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Determination of Harmful Chemical Constituents in Soft Drinks Using Analytical Techniques and Assessment of Health Risks

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Abstract: *Soft drinks are widely consumed beverages, particularly among children and young adults, raising concerns about the presence of potentially harmful chemical constituents and their associated health risks. This study aimed to determine the occurrence and concentration of selected hazardous chemicals in commercially available soft drinks such as Thums Up, Pepsi, Sprite, Coca-Cola, and selected local brands using validated analytical techniques and to assess their potential health impacts on consumers. Samples of commonly consumed soft drinks were analyzed for artificial sweeteners, preservatives, colorants, caffeine, and trace heavy metals using high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC-MS), and atomic absorption spectroscopy (AAS). The detected concentrations were compared with permissible limits established by international regulatory agencies. Health risk assessment was conducted by estimating daily intake and calculating relevant risk indices. The results revealed the presence of several chemical constituents, some of which exceeded recommended safety limits, indicating potential long-term health risks with excessive consumption. This study highlights the importance of continuous monitoring of soft drinks and emphasizes the need for stricter regulatory control and increased consumer awareness regarding chemical exposure from widely consumed beverages.*

Keywords: Soft drinks; Harmful chemicals; Analytical techniques; Health risk assessment; HPLC; GC-MS; Food safety

1. Introduction

Soft drinks constitute a major segment of the global beverage market. Popular brands such as Pepsi, Coca-Cola, **Sprite**, and **Thums Up** are widely consumed across different age groups. Increased intake has been linked to obesity, metabolic disorders, dental erosion, and potential exposure to chemical contaminants.

Soft drinks contain additives including artificial sweeteners (aspartame, saccharin), preservatives (sodium benzoate, potassium sorbate), synthetic colorants, caffeine, and may also contain trace heavy metals introduced during processing, packaging, or water sources. Some preservatives may form benzene in the presence of ascorbic acid under certain conditions. Additionally, chronic exposure to heavy metals such as lead and cadmium poses toxicological concerns.

Analytical techniques such as High-Performance Liquid Chromatography (HPLC), Gas Chromatography–Mass Spectrometry (GC-MS), and Atomic Absorption Spectroscopy (AAS) are widely applied for food safety investigations. This study integrates chemical analysis with quantitative health risk assessment to evaluate consumer safety.

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2. Materials and Methods

2.1 Sample Collection

Five commercial soft drink brands (Thums Up, Pepsi, Sprite, Coca-Cola, and three local brands labeled L1, L2, L3) were purchased from retail outlets. All samples were within shelf-life and stored at 4°C prior to analysis.

2.2 Chemicals and Reagents

Analytical-grade standards of aspartame, sodium benzoate, caffeine, tartrazine, saccharin, lead nitrate, cadmium chloride, and arsenic trioxide were used. HPLC-grade solvents (methanol, acetonitrile, deionized water) were applied.

2.3 Instrumentation

HPLC: Quantification of sweeteners, preservatives, and colorants
GC-MS: Confirmation of volatile organic compounds and benzene
AAS: Determination of heavy metals (Pb, Cd, As)

2.4 Analytical Procedures

2.4.1 Determination of Preservatives and Sweeteners (HPLC)

Samples were filtered and injected into a reverse-phase C18 column. Detection wavelengths were optimized for each analyte. Calibration curves ($R^2 > 0.995$) ensured quantification accuracy.

2.4.2 Determination of Volatile Compounds (GC-MS)

Headspace analysis was performed to detect benzene and related compounds. Identification was based on retention time and mass spectral library matching.

2.4.3 Heavy Metal Analysis (AAS)

Samples were acid-digested and analyzed using flame AAS. Standard reference materials ensured quality control.

2.5 Health Risk Assessment

Estimated Daily Intake (EDI) was calculated using:

EDI=C×IRBWEDI = \frac{C \times IR}{BW}EDI=BWC×IR

Where:
C = concentration (mg/L)
IR = ingestion rate (0.5 L/day)
BW = body weight (60 kg adult, 30 kg child)
Hazard Quotient (HQ):

HQ=EDIADIHQ = \frac{EDI}{ADI}HQ=ADIEDI

HQ > 1 indicates potential risk.

3. Results

Table 1. Concentration of Chemical Constituents in Soft Drinks (Mean ± SD)

No	Analyte	Permissible Limit (mg/L)	Thums Up	Pepsi	Sprite	Coca-Cola	L1	L2	L3
1	Sodium benzoate	150	132±2	140±3	125±2	138±3	162±4	148±3	170±5
2	Aspartame	600	95±2	110±2	ND	100±2	120±3	ND	135±4
3	Caffeine	200	145±3	130±3	ND	140±3	150±4	120±2	160±5
4	Benzene	0.01	0.004	0.003	ND	0.005	0.012	0.015	0.010
5	Lead (Pb)	0.01	0.005	0.006	0.004	0.005	0.013	0.015	0.011

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6	Cadmium (Cd)	0.003	0.001	0.002	0.001	0.001	0.004	0.005	0.003

ND = Not Detected

Local brands L1 and L3 exceeded permissible limits for sodium benzoate, benzene, and lead.

Table 2. Estimated Daily Intake (EDI) and Hazard Quotient (HQ) for Children

Sr.No.	**Analyte**	**ADI (mg/kg/day)**	**Highest EDI**	**HQ**
1	Sodium benzoate	5	0.0028	0.00056
2	Aspartame	40	0.0023	0.00006
3	Lead	0.0036	0.00025	0.069
4	Cadmium	0.001	0.00008	0.08
5	Benzene	0.0005	0.00025	0.50

Although most HQ values were below 1, benzene exposure in local brands approached risk thresholds. Chronic exposure may increase carcinogenic risk.

4. Discussion

The findings indicate that multinational brands generally complied with regulatory standards, while certain local brands exceeded permissible limits for preservatives and heavy metals. Elevated sodium benzoate levels increase the risk of benzene formation.

Heavy metal contamination likely originates from water sources or processing equipment. Chronic exposure to lead and cadmium is associated with neurological damage and kidney dysfunction. Excessive caffeine intake may affect cardiovascular and nervous systems, especially in children.

The health risk assessment suggests low immediate toxicity but highlights potential long-term risks with habitual high consumption. Continuous surveillance is therefore necessary.

5. Conclusion

This study demonstrates that while major soft drink brands generally comply with safety limits, some local products may pose chemical exposure risks. Regular monitoring using validated analytical techniques such as HPLC, GC-MS, and AAS is essential. Regulatory authorities should strengthen quality control measures and promote public awareness regarding excessive soft drink consumption.

6. Future Scope of the Study

Based on the findings that major soft drink brands generally comply with safety standards while some local products may present potential chemical exposure risks, the following future research directions are recommended:

Expanded Surveillance Programs

Future studies should include a larger and more diverse sample size covering different geographic regions and seasonal variations. Continuous surveillance programs can help detect fluctuations in contaminant levels and ensure consistent compliance with national and international standards.

Advanced Analytical Method Integration

Further research can focus on integrating advanced and more sensitive analytical techniques alongside HPLC, GC-MS, and AAS to improve detection limits and identify emerging contaminants such as microplastics, endocrine-disrupting chemicals, and novel food additives.

Long-Term Health Risk Assessment

Prospective epidemiological studies are needed to evaluate the cumulative and long-term health effects of chronic soft drink consumption, particularly concerning heavy metals, preservatives, artificial sweeteners, and other chemical residues.

Comparative Assessment of Packaging Materials

Future investigations should examine the role of packaging (plastic, glass, cans) in chemical migration and contamination, particularly under varying storage and environmental conditions.

Evaluation of Regulatory Frameworks

Comparative studies assessing the effectiveness of existing food safety regulations across different regions can help identify policy gaps. Research can also evaluate the impact of strengthened regulatory interventions on improving product safety.

Development of Rapid Screening Techniques

There is scope for developing cost-effective, rapid, and field-deployable testing methods to assist regulatory bodies in routine quality monitoring, especially in resource-limited settings.

Consumer Awareness and Behavioral Studies

Future research should explore consumer knowledge, attitudes, and practices related to soft drink consumption and chemical safety. This will support targeted public health campaigns to reduce excessive intake and associated risks.

Industry-Based Quality Improvement Strategies

Collaboration with local manufacturers to implement Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP) systems can be explored, along with studies measuring their effectiveness in reducing contamination levels.

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