OPEN ACCESS

Scholars International Journal of Chemistry and Material Sciences

Abbreviated Key Title: Sch Int J Chem Mater Sci
ISSN 2616-8669 (Print) |ISSN 2617-6556 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: http://saudijournals.com

Original Research Article

Quantitative Determination of Caffeine and Taurine Concentrations in Selected Energy Drinks

Ali Abraham Enenche[1], Muhammad B. Etsuyankpa[1], M. B. Nasirudeen[1], Aliyu Mohammed Sakpe[2], John Tsado Mathew[3*]

[1]Department of Chemistry, Federal University, Lafia, Nasarawa State, Nigeria
[2]Department of Basic Sciences, Niger State College of Agriculture, Mokwa, Niger State, Nigeria
[3]Department of Chemistry, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria

DOI: https://doi.org/10.36348/sijcms.2026.v09i03.002 | **Received:** 08.02.2026 | **Accepted:** 03.04.2026 | **Published:** 21.05.2026

***Corresponding author:** John Tsado Mathew
Department of Chemistry, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria

Abstract

Energy drinks are increasingly consumed due to their perceived ability to enhance physical and mental performance. However, concerns remain regarding their stimulant composition and acidic nature. This study quantitatively determined the concentrations of caffeine, taurine, and titratable acidity in six commercially available energy drink brands sold in Abuja Nigeria namely Predator, Fearless, Climax, Monster, Red Bull, and Power Horse. Caffeine and taurine were determined using High-Performance Liquid Chromatography coupled with Ultraviolet detection (HPLC-UV), while titratable acidity was determined using standard acid–base titration methods. The results showed that caffeine concentrations ranged from 129.14 ± 0.74 to 2186.66 ± 5.95 mg/L, with Climax recording the lowest level, while Power horse had the highest. Taurine concentrations varied between 59.16 ± 0.94 and 378.75 ± 0.83 mg/L, with Fearless exhibiting the highest taurine content and Climax showing the lowest concentration. Titratable acidity values ranged from 5.24 ± 0.20 to 9.77 ± 0.56 g/100 mL, indicating varying degrees of acidity among the samples, with Power Horse and Monster showing relatively higher acidity levels. The low standard deviation values recorded demonstrate the precision and reliability of the analytical methods employed and the observed variations in caffeine, taurine, and acidity among the energy drinks highlight the need for continuous quality assessment and regulatory monitoring to ensure consumer safety. This study provides baseline scientific data on the chemical characteristics of energy drinks and supports the need for stricter regulatory oversight, improved labeling, and increased public awareness regarding energy drink consumption.

Keywords: Caffeine, Taurine, Energy Drinks, HPLC-UV, Titratable Acidity.

INTRODUCTION

Energy drinks are non-alcoholic beverages that contains caffeine as a primary key active ingredient, usually combined with other substances such as taurine, glucuronolactone, vitamins, and herbal extracts. These drinks are marketed primarily for their stimulating effects, which include enhancing alertness and physical performance (European Food Safety Authority Panel on Food Additives and Nutrient Sources added to Food, 2020). These beverages contain high concentrations of stimulants, most notably caffeine, a well-known central nervous system stimulant, acting primarily as an adenosine receptor antagonist, which leads to increased neuronal firing and the release of neurotransmitters that enhance alertness and cognitive performance. Also, taurine, a Sulphur-containing amino acid in energy drinks is implicated in various physiological processes. Although taurine is sometimes added to mitigate some of the negative effects of caffeine, the overall efficacy and safety of this combination remain subject to ongoing research (Jagim *et al.,*2021).

The evolution of energy drinks reflects a dynamic interplay between cultural shifts, technological innovation, and evolving consumer demands. Early version of these beverages can be traced back to the mid-20th century, when products like Dr. Enuf marketed as vitamin enriched tonics designed to promote vitality and laid the groundwork for later stimulant beverages (Thompson & Garcia, 2020; Okiemute *et al.,*2024). The transformation of these beverages took a significant turn in Japan during the 1960s and 1970s. As Japan experienced rapid industrialization and urban growth, products such as Lipovitan D emerged. These beverages were specifically formulated to address the physical and mental demands of an increasingly fast-paced society, signaling an early recognition of the role that specialized stimulant drinks could play in modern life. This period marked a critical phase in the evolution of energy drinks, shifting the focus from general health tonics to products designed to provide a quick boost in energy and alertness (Lee & Kim 2021*)*.

A pivotal moment in the global history of energy drinks occurred in the mid-1980s with the introduction of Red Bull. Red Bull's innovative approach, combining a unique blend of caffeine, taurine, and other functional ingredients with aggressive, lifestyle-oriented marketing strategies, redefined the category. The brand not only set new standards for beverage formulation but also established a global image associated with high energy adventurous lifestyles. This rebranding and marketing success catalyzed the widespread acceptance and rapid expansion of energy drinks across international markets (Lee & Kim 2021). Caffeine as the primary functional component of energy drinks are specifically engineered to deliver an immediate and pronounced stimulant effect. This is achieved not only through higher doses of caffeine but also through careful combination with other active ingredients, which together produce the unique sensory and physiological profile of energy drinks (Piccioni *et al.,*2021).

caffeine is usually incorporated at concentrations of approximately 32 mg per 100 mL into many energy drink formulations, though this can vary between 15 and 55 mg per 100 mL depending on the brand and target market (Rubio *et al.,*2022). Caffeine in energy drinks is intended to block adenosine receptors in the central nervous system, thereby increasing the release of neurotransmitters like dopamine and norepinephrine. This action not only enhances alertness and cognitive performance but also boosts metabolic rate, which is why many energy drinks are marketed as ergogenic aids for both mental and physical performance (Martinez & Fernandez 2023). While moderate caffeine consumption can lead to performance benefits, its effects are highly dose-dependent, and excessive intake may result in adverse cardiovascular and neuropsychiatric outcomes such as elevated heart rate, anxiety, and sleep disturbances (Martinez & Fernandez 2023).

Taurine usually contains around 4000 mg/L of taurine, although values can vary considerably from as low as 2000 mg/L to upwards of 8000 mg/L depending on the brand and the target market. Manufacturers may adjust taurine levels in energy drinks to tailor the drink's performance enhancing profile, as taurine is believed to help modulate calcium homeostasis in muscle cells, support cardiovascular function, and exert antioxidant effects (Rubio *et al.,*2022). Taurine is often included in energy drinks to work synergistically with caffeine. While caffeine is the primary stimulant responsible for increased alertness and enhanced cognitive function, taurine may help temper some of the negative cardiovascular effects associated with high caffeine intake (Rubio *et al.,* 2022). In addition to its role in modulating the effects of caffeine, taurine has been studied for its potential impact on the central nervous system and has been described as a key neuromodulator that, in combination with other ingredients such as B vitamins and herbal extracts, contributes to the overall functional profile of energy drinks (Piccioni *et al.,*2021). The combination of these compounds not only drives consumer demand but also raises significant regulatory and public health concerns, particularly given the potential adverse cardiovascular effects, including elevated blood pressure and heart palpitations associated with excessive consumption and to mitigate potential health risks, a clearer labelling of caffeine content on energy drink packaging, along with warnings about excessive intake and potential interactions with alcohol and physical activity is recommended (EFSA Panel, 2020; Ameh *et al.,*2024).

The quantitative determination of caffeine and taurine in energy drinks is therefore essential for accurate measurement of these compounds ensuring that product formulations comply with established food safety standards and regulatory guidelines. The precise quantification supports quality control efforts within the industry, enabling manufacturers to maintain consistency across production batches and ensuring that consumers receive products that meet declared ingredient levels. The European Food Safety Authority Panel emphasized the need for rigorous monitoring of caffeine levels due to its potential adverse health effects when consumed in excess (EFSA Panel, 2020).

MATERIALS AND METHODS

Reagents and Chemical

Standard solutions of Caffeine (1,3,7-trimethylxanthine), Standard solution of Taurine (2-aminoethanesulfonic acid), Acetonitrile (HPLC grade), Water (HPLC grade), Buffer solutions, Distilled water, Sodium hydrogen trioxocarbonate, Sodium trioxocarbonate, Sodium dihydrogen phosphate, Disodium hydrogen phosphate heptahydrate, Dinitrofluorobenzene (DNFB), Sodium Hydroxide solution, Nitric acid solution, and hydrochloric acid. All these reagents are of analytical grades

Sample collection

Six (6) different brands of energy drink all canned, were obtained randomly from available supermarkets in Abuja Nigeria. All samples were kept in a refrigerator until all analyses were completed. The energy drink samples analyzed are Predator, Fearless, Climax, Monster, Red Bull and Power Horse respectively.

Sample preparation and analysis of caffeine and taurine (HPLC Analysis)

Twenty-five ml of the energy drink from each sample were taken into a 150 ml Erlenmeyer flask and degassed by sonication for 10 min. Once sample bottles were open, the drinks were degassed, homogenized and filtered. Each sample was filtered through a 0.45 µm syringe filter with a 5 mL syringe. Dilutions of 1:200 was done for all filtered samples with distilled water (Rai *et al.,*2016). There was no further clean up procedure. 10 µL of filtered sample were injected directly into HPLC. Every sample was injected in triplicate (n=3). The retention times of the peaks for the sample were compared with the retention time of the reference standard and confirmed when the retention time of the sample was identical to those of the pure standards.

Sample preparation and determination of Titratable Acidity in Energy Drink

25 ml of energy drink sample was pipette into a conical flask and the sample was degassed to remove the presence of carbon (iv) oxide. 2–3 drops of phenolphthalein indicator were added to the sample. The burette was filled with a standardized 0.1N NaOH solution and the initial reading was recorded. The titration was done by slowly adding NaOH to the energy drink sample while swirling the conical flask continuously. The endpoint was obtained when a persistent light pink colour appeared and the values were recorded.

RESULTS OF THE ANALYSIS

The following Tables represent the results for the caffeine, taurine, and titratable acidity determinations.

Table 1: Concentrations of Caffeine in Energy Drink Samples

Sample name	Concentration of Caffeine in Energy Drink samples (mg/L)
Predator	187.651167 ± 0.66
Fearless	779.604367 ± 1.23
Climax	129.137567 ± 0.74
Monster	246.031033 ± 1.16
Red Bull	406.646333 ± 1.41
Power Horse	2186.658167 ± 5.95

Energy Drink Caffeine (mg per 250 mL) Compared with FDA 400 mg/day Limit.

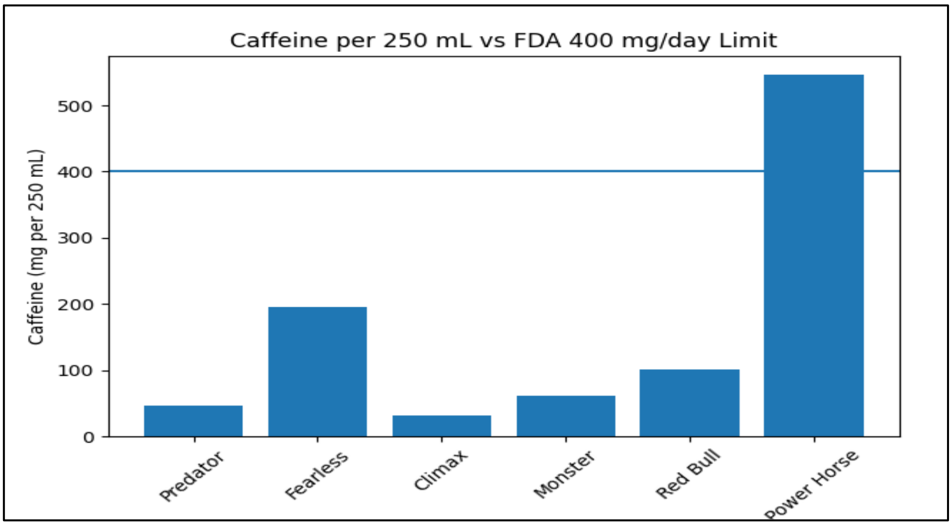

Figure 1: Caffeine Contents in Energy Drinks (250mL) vs FDA/EFSA 400mg limits

Table 2: Taurine Concentrations in Energy Drink Samples

Sample Name	Concentration of Taurine in Energy Drink Samples (Mg/L)
Predator	62.821470 ± 0.06
Fearless	378.747830 ± 0.83
Climax	59.164237 ± 0.94
Monster	68.330900 ± 1.00
Red Bull	134.514840 ± 0.76
Power Horse	79.678917 ± 0.50

Energy Drink Taurine (mg per 250 mL) Compared with EFSA 4000 mg/L Reference

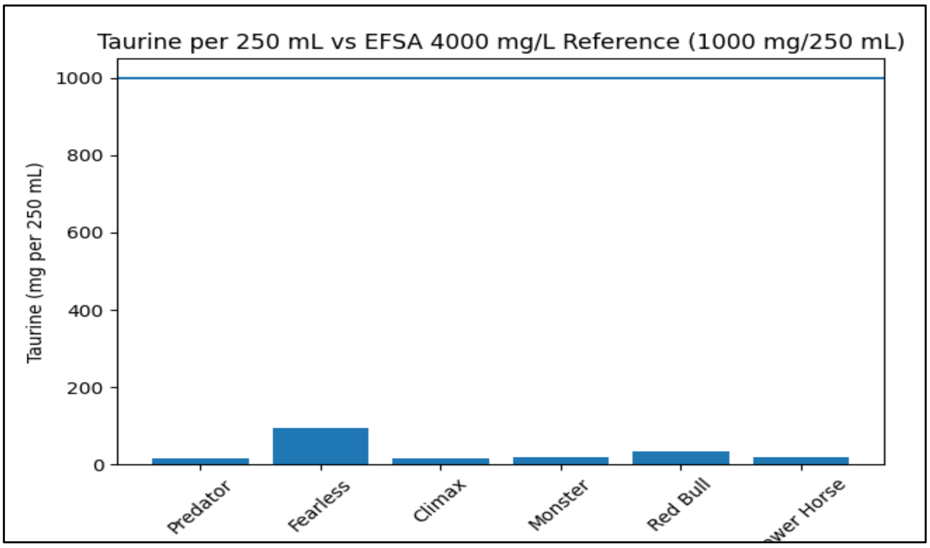

Figure 2: Taurine Content in Energy Drinks VS EFSA Reference (4000mg/L)

Table 3. Titratable Acidity Concentration in Energy Drink Samples

Sample name	Titratable Acidity concentration in Energy Drink Samples (g/100 mL)
Predator	6.186633 ± 0.48
Fearless	5.240467 ± 0.20
Climax	7.046267 ± 0.00
Monster	9.385733 ± 1.88
Red Bull	8.910733 ± 1.68
Power Horse	9.774200 ± 0.56

DISCUSSION OF RESULTS

The results in Table 1 show that the obtained values of caffeine for all the energy drink samples range from 129.14 to 2186.66 mg/L. The lowest caffeine concentration was detected in Climax (129.14 mg/L), while Power horse recorded the highest value (2186.66 mg/L). The Power horse high value could be as a result of regional factor or preference, measurement bias, or unlisted botanical ingredients such as guarana, kola nut, or yerba mate which may serve as additional caffeine sources. The caffeine levels in Monster (246.03 mg/L or 24.60 mg/100 mL), Climax (129.13 mg/L or 12.91 mg/100L) and Predator (187.65 mg/L or 18.77 mg/100mL) when compared with manufacturer declared value of (33.8 mg/100mL, 32 mg/100mL, and 30 mg/100mL) respectively, showed values below their label declarations. These underestimations may arise from differences in batch formulation, degradation during storage or incomplete extraction and chromatographic recovery. These minor deviations fall within the ±20% tolerance often reported in energy drink analyses (Ezeofor, 2022). Red Bull, however, exhibited a higher caffeine content (406.65 mg/L or 40.67 mg/100 mL) than the manufacturer stated 32 mg/100 ML. This 27% elevation may reflect either a stronger batch, analytical bias or regional factor. Similarly, Fearless (779.60 mg/L; 77.96 mg/100 mL) presented caffeine levels more than double the general average reported for commercial energy drinks, suggesting a highly concentrated formulation or analytical overestimation.

The U.S. Food and Drug Administration (FDA, 2024) advise that up to 400 mg of caffeine per day is generally safe for adults, and warns against excessive intake particularly among adolescents and pregnant women. According to EFSA (2020), caffeine intakes of up to 400 mg/day for healthy adults and 200 mg in a single dose are considered safe, whereas the World Health Organization recommends pregnant women limit caffeine intake to below 300 mg/day to minimize risks of miscarriage and low birth weight (WHO, 2023). Based on these standards, a standard 250 mL serving of Predator, Climax, or Monster would deliver 46.9 mg, 32.3 mg, and 61.5 mg of caffeine, respectively well below the EFSA and FDA limits and generally considered safe for moderate consumption. Red Bull, with a measured 101.7 mg per 250 mL can, remain within the 200 mg single-dose threshold. Fearless, containing approximately 194.9 mg per 250 mL, approaches the EFSA single-dose threshold (200 mg), indicating potential risk when consumed alongside other caffeine sources such as coffee or tea. Power Horse, at a staggering 546.7 mg per 250 mL, far exceeds both the EFSA single-dose (200 mg) and the total daily recommended intake (400 mg/day). This finding reveals that only the value of power horse is beyond the recommended daily intake limits while the values obtained from the remaining energy drink samples were found to be within the recommended daily intake limits. This suggest that the consumption of power horse could pose health risks to consumers while the consumption of other energy drink samples is considered to be safe.

The results in Table 2 shows significant variability in taurine composition among the samples, with values varying from 59.16 mg/L to 378.75 mg/L. Fearless has the highest taurine concentration (378.75 mg/L), while Climax has the lowest (59.16 mg/L). The close range of values for Predator (62.82 mg/L), Climax (59.16 mg/L), Monster (68.33 mg/L), and Power Horse (79.68 mg/L) suggests possible similarities in formulation or processing techniques among these brands. Red Bull recorded an intermediate taurine concentration of (134.51 mg/L), which was higher than most samples but significantly lower than Fearless. These differences may be attributed to variations in manufacturing practices, ingredient sources, differences in formulations, dilution factors during production or storage condition. The relatively high taurine value in Fearless (378.75 mg/L) compared to other brands suggests either a higher intentional fortification or better analytical recovery in this sample. Conversely, the very low values in Predator and Climax may result from low quality ingredients, reduced fortification during manufacturing or prolonged exposure to heat or light, which may also slightly alter taurine stability, although taurine is generally stable under normal storage conditions.

The World Health Organization (WHO) has not established a specific recommended daily intake for taurine but classifies it as a conditionally essential amino acid. The U.S. Food and Drug Administration (FDA) lists taurine as "Generally Recognized as Safe (GRAS)" at intake levels up to 3,000 mg/day in adults. The European Food Safety Authority (EFSA, 2020) reports that energy drinks usually contain about 4,000 mg/L taurine and considers these levels safe for general consumption, provided total daily intake does not exceed 3,000 mg. Comparing these values with the present findings shows that all measured samples contain taurine concentrations far below international norms and health-based safety thresholds. Therefore, the taurine contents of the analyzed energy drinks are within safe limits but unexpectedly lower than internationally established product standards.

The titratable acidity values of the analyzed energy drink samples in Table 3, reveal that fearless has the lowest titratable acidity value while power horse shows the highest value, indicating a higher presence of organic acid and the concentrations varies from fearless (5.24 g/100 mL) - Power Horse (9.77 g/100 mL) respectively. The high TA values, particularly in power horse, monster and Red bull are likely due to their high citric acid content, which is used for flavor enhancement, preservation and also enhances microbial stability, as noted by (Garcia *et al.,*2022), but increase the risk of dental erosion due to prolonged acid exposure in the oral cavity (Cochrane *et al.,*2020). The values obtained in this study (5.24 - 9.77 g/100 mL) align with findings by (Ogbeide *et al.,*2021), who reported acidity levels ranging from 5.1–15.6 g/100 mL in similar commercial energy drinks in Nigeria. The WHO and FDA have not established a direct permissible limit for titratable acidity in beverages but recommend that beverage acidity should not cause the pH to drop below 2.0 to avoid dental erosion (WHO, 2023; FDA 2024).

CONCLUSION

The Caffeine concentrations recorded in this study ranged from 129.14 mg/L to 2186.66 mg/L, indicating significant variation among the tested brands. Power Horse showed an extremely high caffeine concentration compared to the other energy drinks, while Climax had the lowest. Such high caffeine levels, especially in Power Horse, may pose health risks including insomnia, heart palpitations, hypertension, and nervous system overstimulation, particularly among young people and individuals with cardiovascular conditions. The Taurine concentrations ranged from 59.16 mg/L to 378.75 mg/L, with Fearless having the highest value and climax the lowest. While the taurine levels recorded are generally within low-to-moderate ranges, regular consumption of drinks with high taurine content may contribute to cumulative exposure, especially in combination with other stimulants. The Titratable Acidity values in this study (5.24–9.77 g/100 mL) fall within the range reported for energy drinks in Nigeria (5.1–15.6 g/100 mL). The high TA values, particularly in Power Horse (9.77 g/100 mL) and Monster (9.39 g/100 mL), enhance microbial stability but increase the risk of dental erosion due to prolonged acid exposure in the oral cavity.

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