# Up-to-date and comprehensive data on the evolving consumption patterns of energy drinks: in search of a nutrigenomics approach

P. Barciela[1], A. Perez-Vazquez[1], F. Mandim[2], A.O.S. Jorge[1, 3], A.G. Pereira[1, 4], M. Carpena[1], M. Carocho[4], S.A. Heleno[4, *], M.A. Prieto[1, *]

[1] Universidade de Vigo, Nutrition and Bromatology Group, Department of Analytical Chemistry and Food Science, Instituto de Agroecoloxía e Alimentación (IAA) – CITEXVI, 36310 Vigo, Spain.
[2] Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolonia, 5300-253 Bragança, Portugal.
[3] REQUIMTE/LAQV, Department of Chemical Sciences, Faculty of Pharmacy, University of Porto, R. Jorge Viterbo Ferreira 228, 4050-313 Porto, Portugal.
[4] Investigaciones Agroalimentarias Research Group, Galicia Sur Health Research Institute (IIS Galicia Sur). SERGAS-UVIGO.

*Corresponding author: S.A. Heleno (sheleno@ipb.pt); M.A. Prieto (mprieto@uvigo.es).

## 1. INTRODUCTION: An overview of energy drinks

Energy drinks (EDs) **have surged in popularity, now ranking as one of the fastest-growing segments in the beverage industry, trailing only bottled water (Figure 1)**. Widely consumed by the general public for their perceived benefits in enhancing performance, mood and alertness, EDs are particularly prevalent among European teenagers, with nearly 70% reporting use. However, **this rise in popularity is concerning due to the low nutritional quality of these stimulant-laden beverages and the lack of stringent regulations.** Previous studies have associated EDs with numerous health issues, including cardiac arrhythmias, gastrointestinal disturbances, and neurological problems such as anxiety and insomnia, exacerbated by high sugar content and substantial caffeine levels. **The presence of additional stimulants like taurine, carnitine, ginseng, and guarana further compounds these risks.**

**Research into genetic factors influencing individual responses to EDs and the potential benefits of nutrigenomics in optimizing consumption and mitigating health risks is ongoing.** Given these concerns, there is a pressing need for more research and safer alternatives. This research aims to provide updated and comprehensive data on the evolving patterns of EDs use to support the development of targeted interventions and policies. **Hence, a systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, searching PubMed and ScienceDirect using the terms "epidemiology" or "prevalence" and "energy drink" without limiting the year published.**

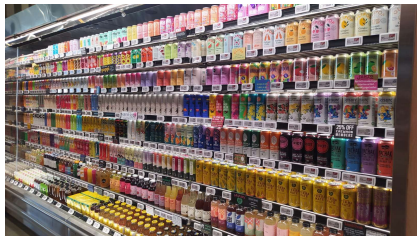

Figure 1. Variety of EDs on supermarket shelves.

### 1. 1. Synergies and antagonisms between constituents of energy drinks

**Foods and beverages often exhibit synergistic effects where the combined action of ingredients differs from their individual effects.** Caffeine, a stimulant, enhances endurance, while taurine is linked to various physiological functions and debated ergogenic effects. A study on 20 professional boxers showed that a combination of 3 g taurine and 6 mg/kg caffeine improved agility and cognitive performance more than either alone. Additionally, taurine may mitigate caffeine's cardiovascular effects and together, they can reduce platelet activity and prolong clot formation. In another study in *Drosophila melanogaster*, high taurine ratios promoted sleep, whereas low ratios inhibited it more than caffeine alone.

## 2. The impact of energy drinks on human health and well-being

The results from the **Table 1** highlights notable adverse effects associated with EDs. Caffeine and taurine have been shown to provoke ventricular arrhythmias in acute studies. Long-term consumption of EDs is linked to an increased risk of depression. In gastrointestinal studies, EDs can reverse gastric dysplasia when consumption is stopped. Metabolic studies indicate that EDs, whether standard or sugar-free, can induce insulin resistance. Renal studies reveal that EDs affect blood urea nitrogen, serum creatinine, sodium, potassium levels, and cause kidney tissue damage. Additionally, chronic ED consumption negatively impacts both the exocrine and endocrine functions of the pancreas.

Table 1. Detailed review of studies on energy drink consumption: types of trials, demographic, pre-existing conditions and findings. NS: Not specified; NA: Not applicable.

| Trials type | Object of the study | Sample (n) | Age | Subject | Race | Medical history | Period (days) | Findings |
|---|---|---|---|---|---|---|---|---|
| **Cardiovascular effects** | | | | | | | | |
| Whole-heart model | Acute electrophysiologic effects of caffeine and taurine | 25 | NS | Rabbit | NA | No | NA | Ventricular arrhythmias were provoked |
| **Neurological effects** | | | | | | | | |
| Cohort study | Effect of. EDs in depression | 80497 | 40-74 | Male and female | Asian | No | 1825 | Sugary and caffeinated drinks may boost depression risk |
| **Gastrointestinal effects** | | | | | | | | |
| Patient with 2 types of abdominal pain | Effect of1-2 EDs consumption | 1 | 34 | Female | Hispanic | No | 5475 | Gastric dysplasia was reversed by stopping consumption of EDs |
| **Metabolic and endocrine effects** | | | | | | | | |
| *in vivo* study | Effect of EDs in the metabolic syndrome | 60 | NA | Male mice | NA | No | 91 | EDs consumption in the standard and sugar-free forms induces insulin resistance |
| **Renal and hepatic effects** | | | | | | | | |
| *in vivo* study | Effect of EDs in kidney | 32 | NA | Male rats | NA | Yes | 15 | EDs affect BUN, serum. Creatinine, NA, K, and damage kidney tissue |
| **Liver and pancreas effects** | | | | | | | | |
| *in vivo* study | Effect of EDs in pancreas | 40 | NA | Male rats | NA | No | 28 | Chronic ingestion of EDs provokes a negative impact on the integrity of exocrine and endocrine portions in pancreas |

## 3. Interaction with other stimulants (alcohol, drugs, and others)

– EDs can alter drug effects due to caffeine and taurine.
– Excessive consumption may cause tachycardia, vomiting, and seizures, worsened by certain medications.
– Caffeine interacts with drugs like fluvoxamine, potentially increasing side effects. Combining EDs with stimulants (e.g., Adderall) can lead to serotonin syndrome.
– EDs may worsen psychiatric symptoms like anxiety and insomnia.
– Mixing EDs with cannabis could impact adolescent brain development.
– Awareness and dosage adjustments are vital to prevent health risks.

## 4. Nutrigenomic approaches to energy drink consumption

**Nutrigenomics:**
– Studies gene-diet interactions and their effects on health.
– Nutrigenetics focuses on gene influence on nutrient response.

**Genetic markers and EDs:**
– Identifies genetic markers for optimizing ED use in athletes.
– CYP1A2 gene affects caffeine metabolism; ADORA2A gene affects caffeine sensitivity.

**Athletic performance:**
– Caffeine improves performance regardless of genetic differences.

**Sugar content and genetics:**
– Examines genetic predisposition to obesity and metabolic diseases from EDs.

**Ethical considerations:**
– Challenges include low awareness, insufficient training, and need for reliable testing.
– Emphasizes ethical practices and protecting consumer rights in genetic testing.

**Precision nutrition:**
– Uses genetic information for personalized nutrition to reduce ED-related health risks.

## 5. Current state of energy drink regulation and oversight worldwide

EDs are subject to different regulatory frameworks around the world. Understanding these regulations is critical for manufacturers and marketers seeking to effectively navigate the global ED market. **Table 2** explores this topic in more detail, covering key individual countries.
The review of EDs legislation in different regions shows a varied approach to regulating consumption, especially among minors. While some regions such as the European Union (EU) and some areas of the United States (EEUU) have implemented stricter bans on the sale and marketing of these drinks to minors, others such as Canada and China allow their sale but restrict their promotion and consumption in school settings. **This highlights the lack of global consensus and the need for more uniform and stringent regulation to protect consumers, especially young people, from the potential adverse effects of EDs.**

Table 2. Energy drink specifications from several of the major food regulatory agencies around the world. CFIA: Canadian Food Inspection Agency; FSANZ: Food Standards Australia New Zealand; EFSA: European Food Safety Authority; FDA: Food and Drug Administration; NHC: National Health Commission. NS: Not specified.

| Country/ Region | Food Authority | Caffeine amounts | Sale to minors | Marketing to minors | Sales in schools | Labelling | Other regulations |
|---|---|---|---|---|---|---|---|
| Canada | CFIA | Maximum 180 mg per serving | Allowed | Banned | Banned | "High caffeine content" warning | Regulated amounts of ingredients |
| Australia | FSANZ | Maximum 32 mg per 100 mL | Allowed | Banned | Allowed | Cautionary statements mandatory | NS |
| UE | EFSA | NS | Banned | Banned | Banned in some countries | "High caffeine content" warning | Regulated amounts of additives |
| EEUU | FDA | Variable | Banned | Banned | Banned in some states | Cautionary statements mandatory | NS |
| China | NHC | NS | Allowed | Banned | Banned | Cautionary statements mandatory | NS |

## Conclusions

1. The surge in ED consumption, particularly among teenagers, poses significant health risks due to high caffeine, sugar, and stimulant levels.
2. Research links EDs to serious cardiovascular, gastrointestinal, and neurological issues.
3. The current regulatory framework is inadequate to address these risks effectively.
4. There is an urgent need for comprehensive research and development of safer alternatives to protect public health.

**Acknowledgments.** The research leading to these results was supported by MICINN supporting the Ramón y Cajal grant for.A. Prieto (RYC-2017-22891), by Xunta de Galicia for supporting the post-doctoral grant of A.G. Pereira (IN606B-2024/011), and the pre-doctoral grants of M. Carpena (ED481A 2021/313); and P. Barciela (ED481A-2024-230). The authors are grateful to the National funding by FCT, Foundation for Science and Technology, through the individual research grants for the individual research grants of A.O.S. Jorge (2023.00981.BD).