready-to-drink beverages

The market is undergoing a profound transformation. Although Italy's per capita consumption (around 50 L/year) is lower than the EU average (95 L/year in 2023), there is a decline in traditional high-sugar products in favor of growing

segments such as *premium*, *craft*, low-sugar, and functional beverages (energy drinks, non-alcoholic aperitifs). Globally, demand is shifting toward clean labels and *natural* ingredients. In this competitive environment, analytical control becomes a strategic necessity not only for regulatory compliance, but also to ensure formulation consistency and *shelf-life stability*.

2. The Analytical Challenge: Critical Parameters and Methodologies

The chemical characterization of soft drinks is essential to ensure regulatory compliance, product safety, and consistent sensory quality. Given the extreme heterogeneity of this category, analytical methods must be carefully selected and tailored to each parameter, considering both its technological role and its sensory impact.

• **Caffeine and Functional Ingredients:** This segment is strictly regulated; in Europe, caffeine concentrations above 150 mg/L require specific labelling.

• **Alcohol and Fermentation Markers:** In *low-alcohol* (< 1.2% vol) and non-alcoholic products, the alcohol content is critical. Even minimal levels (< 0.5% vol) can indicate unwanted fermentation, impacting the aroma profile and legal classification. At the same time, lactic acid (D- and L-) acts as a marker of bacterial contamination and product spoilage.

• **Acidity and Sugar Profile:** pH (typically 2.5–4.0) and acid profile (citric, malic, phosphoric) directly influence microbiological stability and flavor. Similarly, monitoring glucose, fructose, and sucrose is essential to define sweetening power and prevent secondary fermentations.

3. The study: sample selection and analytical workflow

To evaluate the applicability of rapid methods in this complex scenario, a study was conducted on a representative panel of beverages on the Italian market.

Description of the sample panel

Samples belonging to different product categories were selected:

- **Samples A and B:** High-caffeinated coffee-based drinks.

- **Samples C, D, H:** Carbonated wine-based alcoholic beverages (including spritz cocktails).
- **Samples E and I:** Citrus sodas (orange and mandarin).
- **Sample F:** Classic artisanal cola.
- **Sample G:** Non-alcoholic carbonated aperitif.

Analytical Methodology

The analyses were performed using the [CDR DrinkLab system](#). The methods used are based on pre-calibrated enzymatic reagents that require micro-volumes of sample. Pretreatment was limited to simple sample degassing, making the workflow suitable for industrial quality control environments.

4. Results and Discussion

The analysis demonstrated the system's ability to characterize complex matrices with reduced time and minimal preparation.

The main findings emerging from the experimental data are reported below.

Sample type	Caffeine (mg/L)	Alcohol (% vol)	Total acidity (g/L citric acid)	Citric acid (g/L)	Sugars (g/L)	pH	Phosphoric acid (mg/L)
A - Caffeinated drink	249	< 0.002	-	-	-	-	-
B - Caffeinated drink	118	< 0.002	-	-	-	-	-
C - Carbonated alcoholic drink	< 10	8.3	-	-	-	-	-
D - Carbonated alcoholic drink	< 10	8.4	-	-	-	-	-
E - Orange soda	< 10	< 0.002	4.6	3.3	118	3.49	< 10
F - Cola	65	< 0.002	-	-	105	-	886
G - Non-alcoholic aperitif	< 10	9.5	-	-	-	-	-
H - Strawberry cocktail spritz	< 10	7.2	-	-	-	-	-
I - Mandarin soda	< 10	< 0.002	6.9	6.3	146	3.58	< 10

Caffeine Quantification Caffeine determination has been shown to be reliable regardless of the coloration or complexity of the matrix.

- In **Sample A (coffee drink)**, a concentration of **249 mg/L** was detected, confirming the ability of

the method to accurately quantify high dosages typical of energy drinks and special formulations.

- In **Sample F (Cola)**, the value detected was **65 mg/L**, consistent with the standard formulations of this category.

Alcohol Sensitivity and Stability Given the growth of *low- and no-alcohol* beverages, analytical sensitivity was crucial. The method allowed alcohol quantification down to **0.002% vol** in about 10 minutes.

- The non-alcoholic samples (A, B, E, F, I) showed values < 0.002% vol, confirming the absence of ongoing fermentation.
- The wine-based samples (C, D, G, H) showed values between 7.2% and 9.5% vol, demonstrating the versatility of the system over different concentration ranges.

Acid Profile and pH The study highlighted a marked differentiation in the acidimetric profiles, correlating the chemical composition to the stability of the product.

- **Cola (Sample F):** The exclusive presence of **phosphoric acid (886 mg/L)** was detected, consistent with its typical use as the primary acidifying agent in this beverage category.
- **Citrus sodas (Samples E, I):** They showed an acidity dominated by citric acid (3.3 g/L and **6.3 g/L respectively**) and a low pH (range **3.49–3.58**), consistent with the requirements of microbiological stability and sensorial freshness.

5. Comparative Analysis: Official Methods vs. CDR DrinkLab

Although chromatographic techniques (HPLC, GC) represent the regulatory *gold standard*, their implementation in routine quality control presents significant operational limitations in terms of cost and time. A direct comparison between the reference methods and the CDR DrinkLab system highlights how the photometric approach better meets the needs of frequent on-site monitoring.

For the [determination of caffeine](#), the official HPLC method requires expensive instrumentation, highly specialized personnel and long chromatographic run times; on the contrary, the photometric method allows for rapid quantification without the use of toxic solvents, making the analysis accessible even to non-specialized operators. Similarly, for the [determination of alcohol content](#) and [sugars](#), where the classic

methods (Distillation, Gas Chromatography, HPLC-RI) involve laborious procedures, the tested system offers comparable results in about 10 minutes, with sample preparation limited to simple degassing.

Below is a summary table comparing the operational benefits of the CDR DrinkLab system with traditional analytical methods:

	Reference Method (Official)	Critical issues Official Method	CDR DrinkLab approach	CDR Operational Benefits
Caffeine	HPLC (Chromatography Liquid)	High instrumental costs, specialized personnel, long times.	Photometric	Quick analysis, no complex calibration, online use.
Alcohol (% vol)	Distillation/Gas Chromatography (GC)	Complex procedure, long times for single analysis.	Photometric Enzymatic	Result in 10 min, sensitivity up to 0.002% vol, ideal for Low-Alcohol.
Sugars	HPLC with RI Detector	High cost, frequent maintenance, column balancing times.	Photometric Enzymatic	Rapid quantification of glucose, fructose and sucrose for fermentation control.
Workflow	Classic Sample Preparation	Complex filtrations, solvent extractions, large volumes required.	Micro-method	Simple degassing, micro-sample volumes, pre-vialled reagents.

6. Conclusions

The analytical results obtained in this study confirm the importance of a comprehensive and flexible approach to quality control in the modern soft drink and ready-to-drink industry. The wide variety of formulations, ranging from high-caffeine beverages to citrus-based carbonated soft drinks and low-alcohol or non-alcoholic products, requires rapid, sensitive, and reliable analytical methods.

CDR DrinkLab has proven suitable for the determination of key parameters such as caffeine, alcohol content, acidimetric profile ([citric acid](#), [phosphoric acid](#)), sugars and [pH](#), with minimal sample preparation and short analysis times.

This approach supports routine monitoring, regulatory compliance, and product stability assessment, enabling manufacturers to maintain consistent quality and effectively respond to the changing needs of the soft drink market.

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