Original Article

THE PH OF NON-ALCOHOLIC BEVERAGES MARKETED IN PERU: AN EROSION POTENTIAL ANALYSIS

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ABSTRACT

This study aimed to determine the potential of hydrogen (pH) of non-alcoholic beverages (NABs) marketed in Peru. This was a descriptive cross-sectional study including a sample of 83 brands of NABs obtained in triplicate (249 containers) of regional (21.7%; 12 cities), national (47%), and international (31.3%; 14 countries) origin distributed into 10 types (sparkling water, flavored water, tonic water, energy, light/zero soda, regular soda, hydrating, non-natural fruit juice, prepared soft drinks, and tea-based beverages). The mean of triplicate pH measurements was classified according to the erosion potential (EP): no (≥6), minimum (4-<6), medium (3-<4), and extreme (<3). Analysis of variance and chi-square statistical tests were used with $p<0.05$. The NABs had a pH of 3.31±0.71 (range: 2.16 in regular soda of national origin to 5.74 in sparkling water of international origin) and a medium (50.6%), extreme (37.3%), and minimum (12%) EP. The pH from lowest to highest values was tonic water (2.62±0.16), flavored water, energy, regular/light soda, hydrating and tea-based (3.16±0.48), prepared soft drinks (3.41±0.43), and sparkling water (4.59±1.13) ($p<0.001$). A minimum EP was associated with sparkling water (75%), medium with flavored water, energy, hydrating, fruit juice, and prepared soft drinks (62.5% to 81.8%), medium-extreme with regular soda (92.9%), and extreme with tonic water, diet, and tea-based soft drinks (100.0%) ($p<0.001$). The NABs marketed in Peru present an acidic pH with frequent medium and extreme EP. The results indicate the need to establish actions to raise awareness on the EP of different types of NABs.

Key words: Dental erosion, Erosion potential, pH, Soft drinks.

Introduction

A wide variety of beverages are commonly consumed by the public, including energy drinks, tea-based drinks, soft drinks, non-alcoholic beverages (NABs), and artificial fruit juices [1, 2]. Although ethanol is absent from NABs, they do include other substances, such as carbon dioxide, carbohydrates, and acids [3]. NABs' shelf life is extended by the addition of lactic acid; however, this substance also makes saliva more acidic, which is bad for dental health [4]. These beverages also have a high sugar content, particularly carbonated beverages, which have values of 10–11 g/100 mL [5].

Peru is one of the main consumers of sugar-sweetened beverages in Latin America, mainly among the population in coastal areas and with a higher economic income [6-11]. The consumption of these beverages is associated with the male population and young adults, reporting an average consumption of 360 mL/day [12-15]. Moreover, the consumption pattern is intensified when accompanied by fast food or snacks [16]. A diet high in unnaturally sweetened beverages (≥50 kcal/226 g) has an adverse effect on public health and is considered a risk factor for cardiometabolic diseases [5, 17-21].

Dental erosion (DE) is a non-bacterial chemical process of chronic and irreversible dissolution of hard tissues caused by the action of intrinsic or extrinsic acids [22, 23]. The prevalence of DE increases with age, affecting 30% of deciduous dentition and 45% of permanent dentition [24, 25]. Acids from NABs are reported to be one of the extrinsic and common causes of the development of DE [2, 12]. This pathology can cause dentine hypersensitivity, pulp exposure, dental pain, masticatory dysfunction, and dissatisfaction with dental esthetics [25].

The potential of hydrogen (pH) measures the concentration of hydrogen ions (H+) and is a determinant of the potential of DE of NABs [26]. The acidity of these beverages in a natural environment, such as saliva, is critical for teeth [27, 28]. A pH below 4 causes demineralization of the enamel, and loss of Ca++ is evident with dissolution of hydroxyapatite or fluorapatite crystals [1, 29]. The pH of beverages in saliva can be buffered, but the lower the pH, the more necessary it is to add elements, such as NaOH, to neutralize the saliva [27, 29].

The pH of non-natural beverages has been evaluated in previous studies in Australia [22], Malaysia [30], Pakistan [29], Portugal [31], Spain [23], Thailand [32], Switzerland [33], the United Arab Emirates [34], and the United States [26]. No studies have been reported in Peru or South America to date. The common consensus in previous studies was finding of an acidic pH and a positive erosion potential (EP) in NABs. Furthermore, the pH of the NABs marketed varies across brands, possibly due to the composition and processing conditions within each country **(Table 1).**

DE is a multifactorial disorder that impacts quality of life and oral health [1]. The pH measurement could elucidate the erosive risk of ingested beverages. This knowledge is relevant for dentists seeking to guide patient counseling [35-38]. Furthermore, the results of this study may be useful for improving dental public health policies. Therefore, the objective of this study was to determine the erosion potential by pH analysis of NABs marketed in Peru.

Table 1. Potential of hydrogen (mean ± standard deviation [range]) by type of non-alcoholic beverages found by studies published in the last decade.

N°	Beverage	This study (Peru)		Schmidt & Huang (Australia)		Nik *et al.* (Malaysia)		Kumar *et al.* (Pakistan)		Morgado *et al.* (Portugal)	
		n	pH	n	pH	n	pH	n	pH	n	pH
1	Sparkling water	8	4.59 ± 1.13 [2.63–5.71]	19	3.63 ± 0.74 [2.62 – 5.14]					32	5.46 ± 0.51 [4.22 – 6.51]
2	Flavored water	5	3.53 ± 0.43 [2.78–3.78]	7	3.30 ± 0.15 [3.03 – 3.44]	10	3.49 ± 0.55 [2.86 – 4.65]				
3	Tonic water	5	2.62 ± 0.16 [2.4–2.82]								
4	Energetics	8	3.26 ± 0.44 [2.66–4.08]	21	3.20 ± 0.25 [2.73 – 3.57]	14	3.54 ± 0.18 [3.14 – 3.83]	21	3.80 ± 0.00 [3.04 – 4.58]		
5	Light/zero soda	2	2.78 ± 0.06 [2.74–2.82]								
6	Regular soda	14	2.95 ± 0.51 [2.17–4.1]	51	3.07 ± 0.25 [2.56 – 3.81]	10	3.03 ± 0.34 [2.65 – 3.47]	16	3.78 ± 0.01 [3.40 – 4.59]		
7	Hydrating drink	6	3.29 ± 0.49 [2.76–3.83]	20	3.41 [2.70 – 3.64]						
8	Fruit juice	11	3.4 ± 0.28 [2.99–4.06]	29	3.56 ± 041 [2.70 – 3.64]	11	3.58 ± 0.28 [3.20 – 4.12]	33	4.23 ± 0.00 [3.15 – 5.22]		
9	Prepared soft drink	18	3.41 ± 0.43 [2.5–4.23]								
10	Tea-based	4	2.61 ± 0.10 [2.51–2.7]	9	3.17± 0.17 [2.88 – 3.39]	12	5.42 ± 0.46 [4.94 – 6.35]	8	5.99 ± 0.01 [5.08 – 6.88]		
pH Meter Brand		HQ40d		Eutech pH 700		SevenEasy S20		720A		pH-Meter BASIC 20	
Manufacture		Hach, USA		Thermo Scientific, USA		Mettler-Toledo Inc., USA		Thermoelectron Corp., USA		Crison, Spain	
pH Accuracy		±0.002		±0.01		±0.01		±0.002		≤0.01	
Temperature		22 °C		22 °C		22 °C		27 °C		25 °C	
N°	**Beverage**	**Martínez *et al.* (Spain)**		**Lussi *et al.* (Switzerland)**		**Surarit *et al.* (Thailand)**		**Nassar *et al.* (UAE)**		**Reddy *et al.* (USA)**	
		n	**pH**	**n**	**pH**	**n**	**pH**	**n**	**pH**	**n**	**pH**
1	Sparkling water			6	5.13 ± 1.00 [3.20 – 6.1]			16	3.72 ± 0.86 [2.60 – 5.28]		
2	Flavored water			22	3.22 ± 0.41 [2.30 – 4.30]						
3	Tonic water										
4	Energetics	43	3.30 ± 0.00 [2.40 – 3.90]	13	3.54 ± 0.22 [3.30 – 3.90]			16	3.24 ± 0.32 [2.68 – 3.67]	68	3.13 ± 0.29 [2.47 – 3.97]
5	Light/zero soda			3	2.70 ± 0.17 [3.30 – 3.90]						
6	Regular soda			11	2.59 ± 0.18 [2.40 – 2.80]	4	3.00 [2.56–3.50]			95	3.12 ± 0.52 [2.32 – 5.24]

7	Hydrating drink	6	3.18 ± 0.28 [2.90 – 3.70]	4	3.42 [3.13–3.68]	10	3.30 ± 0.41 [2.69 – 3.97]	70	3.31 ± 0.77 [2.67 – 7.40]
8	Fruit juice	24	3.56 ± 0.32 [2.50 – 4.00]	4	3.76 [3.61–4.17]	125	3.43 ± 0.69 [2.32 – 5.86]	51	3.48 ± 0.47 [2.25 – 4.69]
9	Prepared soft drink							78	2.99 ± 0.31 [2.43 – 3.87]
10	Tea-based	8	3.18 ± 0.55 [2.40 – 3.90]	4	3.42 [2.72–5.58]	16	3.33 ± 0.61 [2.88 – 5.48]	17	3.48 ± 0.77 [2.85 – 5.18]
pH Meter Brand		SU 051 026	Standard electrode	3-Star Benchtop		LAQUA		AR 15	
Manufacture		No reference	No reference	Orion, USA		Horiba, Japan		Fisher Scientific, USA	
pH Accuracy		No reference	No reference	±0.002		±0.003		±0.01	
Temperature		25 °C	No reference	No reference		No reference		25 °C	

Materials and Methods

Study design

This descriptive cross-sectional study was approved by the Universidad Científica del Sur (N° 023-DACE-DAFCS-U.CIENTÍFICA-2023) and carried out according to the Strengthening the Reporting of Observational Studies in Epidemiology - STROBE checklist. The sample collection covered 13 cities in Peru. All evaluations were conducted at the Research Laboratory of the Universidad Científica del Sur from May to November 2023.

Study sample

The sample included 83 representative brands of NABs marketed in Peru that were obtained in triplicate (249 containers) and were of regional (n = 18), national (n = 39), and international (n = 26) origin. They were divided into 10 different types, such as sparkling water (n = 8), flavored water (n = 5), tonic water (n = 5), energy (n = 8), light/zero soda (n = 2), regular soda (n = 14), hydrating (n = 6), non-100% fruit juice (n = 11), and tea-based soft drinks (n = 4) **(Table 2)**.

The requirements for inclusion were NABs with a valid consumption date, health registration, and triplicate samples that matched in terms of brand, flavor, type, and container volume. The pH measurement may be impacted by beverage liquids that overflowed when uncorked or that were discovered to be outside of the 20–25°C temperature range.

Table 2. Distribution of groups of non-alcoholic beverages.

N°	Type	Regional		National		International		Subtotal by type (a)	Sub-sample by brand (b)	Total (a*b)	
		n	%	n	%	n	%			n	%
1	Sparkling water	2	11.1%	3	7.7%	3	11.5%	8	3	24	9.6%
2	Flavored water	1	5.6%	1	2.6%	3	11.5%	5	3	15	6.0%
3	Tonic water	0	0.0%	2	5.1%	5	19.2%	7	3	33	8.4%
4	Energetics	0	0.0%	5	12.8%	3	11.5%	8	3	6	9.6%
5	Light/zero soda	0	0.0%	2	5.1%	0	0.0%	2	3	18	2.4%
6	Regular soda	8	44.4%	3	7.7%	3	11.5%	14	3	54	16.9%
7	Hydrating drink	0	0.0%	3	7.7%	3	11.5%	6	3	42	7.2%
8	Fruit juice	3	16.7%	5	12.8%	3	11.5%	11	3	24	13.3%
9	Prepared soft drink	3	16.7%	12	30.8%	3	11.5%	18	3	12	21.7%
10	Tea-based	1	5.6%	3	7.7%	0	0.0%	4	3	21	4.8%
	Total	18	21.7%	39	47.0%	26	31.3%	83	3	249	100.0%

Production of beverages

NABs were categorized as either national (marked as made in Lima or by Peruvian industry), regional (produced in cities other than the capital), or international (produced in other countries). Twelve Peruvian coastal, highland, and jungle cities were included in the regional production.

Fourteen countries were covered by international production: Brazil, Chile, Colombia, France, Ireland, Italy, Korea, Mexico, Poland, Switzerland, Thailand, USA, UK and Venezuela [39-42]. The lead investigators gathered beverages sold in Lima, while research colleagues collected and transported beverages sold beyond the capital to Lima. Three drinks that were identical in terms of brand, flavor, type, and volume were gathered. The samples were kept at ambient temperature, shielded from strong odors and direct sunshine, and in their original, sealed, unrefrigerated containers in the laboratory.

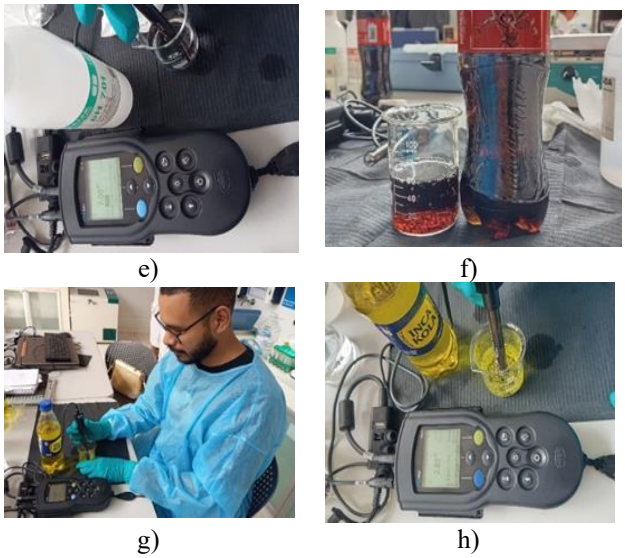
Characteristics of beverages

The beverages were recorded and classified according to label data by brand, type, origin (city of purchase), and manufacturer. Other data were extracted, including the net volume converted to mL, composition (labeled ingredients), container (box, can, plastic, and glass), batch, total cost in Peru's national currency (sol: S/.) and its conversion to US dollars (USD) (exchange rate: 0.27 as of 18 December 2023), and partial cost per 100 mL in USD.

pH and erosion potential assessment

For each beverage, triplicate measurements of temperature and pH were made using a digital multi-parameter pH meter with an accuracy of ± 0.002 (HQ40d, Hach®, USA). A quantity of 60 mL of beverage was poured into a beaker, avoiding gas loss. The electrode of the pH meter was immediately immersed in the solution and recorded with the stability indicator. The instrument was rinsed with distilled water before each measurement of a different beverage. Calibration of the instrument was performed before the starting measurements and every 10 measurements using buffer solution with pH 4 and 7. The average of the pH measurements was calculated and classified according to the EP into non-erosive (pH: ≥ 6), minimum (pH: 4 to < 6), medium (pH: 3 to < 4), and extreme (pH: < 3) EP [43] **(Figure 1).**

a) b) c) d)



e) f) g) h)

Figure 1. pH measurement process: Soft groups (a-b). Data recording (c). pH meter calibration in buffer solution pH 4 (d) and pH 7 (e). Amount of beverage in container (f). pH measurement of beverage (g-h).

Statistical analysis

Descriptive statistics included mean, standard deviation, frequencies, and percentages. Quantitative comparisons were performed with parametric tests due to the representativeness of the selected NABs. Inferential tests included ANOVA analysis of variance with Tukey's post-hoc analysis and Pearson's chi-square. Data were analyzed by IBM-SPSS v.26 statistical software at $p < 0.05$.

Results and Discussion

NAB trade data are displayed in **Supplementary Table 1**. The majority of NABs were of both domestic (47.0%) and foreign (31.3%) origin, and they included prepared soft drinks (21.7%) and ordinary sodas (16.9%). Regional NABs were mostly regular sodas (44.4%), whereas national NABs were prepared soft drinks (30.8%), and international NABs were tonic water (19.2%). Carbonated water, sugars (sucrose, glucose, and fructose), acidity regulators (citric acid, malic acid, sodium citrate, tripotassium citrate, and phosphoric acid), preservatives, colorings, and flavorings made up the main chemical composition. The secondary chemical composition included stimulants (caffeine, taurine, ginseng, and guarana), sweeteners (stevia and saccharin), fruit chunks and extracts, antioxidants, electrolytes (Na, K, Mg, Ca, Zn), and vitamins (A, C, E).

The pH and EP of the NABs are shown in **Table 3** and **Supplementary Table 2**. The mean volume of the NABs was 395.49 ± 151.85 mL (range: 150–1000 mL). Most of the plastic containers were regional (61.1%) and national (56.4%), and the can containers were international (42.3%). The mean total cost was $1.24 ± 0.76 (range: $0.22 for regular sodas – $4.02 for international hydrants), and the mean cost per 100 mL was $0.37 ± 0.28 (range: $0.05 for

sparkling water – $1.34 for international tonic water). The NABs had a mean temperature of 22.18 ± 0.72°C (range: 20.9–25.0°C) and a mean pH of 3.31 ± 0.71 (minimum value: 2.16 in national regular soda – maximum value: 5.74 in international sparkling water). In all the NABs the EP was most frequent at medium (50.6%), and extreme levels (37.3%).

Table 3. pH and erosion potential of non-alcoholic beverages marketed in Peru.

N°	Type	Brand	Manufacturing	Temperature					pH					Erosion potential
				1	2	3	Mean	SD	1	2	3	Mean	SD	
1	Sparkling water	Socosani	Regional	22.1	22.7	22.2	22.33	0.32	5.70	5.67	5.66	5.68	0.02	Minimum
2	Sparkling water	Andea	Regional	21.9	22.1	22.2	22.07	0.15	4.57	4.48	4.58	4.54	0.06	Minimum
3	Sparkling water	San Luis	National	21.4	21.4	21.4	21.40	0.00	2.86	2.52	2.52	2.63	0.20	Extreme
4	Sparkling water	San Mateo	National	21.5	21.9	21.8	21.73	0.21	4.90	4.92	4.92	4.91	0.01	Minimum
5	Sparkling water	S. Pellegrino	International	22.1	22.0	21.9	22.00	0.10	4.91	4.92	4.85	4.89	0.04	Minimum
6	Sparkling water	Ferrarelle	International	22.1	21.9	21.4	21.80	0.36	5.71	5.74	5.69	5.71	0.03	Minimum
7	Sparkling water	Perrier	International	21.2	21.1	21.1	21.13	0.06	5.22	5.23	5.20	5.22	0.02	Minimum
8	Sparkling water	H2oh!	National	22.0	21.8	21.5	21.77	0.25	3.16	3.15	3.14	3.15	0.01	Medium
9	Flavored water	San Luis	National	22.0	21.9	21.8	21.90	0.10	2.77	2.78	2.79	2.78	0.01	Extreme
10	Flavored water	Beauty Drink	International	21.8	21.7	21.6	21.70	0.10	3.74	3.76	3.75	3.75	0.01	Medium
11	Flavored water	Aloe Vera King	International	21.8	21.8	21.7	21.77	0.06	3.74	3.76	3.75	3.75	0.01	Medium
12	Flavored water	Slin	Regional	22.6	22.6	22.8	22.67	0.12	3.60	3.58	3.57	3.58	0.02	Medium
13	Flavored water	La Croix	International	21.7	21.7	21.4	21.60	0.17	3.80	3.77	3.78	3.78	0.02	Medium
14	Sparkling water	Mr. Perkins	National	23.0	23.2	22.8	23.00	0.20	2.71	2.73	2.70	2.71	0.02	Extreme
15	Sparkling water	Ginger Beer	International	22.6	23.0	22.7	22.77	0.21	2.68	2.74	2.72	2.71	0.03	Extreme
16	Sparkling water	Canada Dry	International	21.7	21.4	21.4	21.50	0.17	2.41	2.39	2.40	2.40	0.01	Extreme
17	Sparkling water	Britvic	International	21.5	21.4	21.5	21.47	0.06	2.85	2.82	2.48	2.72	0.21	Extreme
18	Sparkling water	Superior Italian tonic	International	21.8	21.7	21.7	21.73	0.06	2.82	2.82	2.81	2.82	0.01	Extreme
19	Sparkling water	Sirana	National	21.5	21.4	21.4	21.43	0.06	2.46	2.48	2.47	2.47	0.01	Extreme
20	Sparkling water	The London Essence	International	23.1	23.2	23.1	23.13	0.06	2.50	2.56	2.50	2.52	0.03	Extreme
21	Energetics	Volt	National	21.2	21.3	21.4	21.30	0.10	3.17	3.19	3.18	3.18	0.01	Medium
22	Energetics	Hype	International	22.0	22.2	22.1	22.10	0.10	3.25	3.27	3.27	3.26	0.01	Medium
23	Energetics	Red Bull	International	21.9	21.7	21.9	21.83	0.12	3.28	3.29	3.28	3.28	0.01	Medium
24	Energetics	Monster	International	22.1	22.1	22.3	22.17	0.12	3.42	3.40	3.43	3.42	0.02	Medium
25	Energetics	V220	National	22.6	22.7	22.4	22.57	0.15	2.67	2.66	2.64	2.66	0.02	Extreme
26	Energetics	Slow Cow	National	21.9	21.7	21.4	21.67	0.25	3.43	3.42	3.42	3.42	0.01	Medium
27	Energetics	Yuyu	National	22.7	22.9	23.7	23.10	0.53	2.76	2.80	2.76	2.77	0.02	Extreme
28	Energetics	Maltin Power	National	21.8	21.9	21.6	21.77	0.15	4.06	4.07	4.10	4.08	0.02	Minimum
29	Light/zero soda	Inka Kola zero	National	21.9	22.0	21.7	21.87	0.15	2.77	2.84	2.84	2.82	0.04	Extreme
30	Light/zero soda	Coca Cola Zero	National	21.7	21.7	22.0	21.80	0.17	2.74	2.73	2.74	2.74	0.01	Extreme
31	Regular soda	Dr Pepper	International	22.2	22.4	22.6	22.40	0.20	2.87	2.84	2.86	2.86	0.02	Extreme
32	Regular soda	Condor Cola	Regional	23.4	23.2	23.1	23.23	0.15	2.44	2.46	2.48	2.46	0.02	Extreme

33	Regular soda	Casinelli	Regional	23.0	23.2	23.3	23.17	0.15	3.10	3.13	3.13	3.12	0.02	Medium
34	Regular soda	Fulls Cola	Regional	23.8	23.4	23.8	23.67	0.23	3.50	3.40	3.51	3.47	0.06	Medium
35	Regular soda	Big Cola	Regional	22.5	22.2	22.2	22.30	0.17	2.37	2.38	2.32	2.36	0.03	Extreme
36	Regular soda	Black cabbage	Regional	21.9	21.6	21.8	21.77	0.15	2.35	2.40	2.39	2.38	0.03	Extreme
37	Regular soda	Sunkist	International	21.9	21.8	21.5	21.73	0.21	3.02	3.00	2.99	3.00	0.02	Medium
38	Regular soda	Energine	Regional	21.8	21.9	21.9	21.87	0.06	4.10	4.09	4.10	4.10	0.01	Minimum
39	Regular soda	Frescolita	International	21.3	21.1	21.0	21.13	0.15	3.27	3.26	3.27	3.27	0.01	Medium
40	Regular soda	Cool Fresh	Regional	21.2	20.9	20.9	21.00	0.17	3.03	3.03	3.03	3.03	0.00	Medium
41	Regular soda	Wanka Cola	Regional	23.1	22.8	23.1	23.00	0.17	3.27	3.27	3.29	3.28	0.01	Medium
42	Regular soda	Kris	National	23.0	22.7	22.9	22.87	0.15	2.97	2.96	2.96	2.96	0.01	Extreme
43	Regular soda	Inka Kola	National	24.2	23.8	24.3	24.10	0.26	2.83	2.83	2.85	2.84	0.01	Extreme
44	Regular soda	Coca-Cola	National	24.4	24.8	25.1	24.77	0.35	2.16	2.18	2.16	2.17	0.01	Extreme
45	Hydrating drink	Gatorade	National	21.6	21.6	21.9	21.70	0.17	3.02	3.00	3.01	3.01	0.01	Medium
46	Hydrating drink	Electroligth	National	21.2	21.2	21.2	21.20	0.00	2.81	2.79	2.82	2.81	0.02	Extreme
47	Hydrating drink	Suerox	International	22.3	22.2	21.9	22.13	0.21	3.53	3.52	3.54	3.53	0.01	Medium
48	Hydrating drink	Electrolife	International	22.6	22.5	22.7	22.60	0.10	3.82	3.83	3.85	3.83	0.02	Medium
49	Hydrating drink	Power Ade	National	22.7	22.1	22.3	22.37	0.31	2.77	2.76	2.76	2.76	0.01	Extreme
50	Hydrating drink	Bodyarmor	International	22.8	22.6	22.6	22.67	0.12	3.85	3.82	3.79	3.82	0.03	Medium
51	Fruit juice	Coco Mania	National	23.4	22.9	22.4	22.90	0.50	4.05	4.08	4.06	4.06	0.02	Minimum
52	Fruit juice	Frutalia	International	22.0	21.9	22.0	21.97	0.06	3.34	3.32	3.33	3.33	0.01	Medium
53	Fruit juice	King Fruits	National	22.5	23.1	22.5	22.70	0.35	3.51	3.55	3.52	3.53	0.02	Medium
54	Fruit juice	Mogu Mogu	International	22.0	22.2	22.1	22.10	0.10	3.48	3.52	3.52	3.51	0.02	Medium
55	Fruit juice	Kero Exotic Fruits	Regional	22.9	22.7	22.7	22.77	0.12	3.47	3.49	3.48	3.48	0.01	Medium
56	Fruit juice	Casa de Bento	International	20.9	21.3	21.0	21.07	0.21	3.32	3.38	3.31	3.34	0.04	Medium
57	Fruit juice	Fru	Regional	22.8	22.3	22.3	22.47	0.29	3.05	3.07	3.03	3.05	0.02	Medium
58	Fruit juice	Bio Amayu	National	22.4	22.2	22.7	22.43	0.25	3.21	3.21	3.22	3.21	0.01	Medium
59	Fruit juice	Fruvi	Regional	21.8	21.7	21.5	21.67	0.15	3.47	3.42	3.42	3.44	0.03	Medium
60	Fruit juice	Nisfrut	National	22.2	22.2	22.1	22.17	0.06	3.44	3.36	3.49	3.43	0.07	Medium
61	Fruit juice	Hoop	National	21.8	21.5	21.4	21.57	0.21	2.98	2.99	3.00	2.99	0.01	Extreme
62	Prepared soft drink	Ecofresh	National	23.1	22.8	22.7	22.87	0.21	3.26	3.39	3.27	3.31	0.07	Medium
63	Prepared soft drink	Cruz Campo	National	20.8	21.1	21.2	21.03	0.21	3.72	3.70	3.71	3.71	0.01	Medium
64	Prepared soft drink	Selva	National	22.0	22.0	22.0	22.00	0.00	3.65	3.70	3.66	3.67	0.03	Medium
65	Prepared soft drink	Kombucha Qambu	Regional	22.8	22.7	23.1	22.87	0.21	3.49	3.59	3.54	3.54	0.05	Medium
66	Prepared soft drink	Buly	Regional	23.2	23.7	23.8	23.57	0.32	3.39	3.38	3.37	3.38	0.01	Medium
67	Prepared soft drink	Shift	National	22.8	22.7	23.1	22.87	0.21	3.48	3.64	3.65	3.59	0.10	Medium
68	Prepared soft drink	Union	National	23.8	23.0	23.4	23.40	0.40	3.32	3.33	3.32	3.32	0.01	Medium
69	Prepared soft drink	Ama	International	23.0	23.1	22.9	23.00	0.10	3.54	3.53	3.55	3.54	0.01	Medium
70	Prepared soft drink	Union	Regional	21.8	21.9	21.9	21.87	0.06	3.51	3.52	3.53	3.52	0.01	Medium
71	Prepared soft drink	Slim	National	21.6	21.6	21.7	21.63	0.06	3.76	3.82	3.76	3.78	0.03	Medium

72	Prepared soft drink	Frutaris	National	22.2	22.2	22.2	22.20	0.00	2.45	2.47	2.59	2.50	0.08	Extreme
73	Prepared soft drink	Pink Lemonade	National	22.8	22.9	22.8	22.83	0.06	2.76	2.75	2.75	2.75	0.01	Extreme
74	Prepared soft drink	Tampico	National	21.6	21.5	21.6	21.57	0.06	2.90	2.88	2.71	2.83	0.10	Extreme
75	Prepared soft drink	Saffron	National	22.3	22.3	22.6	22.40	0.17	2.88	2.84	2.89	2.87	0.03	Extreme
76	Prepared soft drink	Beberash Emollient	National	21.6	22.0	22.0	21.87	0.23	3.44	3.42	3.42	3.43	0.01	Medium
77	Prepared soft drink	Beauty Drink	International	21.8	21.7	21.6	21.70	0.10	3.76	3.76	3.75	3.76	0.01	Medium
78	Prepared soft drink	Floridas Natural	International	21.8	21.6	21.7	21.70	0.10	3.79	3.59	3.58	3.65	0.12	Medium
79	Prepared soft drink	Yaqura Kay Pacha	National	21.7	22.3	22.3	22.10	0.35	4.23	4.22	4.24	4.23	0.01	Minimum
80	Tea-based	Drink T	Regional	22.2	21.5	21.4	21.70	0.44	2.52	2.52	2.50	2.51	0.01	Extreme
81	Tea-based	Leaf Te	National	21.7	21.7	21.6	21.67	0.06	2.52	2.51	2.53	2.52	0.01	Extreme
82	Tea-based	Hornimans	National	22.0	22.0	22.0	22.00	0.00	2.70	2.69	2.70	2.70	0.01	Extreme
83	Tea-based	Free Tea	National	21.8	21.5	22.6	21.97	0.57	2.71	2.68	2.69	2.69	0.02	Extreme

The volume and cost of NABs according to their commercial characteristics are shown in **Table 4.** Higher volume was found for hydrating versus tonic water ($p = 0.007$) and for beverages with plastic containers versus other groups ($p < 0.001$). Total cost was higher for prepared soft drinks versus regular sodas ($p = 0.012$), and cost per 100 mL was higher for tonic water versus sparkling or flavored water, sodas, and hydrating and tea-based drinks ($p < 0.001$). The total cost and cost per 100 mL were higher for those of international origin and lower for those in plastic containers compared to other groups ($p < 0.001$).

Table 4. Volume and costs of non-alcoholic beverages by type, origin and container.

Characteristics of non-alcoholic beverages	n	Volume (mL)		Total cost S/.		Total cost USD		Cost x 100 mL USD	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Type (*p* value)		0.007*		0.012*		0.012*		< 0.001*	
Sparkling water	24	415.00^{AB}	140.43	4.26^{AB}	2.70	1.15^{AB}	0.73	0.35^{B}	0.29
Flavored water	15	468.00^{AB}	113.06	4.16^{AB}	2.66	1.12^{AB}	0.72	0.26^{B}	0.17
Tonic water	33	221.00^{B}	63.67	5.90^{AB}	2.11	1.59^{AB}	0.57	0.76^{A}	0.33
Energetics	6	325.38^{AB}	89.19	4.98^{AB}	2.57	1.34^{AB}	0.69	0.46^{AB}	0.30
Light/zero soda	18	500.00^{AB}	0.00	2.90^{AB}	0.00	0.78^{AB}	0.00	0.16^{B}	0.00
Regular soda	54	379.64^{AB}	95.18	2.28^{B}	2.08	0.61^{B}	0.56	0.17^{B}	0.16
Hydrating drink	42	546.67^{A}	80.73	5.98^{AB}	4.89	1.62^{AB}	1.32	0.31^{B}	0.30
Fruit juice	24	430.00^{AB}	205.52	5.65^{AB}	1.49	1.53^{AB}	0.40	0.41^{AB}	0.18
Prepared soft drink	12	419.44^{AB}	172.60	5.59^{A}	2.88	1.51^{A}	0.78	0.42^{AB}	0.26
Tea-based	21	337.50^{AB}	110.87	2.38^{AB}	0.42	0.65^{AB}	0.11	0.21^{B}	0.09
Origin (*p* value)		0.119		< 0.001*		< 0.001*		< 0.001*	
Regional	54	401.94	177.91	3.28^{A}	2.90	0.88^{A}	0.78	0.24^{B}	0.22
National	117	428.33	151.51	3.61^{A}	1.95	0.98^{A}	0.53	0.27^{B}	0.20
International	78	349.81	119.82	7.00^{B}	2.37	1.89^{B}	0.64	0.60^{A}	0.27
Container (*p* value)		< 0.001*		< 0.001*		< 0.001*		< 0.001*	
Box	3	1000.00		4.95		1.34		0.13	-

Can	45	328.67^{B}	105.83	5.72^{A}	2.05	1.54^{A}	0.55	0.54^{A}	0.28
Plastic	120	453.75^{A}	148.01	3.25^{B}	2.83	0.88^{B}	0.76	0.20^{B}	0.18
Glass	81	331.67^{B}	82.53	5.97^{A}	2.29	1.61^{A}	0.62	0.52^{A}	0.26

SD, standard deviation. Different letters indicate significant differences by ranks with Tukey's one-way ANOVA post-hoc analysis of variance test. *p < 0.05.

The mean pH and EP of the NABs according to their commercial characteristics are shown in **Table 5.** The mean pH was similar by origin (p = 0.074) and lower for can (3.02 ± 0.47) and plastic (3.21 ± 0.59) compared to glass containers (3.60 ± 0.88) (p = 0.034). The mean pH from lowest to highest value according to type of beverage was tonic water (2.62 ± 0.16), flavored water, energy, regular or diet soda, hydrating and tea-based water (3.16 ± 0.48), prepared soft drink (3.41 ± 0.43), and sparkling water (4.59 ± 1.13) (p < 0.001). The EP of the NABs was not associated with origin and container (p = 0.062 and 0.328, respectively), but was associated with type, with which the minimal EP was associated with sparkling water (75%); erosive with flavored water, energy, hydrating, fruit juice, and prepared soft drinks (62.5% to 81.8%); medium and extremely erosive with regular soda (92.9%); and extreme with tonic water, diet soda, and tea-based drinks (100.0%) (p < 0.001).

Dental hard tissues are affected by DE with the acid exposure of saliva that can be influenced by food such as artificial beverages [27, 43]. The composition of NABs is usually protected by the industry, but in many countries, including Peru, there are laws on octagonal advertising warnings informing consumers of the sugar content. However, there are other characteristics, such as the level of acidity, that are not disclosed [22, 31]. The present study found that non-alcoholic beverages marketed in Peru had an acid pH of 3.31 and a concentrated EP, mainly at medium and extreme pH levels.

Table 5. pH and erosion potential of non-alcoholic beverages according to type, origin and container.

Characteristics of non-alcoholic beverages	Average temperature		Average pH		Erosion potential, n (%)		
	Mean	SD	Mean	SD	Minimal (pH: 4 to < 6)	Medium (pH: 3 to < 4)	Extreme (pH < 3)
Type (*p* value)	0.269		< 0.001*			< 0.001*	
Sparkling water	21.78	0.38	4.59^{A}	1.13	6 (75.0%)	1 (12.5%)	1 (12.5%)
Flavored water	21.93	0.43	3.53^{BC}	0.43	0 (0.0%)	4 (80.0%)	1 (20.0%)
Tonic water	22.15	0.78	2.62^{C}	0.16	0 (0.0%)	0 (0.0%)	7 (100.0%)
Energetics	22.06	0.56	3.26B^{C}	0.44	1 (12.5%)	5 (62.5%)	2 (25.0%)
Light or zero soda	21.83	0.05	2.78B^{C}	0.06	0 (0.0%)	0 (0.0%)	2 (100.0%)
Regular soda	22.64	1.10	2.95B^{C}	0.51	1 (7.1%)	6 (42.9%)	7 (50.0%)
Hydrating drink	22.11	0.57	3.29B^{C}	0.49	0 (0.0%)	4 (66.7%)	2 (33.3%)
Fruit juice	22.16	0.57	3.40B^{C}	0.28	1 (9.1%)	9 (81.8%)	1 (9.1%)
Prepared soft drink	22.30	0.70	3.41^{B}	0.43	1 (5.6%)	13 (72.2%)	4 (22.2%)
Tea-based	21.83	0.17	2.61^{BC}	0.10	0 (0.0%)	0 (0.0%)	4 (100.0%)
Origin (*p* value)		0.081	0.074			0.062	
Regional	22.44	0.73	3.38	0.81	3 (16.7%)	11 (61.1%)	4 (22.2%)
National	22.22	0.78	3.13	0.57	4 (10.3%)	14 (35.9%)	21 (53.8%)
International	21.96	0.55	3.53	0.78	3 (11.5%)	17 (65.4%)	6 (23.1%)
Container (*p* value)		0.797	0.034*			0.328	
Box	21.63	-	3.78	-	0 (0.0%)	1 (100.0%)	0 (0.0%)
Can	21.16	1.01	3.02^{B}	0.47	0 (0.0%)	8 (53.3%)	7 (46.7%)
Plastic	22.15	0.62	3.21^{B}	0.59	4 (10.0%)	19 (47.5%)	17 (42.5%)
Glass	22.27	0.70	3.60^{A}	0.88	6 (22.2%)	14 (51.9%)	7 (25.9%)

SD, standard deviation. Different letters indicate significant differences by columns Tukey's one-way ANOVA post-hoc analysis of variance test (temperature and pH). Fisher's chi-square test (erosion potential). *p < 0.05.

All the brands of NABs in this study were acidic (pH ≤ 5.74). A lower mean pH of 2.17 was found for regular Coca-Cola®, which was lower than that found by other studies with ranges of 2.37–3.54 [22, 26, 29, 30, 32–34]. In regard to other brands, Dr. Pepper® [26] presented an extreme pH in contrast to Sunkist, which showed a medium pH value [22, 26] **(Table 6).** These differences could be due to variations in the manufacturing [22, 26, 29, 30, 32, 33], pH meter accuracy [22, 26, 30, 34], and measurement temperature [26, 29]. Despite the differences between studies, the EP was extreme, and consumers should be made aware of the potential impact on oral health [1, 3].

Table 6. pH by brand of non-alcoholic beverages found by studies published in the last decade.

Brand of beverage	Type of beverage	Study	Country	°C	pH	Erosion potential
S. Pellegrino	Sparkling water	This study	Peru	22	4.89 ± 0.04	Minimum
		Morgado *et al*., 2022	Portugal	25	5.07 ± 0.04	Minimum
		Nassar *et al*., 2023	UAE	NR	4.52 ± 0.01	Minimum
		Reddy *et al*., 2016	USA	25	4.96 ± 0.09	Minimum
Perrier	Sparkling water	This study	Peru	22	5.22 ± 0.02	Minimum
		Morgado *et al*., 2022	Portugal	25	5.09 ± 0.10	Minimum
		Nassar *et al*., 2023	UAE	NR	4.63 ± 0.01	Minimum
		Reddy *et al*., 2016	USA	25	5.25 ± 0.10	Minimum
Aloe Vera King premium	Flavored water	This study	Peru	22	3.75 ± 0.01	Medium
		Nik *et al*., 2023	Malaysia	22	4.27 ± 0.01	Minimum
Canada Dry tonic water	Tonic water	This study	Peru	22	2.40 ± 0.01	Extreme
		Nassar *et al*., 2023	UAE	NR	2.50 ± 0.01	Extreme
		Reddy *et al*., 2016	USA	25	2.82 ± 0.01	Extreme
Red Bull energy drink blue	Energetics	This study	Peru	22	3.28 ± 0.01	Medium
		Schmidt C Huang, 2020	Australia	22	3.42 ± 0.01	Medium
		Nik *et al*., 2023	Malaysia	22	3.6 ± 0.01	Medium
		Kumar *et al*., 2022	Pakistan	27	3.65 ± 0.00	Medium
		Martinez *et al*., 2024	Spain	25	3.1 ± 0.00	Medium
		Lussi *et al*., 2023	Switzerland	NR	3.37 ± 0.12	Medium
		Nassar *et al*., 2023	UAE	NR	3.42 ± 0.01	Medium
Monster energy black	Energetics	This study	Peru	22	3.42 ± 0.02	Medium
		Schmidt C Huang, 2020	Australia	22	3.46 ± 0.01	Medium
		Martinez *et al*., 2024	Spain	25	3.3 ± 0.00	Medium
		Lussi *et al*., 2023	Switzerland	NR	3.30 ± 0.00	Medium
		Nassar *et al*., 2023	UAE	NR	3.66 ± 0.01	Medium
		Reddy *et al*., 2016	USA	25	3.48 ± 0.01	Medium
Coca-Cola Zero	Light/zero soda	This study	Peru	22	2.74 ± 0.01	Extreme
		Schmidt C Huang, 2020	Australia	22	3.12 ± 0.00	Medium
		Lussi *et al*., 2023	Switzerland	NR	2.60 ± 0.00	Extreme
		Nassar *et al*., 2023	UAE	NR	2.68 ± 0.01	Extreme
		Reddy *et al*., 2016	USA	25	2.96 ± 0.03	Extreme
Dr Pepper	Regular soda	This study	Peru	22	2.86 ± 0.02	Extreme

		Nassar *et al*., 2023	UAE	NR	2.99 ± 0.01	Extreme
		Reddy *et al*., 2016	USA	25	2.88 ± 0.04	Extreme
Sunkist orange	Regular soda	This study	Peru	22	3.00 ± 0.02	Medium
		Schmidt C Huang, 2020	Australia	22	2.98 ± 0.01	Extreme
		Reddy *et al*., 2016	USA	25	2.98 ± 0.01	Extreme
Coca-Cola	Regular soda	This study	Peru	22	2.17 ± 0.01	Extreme
		Schmidt C Huang, 2020	Australia	22	2.61 ± 0.01	Extreme
		Nik *et al*., 2023	Malaysia	22	2.74 ± 0.02	Extreme
		Kumar *et al*., 2022	Pakistan	27	3.54 ± 0.00	Medium
		Lussi *et al*., 2023	Switzerland	NR	2.50 ± 0.10	Extreme
		Surarit *et al*., 2023	Thailand	NR	2.62 ± 0.08	Extreme
		Nassar *et al*., 2023	UAE	NR	2.62 ± 0.02	Extreme
		Reddy *et al*., 2016	USA	25	2.37 ± 0.03	Extreme
Tropical Gatorade	Hydrating drink	This study	Peru	22	3.01 ± 0.01	Medium
		Schmidt C Huang, 2020	Australia	22	3.33 ± 0.01	Medium
		Kumar *et al*., 2022	Pakistan	27	4.09 ± 0.00	Minimum
		Lussi *et al*., 2023	Switzerland	NR	3.20 ± 0.10	Medium
		Nassar *et al*., 2023	UAE	NR	3.17 ± 0.00	Medium
Powerade	Hydrating drink	This study	Peru	22	2.76 ± 0.01	Extreme
		Reddy *et al*., 2016	USA	25	2.77 ± 0.01	Extreme

NR, no reference

An extreme EP and similar pH (2.62–2.95) were found in the NABs of tonic, tea-based, and regular/light/zero soda waters. In a previous study, the EP of Canada Dry® tonic water was also described as extreme [26, 34]. Tonic waters are often added to alcoholic beverages, thereby enhancing acidity [2]. The extreme EP differed from other studies on tea-based (medium-minimal) and regular soda (medium) NABs [22, 23, 26, 29, 30, 32-34]. In addition, according to other studies, Coca-Cola® Zero soda had a similar medium-to-extreme EP [22, 26, 33, 34]. It should be noted that replacing sugars with sweeteners (diet soda), increasing sugars to reduce the bitter taste of quinine (tonic water), or the use of antioxidants (tea-based) do not counteract the extreme EP of NABs, as corroborated by this study [3, 30].

In contrast to the extreme EP reported by another study on soft drinks [26], another group of NABs displayed a similar medium EP and pH (3.26–3.53), with results that were comparable to other studies on energy drinks [22, 23, 26, 29, 30, 33, 34], hydrating drinks [22, 26, 32-34], artificial fruit juices [22, 26, 30, 32-34], and flavored water drinks [22, 30, 33]. Regarding brands, our findings align with the medium EP of Gatorade® [22, 33, 34] and the extreme EP of Powerade® (hydrating drinks) [26], as well as the medium EP of Red Bull® [22, 23, 29, 30, 33, 34] and Monster® (energy drinks) [22, 23, 26, 33, 34]. However, our findings did not align with the minimum EP of Aloe Vera King® (flavored water) [30]. Increased use of these categories of NABs is linked to their presence in school lunchboxes (juices, soft drinks, flavored waters) and endurance activities (energy) or sports (hydrating drinks) [3, 23, 27, 30]. The examination of the effects of DE on tooth enamel necessitates a stronger study design. A scenario involving frequent, nocturnal drinking, holding, or swishing the liquid in the mouth would have an even greater impact on DE [3, 31].

Minimal EP was found with sparkling water in the present study, similar to a previous report [31, 33], but did not coincide with the mean EP described in other studies [22, 34]. Minimal EP was also found in the S. Pellegrino® and Perrier® brands [26, 31, 33, 34]. The weak acidity of sparkling water would result from the use of mineral/spring water that acquires carbon dioxide gas from the source or artificially, while other types of NABs that were more acidic had carbon dioxide, acidulant ingredients, and chelating properties [2, 3]. The mean pH of 6.81 of the still waters in this study did not exceed the critical threshold for demineralization of enamel (pH ≤ 5.5) and root dentine (pH ≤ 6.8), but it remained positive for EP [3, 23, 30, 31]. Carbonated beverages stimulate the sense of taste with ionic effects, which may have reduced the pattern of drinking water consumption [2, 27].

This study also evaluated other variables of health and environmental concern [44, 45]. The origin of manufacture did not affect pH values, implying that the ingredients and formulations did not significantly affect the average acidity. The pH was higher in glass-container NABs than in plastic and can containers, probably because glass was used more

in the containers of carbonated soft drinks (minimum EP) and plastic and can containers were used more in the containers of soda (extreme EP). The cost of carbonated soft drinks was lower which makes their consumption accessible as opposed to the health effects. Lower cost is also associated with plastic containers. In 2021, Peru joined the list of countries that increased taxes on sugar-sweetened beverages by levying an additional 8% on quantities ≥5 g/100 mL (Supreme Decree N° 266-2021-EF). However, there are still no regulations on industrial publication of the acidity levels of NABs [16].

In general, NABs have poor nutritional benefits and have a negative impact on both general health (obesity, type 2 diabetes) and oral health (dental caries, tooth sensitivity, and DE) [3, 16]. DE is becoming more prevalent in the population, particularly among young persons [16, 17, 22-24]. The early phase of DE causes roughness with a porosity around 0.2 μm, leading to bacterial adherence, particularly in the anterosuperior teeth [1]. It is critical to develop strong preventive-promotional programs to raise public awareness and educate health professionals [29, 30, 32, 46-49], as well as at the global health policy level with taxation strategies that influence prices, reformulation of harmful compounds, and advertising transparency [1, 23].

The measurement of pH in this study was based on its concentration and not on the total amount of H+, as it has been described as a critical determinant of the EP of beverages [26]. pH values, which are normally classified as acidic, neutral, or alkaline, were not considered in the present study, but rather the inverse logarithmic relationship of minimum to extreme pH values with EP was observed, which may be useful for dentists providing dietary advice [26, 43]. This study used highly accurate pH measuring devices that demonstrated low variability (coefficient of variation < 10%). Maintaining room temperature at 22° was essential to avoid bias, as elevated temperatures are reported to lower pH values [22, 50, 51]. However, under natural conditions, people tend to consume cold BNAs. Higher temperatures can raise pH and lessen the erosive effect on teeth because they maintains the cohesion of the molecules [33].

The EP of NABs can be monitored *in vivo* (organism), in situ (specimens in a natural environment), and *in vitro* (laboratory) [52-57]. The feasibility of the subject of this study leaned towards an *in vitro* design, which is considered a limitation compared to an oral environment involving salivary function (buffering, flow, composition, and remineralization) and swallowing method [1, 29]. Other beverage characteristics that could accelerate or slow DE were also not analyzed. Regardless of pH, liquids saturated with minerals and proteins, with less adherence and high viscosity, would have a lesser erosive effect on the oral environment [33]. Therefore, it is recommended that these parameters be evaluated in future studies.

Conclusion

Considering the limitations of this study, it was concluded that all NABs marketed in Peru have an acidic pH associated with a potential to cause DE at medium and extreme levels. The reported acidity of carbonated, flavored, tonic, energy, soda, hydrating, artificial fruit juices, and prepared soft drinks and tea-based drinks suggests possible risks to oral and general health. Therefore, it is necessary to establish actions to raise awareness of the EP of different types of NABs [58-61]. The findings highlight the acidic pH of NABs that could affect salivary protection against DE in the population. Identifying the frequent consumption of acidic beverages in patients is a factor that should be considered by dentists in preventive strategies against DE.

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Conflict of interest: None

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Ethics statement: This study was approved by the Universidad Científica del Sur with registration N° 0023-DACE-DAFCS-U.CIENTÍFICA-2023.

Supplementary materials: Table S1. The Composition of non-alcoholic beverages of this study and Table 2. Characteristics and costs of non-alcoholic beverages marketed in Peru are available at https://doi.org/10.6084/m9.figshare.29441465.v2

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