

Research Article

Caffeine Variability in Unlabelled Ready-to-Drink Beverages: Laboratory Quantification and Compliance with Indonesian National Standard and U.S. Food and Drug Administration Standards

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Article History:

Received 15-09-2025

Revised 26-11-2025

Accepted 22-01-2026

Published 31-03-2026

Keywords:

athletes, caffeine, ready-to-drink, unlabelled beverages

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ABSTRACT

This study quantified the caffeine content of unlabelled Ready-To-Drink (RTD) caffeinated beverages commonly consumed by Malaysian university athletes, focusing on products from tea- and coffee-shops, and to evaluate their compliance with international (U.S. Food and Drug Administration (U.S. FDA) and Indonesian National Standard (INS) safe guidelines. A total of 31 RTD beverages (20 tea shops, 11 coffee shops) were selected using purposive sampling and analysed in triplicate by validated High-Performance Liquid Chromatography (HPLC). Results were analysed using descriptive statistical analysis and inferential testing to compare mean caffeine levels between beverages. Caffeine concentrations varied markedly, ranging from 2.94–69.47 mg/100 mL in tea beverages and 9.86–432.21 mg/100 mL in coffee beverages. Most tea beverages (12 of 20) and nearly all coffee beverages (10 of 11) exceeded the INS per-serving threshold (≤ 50 mg), and several coffee products also surpassed the FDA limit (≤ 200 mg). Statistical analysis confirmed significantly higher caffeine levels in coffee-shop compared with tea-shop beverages ($p < 0.001$). When expressed relative to body mass, multiple beverages delivered caffeine doses within or above the commonly recommended ergogenic range of 3–6 mg/kg, indicating potential for unintentional high exposure. The absence of mandatory caffeine labelling limits consumers' ability to estimate intake and may increase the risk of excessive consumption. These findings highlight the need for regulatory action mandating accurate caffeine disclosure and reinforce the importance of caffeine literacy among athletes, practitioners and the general-public to support informed and safe caffeine use.

INTRODUCTION

Caffeine is one of the most widely researched and utilised ergogenic aids in sport, valued for its ability to enhance endurance, improve alertness and reduce perceived exertion during exercise (Pickering & Grgic 2021). When consumed in appropriate doses, typically 3–6 mg/kg body mass about 30–60 minutes before

activity, caffeine has been shown to improve performance across endurance, team and high-intensity sports (Silva *et al.* 2025). These benefits have been recognised by the International Olympic Committee (IOC), the American College of Sports Medicine (ACSM), World Anti-Doping Agency (WADA) and other leading bodies in sports nutrition (Guest *et al.* 2021).

Ready-To-Drink (RTD) caffeinated beverages, including coffee- and tea-based products, have indeed become popular among athletes and physically active individuals. This trend is driven by their convenience, wide availability and appealing taste profiles (Jiménez *et al.* 2021). Among Malaysian university athletes, coffee drinks are the most preferred type of caffeinated beverage, followed by tea, reflecting broader consumption trends in the general population (Musa *et al.* 2025). In training and competition settings, athletes often use these beverages before, during or after sessions to maintain wakefulness, optimise performance or aid recovery (Jiménez *et al.* 2021). However, unlike sports-specific caffeine supplements, many RTD products do not provide accurate or visible caffeine content information on labels, menus or online platforms (Uddin *et al.* 2025).

The absence of clear caffeine labelling presents a challenge for athletes aiming to align their intake with evidence-based sports nutrition strategies. Without knowing the exact dose, athletes risk underdosing (and missing potential performance benefits) or overdosing, which may result in side effects such as tachycardia, anxiety, sleep disturbance or gastrointestinal upset (Cadoni & Peana 2023). Excessive late-day caffeine intake can impair recovery and disrupt sleep, both critical to training adaptation and competitive performance (Nobleza 2025). Alarmingly, a recent study reported that 69.1% of Malaysian university athletes consumed caffeine above the recommended safe daily allowance of ≤ 400 mg/day during sports events, underscoring the real-world risks of unregulated intake (Musa *et al.* 2025).

International health authorities such as the European Food Safety Authority (EFSA) and the U.S. Food and Drug Administration (USFDA) have set a maximum safe daily caffeine intake of 400 mg and 200 mg per serving for healthy adults (Sulaiman *et al.* 2024). In contrast, the Indonesian National Standard (INS) recommends a much lower limit of 150 mg/day and no more than 50 mg per serving (Rahmawati *et al.* 2024). While these regulatory limits aim to protect public health, they do not account for the higher, targeted intakes often recommended in sports nutrition for ergogenic purposes. This mismatch which refers to the discrepancy between public-health caffeine limits (e.g., INS: ≤ 150 mg/day and ≤ 50 mg/serving; FDA: ≤ 400 mg/

day and ≤ 200 mg/serving) and the safe doses recommended used in sports nutrition (3–6 mg/kg) for ergogenic purposes, combined with the absence of labelling, means that athletes may unknowingly exceed both safe health thresholds and optimal sports performance ranges.

In Malaysia, there is currently no national database of caffeine-containing beverages and no specific regulation mandating disclosure of caffeine content in RTD products. This regulatory gap reflects a broader Southeast Asian trend, where policies vary widely across countries: Indonesia enforces strict limits, while Singapore, Brunei, Philippines and Thailand do not have legally binding caffeine limits per day or per serving (Pandejpong *et al.* 2014; National Nutrition Council (NNC) 2025; Ministry of Health Singapore (MoHS) 2024; Attorney General's Chambers (AGN) 2001). Against this backdrop, Malaysia faces a dual challenge ensuring consumer safety while addressing the unique performance demands of athletes. At the same time, global market trends show that RTDs are among the fastest-growing functional beverages, particularly popular among adolescents, young adults and athletes (Gupta *et al.* 2023). In Malaysia, cultural practices such as daily consumption of 'kopi ais' and 'teh ais' further blur the line between recreational and performance-driven caffeine use, underscoring the urgent need for systematic monitoring and regulation.

Therefore, the present study aimed to (i) quantify the caffeine content of unlabelled RTD tea and coffee beverages commonly consumed by Malaysian athletes, and (ii) to evaluate these values against both international public health limits (INS, FDA). By providing this information, we aim to inform athletes, coaches and sports nutrition practitioners, as well as to highlight the need for clearer labelling policies to safeguard athlete health and optimise performance outcomes

METHODS

Design, location, and time

The research was an experimental study with a post-test control group design. The study was conducted at the Laboratory of Nutrition and Dietetic Programme, Faculty of Health Sciences, National University Malaysia, and the assessment implemented from April to July 2022. The research obtained the research ethical

approval on December 2020 from Research Ethics Committee, National University of Malaysia with approval number JEP-2020-729.

Materials and tools

All beverages were analysed within one week of purchase to preserve freshness and replicate real-world consumption conditions. Each sample was processed in triplicate. Caffeine content was quantified using a validated High-Performance Liquid Chromatography (HPLC) method. The procedure demonstrated excellent linearity ($R^2=0.9999$), high recovery (94–104%) and low relative standard deviations ($<0.02\%$), confirming method accuracy and precision.

Procedure

Samples selection, preparation and caffeine analysis. A purposive sampling strategy was used to select 31 unlabelled RTD beverages (20 from tea shops, 11 from coffee shops) in the Klang Valley, Malaysia. Selection was based on popularity among athletes as identified through previous study by Musa *et al.* (2025). Beverages were purchased in their original commercial packaging and in serving sizes typically available to consumers (250 mL, 350–400 mL, 473–500 mL and 700 mL). The names and flavours teashops drinks were coded as (T1) Milk tea, (T2) Hazelnut milk tea, (T3) Earl grey milk tea, (T4) Nisho matcha pearl, (T5) Hazelnut coco, (T6) Signature coco, (T7) Plum green tea, (T8) Caramel milk tea, (T9) Jasmine green milk tea, (T10) Tea tarik, (T11) Tea c ice. While the coffee shops coded were CS1, CS2, CS3, CS4, CS5, CS6, and CS7 as Espresso macchiato, Hazelnut latte, Caffe americano, Sea salt caramel macchiato latte, Kopi o, Traditional coffee o and Nescafe ice. Hence, the sub-coded for tea shops based on the actual serving sizes as T1a, T2a, T3a, T4a, T5a, T6a, T7a, T8a, T9a, T1b, T2b, T3b, T4b, T5b, T6b, T7b, T8b, T9b, T10 and T11, whereas the coffee shops were CS1a, CS1b, CS2a, CS2b, CS3a, CS3b, CS4a, CS4b, CS5, CS6 and CS7. The amounts of caffeine in specific coffee drink and tea drink are illustrated in Table 3. Before analysis, 5 mL of all liquid samples were put in the 50 mL volumetric flask using pipette and were sonicated in a sonicator bath for 15 min to eliminate entrapped air and degasses. A 45 mL distilled water was top up in the volumetric flask to make up 50 mL and centrifuged for 10 min with 3,500 rpm to separate the components that

had been constituted in the sample. The final solution was filtered using 0.45 μm membrane filters and directly transferred to a 2 mL vial prior to injecting into HPLC and analysed.

Data analysis

Data in triplicates were statistically analysed using one-sample t-test to compare the mean caffeine content of each beverage against fixed regulatory thresholds (INS 50 mg/serving and daily limit: 150 mg; FDA: 200 mg/serving and daily limit: 400 mg) at $p<0.001$. The results are presented as means with standard deviations. The SPSS software version 27 has been used for all measurements.

RESULTS AND DISCUSSION

The findings reveal significant variability in caffeine levels among RTD beverages, with coffee shop drinks consistently having higher caffeine content per mg/100 mL compared to tea shop drinks. This section discusses the variations and assesses whether the products comply with established guideline limits. Caffeine content was compared using mg/100 mL for standardized evaluation, while mg/serving values were included to reflect the actual caffeine delivered based on each product's commercial serving sizes.

For tea shop beverages, caffeine concentrations ranged from 2.94 to 69.47 mg/100 mL. Tea drink (T3a and T3b) was exceeding the INS limit per serving with another three drinks (T1a, T1b and T10) approached the upper threshold and the rest below the standard limits. While all tea beverages under the accepted recommended allowance of INS per day, and both FDA limits per serving and daily. Mean caffeine content in eighteen unlabeled tea drinks significantly lower from the INS (50 mg/serving; 150 mg/day) and FDA (200 mg/serving; 400 mg/day) limits ($p<0.001$) except (T3) tea drink differ from the reference value ($p<0.001$) in Table 1.

Earl Grey milk tea (T3) demonstrated the highest caffeine concentration (69.47 mg/100 mL) among the beverages analyzed, and this finding is consistent with several tea-related compositional and processing factors. Earl Grey is formulated using a pure black tea base, which is inherently rich in caffeine due to full oxidation and cultivar characteristics, and recent analytical studies confirm that black teas exhibit higher

Table 1. Caffeine content and regulatory compliance of unlabeled RTD tea-shop beverages

Tea shop	Caffeine content			Adherence to recommended intake limits			
	mg/100 mL	Actual serving size (mL)	mg	p (INS=50 mg/ serving)	p (INS=150 mg/day)	p (FDA=200 mg/serving)	p (FDA=400 mg/day)
T1a	36.82±0.03	500	184.11±0.14	0.001*	0.001*	0.001*	0.001*
T1b		700	257.75±0.20	0.001*	0.001*	0.001*	0.001*
T2a	29.73±0.06	500	148.62±0.30	0.001*	0.001*	0.001*	0.001*
T2b		700	208.07±0.42	0.001*	0.001*	0.001*	0.001*
T3a	69.47±0.09 ^{†a}	500	347.35±0.44	0.001*	0.001*	0.001*	0.001*
T3b		700	486.29±0.61	0.001*	0.001*	0.001*	0.001*
T4a	5.04±0.01	500	25.18±0.03	0.001*	0.001*	0.001*	0.001*
T4b		700	35.25±0.05	0.001*	0.001*	0.001*	0.001*
T5a	2.94±0.03 [‡]	500	14.72±0.16	0.001*	0.001*	0.001*	0.001*
T5b		700	20.61±0.22	0.001*	0.001*	0.001*	0.001*
T6a	3.71±0.00	500	18.54±0.01	0.001*	0.001*	0.001*	0.001*
T6b		700	25.95±0.02	0.001*	0.001*	0.001*	0.001*
T7a	10.24±0.04	500	51.18±0.22	0.001*	0.001*	0.001*	0.001*
T7b		700	71.65±0.31	0.001*	0.001*	0.001*	0.001*
T8a	8.23±0.16	500	41.14±0.78	0.001*	0.001*	0.001*	0.001*
T8b		700	57.59±1.10	0.001*	0.001*	0.001*	0.001*
T9a	8.01±0.16	500	40.05±0.82	0.001*	0.001*	0.001*	0.001*
T9b		700	56.06±1.14	0.001*	0.001*	0.001*	0.001*
T10	41.07±0.12	250	102.67±0.31	0.001*	0.001*	0.001*	0.001*
T11	25.42±0.48	250	63.55±1.19	0.001*	0.001*	0.001*	0.001*

[†]: Highest value caffeine content; [‡]: Lowest value caffeine content; ^a: More than recommended per serving >50 mg by INS; ^b: More than recommended per day >150 mg by INS; ^c: Over than recommended per serving >200 mg by FDA; ^d: Over than recommended per day >401 mg by FDA; $p < 0.001$ * comparison with INS and FDA using one-sample t-test; INS: Indonesian National Standard; FDA: Food and Drug Administration; RTD: Ready-To-Drink; T1: Milk tea; T2: Hazelnut milk tea; T3: Earl grey milk tea; T4: Nisho matcha pearl; T5: Hazelnut coco; T6: Signature coco; T7: Plum green tea; T8: Caramel milk tea; T9: Jasmine green milk tea; T10: Tea tarik; T11: Tea c ice

caffeine levels than other tea categories (Ayakdas & Ağagündüz 2025). In commercial preparation, Earl Grey milk tea is typically brewed using a higher tea-to-water ratio and longer steeping duration to preserve the characteristic bergamot aroma, both of which significantly enhance caffeine extraction. Brewing often occurs at near-boiling temperatures or employs machine-assisted methods like steam or ultrasonic brewers, which improve caffeine solubility and extraction efficiency (Piyasena 2025). Additionally, many Earl Grey blends use broken or Crush-Tear-Curl (CTC) tea grades with smaller particles, enabling faster caffeine diffusion into the beverage. Compared to other milk teas or Tea tarik versions, Earl Grey milk tea usually contains less milk or sugar, resulting in a more concentrated flavour. These formulation and processing features collectively explain why Earl Grey milk tea showed the highest caffeine density in this study.

Tarik (T10) and Milk tea (T1) showed moderate caffeine levels (41.07 mg/100 mL and 35.82 mg/100 mL), influenced by black tea brewing strength and considerable dilution

during preparation. Though both use black tea dust, known for rapid caffeine release due to its fine particles, the caffeine content is lowered by the high amounts of condensed milk, added water, and air incorporation during the “pulling” process. These steps increase the beverage volume and dilute the tea extract, resulting in a lower caffeine density per 100 mL compared to Earl Grey milk tea. Shorter steeping times, usually 1 to 3 minutes in hawker-style drinks, limit caffeine extraction compared to longer brewing times in speciality milk teas. Repeated pouring also causes temperature fluctuations, which may reduce extraction efficiency versus continuous high-temperature steeping. Consistent with these observations, recent studies report wide variation in caffeine content across ready-to-drink black tea beverages, highlighting dilution as a key factor affecting caffeine levels (Rocha *et al.* 2022; Chen *et al.* 2024). Thus, the caffeine content in Tarik reflects its preparation approach, which emphasises a strong flavour while using significant dilution with milk, sugar, and aeration.

Caffeine variability in unlabelled ready-to-drink beverages

Hazelnut cocoa tea (T5) had the lowest caffeine level at 2.94 mg/100 mL, as tea is usually used in smaller amounts compared to cocoa powder, milk, non-dairy creamer, sugar syrup, and flavouring agents. As a result, the volume of water that directly contacts tea leaves is greatly reduced, leading to minimal caffeine diffusion from the tea fraction as given the composition and extraction characteristics of cocoa-based beverages. Cocoa drinks are theobromine-dominant and naturally contain minimal caffeine, with large-scale food composition data indicating that chocolate milk and hot cocoa typically provide only ~2–5 mg caffeine per 100 mL (Rocha *et al.* 2022). In addition, cocoa powders used in commercial beverages undergo processing steps such as alkalization, roasting and fat reduction, which further lower caffeine concentration relative to native cocoa beans. The beverage matrix of hazelnut cocoa also contributes to its low caffeine density, a substantial proportion of the drink consists of milk, sugar syrup, and flavouring agents, all of which dilute any caffeine contributed by the small amount of tea or cocoa solids incorporated into the recipe. The fat content in milk can further impede the diffusion of methylxanthines, thus decreasing overall extraction efficiency. Consistent with recent research on cocoa-based drinks, the current findings show that beverages mainly made with cocoa and dairy ingredients have significantly lower caffeine levels compared

to tea-based drinks. This trend results from both the composition of ingredients and processing limitations that restrict caffeine availability (Gonzales-Yépez *et al.* 2023).

The significant variation in caffeine levels found across tea shop beverages shows how factors like tea grade, extraction strength, and dilution methods directly affect the caffeine content of unlabeled commercial drinks. Without caffeine labelling, consumers including athletes may unknowingly ingest caffeine beyond their personal tolerance or safety limits.

For athletes relying on accurate caffeine doses to boost performance and avoid side effects, inconsistent or hidden caffeine levels can cause unintended overstimulation, gastrointestinal issues, sleep problems, or poorly timed caffeine intake. These points highlight the need for clear caffeine labelling and increased awareness of how beverages are prepared, especially for those needing to monitor their overall caffeine consumption carefully. Building on this, the next section explores how caffeine levels vary in unlabeled coffee shop drinks, where factors like bean type, roasting level and brewing techniques can further affect caffeine content.

Table 2 displays considerable variation in caffeine levels among the 11 coffee shop drinks analyzed, with amounts ranging from 9.86 to 432.21 mg/100 mL. CS1 showed the highest caffeine content and, along with CS2, CS3, and CS4, significantly surpassed both INS and FDA

Table 2. Caffeine content and regulatory compliance of unlabeled RTD coffee-shop beverages

Coffee shop	Caffeine content			Adherence to recommended intake limits			
	mg/100 mL	Actual serving size (mL)	mg	p (INS=50 mg/serving)	p (INS=150 mg/day)	p (FDA=200 mg/serving)	p (FDA=400 mg/day)
CS1a	432.21±0.00 ^{†abcd}	35	151.27±0.11	0.001*	0.001*	0.001*	0.001*
CS1b		70	302.55±0.21	0.001*	0.001*	0.001*	0.001*
CS2a	80.02±0.00 ^a	354	283.28±0.12	0.001*	0.001*	0.001*	0.001*
CS2b		473	378.50±0.15	0.001*	0.001*	0.001*	0.001*
CS3a	64.75±0.01 ^a	354	229.20±4.10	0.002**	0.001*	0.001*	0.001*
CS3b		473	306.24±5.48	0.002**	0.001*	0.001*	0.001*
CS4a	63.85±0.01 ^a	350	223.46±0.12	0.001*	0.001*	0.001*	0.001*
CS4b		400	255.38±0.14	0.001*	0.001*	0.001*	0.001*
CS5	9.86±0.01 [‡]	250	24.66±0.03	0.001*	0.001*	0.001*	0.001*
CS6	39.94±0.00	250	99.86±0.02	0.001*	0.001*	0.001*	0.001*
CS7	39.45±0.00	250	98.62±0.02	0.001*	0.001*	0.001*	0.001*

†: Highest value caffeine content; ‡: Lowest value caffeine content; ^a: More than recommended per serving >50 mg by INS; ^b: More than recommended per day >150 mg by INS; ^c: Over than recommended per serving >200 mg by FDA; ^d: Over than recommended per day >401 mg by FDA; p<0.001* and p<0.01** comparison with INS and FDA using one-sample t-test; INS: Indonesian National Standard; FDA: Food and Drug Administration; RTD: Ready-To-Drink; CS1: Espresso macchiato; CS2: Hazelnut latte; CS3: Caffè americano; CS4: Sea salt caramel macchiato latte; CS5: Kopi o; CS6: Traditional coffee o; CS7: Nescafe ice

Table 3. Caffeine content of RTD beverages compared with INS and FDA per-serving limits

Product code	Caffeine (mg/serving)	Estimation relative body-mass (mg/kg)		>INS per serving (50 mg)	>FDA per serving (200 mg)	≥ 3–6 mg/kg ergogenic dose (ACSM/ IOC/ WADA)
		Athlete (60 kg)	Athlete (75 kg)			
T1a	184.11	3.07	2.45	Yes	No	No
T2a	148.62	2.48	1.98	Yes	No	No
T3a	347.35	5.79	4.63	Yes	Yes	Yes
T4a	25.18	0.42	0.34	No	No	No
T5a	14.72	0.25	0.20	No	No	No
T6a	18.54	0.31	0.25	No	No	No
T7a	51.18	0.85	0.68	Yes	No	No
T8a	41.14	0.69	0.55	No	No	No
T9a	40.05	0.67	0.53	No	No	No
T1b	257.75	4.30	3.44	Yes	Yes	No
T2b	208.07	3.47	2.77	Yes	Yes	No
T3b	486.29	8.10	6.48	Yes	Yes	Yes
T4b	35.25	0.59	0.47	No	No	No
T5b	20.61	0.34	0.27	No	No	No
T6b	25.95	0.43	0.35	No	No	No
T7b	71.65	1.19	0.96	Yes	No	No
T8b	57.59	0.96	0.77	Yes	No	No
T9b	56.06	0.93	0.75	Yes	No	No
T10	102.67	1.71	1.37	Yes	No	No
T11	63.55	1.06	0.85	Yes	No	No
CS1a	151.27	2.52	2.02	Yes	No	No
CS1b	302.55	5.04	4.03	Yes	Yes	Approaching
CS2a	283.28	4.72	3.78	Yes	Yes	Approaching
CS2b	378.5	6.31	5.05	Yes	Yes	Yes
CS3a	229.2	3.82	3.06	Yes	Yes	No
CS3b	306.24	5.10	4.08	Yes	Yes	Approaching
CS4a	223.46	3.72	2.98	Yes	Yes	No
CS4b	255.38	4.26	3.41	Yes	Yes	No
CS5	24.66	0.41	0.33	No	No	No
CS6	99.86	1.66	1.33	Yes	No	No
CS7	98.62	1.64	1.31	Yes	No	No

INS: Indonesian National Standard; FDA: Food and Drug Administration; ACSM: American College of Sports Medicine; IOC: International Olympic Committee; WADA: World Anti-Doping Agency; T1: Milk tea; T2: Hazelnut milk tea; T3: Earl grey milk tea; T4: Nisho matcha pearl; T5: Hazelnut coco; T6: Signature coco; T7: Plum green tea; T8: Caramel milk tea; T9: Jasmine green milk tea; T10: Tea tarik; T11: Tea c ice; CS1: Espresso macchiato; CS2: Hazelnut latte; CS3: Caffe americano; CS4: Sea salt caramel macchiato latte; CS5: Kopi o; CS6: Traditional coffee o; CS7: Nescafe ice

reference limits ($p < 0.001$). Although CS6 and CS7 contained moderate caffeine amounts, they still exceeded the INS recommended per-serving threshold ($p < 0.001$). Conversely, CS5 (Kopi o) had the lowest caffeine level; however, it was still significantly different from the regulatory limits ($p < 0.001$). These results emphasize the wide variation in caffeine content among coffee beverages and suggest that many unlabeled products could pose a risk of consumers consuming more caffeine than advised.

In this study, Espresso macchiato showed the highest caffeine level at 432.21 mg/100

mL. This aligns with earlier research indicating that espresso extraction yields the highest caffeine concentration per milliliter among common brewing methods (Olechno *et al.* 2021; Mystkowska *et al.* 2024; Genovese *et al.* 2025). The espresso brewing process employs high pressure (around 9–15 bar), a very fine grind, and a relatively large amount of coffee, all of which boost solute extraction efficiency (Guerra *et al.* 2023; Guerra *et al.* 2024). Typically, caffeine levels in espresso drinks range from 210 to 420 mg/ 100 mL (Cižmarová *et al.* 2025), closely matching the concentration observed

here. Additionally, Macchiato contains only a "mark" of foam, resulting in minimal dilution and a highly concentrated beverage. Espresso-based drinks with limited milk addition tend to retain higher caffeine levels per volume due to their high espresso-to-milk ratio (Wierzejska & Gielecińska 2024). Moreover, coffee shops often use higher coffee doses (18–22 g) or Robusta bean blends, both of which are known to increase caffeine content (Khamitova *et al.* 2020).

In contrast, beverages like Hazelnut latte (80.20 mg/ 100 mL), Caffè americano (64.75 mg/ 100 mL), and Sea salt caramel macchiato latte (63.85 mg/ 100 mL) show significantly lower caffeine levels, mainly due to dilution effects. Latte drinks generally contain large amounts of milk (around 150–250 mL), which reduces caffeine concentration when measured per 100 mL (Cižmarová *et al.* 2025). Adding flavouring syrups in hazelnut or caramel drinks further increases the total liquid volume without caffeine, causing more dilution (Wierzejska & Gielecińska 2024). Likewise, Caffè americano is made by diluting one espresso shot with 120–200 mL of hot water, explaining its lower caffeine content despite sharing the same espresso base (Olechno *et al.* 2021).

Coffee o (Kopi o) had the lowest caffeine concentration (9.86 mg/ 100 mL), and several mechanisms may account for this. First, bean species and blend composition may influence the baseline caffeine content. For example, analyses of Malaysian-grown Liberica beans have reported relatively low caffeine levels (~5.4% w/w), suggesting that if such low-caffeine species or lower-grade blends are used, the resulting brew will naturally contain less caffeine. Second, roasting profile and coffee dose may contribute; lighter roasts retain more caffeine, whereas heavier roasts and lower coffee doses yield reduced caffeine extraction (Ihsan *et al.* 2023). Third, brewing parameters such as coarse grind size, shorter extraction time, lower water temperature and high-water volume can reduce caffeine extraction efficiency; gravity-based filtration methods, such as the traditional cloth "sock" used for Coffee o, are typically less efficient than pressure-based espresso extraction (Olechno *et al.* 2021). Lastly, serving volume plays a role; when a modest caffeine dose is diluted into a large beverage volume, the resulting caffeine concentration per 100 mL becomes substantially lower. Collectively, these factors (bean species,

roast level, coffee dose, brew method and dilution) provide a multifactorial explanation for the very low caffeine concentration observed in Coffee o. Nevertheless, direct contemporary evidence specifically examining Malaysian Coffee o remains limited, highlighting the need for future studies to quantify coffee dose, bean composition, brewing practices and serving volumes in real-world cafe settings.

The variability seen in this study aligns with global patterns, where commercial coffee and tea products often show wide caffeine content ranges, frequently without proper labelling (Aung *et al.* 2020; Putithanarak *et al.* 2022; Wierzejska & Gielecińska 2024). This inconsistency can challenge athletes trying to regulate caffeine intake according to periodized nutrition plans, such as tapering caffeine before major competitions to regain sensitivity or timing doses during endurance events to maintain performance (Kreutzer *et al.* 2022). Due to the significant variability, Table 2 displays caffeine content per serving and per 100 mL for straightforward comparison with INS and FDA limits.

In order to evaluate compliance with international public health standards, total caffeine per serving was compared against the INS limit of ≤ 50 mg/serving and the U.S. FDA threshold of ≤ 200 mg/serving. Table 3 summarizes the caffeine content of each RTD product relative to these regulatory benchmarks. Most tea shop products (12 of 20) and nearly all coffee shop products (10 of 11) exceeded the INS per-serving threshold, while several coffee shop beverages also surpassed the FDA limit. These findings indicate that unlabelled RTD beverages commonly consumed by athletes frequently exceed established public-health safety thresholds. The significant differences in caffeine levels among products are due to variations in raw ingredients like Robusta, Arabica, or Liberica beans, as well as factors such as brewing strength, extraction pressure, tea oxidation level, and serving size. All of these elements are known to affect caffeine content in commercial drinks. Together, these preparation-related factors probably account for why coffee shop beverages typically have higher caffeine concentrations than those from tea shops.

Although current regulatory limits are designed for the general population, they do not accurately represent how athletes typically

consume caffeine. This highlights the need for two practical actions: firstly, providing clear and precise caffeine labels for all consumers; and secondly, implementing targeted education to help athletes better gauge their caffeine consumption and prevent accidental overuse. Studies also underline that transparent labelling, regular monitoring of caffeine intake, and structured educational programs are essential for safeguarding consumers and minimising health risks associated with high-caffeine products (Morris *et al.* 2022; Corbett *et al.* 2024). Since these drinks are often consumed by university athletes and the general public, the absence of clear caffeine information could lead to unintentional excessive intake.

Athletes need accurate and consistent caffeine dosing to achieve performance benefits while minimising risks like overconsumption, stomach discomfort, and sleep issues. However, this study reveals significant variation in caffeine content across unlabelled tea and coffee shop beverages, with many exceeding INS and FDA reference limits. For example, beverages such as Earl Grey milk tea and espresso-based drinks reached very high concentrations, sometimes up to 432 mg/ 100 mL, potentially placing athletes above safe intake levels unintentionally. These results support a “known-dose” approach, where athletes focus on labelled or standardised caffeine sources and base intake on body weight (mg/kg). This method aligns with current sport nutrition guidelines emphasising individualised and periodized caffeine use (Kreutzer *et al.* 2022; Pickering & Grgic 2020). In practice, athletes should trial caffeine strategies before competitions, monitor timing and personal responses, and adjust to minimise adverse effects. From a policy standpoint, the considerable variability found in this study advocates for mandatory caffeine labelling on ready-to-drink and café-prepared beverages, in line with recent calls for greater transparency in commercial caffeine products (Wierzejska & Gielecińska 2024; Rocha *et al.* 2022). For athletes and practitioners, education on brewing methods, serving sizes, and hidden caffeine sources is crucial, as preparation differences can significantly impact caffeine exposure (Chen *et al.* 2024; Genovese *et al.* 2025). Overall, enhancing caffeine literacy is vital to promote safe and effective caffeine use in athletic contexts.

CONCLUSION

This study revealed significant variation in caffeine levels among unlabelled ready-to-drink tea and coffee products, many surpassing the per-serving limits established by INS and the U.S. FDA. Several beverages also contained caffeine quantities within or above the ergogenic range recommended by ACSM/IOC/WADA, especially for lighter athletes, which raises the risk of unintentionally high intake. The absence of mandatory caffeine labelling limits consumers, particularly athletes who need precise mg/kg dosing- from accurately estimating their caffeine consumption. This can lead to overconsumption, sleep issues, and cumulative excess intake. These results emphasise the urgent need for clearer regulations, including mandatory caffeine labelling on ready-to-drink and café beverages, along with targeted education for athletes, coaches, and health practitioners. Improving both labelling transparency and caffeine literacy is essential to support safer consumption, more informed and evidence-based caffeine use.

ACKNOWLEDGMENT

We would like to extend our special thanks to the National University of Malaysia for their financial support for this article (FRGS/1/2023/SKK06/UKM/02/3).

DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest.

DECLARATION OF GENERATIVE AI IN SCIENTIFIC WRITING

No generative AI were used for content creation, data analysis or scientific interpretation. Proofreading services were used solely for language and grammar polishing.

REFERENCES

- [AGN] Attorney General's Chambers. 2001. Laws of Brunei, Public Health (Food). Public Health (Food) Act (Chapter 182 Public Health (Food) Regulation. Revised Edition 2001. Bandar Seri Begawan (BN): AGN.

- Aung WL, Hlaing TM, Kyaw M, Zaw T, Myint K. 2020. Determination of caffeine content in different brands of pure coffee, instant coffee and tea available in the Naypyitaw market. *Int J Eng Appl Sci* 5(4):500–504. <https://doi.org/10.33564/IJEAST.2020.v05i04.079>
- Ayakdaş G, Ağagündüz D. 2025. Determination of L-theanine and caffeine contents in tea infusions with different fermentation degrees and brewing conditions using the chromatographic method. *Food* 14(13):2313. <https://doi.org/10.3390/foods14132313>
- Cadoni C, Peana AT. 2023. Energy drinks at adolescence: Awareness or unawareness? *Front Behav Neurosci* 17(2023):1080963. <https://doi.org/10.3389/fnbeh.2023.1080963>
- Chen N, Jioa Z, Xie K, Liu J, Yoa P, Lou Y, Zhang T, Cheng K, Zhao C. 2024. Effects of protein on green tea quality in a milk-tea model during heat treatment: Antioxidant activity, foaming properties, and unbound small-molecule metabolome. *J Dairy Sci* 107(12):10462–10480. <https://doi.org/10.3168/jds.2024-25167>
- Cižmárová B, Kraus Jr V, Birková A. 2025. Caffeinated beverages—Unveiling their impact on human health. *Beverages* 11(1):18. <https://doi.org/10.3390/beverages11010018>
- Corbett LJ, Bunch MR, Smith MB, Bunch TJ. 2024. An overview of the risks and impact of pre-exercise supplements for exercise performance, recovery, and cardiovascular health. *Curr Cardiovasc Risk Rep* 18(3):45–54. <https://doi.org/10.1007/s12170-024-00735-8>
- Genovese A, Caporaso N, Caporaso A. 2025. The impact of brewing methods on the quality of a cup of coffee. *Beverages* 11(5):125. <https://doi.org/10.3390/beverages11050125>
- Gonzales-Yépez KA, Vilela JL, Reátegui O. 2023. Determination of caffeine, theobromine, and theophylline by HPLC-DAD in beverages commonly consumed in Lima, Peru. *Int J Food Sci* 2023(1):4323645. <https://doi.org/10.1155/2023/4323645>
- Guerra MV, Harshe YM, Fries L, Rothberg S, Palzer S, Heinrich S. 2023. Influence of particle size distribution on espresso extraction via packed bed compression. *J Food Eng* 340:111301. <https://doi.org/10.1016/j.jfoodeng.2022.111301>
- Guerra MV, Harshe YM, Fries L, Lozada JP, Atxutegi A, Palzer S, Heinrich S. 2024. Modeling the extraction of espresso components as dispersed flow through a packed bed. *J Food Eng* 368:111913. <https://doi.org/10.1016/j.jfoodeng.2023.111913>
- Guest NS, VanDusseldorp TA, Nelso MT, Grgic J, Schoenfeld BJ, Jenkins NDM, Arent SM, Antonio J, Stout JR, Trexler ET *et al.* 2021. International society of sports nutrition position stand: Caffeine and exercise performance. *JISSN* 18(1):1. <https://doi.org/10.1186/s12970-020-00383-4>
- Gupta A, Sanwal N, Bareen MA, Barua A, Sharma N, Olatunji OJ, Nirmal NP, Sahu JK. 2023. Trends in functional beverages: Functional ingredients, processing technologies, stability, health benefits, and consumer perspective. *Food Res Int* 170:113046. <https://doi.org/10.1016/j.foodres.2023.113046>
- Ihsan BRP, Shalas AF, Elisabeth Y, Claudia LM, Putri AR. 2023. Determination of caffeine in robusta coffee beans with different roasting method using UV-Vis spectrophotometry. *Food Res* 7(6):29–34. [https://doi.org/10.26656/fr.2017.7\(6\).1006](https://doi.org/10.26656/fr.2017.7(6).1006)
- Jiménez S, Díaz-Lara J, Pareja-Galeano H, Del Coso J. 2021. Caffeinated drinks and physical performance in sport: A systematic review. *Nutr* 13(9):2944. <https://doi.org/10.3390/nu13092944>
- Khamitova G, Angeloni S, Borsetta G, Xiao J, Maggi F, Sagratini G, Vittori S, Caprioli G. 2020. Optimization of espresso coffee extraction through variation of particle sizes, perforated disk height and filter basket aimed at lowering the amount of ground coffee used. *Food Chem* 314:126220. <https://doi.org/10.1016/j.foodchem.2020.126220>
- Kreutzer A, Graybeal AJ, Moss K, Braun-Trocchio R, Shah M. 2022. Caffeine supplementation strategies among endurance athletes. *Front Sports Act Living* 4:821750. <https://doi.org/10.3389/fspor.2022.821750>
- [MoHS] Ministry of Health Singapore. 2024. Health risks of high caffeine consumption on young people. <https://www.moh.gov.sg/>

- newsroom/health-risks-of-high-caffeine-consumption-on-young-people?utm_source=chatgpt.com [Accessed on 27th August 2025].
- Morris GB, Manders RJF, Hulton AT. 2022. Caffeine consumption within British fencing athletes. *Front Nutr* 9:999847. <https://doi.org/10.3389/fnut.2022.999847>
- Musa SJ, Ghazali AR, Mohamad Fauzi NF, Abd Rahman AH, Mohamad MZ, Safi NS. 2025. Caffeine ingestion among athletes based on safe dose daily allowance in Malaysia. *J Gizi Pangan* 20(1):31–40. <https://doi.org/10.25182/jgp.2025.20.1.31-40>
- Mystkowska I, Dmitrowicz A, Sijko-Szpańska M. 2024. Quantitative analysis of caffeine in roasted coffee: A comparison of brewing methods. *Appl Sci* 14(23):11395. <https://doi.org/10.3390/app142311395>
- [NNC] National Nutrition Council. 2025. How much coffee is safe? https://nnc.gov.ph/visayas-region/how-much-coffee-is-safe/?utm_source=chatgpt.com [Accessed on 28th August 2025].
- Nobleza D. 2025. Mental health care of the baseball player. *Clin Sports Med* 44(2):369–386. <https://doi.org/10.1016/j.csm.2024.05.007>
- Olechno E, Puścion-Jakubik A, Zujko ME, Socha K. 2021. Influence of various factors on caffeine content in coffee brews. *Foods* 10(6):1208. <https://doi.org/10.3390/foods10061208>
- Pandejpong D, Paisansudhi S, Udornpunthurak S. 2014. Factors associated with consumption of caffeinated-beverage among Siriraj pre-clinical year medical students, A 2-year consecutive survey. *J Med Assoc Thai* 97(3):S189–S196.
- Pickering C, Grgic J. 2020. Is coffee a useful source of caffeine pre-exercise? *Int. J Sport Nutr Exerc Metab* 30(1):69–82. <https://doi.org/10.1123/ijsnem.2019-0092>
- Pickering C, Grgic J. 2021. A time and a place: A framework for caffeine periodization throughout the sporting year. *Nutr* 82:111046. <https://doi.org/10.1016/j.nut.2020.111046>
- Piyasena NP. 2025. Milk in tea: Exploring the chemistry and biological activities. *Food Sci Biotechnol* 1–17. <https://doi.org/10.1007/s10068-025-01841-y>
- Putithanarak N, Klongthong W, Thavorn J, Ngamkroekjoti C. 2022. Predicting consumers' repurchase intention of ready-to-drink coffee: A supply chain from Thai producers to retailers. *J Distrib Sci* 20(5):105–117. <http://dx.doi.org/10.15722/jds.20.05.202205.105>
- Rahmawati I, Arori SH. 2024. Comparative analysis of caffeine content in cold and hot brewed robusta coffee using High-Performance Liquid Chromatography (HPLC). *J Kim Pendidik Kim* 9(1):15–25. <https://doi.org/10.20961/jkpk.v9i1.84991>
- Rocha PLDA, Lima ALC, Saunders B, Reis CEG. 2022. Development of a caffeine content table for foods, drinks, medications and supplements typically consumed by the Brazilian population. *Nutr* 14(20):4417. <https://doi.org/10.3390/nu14204417>
- Silva H, Del Coso J, Pickering C. 2025. Caffeine and sports performance: The conflict between caffeine intake to enhance performance and avoiding caffeine to ensure sleep quality. *Sports Med* 1–14. <https://doi.org/10.1007/s40279-025-02245-y>
- Sulaiman N, Ali A, Zakaria MK, Abu SM, Sim WJ, Mhd JA. 2024. Caffeine consumption, sleep quality and mental health outcomes among Malaysian University students. *Nat J Community Med* 15(5):370–378. <https://doi.org/10.55489/njcm.150520243858>
- Uddin MJ, Mohaimenul M, Aktaruzzaman M, Islam MT, Hasan AR, Rahman MH, Akter T, Rahman MM, Amin MZ, Raihan MO. 2025. Isolation and quantification of caffeine in marketed tea and carbonated beverage products in Bangladesh. *Toxicol Anal Clin* 37(2):159–166. <https://doi.org/10.1016/j.toxac.2024.09.001>
- Wierzejska RE, Gielecińska I. 2024. Evaluation of the caffeine content in servings of popular coffees in terms of its safe intake—can we drink 3–5 cups of coffee per day, as experts advise? *Nutr* 16(15):2385. <https://doi.org/10.3390/nu16152385>