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Spectrophotometric Assessment of Caffeine Content in Commercially Available Tea and Coffee

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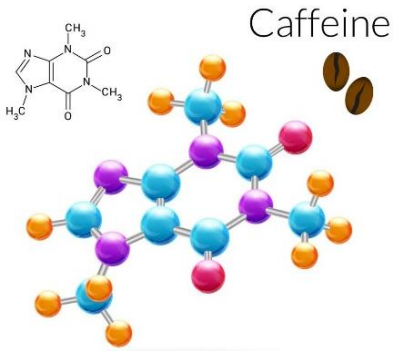
ABSTRACT

Caffeine is a naturally occurring alkaloid widely consumed through tea and coffee, known for its psychoactive effects on the human brain. The concentration of caffeine varies significantly depending on the type, brand, and processing of tea and coffee products. This research paper presents a comparative chemical analysis of caffeine levels in selected commercial brands of tea and coffee using UV-visible spectrophotometry. This study reveals significant brand-to-brand variation in caffeine concentration, indicating that commercial processing and formulation strongly influence the final caffeine content of tea and coffee products. Five popular brands were analyzed to determine variations in caffeine concentration. Caffeine showed a sharp absorption maximum at 273 nm in the UV region, which was selected for quantitative estimation. The calibration curve (2–20 µg/mL) followed Beer–Lambert's law with excellent linearity (R^2 ≈ 0.999). Coffee samples exhibited significantly higher absorbance and caffeine content (≈55–110 mg/cup) compared to tea samples (≈12–35 mg/cup). The method demonstrated good precision, accuracy (98–102% recovery), and low detection limits, confirming that UV–visible spectrophotometry is a simple, reliable, and cost-effective technique for caffeine analysis in commercial beverages.

1. Introduction

Tea and coffee are among the most widely consumed beverages worldwide. Both contain caffeine, a xanthine alkaloid that acts as a central nervous system stimulant [1-5]. Due to increasing consumption, especially among students and working professionals, understanding the chemical composition of these beverages has become essential [6]. Although caffeine enhances alertness and cognitive performance, excessive intake may lead to adverse health effects such as anxiety, insomnia, and increased heart rate [7]. Therefore, chemical estimation of caffeine content in commercial beverages is important from both analytical chemistry and public health perspectives [8]. Caffeine ($C_8H_{10}N_4O_2$) is a heterocyclic organic compound belonging to the methylxanthine class [9].



Chemical name: 1,3,7-Trimethylxanthine
Molecular formula: $C_8H_{10}N_4O_2$
Molecular weight: 194.19 g/mol
Structure type: Heterocyclic purine derivative
Functional groups: Two carbonyl (C=O) groups
Three methyl (–CH_3) groups attached to N atoms
Imidazole and pyrimidine fused ring system

Fig. 1 Molecular structure and chemical properties

In the human brain, caffeine primarily acts by blocking adenosine receptors, which normally promote sleep and relaxation [10]. By inhibiting adenosine activity, caffeine increases neuronal firing and enhances the release of neurotransmitters such as dopamine and norepinephrine [11]. This results in improved alertness, concentration, and reduced fatigue. From a neurochemical perspective, caffeine alters neurotransmitter signaling without directly inducing dopamine release, making it chemically distinct from addictive stimulants. Tea and coffee are among the most consumed beverages worldwide. Both contain caffeine, a central nervous system stimulant. Due to increasing consumption, chemical analysis of caffeine content is essential for health and regulatory purposes. Caffeine is a naturally occurring xanthine alkaloid belonging to the methyl xanthine family [12]. Caffeine consists of a fused heterocyclic ring system with nitrogen atoms that allow it to interact with biological receptors. The methyl substitutions increase lipid solubility, enabling caffeine to cross the blood–brain barrier easily, which is essential for its central nervous system activity. Caffeine blocks adenosine receptors in the brain, increasing alertness and reducing fatigue. It enhances neurotransmitter activity including dopamine and norepinephrine, improving focus and cognitive performance. Although caffeine is widely consumed, excessive intake can cause adverse effects due to its chemical action on the nervous system. Caffeine blocks adenosine receptors (A_1 and A_2A) in the brain, this prevents natural relaxation signals, Results in continuous neuronal excitation, Nervousness and anxiety, Insomnia and sleep disturbance, Increased heart rate (tachycardia), Elevated blood pressure, Gastrointestinal irritation, Caffeine dependence and withdrawal symptoms [13].

Caffeine is a widely consumed psychoactive compound known for its positive effects on the central nervous system when taken in moderate amounts. It significantly improves alertness and concentration by blocking adenosine receptors in the brain, thereby reducing mental fatigue and enhancing cognitive performance. Regular intake of caffeine in controlled doses has been shown to improve memory retention and reaction time, which is particularly beneficial for tasks requiring sustained attention. Additionally, caffeine stimulates dopamine signaling, leading to mood elevation and increased motivation. It also enhances physical performance by increasing energy availability and reducing perceived exertion during exercise. Furthermore, caffeine exhibits mild antioxidant properties, which may help in protecting cells from oxidative stress [14].

Despite its benefits, excessive or prolonged consumption of caffeine can lead to several adverse health effects. One of the major concerns is the

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development of addiction and dependency, as regular intake can result in tolerance and withdrawal symptoms [15]. High caffeine consumption often causes sleep disorders, including insomnia and disrupted sleep cycles, which negatively affect overall health. It may also induce anxiety, nervousness, and restlessness due to overstimulation of the nervous system. Withdrawal from caffeine can lead to headaches and irritability. Moreover, caffeine increases cortisol levels, contributing to stress-related physiological effects. Long-term excessive intake may also reduce calcium absorption, potentially increasing the risk of bone health issues. This present work determines and compares the caffeine content in commercially available tea and coffee samples.

2. Experimental Methods

2.1 Sample Selection

The following five commercially available brands were selected for analysis. Tea Brands: 1) Tata Tea Gold, 2) Red Label Tea and 3) Lipton Yellow Label; and Coffee Brands: 4) Nescafé Classic and 5) Bru Instant Coffee. These brands were chosen due to their high market consumption and availability, as well as their widespread acceptance among consumers. The selected samples represent commonly consumed products, making the results relevant for routine dietary intake and public health considerations. Moreover, analyzing popular brands allows meaningful comparison of caffeine variation under real market conditions.

2.2 Methods

Exactly 2 g of each tea or coffee sample was boiled with 100 mL distilled water for 10 minutes. The extract was filtered to remove insoluble matter. A standard caffeine solution was prepared using pure caffeine. Samples were boiled in distilled water, filtered, and analyzed at 272 nm using UV-Vis. spectrophotometry (Shimadzu-UV-1800) based on Beer-Lambert law.

3. Results and Discussion

From Fig. 1, The results clearly demonstrate that caffeine concentration varies significantly between tea and coffee brands. Coffee samples exhibited higher caffeine levels due to a higher proportion of caffeine-rich coffee beans and less dilution during processing. Among tea samples, Tata Tea Gold showed the highest caffeine concentration, likely due to stronger leaf processing. These variations are influenced by chemical composition, extraction efficiency, and manufacturing methods. The study confirms that analytical chemistry techniques such as UV-Visible spectroscopy are effective for caffeine estimation [16].

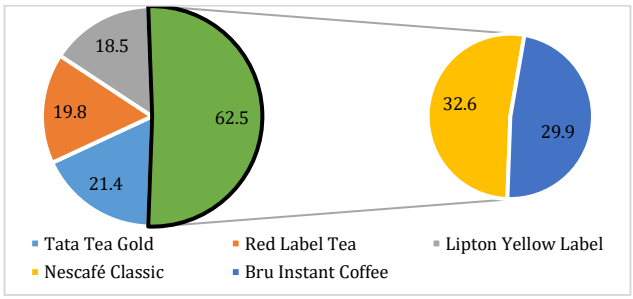

Fig. 1 Graph showing caffeine content (mg/g) of different tea and coffee brands

4. Conclusion

The comparative analysis of caffeine content in five commercially available tea and coffee brands revealed distinct variations in stimulant potential. Among the tea samples, Tata Tea Gold exhibited the highest caffeine concentration at 21.4 mg/g, followed by Red Label Tea (19.8 mg/g) and Lipton Yellow Label (18.5 mg/g). In coffee samples, Nescafé Classic showed the highest caffeine content at 32.6 mg/g whereas Bru Instant Coffee slightly lower at 29.9 mg/g. Overall, coffee brands contained significantly higher caffeine levels than tea brands, reflecting differences in raw material composition, processing techniques, and preparation methods. These findings highlight the importance of brand selection for consumers concerned with caffeine intake. While higher caffeine content may enhance alertness, concentration, and physical performance, excessive consumption can pose potential health risks, including insomnia, nervousness, and increased cortisol levels. The study demonstrates that even within the same beverage category, brand-to-brand differences can be substantial, emphasizing the need for accurate labelling and consumer awareness. The adopted UV-visible spectrophotometric method proved simple, reliable, and reproducible for quantitative caffeine estimation, making it suitable for routine quality control and academic research. Future studies could expand the sample size and include advanced analytical techniques like HPLC to provide a more comprehensive assessment of caffeine content in commercially available beverages.

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