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Label-Declared Caffeine, Taurine, and Co-Ingredient Disclosure in 532 Energy Drinks: A Cross-Sectional Survey across Eleven Markets

Minhae Cho ¹, Ansar Ali ², Heayyeon Lee ^{1,*} and Rabia Naz ^{3,*}

¹ Plamica Labs, Batten Hall, 125 Western Ave, Allston, MA 02163, USA

² Department of Molecular Biosciences, The University of Texas at Austin, Austin, TX 78712, USA

³ Department of Food Science and Human Nutrition, Kinnaird College for Women, Lahore 54000, Pakistan

* Correspondence: heayyeon.lee@plamica.com (H.L.); rabia.naz@kinnaird.edu.pk (R.N.)

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Abstract: Energy drinks are sold worldwide as a compositionally defined category, with no harmonized definition across jurisdictions. Typical concentrations have been reported market by market, but whether they are set product by product or held constant across a market, and whether the amounts determining co-ingredient exposure can be read from the label, remain unknown. This study examined label-declared caffeine and co-ingredient composition in a cross-sectional convenience sample of 532 commercially available ready-to-drink products from 43 brands across eleven markets with differing compositional and labeling regulations; products entered the sample where composition was published for the market concerned, so the findings describe the sampled products rather than national markets. One caffeine concentration recurred across the category, as did one taurine concentration among products stating an amount, held at the market level in several European markets, though not in the United States or Japan. The two varied independently, so the fixed ratio they appear to form is arithmetic rather than a formulation rule. Most co-ingredient declarations carried no amount, and the labeling regime, not the ingredient, decided whether one appeared, with quantification scarcest for constituents carrying published safety thresholds. Where a concentration is a market constant, intake is governed by the volume consumed rather than the product chosen, and across much of the category the amounts needed to apply an existing exposure assessment are absent from the label. Because these concentrations are declared rather than measured, chromatographic assay of these products would test their validity for exposure assessment and quantify the botanical caffeine the declared values omit.

Keywords: compositional clustering; cross-market survey; caffeine; taurine; label declaration; co-exposure

1. Introduction

Ready-to-drink (RTD) energy drinks constitute a compositionally defined beverage class characterized by added caffeine well above the concentrations of cola-type soft drinks, in combination with a recurring set of non-nutritive co-ingredients including taurine, glucuronolactone, inositol and botanical extracts; the European Food Safety Authority (EFSA) describes typical concentrations of approximately 300–320 mg/L caffeine, 4000 mg/L taurine and 2400 mg/L D-glucurono- γ -lactone [1]. EFSA concluded that co-ingredients at those concentrations would not affect the safety of single caffeine doses up to 200 mg for adults, and that the available information was insufficient to derive a safe caffeine intake for children and adolescents [1]; neither assessment addressed the



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proportional relationship between caffeine and taurine as distinct from their individual concentrations, and the earlier evaluation of taurine and D-glucuronolactone noted that other interactions between the two were not investigated [2]. The term “energy drink” is primarily a commercial designation, and where a legal definition exists, it is jurisdiction-specific; products are classified principally by their composition [3].

Previous studies have quantified caffeine content by country or market, but the relationship between co-ingredient levels and caffeine remains largely unexamined. Cross-sectional analyses from Brazil and Croatia have documented discrepancies between declared and analytically determined caffeine and taurine concentrations [4,5], and German surveillance by NMR spectroscopy found average caffeine at 0.30 g/L against a 0.32 g/L maximum [6]; none addressed co-ingredient stoichiometry across the category. The recurring concentrations also stand close to limits in force; several jurisdictions cap caffeine and one sets a taurine concentration ceiling, yet the distribution of observed concentrations relative to those limits has not been described against product-level data spanning regulated and unregulated markets together. Whether co-ingredient concentrations stand in a fixed relation to caffeine has not been described across markets, and single-agent evaluation does not address the combination [7,8]. Nationally representative intake data show that energy drinks contribute little to total adult caffeine intake at population level [9], which does not address whether individual-product co-exposure differs from what independent evaluation assumes.

Every label-based caffeine exposure assessment inherits the completeness of the declaration. The EU requires beverages containing more than 150 mg/L caffeine from any source to bear a “high caffeine content” warning and to state the amount [3], and the compositional limits in force in Australia, Canada and Germany are likewise defined on total caffeine. These provisions require the declared value to account for botanical sources such as guarana (*Paullinia cupana*) and green tea extract [10]. Analytical studies have found label-declared and measured caffeine to differ by up to 15% [11,12], and more recent work indicates that unlabeled ready-to-drink beverages may deliver doses exceeding recommended thresholds [13]. How much a label states about a co-ingredient is not uniform either: a quantitative declaration is mandatory in some jurisdictions, threshold-triggered in others, and voluntary elsewhere, so what a reader can establish about composition depends on where a product is sold. Whether that variation is systematic, and how much of the category it leaves unquantified, has not been described across markets.

This study determines whether the recurring caffeine and taurine concentrations of the category are set product by product or held at the level of the market, and whether the ratio they form is maintained within products. It quantifies how often a declared co-ingredient has no stated amount, what governs whether it does, and expresses caffeine exposure in a form independent of container size. It also locates the recurring concentrations relative to the compositional limits in force, in markets that legislate those values and in markets that do not.

2. Materials and Methods

2.1. Study Design

Cross-sectional survey of label-declared composition for 532 commercially available RTD energy drinks in eleven countries (Australia, Canada, Czech Republic, France, Germany, Italy, Japan, Korea, Spain, United Kingdom, United States), collected in 2026. Products were included if marketed as energy drinks by their manufacturer, sold in a conventional ready-to-drink format, and carrying a declared caffeine content and container volume; products the manufacturer classifies as nutritional or tonic drinks, and single-shot formats, fall outside that definition. A record is a single product as offered in one market: a distinct combination of brand, product name, and market, each carrying one container volume. Flavors, editions, and sugar-free versions were recorded as separate products, and a variant listed in more than one container size with the same declared concentration was retained once. A product sold in more than one market contributes one record per market, as the cross-market comparison requires. Collection proceeded in two stages. Records were first compiled from Open Food Facts and USDA FoodData Central. Each market was then validated against the official sites of the widest-distribution brands in that market and the online product listings serving it. Where compiled records disagreed with the manufacturer’s official site for that market, the label of the product as sold there was consulted through online product listings serving that market, and the value shown on that label was retained. Inclusion was conditional on published composition for the market in question. Brand coverage therefore varies, and is most complete for brands whose composition is published across markets. The 43 brands include the international lines present in most markets, and each market contributes between three and fourteen brands. Of the 67 brand-by-market cells contributing three or more products, 38 show no variation in caffeine concentration and the median within-cell spread is zero. Shares of the sample by product class are therefore not reported. Products offered only as parallel imports were not treated as belonging to the market listing them. All fields were extracted manually. English, Korean, and German sources were read directly by the authors; sources in other languages were read with machine translation, with numerical values and units taken directly from the source.

2.2. Compositional Variables

Caffeine concentration (mg/L) was recomputed for every product as the declared caffeine content divided by the container volume; no stored concentration value was used. Container volume is the declared net volume of the package as sold, and where a label declared a serving smaller than that volume, concentration was computed from the net volume, so that the value is a property of the beverage rather than of the advised serving. A product is counted as sitting at a nominal concentration when its computed value falls within 0.5 mg/L of it. Nine co-ingredients were recorded: non-nutritive constituents added for a claimed effect on alertness, performance, or energy metabolism, together with botanical extracts that themselves contribute caffeine. Vitamins, sweeteners, acidulants, and amino acids present as protein substrates fall outside that definition; taurine and arginine are included despite being amino acids, since they are added for a claimed functional effect rather than as a protein source. Co-ingredients were recorded in two fields: whether the label declares the ingredient (declared/checked and not declared/not ascertainable; the latter for a single product), and the amount, where stated. Where a label expressed that amount as a percentage of the finished beverage, the percentage was converted to mg per container using the container volume; taurine at 0.4% in 500 mL is 2000 mg, or 4000 mg/L. A blank amount against a declared ingredient is a label observation, not a missing value. The taurine-to-caffeine mass ratio was computed within the container. A botanical caffeine indicator was set where guarana or green tea extract was declared.

2.3. Exposure Metric

Required volume (mL) = reference dose (mg) / caffeine concentration (mg/L) $\times$ 1000, evaluated for body weights of 40 and 55 kg, which approximate median body weights at 12 and 15 years in the WHO growth reference for children and adolescents aged 5–19 years, and across 30–70 kg in a sensitivity analysis, at 3 mg/kg (EFSA's single-dose level of no safety concern, derived for adults and considered applicable to children and adolescents) and at 2.5 mg/kg/day (the Korean MFDS advisory maximum for children and adolescents), and at 400 mg for adults [1]. The 500 mL reference serving is a fixed scenario volume, not a market property. No consumption data are used: the calculation states the volume at which a reference value would be reached, not the volume consumed.

2.4. Regulatory Context Variable

Markets were classified by whether a binding limit on caffeine concentration is in force. This classification is a descriptive stratum defined by the instrument identified for each market, not an equivalence claim between instruments, and no comparison in this study estimates a regulatory effect. The four markets with identified caffeine limits were Australia (145–320 mg/L; Food Standards Code Standard 2.6.4), Canada ($\leq$ 400 mg/L and $\leq$ 180 mg per serving; Division 29, Food and Drug Regulations), Germany ($\leq$ 320 mg/L; Fruchtsaft- und Erfrischungsgetränkeverordnung §5 with Anlage 8) and Italy ($\leq$ 320 mg/L; Circolare del Ministero della Salute, 3 April 1998, n. 5). In Australia, Canada, and Germany, the limit is expressly defined as total caffeine from all sources, including botanical caffeine. For the markets without an identified caffeine limit, national legal databases were searched in the national language; the United Kingdom, Spain, the Czech Republic, and Korea state the absence in regulatory guidance, and the United States provision at 21 CFR 182.1180 applies to cola-type beverages only. Taurine provisions were recorded separately. Germany sets a fixed concentration ceiling of 4000 mg/L. The Italian circular of 1998 names 320 mg/L caffeine and 4 g/L taurine in the same clause and is permissive; the taurine figure is recorded on the same footing as the caffeine figure, not as a ceiling. Canada sets a maximum of 2000 mg per serving of stated size, covering added and naturally occurring sources. Australia constrains no concentration: its permitted amount of 2000 mg applies to the one-day quantity the label advises, and therefore bounds the intake a product may recommend; it places no limit on the concentration at which taurine may be present. The Italian 1000 mg maximum daily intake for taurine applies to food supplements, not beverage composition. No taurine provision was identified in the remaining seven markets. Markets were classified in parallel by labeling regime: mandatory quantitative, where a declared co-ingredient must carry an amount; high-caffeine threshold labeling, where a quantitative declaration follows from the EU high-caffeine provision (Regulation (EU) No 1169/2011, Annex III); and voluntary, where no instrument requiring an amount was identified.

2.5. Statistical Analysis

Dispersion between groups is compared with the Brown–Forsythe test. Association between disclosure and labeling regime was tested by chi-square with Yates correction and ϕ as effect size, and monotonic association between continuous quantities by Spearman rank correlation. Unadjusted *p*-values in the Results are reported as descriptive. For the two principal comparisons, a brand-cluster bootstrap was run in addition: the 43 brands were

resampled with replacement 2000 times and a percentile confidence interval taken across resamples. The clustering of taurine-to-caffeine ratios was tested by re-pairing caffeine and taurine values at random among products declaring both, under three nulls: unrestricted, permuting within markets, and restricted to the strata in which taurine varies. No seed was fixed, so resampling results carry Monte Carlo error; Monte Carlo *p*-values are computed as $(b + 1)/(B + 1)$ over $B = 10,000$ resamples. No correction for multiple testing was applied, since the unadjusted *p*-values are not used inferentially; the bootstrap intervals, which treat the brand as the sampling unit, are the inferential results. A blank amount against a declared ingredient is treated as an observation rather than a missing value and is not imputed, and no other field was imputed. Analyses were conducted in Python 3.13 (pandas 2.2.3, NumPy 2.1.3, SciPy 1.16.3).

3. Results

3.1. Caffeine Distribution by Market

The descriptive profile by market is presented in Table 1. Caffeine medians cluster near 320 mg/L in most European markets and Australia, while Canada, Japan, and the United States show substantially higher medians.

Table 1. Caffeine concentration by market ($n = 532$). Brands contributing counts in this sample.

Country	Products	Brands Contributing	Caffeine, mg/L (Median, IQR)	Range (Min–Max)	Compositional Limit (mg/L)
Korea	27	4	282 (250–282)	225–282	None identified
Australia	48	8	310 (300–320)	150–320	145–320
France	16	4	320 (320–320)	200–320	None identified
Czech Republic	23	4	320 (320–320)	200–320	None identified
Italy	29	4	320 (300–320)	300–321	≤ 320
Germany	51	7	320 (300–320)	220–320	≤ 320
Spain	17	4	320 (320–320)	300–320	None identified
UK	76	13	320 (300–400)	70–563	None identified
Japan	38	3	375 (219–400)	150–400	None identified
Canada	82	11	378 (349–394)	233–394	≤ 400 ; $\leq 180/\text{serving}$
USA	125	14	423 (321–563)	188–634	None identified

Caffeine medians differ across regulatory categories: 318.1 mg/L in markets with a concentration limit, 378.4 mg/L in the single market carrying both a concentration and a per-serving limit (Canada), and 320 mg/L in markets with no identified limit. One Italian product exceeds its limit, at 321.1 mg/L, or 0.35% above it. Brown–Forsythe $W = 43.2$ ($p = 4.1 \times 10^{-18}$) indicates that regulation is associated with narrower dispersion. Among the European markets, convergence on 320 mg/L is nonetheless tightest where no limit was identified. Spain records 94% of products within ± 0.5 mg/L of 320, France 88% and Czech Republic 87%, against 55% in Italy, 55% in Germany and 27% in Australia, where a limit is in force. Pooled across these six markets, which share an EU labeling regime and much of their brand roster, the contrast is 89.3% against 44.5%, a difference of 44.8 percentage points. The contrast is a within-Europe one: taken over all eleven markets, 25.8% of products sit at 320 mg/L where no limit was identified against 31.0% where one is in force, since that first category also contains Japan, Korea, the United Kingdom and the United States, whose distributions are wider. The contrast persists when the brand is treated as the sampling unit. Over 2000 brand resamples, the 95% bootstrap interval runs from 20.8 to 69.4 points, and no resample returned a difference of zero or less.

3.2. Taurine–Caffeine Proportionality

Taurine is the most frequently declared co-ingredient, present in 68% of products. The analysis is conditional on a declared taurine value: 273 of 532 products (51%) provide one. That subset is unevenly distributed: no Japanese product states a taurine amount, and five do so in the United States, while the European markets state one for most declaring products, so the taurine results characterize the products and markets in which taurine is quantified. Among the 273 with a stated taurine content, 167 declare exactly 4000 mg/L and 112 of those combine it with a caffeine concentration within 0.5 mg/L of 320. The pooled taurine-to-caffeine mass ratio has a median of 12.50, and 65.6% of products (179 of 273) fall within ± 1.5 of this value (Table 2). The 12.5:1 ratio is arithmetically equivalent to the quotient of the two modal concentrations ($4000/320 = 12.5$). Under an unrestricted permutation null, a mean of 141.2 products (51.7%) fell within the ± 1.5 band, against the observed 179 (65.6%); $p < 0.001$. Permuting only within markets raises the null to 166.3 products (60.9%), with the observed 179 still above it ($p = 0.0002$). Approximately 9.2 of the 13.9-percentage-point excess produced by the unrestricted null is therefore attributable to between-market heterogeneity, and 4.7 points survive stratification by market; restricting the comparison to the strata in which taurine varies leaves a comparable excess (58.0% observed against 51.9%, $p = 0.0002$). Figure 1 shows the joint

distribution of the two concentrations. A brand within a market generally holds a single taurine concentration: 205 of the 273 products (75%) fall in brand-by-market strata in which taurine takes one value.

Table 2. Taurine-to-caffeine mass ratio by market among the 273 products with a stated taurine content. No Japanese product in the analysis set states a taurine amount.

Market	n (Stated Taurine)	At 4000 mg/L, n (%)	Ratio within 12.5 ± 1.5, %
Spain	17	17 (100)	100
Italy	28	28 (100)	100
France	16	16 (100)	88
Czech Republic	18	17 (94)	94
Germany	27	19 (70)	70
Australia	41	26 (63)	63
UK	49	30 (61)	61
Korea	16	6 (38)	0
Canada	56	8 (14)	50
USA	5	0 (0)	0

Of the 167 declarations at 4000 mg/L, 120 (72%) come from outside the two markets naming a fixed taurine concentration, and 86 (51%) from the seven markets in which no taurine maximum of either kind was identified (Table 2). The comparison does not run in one direction for taurine as it does for caffeine: Italy, which names the concentration, declares it in every product with a stated value, the highest rate in the sample, while Germany, which sets it as a ceiling, does so in 70%. Two within-brand exceptions were recorded: Monster Ultra Peachy in Germany declares caffeine at 30 mg/100 mL (300 mg/L) and Monster Juiced Mango Loco in France at 21 mg/100 mL (210 mg/L). Both declare taurine at 4000 mg/L, so the difference is in the caffeine value; in the French product, it gives a taurine-to-caffeine ratio of 19 rather than 12.5. Table 3 shows the relationship between label regime and the availability of a stated taurine value. The threshold regime requires a quantitative caffeine declaration above 150 mg/L but imposes no corresponding requirement on taurine, so the grouping indexes disclosure practice rather than an obligation for taurine. The United States and Japan comprise a third of the sample and contribute five of the 273 products with a stated taurine value.

Table 3. Stated taurine availability by label regime.

Label Regime	Products (n)	With Stated Taurine (n)	With Stated Taurine (%)
Mandatory quantitative	130	97	74.6
High-caffeine threshold labeling (>150 mg/L)	239	171	71.5
Voluntary/industry (US, JP)	163	5	3.1

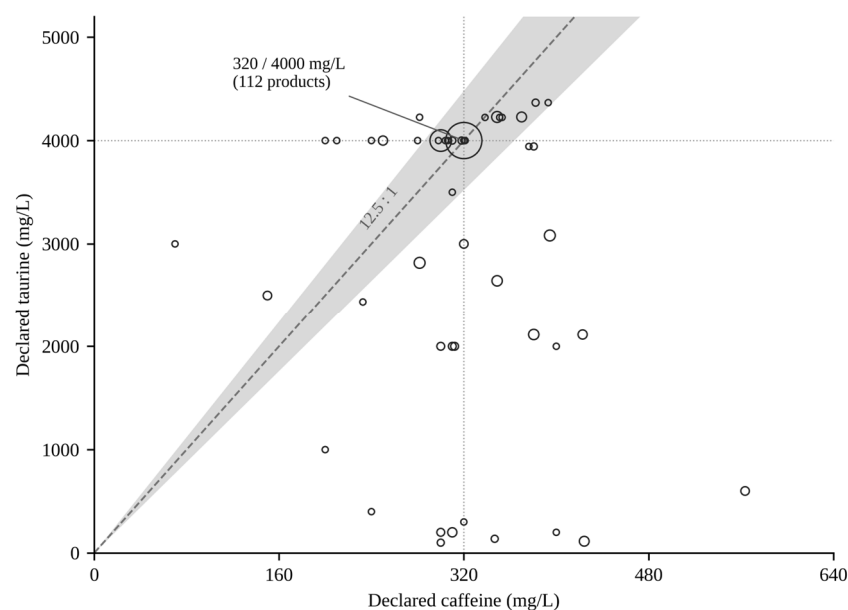


Figure 1. Declared caffeine and taurine concentrations in the 273 products stating a taurine amount. Marker area is proportional to the number of coincident products; the dashed line is a 12.5:1 taurine-to-caffeine ratio, and the shaded band is the ±1.5 tolerance used in the text.

3.3. Exposure

Expressed as volume-to-reference, 3 mg/kg is reached at 426 mL of the median Korean product and at 284 mL of the median US product for a 40 kg adolescent, and at 189 mL of the most concentrated product in the sample; the same reference requires 586 and 390 mL at 55 kg, so the volume that reaches the reference level scales with body weight while the container does not. Against the Korean MFDS advisory maximum of 2.5 mg/kg/day for children and adolescents, the corresponding 40 kg volumes are 355, 236, and 158 mL. At the reference 500 mL serving, 495 of the 532 products (93.0%) deliver more than 3 mg/kg to a 40 kg adolescent, and 57 (10.7%) deliver at least twice that level; the median product exceeds 3 mg/kg in all eleven markets, Korea included, since $426 \text{ mL} < 500 \text{ mL}$; the delivered dose runs from 3.5 mg/kg for the median Korean product to 5.3 mg/kg for the median US product, and reaches 7.9 mg/kg for the most concentrated product. At 55 kg, the same serving falls below the reference level in the European markets, Korea and Australia, while remaining above it in Japan, Canada and the United States. For an adult, 946 mL of the median US product and 1250 mL of the median European product reach the EFSA habitual-intake reference of 400 mg/day, which is expressed per person rather than per kilogram of body weight [1]. This metric depends only on concentration and is therefore independent of the container size at which a product was recorded. Across 30–70 kg, the volume of the modal 320 mg/L product required to reach 3 mg/kg runs from 281 to 656 mL, so a 500 mL serving reaches the reference level below 53 kg and falls below it above that weight; for the most concentrated product in the sample, the corresponding range is 142 to 331 mL.

3.4. Quantitative Disclosure of Co-Ingredients

Of the nine co-ingredients recorded, most declarations state the ingredient without stating how much of it a product contains. Of the 1364 co-ingredient declarations recorded, 834 (61.1%) include no figure, and of the 480 products declaring at least one co-ingredient, 168 (35.0%) quantify none. Quantification rates differ widely by ingredient, from 75.0% for taurine to 13.6% for D-glucuronolactone and 0.9% for green tea extract (Table 4). Where a product falls on that scale tracks the labeling regime under which it is sold. Among products declaring at least one co-ingredient, 82.7% (110 of 133) quantify none under voluntary labeling, against 21.1% (26 of 123) under mandatory quantitative declaration and 14.3% (32 of 224) under the EU threshold regime. Contrasting the voluntary regime with the two mandatory regimes combined gives $\chi^2 = 181.2$, $p = 2.7 \times 10^{-41}$, $\phi = 0.614$ with Yates correction. The extremes are the United States, where 94.7% of declaring products (90 of 95) state no co-ingredient amount at all, and France, Spain, and the Czech Republic, where every declaring product states at least one. The contrast between the voluntary regime and the other two survives brand clustering: across 2000 brand resamples, the 66.0-point gap has a 95% interval of 29.1 to 87.5 points, with 0.1% of resamples at or below zero. Caffeine-bearing botanicals are quantified in 22.5% of declarations (67 of 298), a rate that falls within the range spanned by the non-caffeine co-ingredients, so the shortfall is not specific to botanical caffeine sources. D-glucuronolactone is declared in 110 products and quantified in 15, a lower rate than any other non-botanical constituent declared in more than 100 products. Figure 2 shows how that shortfall is distributed across markets.

A total of 259 of 532 products (49%) declare guarana or green tea extract. Guarana is quantified in 66 of 189 declarations; green tea extract in 1 of 109. Quantified guarana content has a median of 20 mg/L and an upper quartile of 100 mg/L; only 8 of the 66 quantified declarations exceed 500 mg/L, and the maximum of 2000 mg/L derives from a single French brand line (five flavor variants each declaring 500 mg per 250 mL). Green tea extract has no comparable distribution: with one quantified declaration in 109, no median, tail, or maximum can be computed, and it supplies 108 of the 231 botanical declarations that carry no figure at all.

Table 4. Quantitative disclosure by co-ingredient. Rates are per declaration on the 532-product analysis set.

Co-Ingredient	Declarations (n)	Amount Stated (n)	Amount Stated (%)
Taurine	364	273	75.0
Arginine	46	25	54.3
Ginseng	174	70	40.2
Guarana	189	66	34.9
Carnitine	124	41	33.1
Inositol	223	38	17.0
D-glucuronolactone	110	15	13.6
Ginger	25	1	4.0
Green tea extract	109	1	0.9
All co-ingredients	1364	530	38.9

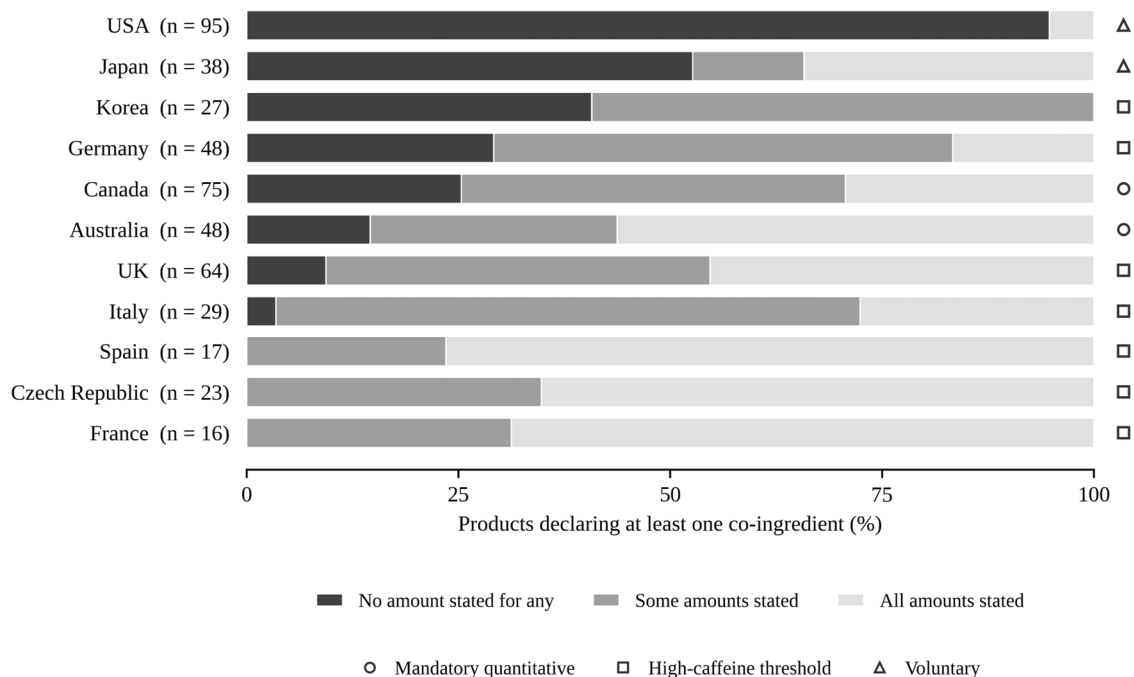


Figure 2. Quantitative disclosure of co-ingredient amounts by market, among the 480 products declaring at least one co-ingredient. Bars give the share of those products stating no amount for any declared co-ingredient, an amount for some, and an amount for all. Markers to the right of each bar denote the labeling regime: ○ mandatory quantitative, □ high-caffeine threshold, Δ voluntary.

3.5. Within-Product Comparison across Markets

Eight products were matched across four or more markets, all from two brands, with a median cross-market spread of 118.3 mg/L. Across the broader set of 54 products matched in two or more markets, the median spread is 56.4 mg/L, and 42 differ by more than 5 mg/L. Red Bull Original holds 320 mg/L in seven of the nine markets in which it was matched, departing only in Korea (250 mg/L) and the United Kingdom (300 mg/L), whereas matched Monster products range from 280 mg/L in Australia to 400 mg/L in Japan.

4. Discussion

Caffeine and taurine behave as market-level constants, not product-level formulation targets. The 4000 mg/L taurine and 320 mg/L caffeine pair describe the modal product across markets that differ in law, taste, and brand mix, and three features of the data place that pairing at that level. Reshuffling the two values within a market removes most of the apparent clustering. A brand within a single market generally declares a single taurine value across its products, leaving little product-to-product variation to explain. The two concentrations are effectively uncorrelated (Spearman $\rho = -0.02$, $p = 0.70$), with caffeine the less variable of the pair (CV 0.17 against 0.35), as two separately held constants would produce. Existing descriptions of the category report the two typical values separately [1], and these data are consistent with that reading: the 12.5:1 quotient the pair generates behaves as an arithmetic consequence of two co-occurring modes and not as a specification held within products. The present data identify the market as the level at which each recurring concentration is maintained, though not in every market, since brand medians span 192 to 634 mg/L in the United States and 188 to 400 mg/L in Japan while all four contributing brands sit at 320 mg/L in Spain and the Czech Republic; earlier cross-sectional surveys in Ireland and the UK documented comparable caffeine concentrations without examining co-ingredient stoichiometry [14].

Both concentrations coincide with values named in instruments applying to part of the sample: 320 mg/L is the caffeine ceiling in force in Australia, Germany and Italy and the figure named in the French industry code, and 4000 mg/L is Germany's statutory taurine ceiling and the concentration named in the same Italian circular. The distribution of each value across markets does not follow the distribution of the instruments naming it. Caffeine sits at 320 mg/L far more often in Spain, France and the Czech Republic, where no limit was identified, than in Australia, Germany and Italy, where one is in force, partly because Australia and Germany define their limit on total caffeine from all sources, so a product carrying a botanical source must leave headroom below it. Taurine

shows no such inversion: Italy, whose circular names 4000 mg/L, declares it in every product with a stated amount, and Germany, whose statute sets it as a ceiling, in 70% of products. Whether the recurring values originated in those instruments or were codified by them is not something a cross-section can settle. A ceiling adopted in one large market supplies a specification that a manufacturer can apply across its entire range, which would place the value in markets that never legislated it. The reverse order is equally consistent with the data: Red Bull's original 250 mL formulation already contained 320 mg/L caffeine and 4000 mg/L taurine, and the Italian circular was issued after the European Commission opened an infringement procedure and named the composition of products already in circulation, placing an administrative figure downstream of a formulation. Neither account changes the level at which the values are held. The same products matched across four or more markets, with brand and flavor held constant, differ by a median of 118 mg/L, so the pattern is not an artifact of the sampling frame.

Nearly half of products declare a botanical caffeine source, and more than a third declare one without stating its amount. Australia, Canada, Germany, and the EU markets define their caffeine limit or labeling threshold on caffeine from all sources, so in those markets the declared value is required to account for the botanical contribution, but the label offers no way to confirm that it does. A product declaring 320 mg/L while listing green tea extract without an amount may deliver that figure or more, and the label does not distinguish the two cases. Whether the declared value fully reflects what a product delivers therefore varies by market. The size of that gap is bounded by the declarations that do carry a figure. Guarana seed contains 2.5–6% caffeine by mass [15]. At the median stated guarana content of 20 mg/L, the unstated caffeine is 0.5–1.2 mg/L, negligible against a 320 mg/L declaration; at the maximum of 2000 mg/L, it is 50–120 mg/L, an increment of 16–37%. Only 8 of the 66 quantified guarana declarations exceed 500 mg/L, so discrepancies are concentrated in a small number of products. This differs from manufacturing tolerance, which analytical studies in Brazil [12], Serbia [16], and Saudi Arabia [17] place at ± 5 –15% of the declared value and which is bidirectional in sign. The label data locate the gap. Of the 231 botanical declarations carrying no figure, 108 are green tea extract, for which no upper bound can be placed at all; the remainder are guarana, for which the quantified distribution supplies one. An HPLC survey of a few dozen products drawn from that upper tail, stratified by botanical content and market, would establish whether the declared caffeine value is a reliable proxy for measured total caffeine.

Whether a label states a co-ingredient amount depends on the market in which the product is sold, not the ingredient. Under voluntary labeling, more than four-fifths of declaring products state no co-ingredient amount at all, against roughly one in five and one in seven under the two mandatory regimes, a 66-percentage-point contrast that survives brand clustering. Caffeine-bearing botanicals are not a special case: at 22.5% quantified, they sit within the range the non-caffeine co-ingredients span, from 75.0% for taurine down to 0.9% for green tea extract. Cross-market surveys of energy drink ingredients have reported the prevalence and amounts of individual constituents without examining that relationship [18]. D-glucuronolactone, whose quantification rate is the lowest of any non-botanical constituent declared in more than 100 products, is also the constituent for which a margin-of-safety problem has actually been identified: the exposure assessment cited above finds a margin of safety below the conventional threshold of 100 for a 40 kg consumer at every serving size it examined, and at or above it for heavier consumers only when intake is held to 250 mL [19]. The constituent whose safety margin is narrowest is therefore the one whose amount is least often available on the label, and the products in which it is least often stated are those sold under voluntary labeling. Green tea extract raises the same disclosure problem against a different safety threshold. Its principal catechin, epigallocatechin-3-gallate (EGCG), occurs at higher concentration in extracts than in infusions, and EFSA concluded that intakes at or above 800 mg EGCG per day taken as a food supplement produce a statistically significant rise in serum transaminases, without being able to identify a safe level below it [20]; the European Commission subsequently restricted an individual portion of a food to less than 800 mg EGCG [21]. EFSA also recommended that green tea products state their catechin content and the proportion of EGCG. The restriction excludes aqueous green tea extracts whose composition after reconstitution in a beverage is comparable to a traditional infusion, so whether it reaches a given ready-to-drink product depends on the extract used, its EGCG content, and the serving conditions, none of which the labels surveyed here state. Where it does apply, the label is required to state the EGCG content per portion, and no label in this sample does; the single quantified declaration is 100 mg/L of extract. Neither constituent bears on whether the declared caffeine value is complete. Both illustrate a different limit: where an amount is not stated, the label gives no basis for applying an exposure assessed elsewhere to the product in front of the reader.

Because the modal caffeine concentration is held constant within a market, intake at that concentration varies with the volume consumed, not with the product selected. That has a specific consequence in adolescents, because the reference level scales with body weight and the container does not. At the modal 320 mg/L, a 40 kg adolescent reaches 3 mg/kg at 375 mL and a 55 kg adolescent at 516 mL, so a 250 mL container delivers 2.0 mg/kg to the lighter of the two and a 500 mL container 4.0 mg/kg, 33% above EFSA's adult-derived level of no safety concern

in that scenario [1]. The median product exceeds that level at a 500 mL serving in all eleven markets, as do 93% of the individual products surveyed, and it does so at the category's modal specification, well short of its extreme. Recent *in vitro* bioavailability data indicate that 52–76% of caffeine in energy drinks is absorbed intestinally [22]. The reference level is expressed on an intake basis, so this bears on internal dose and does not offset the comparison above.

Three qualifications bear on that arithmetic. The exceedance sits at the ceiling, not above it: a concentration ceiling truncates the upper tail without moving the center, and 320 mg/L is both the limit in force in four markets and the modal value where none is set, so it occurs at the concentration those limits permit; at the upper end of the distribution the most concentrated product delivers 3 mg/kg to a 40 kg adolescent in 189 mL. Label data do not fix its upper bound, since the unstated botanical contribution is negligible for the median declaring product but reaches 50–120 mg/L on the upper tail of quantified guarana content, which would place a 320 mg/L declaration at 370–440 mg/L and a 500 mL serving at 4.6–5.5 mg/kg; for the 231 botanical declarations carrying no figure, it is bounded only by the range of the category. And the reference level itself is derived from adult data, while adolescents show amplified sympathetic responses to caffeine [23], the developing brain is differentially sensitive to caffeine and taurine [24,25], and rodent work reports sex-specific cognitive effects of adolescent taurine supplementation at doses that do not map onto beverage exposure [26]. National surveys place the same threshold in a consumption context: an Icelandic study of 10,358 adolescents found energy drink consumers 6–7 times more likely to exceed it, with intake above 3 mg/kg associated with a 4.5-fold higher prevalence of sleeping under six hours [27]; the German EsKiMo II survey found 2.2% of 12–17-year-olds exceeding it from energy drinks alone [28]; and 46% of US caffeine overdoses reported in 2007 occurred in those under 19 [29].

Taurine exposure has been assessed separately from caffeine, and it turns on volume rather than concentration. EFSA derived a daily reference intake of 1400 mg taurine for a 70 kg adult, and a later exposure assessment applying that reference across body weights found that 250 and 333 mL of a 4000 mg/L product keep a 40 kg consumer below it, whereas 500 mL delivers 2000 mg, 50 mg/kg, and exceeds it, as it does at 60 and 80 kg [19]. The taurine concentration recorded here is that same 4000 mg/L and does not vary with the caffeine concentration a product carries, so the volume relation established above for caffeine holds for taurine as well. In products whose stated taurine content falls within the ± 1.5 band, a consumer encountering caffeine from an energy drink encounters taurine at approximately a 12.5:1 ratio. That is a conditional co-exposure that holds in a third of the sample; it is not a property of the category, since half the products state no taurine amount at all, so the pattern is established only within the measurable subset.

Whether risk assessments that evaluate each compound separately describe the exposure that occurs in those products depends on whether the two interact pharmacologically. External evidence suggests they may, though it is narrower than often reported and does not establish the direction of any interaction. Caffeine is a non-selective antagonist at adenosine A1 and A2A receptors [30], and the resulting shift toward sympathetic drive has been measured in adolescents [23], while taurine modulates intracellular calcium handling and fast voltage-gated sodium channels [31], distinct targets that converge on cardiac repolarization. The most direct human evidence is a randomized controlled trial in which a single high-volume energy drink prolonged QTc and reduced insulin sensitivity, while caffeine alone raised blood pressure without prolonging QTc and taurine and glucuronolactone alone did neither; the authors could not attribute the effects to any single constituent [32]. Isolated whole-heart work is consistent with an effect of each compound but does not test the combination: the two were perfused in separate arms at micromolar concentrations, taurine showing a biphasic dose-response in which the higher concentrations provoked more ventricular arrhythmias [33,34]. Those perfusate concentrations are not the beverage concentrations reported here, and no published experiment has administered the two together at 12.5:1. The remaining evidence is indirect: caffeine with taurine raised contractile force in isolated human atrial myocardium more than caffeine alone, though not significantly [35]; and taurine potentiated caffeine-induced locomotor activity in mice through a nitric oxide-dependent pathway [36].

If these findings generalize *in vivo*, the 12.5:1 co-exposure would place caffeine and taurine together at a proportion at which their separately documented actions on cardiac repolarization coincide, a pharmacologically active combination that single-agent assessment does not evaluate. Assessing such combinations is routine in drug-drug interaction work but is not applied to beverage composition [7,8]. These data set the conditions under which that inference could be tested: the ratio, the concentrations, and the product subset, in adolescents, in whom the combination has yet to be studied.

The compositional limits in force bound the caffeine distribution from above: where a binding ceiling exists, the distribution is truncated, and where none was identified, dispersion is several times wider. Products press against the ceiling in all four markets that set one, but to varying degrees: 72.9% of Australian products lie within 5% of it, compared with 66.7% in Germany, 58.6% in Italy, and 50.0% in Canada. Canada is the only market with a per-serving limit and a concentration limit, and no Canadian product exceeded it: the highest declared content in

the Canadian sample is exactly 180 mg per container. The ceiling is nonetheless a poor predictor of where products actually sit, since convergence on 320 mg/L is tightest in the European markets where no limit was identified. The cross-sectional design leaves open what generates that convergence, and the policy consequences differ. If the statutes codify an existing convention, introducing a limit in a new market would not change the composition. If instead the convention is sustained by statutes that exist elsewhere, removing those limits could widen the distribution in markets that never had them, a risk these data cannot rule out.

The French caffeine tax (Code général des impôts art. 1613 bis A) set a 220 mg/L threshold, applied from 2014 and was repealed with effect from 1 January 2017; Carreño [37] describes the instrument at enactment. Regulatory commentary reports that manufacturers reformulated below the threshold in response, but no peer-reviewed source establishes it, and no such effect is claimed here. The present data, collected nine years after repeal, show French products clustering at 320 mg/L, the same level as in markets that never had the tax, consistent with the category-wide clustering at 320 mg/L described above rather than with residual legislation, although a cross-section does not separate the two. A UK monitoring survey found caffeine in energy drinks unchanged at approximately 315 mg/L across 2015–2017 while a fiscal instrument was reshaping other parts of the same formulations [38]; policy responses to energy drinks in Europe have otherwise centered on labeling and age-of-sale restrictions instead of composition [39], and no caffeine-specific levy was identified in force in any of the eleven markets sampled here. The present data provide a compositional description of that distribution and do not evaluate any of these instruments. Establishing the effect of any particular instrument would require composition data from before and after its introduction, which a cross-sectional design cannot provide.

Three boundaries define what these data support. The design establishes the distribution of label-declared values within the sampled products and the association between labeling regime and quantitative disclosure; it does not establish national market composition, does not identify the effect of any regulatory instrument, and does not establish delivered composition, since composition is taken as declared on product labels and those values are unverified against measurement. Taurine can be counted only where a label states it, a coverage limit imposed by the labeling regimes themselves rather than by sampling, so the ratio analysis rests largely on the European markets. The regulatory contrast is therefore reported as a market-level association rather than a brand-controlled estimate; the bootstrap intervals rather than the unadjusted *p*-values carry the inference; and a cross-section can locate a recurring concentration relative to an instrument without showing that the instrument placed it there, or that no unidentified standard applies. Each of these points to work that would settle it, and none requires a larger survey. Analytical assay of a few dozen botanical-bearing products would establish whether declared caffeine values are complete, most usefully for green tea extract, which supplies 108 of the 231 unquantified botanical declarations and admits no bound at all. Composition records from before and after a regulatory instrument would separate placement from codification. A controlled human study administering caffeine and taurine at 12.5:1 would establish whether the recurring pair has a combined effect. Each of those studies can be specified from the compositional map reported here.

5. Conclusions

This study examined the level at which recurring concentrations in the energy drink category are set, and whether label-declared composition across eleven markets with differing compositional and labeling regulations establishes the amounts that determine co-ingredient exposure. The category converged on a single caffeine concentration and a single taurine concentration; each is held at the level of the market, closely in several European markets but not in the United States or Japan. The two are held independently of one another, so the fixed ratio they appear to form is arithmetic rather than a formulation rule, and what a consumer receives is determined by the volume drunk rather than by the product chosen—at a 500 mL scenario serving size, the modal product delivers more caffeine per kilogram to a 40 kg adolescent than the adult-derived reference level of no safety concern. Label transparency follows the same structure: co-ingredient amounts are absent more often than they are given, and whether one appears depends on the labeling regime and not on the ingredient, most conspicuously for constituents with published safety thresholds. Treating regulated and unregulated markets in a single product-level dataset locates these values with respect to the law, and reading composition as a set of related quantities rather than a list of independent ones connects them to co-exposure. Because the values are declared rather than measured, the account is bounded, and analytical verification is the natural next step; where labeling rules do not require a co-ingredient amount, manufacturers and labeling authorities could close the same gap by stating one, without any further study.

Author Contributions

M.C.: conceptualization, investigation, data curation, formal analysis, visualization, writing—original draft preparation; A.A.: methodology, formal analysis, interpretation, writing—review and editing; H.L.: conceptualization, supervision, writing—review and editing; R.N.: methodology, validation, interpretation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The compositional dataset supporting this study's findings is available from the authors upon reasonable request. It comprises the 532-product analysis set, a ledger of the 23 records excluded at screening with their reasons, the log of cross-market product merges, and the documented per-country regulatory search. Source URLs and check dates are populated for a subset of records only, so independent re-checking of an individual record may require re-consulting the source listed at worksheet level. The Brown–Forsythe test was computed as Levene's test centered on the median, and the chi-square with Yates's continuity correction.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

AI-based tools were used to translate product labels and for language editing. The authors take full responsibility for the content.

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