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Original Article

# The Acidity of Non-alcoholic Beverages in Australia: Risk of Dental Erosion

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## Abstract

**Introduction:** Extrinsic acids play a key role in the etiology of dental erosion (DE), particularly acidic beverages. Of the factors considered, pH appears to be the most significant influencing a beverage's ability to cause DE. This study tested the pH and subsequent erosive potential of non-alcoholic beverages commercially available in Australia.

**Purpose:** Internationally, the consumption of non-alcoholic beverages is increasing. Regional differences in beverage availability and manufacturing processes may alter beverage pH. To date, little research outside of the United States has been conducted investigating the erosive potential of non-alcoholic beverages. This information should serve as a resource to professionals to facilitate dietary counseling and identify potentially acidic beverages that have not been previously identified in the literature.

**Methods:** A total of 177 commercially available non-alcoholic beverages were purchased from a supermarket in Orange, Australia, and their pH tested in triplicate at room temperature, using a temperature calibrated benchtop pH meter and probe. Beverages were classified by beverage type and subsequent erosive potential. The mean and median pH of beverage types was taken where appropriate.

**Results:** As high as, 93.8% of the beverages had a potential to cause DE. These included 34 (19.2%) extremely erosive ($pH < 3$), 114 (64.4%) erosive ($3 \leq pH < 4$), and 18 (10.2%) minimally erosive beverages ($4 \leq pH \leq 5.5$). Only 11 beverages (6.2%) were unlikely to be erosive ($pH > 5.5$).

**Conclusions:** Of the beverages tested, most beverages (93.8%) had the potential to cause some degree of DE. The results provided could serve as a resource to health professionals to facilitate dietary counseling and healthy dietary decisions among consumers.

**Key words:** Acidic, Australia, Beverages, Erosive potential, pH, Tooth erosion

## INTRODUCTION

The consumption of commercial beverages is increasing.[1] Australia saw a 14% decrease in the consumption of sugar-sweetened carbonated throughout Australia between 2009 and 2017, yet 37% increase in "diet" or "low sugar" beverages and 18% increase in the consumption of packaged water.[2] Aggressive marketing tactics by companies to highlight "zero sugar" beverages act to shift negative attention from the sugar-sweetened beverages they also sell. To date, little attention has been given to the role that non-sweetened beverages play on an individual's general and dental health.[3] One concern that remains is due to acid content of these beverages capable of causing dental erosion (DE).[4] DE is the irreversible loss of tooth structure due to acids, through a chemical dissolution process, without the involvement of microorganisms.[5] DE is caused by hydrogen ions from extrinsic and intrinsic acid sources contacting the tooth surface, resulting in the dissolution of the inorganic calcium hydroxyapatite.[6] Sources of intrinsic acids include stomach acids (due to gastroesophageal reflux disease and other purging behaviors related to pregnancy), alcoholism, and psychological disorders.[7] Sources of extrinsic acids include the previously mentioned commercially and non-commercially available beverages, foods (e.g., citrus fruits

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and vinegar), acidic drugs (e.g., aspirin and Vitamin C), acidic vapors in battery factories, and chlorinated swimming pool water.[4] The chemical dissolution process can be simplified to the following equation: $Ca_{10}(PO_4)_6OH_{2(s)}+H^+_{(aq)} \rightarrow Ca^{2+}_{(aq)}+H_3PO_{4(aq)}+OH^-_{(aq)}$.[8] The consequences of these acid exposures can be quite severe in terms of function, esthetics,[9] psychologically,[10] and holistically.[11] The prevalence of DE ranged from 20%[12] to 90%[13] in developed countries in recent years.

The capacity for acidic beverages to cause DE is termed erosive potential[14,15] and plays a key role in its etiology.[15] Factors shown to influence a beverage's erosive potential include pH,[16-21] titratable acidity,[17,21,22] buffering capacity,[5,23] calcium,[24,25] phosphate,[24] fluoride,[26] and casein phosphopeptide-amorphous calcium phosphate content.[27] Of these factors, the pH of beverages appears to be the most critical factor in determining its erosive potential (therefore, its ability to cause DE), with several studies identifying it as the only statistically significant factor.[18-21] It has also been shown that the dissolution of enamel increased inversely logarithmically with the pH of beverages [Figure 1].[16] Surprisingly, information relating to the beverages final pH is often not published by manufacturers nor is it available on the container of the beverage. The aim of this study was to address this gap in the literature and information available to consumers. It is hoped that by determining commercially available beverages erosive potential and making this information available will empower professionals and individuals to make healthy dietary choices.

## METHODS

From a range of non-alcoholic, non-dairy beverages, a total of 177 were purchased from a supermarket in Orange, Australia. Beverage types purchased were soft drink, energy drink, juice, still and sparkling bottled water, flavored water, iced tea, coconut water, and *Aloe vera* water. A temperature calibrated benchtop pH meter and probe (Eutech pH 700, Thermo Scientific) was calibrated using CertiPUR buffer solutions (pH 10, 7, and 4 buffer solutions, CertiPUR®) and operated according to the manufacturer's instructions. The pH of different beverages was tested in triplicate at room temperature (22°C) immediately after opening. The mean pH, standard deviation, acids added, and manufacturer information from the products label were recorded. The mean pH of the beverage was used to determine the beverage's relative erosive potential based on the solubility of enamel at a given pH,[16] similar to the method of the previous studies.[28] Erosive potential was classified as extremely erosive ($pH < 3$), erosive ($3 \leq pH < 4$), minimally erosive ($4 \leq pH \leq 5.5$), and unlikely to be erosive ($pH > 5.5$).[28]

## RESULTS

Of the 177 beverages tested, Pepsi® original (pH = 2.56) was most acidic, while Alka Power water (pH = 10.29) was the most basic beverage in Australia. Individual beverage pH is summarized in Table 1. The results of the different beverage types are summarized in Table 2. The pH levels recorded for sports drinks and "other" beverages failed

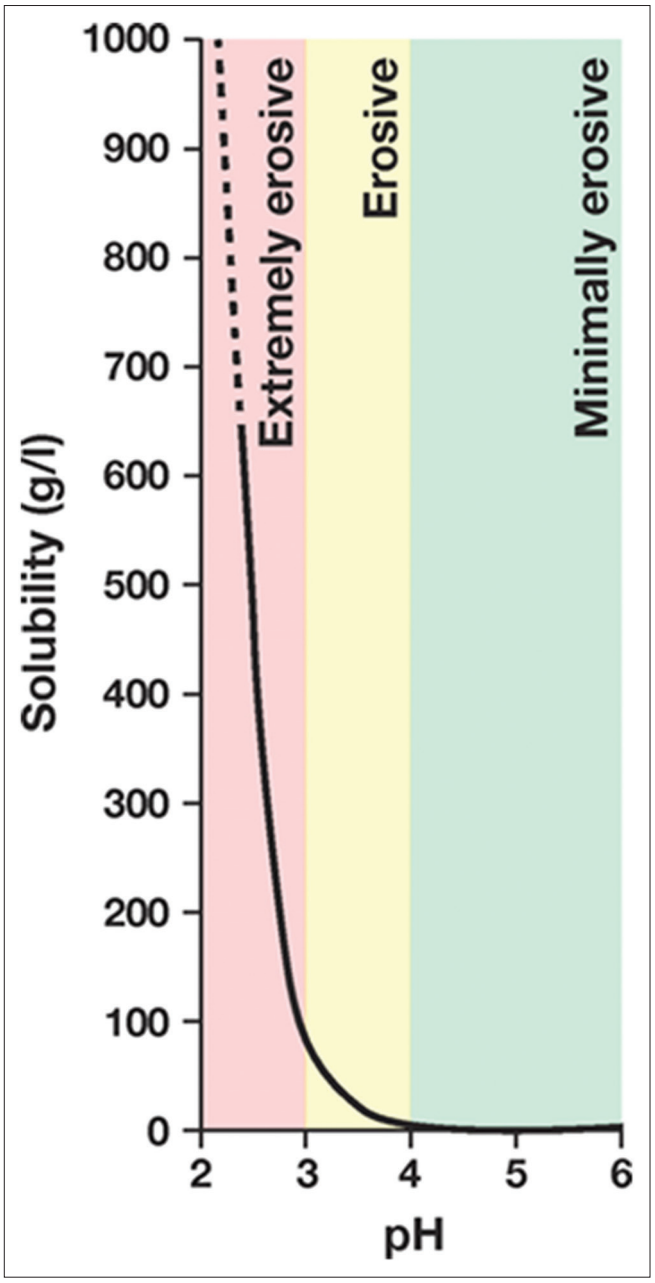


**Figure 1: Solubility of enamel by pH and subsequent erosive potential28; Elsevier Reuse Licence Number: 4463380957145**

**Table 1: Beverage measured pH and subsequent erosive potential**

| Beverage type | Beverage name | x̄ pH (s) | Erosive potential |
|---|---|---|---|
| Soft drink | Pepsi® – original | 2.56 (0.00) | Extremely erosive |
| Soft drink | Coca-Cola® – classic | 2.61 (0.01) | Extremely erosive |
| Sparkling water | Schweppes® – raspberry sparkling | 2.62 (0.00) | Extremely erosive |
| Sparkling water | Schweppes® – Indian tonic | 2.63 (0.01) | Extremely erosive |
| Soft drink | Woolworths® – cola | 2.64 (0.00) | Extremely erosive |
| Sparkling water | Woolworths® – tonic | 2.68 (0.00) | Extremely erosive |
| Sports drink | Lucozade® – original | 2.70 (0.01) | Extremely erosive |
| Juice | Ocean Spray® – cranberry classic | 2.70 (0.01) | Extremely erosive |
| Soft drink | LA Ice® – cola | 2.71 (0.01) | Extremely erosive |
| Juice | Ocean Spray® – light cranberry classic | 2.71 (0.01) | Extremely erosive |
| Sparkling water | Woolworths® – diet tonic | 2.71 (0.01) | Extremely erosive |
| Soft drink | Coca-Cola® – stevia | 2.73 (0.01) | Extremely erosive |
| Energy drink | 28 Black® – pink grapefruit and mint | 2.73 (0.02) | Extremely erosive |
| Soft drink | Schweppes® – agrum blood orange | 2.75 (0.00) | Extremely erosive |
| Energy drink | 28 Black® – acai | 2.75 (0.01) | Extremely erosive |
| Soft drink | Woolworths® – ginger beer | 2.78 (0.01) | Extremely erosive |
| Soft drink | Coca-Cola® – vanilla | 2.80 (0.01) | Extremely erosive |
| Juice | Golden Circle® – pine orange | 2.84 (0.01) | Extremely erosive |
| Juice | Ocean Spray® – low sugar cranberry | 2.87 (0.01) | Extremely erosive |
| Iced tea | Arizona® – lemon-flavored iced tea | 2.88 (0.01) | Extremely erosive |
| Soft drink | Kirks® – lemonade | 2.89 (0.01) | Extremely erosive |
| Soft drink | Pepsi® – max vanilla | 2.89 (0.01) | Extremely erosive |
| Soft drink | Woolworths® – passion fruit | 2.90 (0.01) | Extremely erosive |
| Energy drink | Bunderim® – ginger fresh | 2.91 (0.01) | Extremely erosive |
| Iced tea | Arizona® – pomegranate iced green tea | 2.93 (0.01) | Extremely Erosive |
| Soft drink | Kirks® – Pasito | 2.94 (0.00) | Extremely erosive |
| Energy drink | Rockstar® – tropical guava (SF) | 2.95 (0.00) | Extremely erosive |
| Energy drink | Rockstar® – tropical guava | 2.95 (0.01) | Extremely erosive |
| Soft drink | Woolworths® – lemonade | 2.96 (0.01) | Extremely erosive |
| Sparkling water | Schweppes® – lime sparkling (SF) | 2.97 (0.01) | Extremely erosive |
| Soft drink | Sunkist® – original | 2.98 (0.01) | Extremely erosive |
| Soft drink | Woolworths® – orange flavor | 2.98 (0.01) | Extremely erosive |
| Soft drink | Bundaberg® – diet ginger beer | 2.99 (0.00) | Extremely erosive |
| Soft drink | Pepsi® – lite (caffeine free) | 2.99 (0.01) | Extremely erosive |
| Soft drink | Solo® – original | 3.00 (0.01) | Erosive |
| Sports drink | Lucozade® – orange | 3.01 (0.01) | Erosive |
| Soft drink | Crush® – orange flavor | 3.03 (0.00) | Erosive |
| Juice | Golden Circle® – Golden Pash | 3.03 (0.00) | Erosive |
| Flavored water | Schweppes® – lemon water | 3.03 (0.00) | Erosive |
| Soft drink | LA Max® – ice (SF) | 3.04 (0.01) | Erosive |
| Soft drink | Solo® – zero (SF) | 3.05 (0.01) | Erosive |
| Soft drink | Kirks® – lemon squash | 3.05 (0.01) | Erosive |
| Soft drink | Woolworths® – cola zero (SF) | 3.06 (0.00) | Erosive |
| Soft drink | Lido® – lemonade | 3.08 (0.00) | Erosive |
| Energy drink | Mother® – kicked apple | 3.08(0.01) | Erosive |
| Soft drink | Kirks® – ginger beer | 3.09 (0.01) | Erosive |
| Sparkling water | Waterfords® – lite and fruity sparkling lemon-lime-bitters | 3.10 (0.00) | Erosive |
| Soft drink | Woolworths® – lemon | 3.10 (0.01) | Erosive |
| Soft drink | Coca-Cola® – zero (SF) | 3.12 (0.00) | Erosive |
| Energy drink | Red Bull® – zero (SF) | 3.12 (0.01) | Erosive |
| Energy drink | Mother® (SF) | 3.12(0.02) | Erosive |
| Soft drink | Schweppes® – sarsaparilla | 3.13 (0.00) | Erosive |
| Soft drink | Schweppes® – agrum citrus blend (SF) | 3.14 (0.01) | Erosive |
| Energy drink | Red Bull® – coconut and berry | 3.15 (0.01) | Erosive |
| Energy drink | V® – blue | 3.15 (0.01) | Erosive |
| Soft drink | Bundaberg® – ginger beer | 3.16 (0.00) | Erosive |
| Juice | Golden Circle® – pine mango | 3.16 (0.01) | Erosive |
| Iced tea | Lipton® – peach ice tea | 3.16 (0.02) | Erosive |
| Soft drink | Diet Rite® – Portello | 3.17 (0.00) | Erosive |
| Iced tea | Lipton® – ice green tea jasmine and lychee | 3.17 (0.00) | Erosive |
| Iced tea | Lipton® – lemon ice tea | 3.17 (0.01) | Erosive |

(*Contd...*)

**Table 1: (*Continued*)**

| | | | |
|---|---|---|---|
| Soft drink | Sprite® – zero (SF) | 3.18 (0.01) | Erosive |
| Soft drink | Sprite® – original | 3.19 (0.01) | Erosive |
| Sparkling water | Schweppes® – diet Indian tonic | 3.19 (0.01) | Erosive |
| Soft drink | Schweppes® – raspberry | 3.21 (0.00) | Erosive |
| Soft drink | Fanta® – raspberry | 3.21 (0.00) | Erosive |
| Soft drink | Schweppes® – lemonade zero (SF) | 3.21 (0.01) | Erosive |
| Sports drink | Gatorade® – blue bolt | 3.21 (0.01) | Erosive |
| Flavored water | Gatorade® – active electrolyte lemon (SF) | 3.21 (0.01) | Erosive |
| Soft drink | Coca-Cola® – diet | 3.22 (0.01) | Erosive |
| Soft drink | Schweppes® – lemonade | 3.22 (0.01) | Erosive |
| Energy drink | Mother® – passion | 3.25 (0.01) | Erosive |
| Flavored water | Gatorade® – active electrolyte orange (SF) | 3.25 (0.01) | Erosive |
| Iced tea | Arizona® – peach flavor ice tea | 3.25 (0.01) | Erosive |
| Sports drink | Gatorade® – orange (SF) | 3.25(0.01) | Erosive |
| Iced tea | Lipton® – ice green tea original | 3.26 (0.00) | Erosive |
| Iced tea | Lipton® – raspberry ice tea | 3.26 (0.00) | Erosive |
| Sports drink | Gatorade® – orange ice | 3.26 (0.01) | Erosive |
| Sparkling water | Waterfords® – lite and fruity sparkling apple berry | 3.26 (0.01) | Erosive |
| Soft drink | Mountain Dew® – energized | 3.27 (0.00) | Erosive |
| Sports drink | Gatorade® – lemon-lime | 3.27 (0.01) | Erosive |
| Soft drink | Schweppes® – dry ginger ale | 3.28 (0.01) | Erosive |
| Soft drink | Woolworths® – dry ginger ale | 3.28 (0.01) | Erosive |
| Soft drink | Coca-Cola® – diet caffeine free | 3.29 (0.00) | Erosive |
| Soft drink | Woolworths® – creaming soda | 3.29 (0.01) | Erosive |
| Iced tea | Arizona® – green tea with honey | 3.29 (0.01) | Erosive |
| Sports drink | Gatorade® – pineapple | 3.29 (0.02) | Erosive |
| Flavored water | Cool Ridge® – restore raspberry and blueberry flavor | 3.30 (0.01) | Erosive |
| Soft drink | Ceda® – creaming soda | 3.32 (0.00) | Erosive |
| Soft drink | Diet Rite® – ginger beer | 3.33 (0.00) | Erosive |
| Sports drink | Gatorade® – tropical | 3.33 (0.01) | Erosive |
| Juice | Golden Circle® – tropical punch | 3.33 (0.01) | Erosive |
| Sports drink | Gatorade® – grape | 3.35 (0.01) | Erosive |
| Energy drink | V® – original | 3.36 (0.01) | Erosive |
| Soft drink | Kirks® – creaming soda | 3.37 (0.01) | Erosive |
| Juice | Golden Circle® – sunshine punch | 3.38 (0.01) | Erosive |
| Energy drink | V® (SF) | 3.39 (0.01) | Erosive |
| Sparkling water | Waterfords® – lite and fruity sparkling Tahitian Lime | 3.39 (0.01) | Erosive |
| Sports drink | Powerade® – mountain blast | 3.39 (0.02) | Erosive |
| Sports drink | Powerade® – gold rush | 3.40 (0.01) | Erosive |
| Juice | Golden Circle® – pine coconut | 3.40 (0.01) | Erosive |
| Energy drink | Red Bull® (SF) | 3.41 (0.00) | Erosive |
| Sports drink | Powerade® – lemon-lime | 3.41 (0.00) | Erosive |
| Flavored water | Cool Ridge® – immunity blood orange and lemon flavor | 3.41 (0.01) | Erosive |
| Energy drink | Monster® – 44 | 3.42 (0.01) | Erosive |
| Energy drink | Red Bull® – original | 3.42 (0.01) | Erosive |
| Energy drink | Mother® – frosty berry | 3.43 (0.01) | Erosive |
| Sports drink | Gatorade® – watermelon chill | 3.43 (0.01) | Erosive |
| Flavored water | Cool Ridge® – revitalize green tea and peach | 3.44 (0.00) | Erosive |
| Flavored water | Gatorade® – active berry water | 3.44 (0.01) | Erosive |
| Sports drink | Powerade® – berry ice | 3.45 (0.01) | Erosive |
| Sports drink | Powerade® – zero mountain blast (SF) | 3.45 (0.01) | Erosive |
| Energy drink | Monster® – original | 3.46 (0.01) | Erosive |
| Energy drink | Monster® – VR46 | 3.46 (0.01) | Erosive |
| Sports drink | Powerade® – zero berry ice (SF) | 3.47 (0.01) | Erosive |
| Juice | Berri® – apple and blackcurrant | 3.50 (0.01) | Erosive |
| Juice | Just Juice® – apple | 3.53 (0.00) | Erosive |
| Soft drink | Kirks® – lemonade (SF) | 3.53 (0.01) | Erosive |
| Juice | Berri® – apple, celery, coconut water, and lemon juice | 3.53 (0.01) | Erosive |
| Soft drink | Schweppes® – diet dry ginger ale | 3.56 (0.00) | Erosive |
| Energy drink | Monster® – zero ultra (SF) | 3.57 (0.01) | Erosive |
| Sports drink | Maximus® – green | 3.59 (0.01) | Erosive |
| Juice | Just Juice® – apple blackcurrant | 3.59 (0.01) | Erosive |
| Sports drink | Maximus® – red | 3.61 (0.01) | Erosive |

(*Contd...*)

**Table 1: (*Continued*)**

| | | | |
|---|---|---|---|
| Sports drink | Powerade® – pineapple storm | 3.61 (0.01) | Erosive |
| Juice | Berri® – grape | 3.61 (0.01) | Erosive |
| Sports drink | Maximus® – blue | 3.62 (0.01) | Erosive |
| Sports drink | Maximus® – the big O | 3.64 (0.00) | Erosive |
| Juice | Woolworths® – apple | 3.69 (0.00) | Erosive |
| Juice | Berri® – apple, carrot, pear, and ginger | 3.70 (0.01) | Erosive |
| *Aloe vera* drink | Ya-Coya Aloe Crush® – original | 3.70 (0.01) | Erosive |
| Juice | Woolworths® – apple and blackcurrant | 3.71 (0.01) | Erosive |
| *Aloe-Vera* drink | Ya-Coya Aloe Crush® –(SF) | 3.74 (0.00) | Erosive |
| Juice | Golden Circle® – pineapple | 3.75 (0.01) | Erosive |
| Juice | Berri® – apple and pear juice | 3.75 (0.01) | Erosive |
| Juice | Berri® – apricot | 3.76 (0.00) | Erosive |
| Juice | Berri® – Multi V Juice | 3.76 (0.00) | Erosive |
| Juice | Berri® – apricot | 3.76 (0.00) | Erosive |
| Juice | Berri® – Multi V Juice | 3.76 (0.00) | Erosive |
| Sparkling water | Mount Franklin® – sparkling wild berry | 3.76 (0.01) | Erosive |
| Soft drink | Kirks® – creaming soda (SF) | 3.81 (0.01) | Erosive |
| Juice | V8® – breakfast fusion | 3.83 (0.00) | Erosive |
| Juice | Berri® – apple, mango, and banana | 3.88 (0.02) | Erosive |
| Juice | Woolworths® – orange juice | 3.94 (0.01) | Erosive |
| Sparkling water | Mount Franklin® – sparkling raspberry and lemon | 3.95 (0.01) | Erosive |
| Juice | V8® – tropical fusion | 3.96 (0.01) | Erosive |
| Juice | Just Juice® – orange | 3.98 (0.01) | Erosive |
| Juice | Berri® – orange juice | 3.99 (0.00) | Erosive |
| Sparkling water | Mount Franklin® – lightly sparkling | 4.00 (0.01) | Minimally erosive |
| Sparkling water | Mount Franklin® – lightly sparkling lime | 4.03 (0.01) | Minimally erosive |
| Juice | Berri® – Tomato | 4.06 (0.00) | Minimally erosive |
| Sparkling Water | Mount Franklin® – lightly sparkling lemon | 4.12 (0.01) | Minimally erosive |
| Juice | V8® – vegetable juice | 4.21 (0.00) | Minimally erosive |
| Sparkling water | Woolworths® – soda water | 4.24 (0.01) | Minimally erosive |
| Bottled water | Pump® | 4.28 (0.01) | Minimally erosive |
| Sparkling water | Icelandic® – glacial sparkling | 4.33 (0.01) | Minimally erosive |
| Sparkling water | Woolworths® – lightly sparkling lemon (SF) | 4.38 (0.01) | Minimally erosive |
| Bottled water | Mount Franklin® | 4.38 (0.01) | Minimally erosive |
| Bottled water | Balance® – cleanse | 4.39 (0.01) | Minimally erosive |
| Bottled water | Balance® – with flower essence | 4.40 (0.01) | Minimally erosive |
| Sparkling water | Woolworths® – lightly sparkling | 4.48 (0.01) | Minimally erosive |
| Sparkling water | Schweppes® – soda water | 5.14 (0.01) | Minimally erosive |
| Bottled water | Cool Ridge® | 5.17 (0.00) | Minimally erosive |
| Coconut water | Rawsome® – coconut water | 5.27 (0.00) | Minimally erosive |
| Coconut water | Woolworths® – coconut water | 5.31 (0.00) | Minimally erosive |
| Coconut water | H2COCO® – coconut water | 5.48 (0.01) | Minimally erosive |
| Bottled water | Aroona® – water | 5.56 (0.01) | Not erosive |
| Bottled water | Voss® – water | 6.02 (0.02) | Not erosive |
| Bottled water | Frantelle® – water | 6.28 (0.02) | Not erosive |
| Bottled water | Woolworths® – spring water | 6.90 (0.01) | Not erosive |
| Bottled water | Thank You® – water | 6.92 (0.02) | Not erosive |
| Bottled water | Fiji® – water | 7.15 (0.01) | Not erosive |
| Bottled water | Evian® – water | 7.41(0.02) | Not erosive |
| Bottled water | Acqua Panna® – Toscana water | 8.13 (0.00) | Not erosive |
| Bottled water | Icelandic Glacial® – water | 8.47 (0.02) | Not erosive |
| Bottled water | Aqua Love® – water | 9.18 (0.01) | Not erosive |
| Bottled water | Alka Power® – water | 10.29 (0.02) | Not erosive |

normality testing; thus, the median pH was determined and reported in Table 2. For all other beverage types, the pH measurements were normally distributed; thus, the mean and standard deviation was calculated. Of the beverages tested, 166 (93.8%) beverages had the potential to cause some degree of DE. These included 34 (19.2%) extremely erosive (pH < 3), 114 (64.4%) erosive (3 ≤ pH < 4), and 18 (10.2%) minimally erosive beverages (4 ≤ pH ≤ 5.5). Only 11 beverages (6.2%) were unlikely to be erosive (pH > 5.5).

## DISCUSSION

Understanding and identifying the factors contributing to the etiology of DE in patients are an essential step before delivering restorative treatment. Furthermore,

it has been well established that there is a significant relationship between low oral health literacy and poorer health outcomes.[29] It is alarming to note that until this study, the most comprehensive Australian study to date tested 39 commercially available beverages.[30] Our study looked at 177 Australian beverages categorized by type and their pH at room temperature (22°C). This was because studies have indicated that of all factors to be considered of beverages, pH is likely the most important in determining the beverage's erosive potential.[19,21] From the measured pH, the erosive potential of the beverages was determined using the established inverse logarithmic relationship by Larsen and Nyvad [Figure 1].[16] This is similar to the method used by the most comprehensive international study to date of 379 commercially available beverages in the United States.[28] This study was repeated in Australia as the pH measurements of beverages are not routinely published by manufacturing companies; therefore, this study and previously conducted studies provide a valuable resource to health professionals and, subsequently, the general population. While the pH and subsequent erosive potential of beverages have been investigated previously by numerous authors,[17-19,28,30] extrapolations of international data to Australian beverages have its limitations. This is due to regional variations in the fabrication process of beverages and beverage availability. Some examples of similarities and differences between this study and others are noted in Table 3. Variations in laboratory methodologies, including the temperature the beverage was tested at and equipment accuracy may also be attributed to minor variations in pH measurements among comparable beverages. This is because those beverages tested at higher temperatures are likely to have a lower pH reading.[31]

**Table 2: Beverage type descriptive statistics**

| Beverage type | *n* (*n* = 177) | pH range | x̄ pH (s) | x̃ pH |
|---|---|---|---|---|
| Soft drink | 51 | 2.56–3.81 | 3.07 (0.25) | |
| Iced tea | 9 | 2.88–3.39 | 3.17 (0.17) | |
| Energy drink | 21 | 2.73–3.57 | 3.20 (0.25) | |
| Flavored water | 7 | 3.03–3.44 | 3.30 (0.15) | |
| Sports drinks | 20 | 2.70–3.64 | | 3.41 |
| Juice | 29 | 2.70–3.64 | 3.56 (0.41) | |
| Sparkling water | 19 | 2.62–5.14 | 3.63 (0.74) | |
| Bottled water | 16 | 4.28–10.29 | 6.56 (1.84) | |
| Other | 6 | 5.27–5.53 | | 5.29 |

The most common acids found in the beverages tested were carbonic, citric, ascorbic, phosphoric, and malic acid. Acidic beverage types included soft drinks, iced tea, energy drinks, flavored water, sports drinks, juice, and sparkling water. From this study, it was determined that 93.8% of commercially available, non-alcoholic beverages in Australia have the potential to cause DE. In contrast, the pH of gastric acid is 3.0,[32] of the tested beverages, 19.2% of beverages available are extremely erosion (pH < 3) and are, therefore, more acidic than human gastric juice. With the increase in consumption of these beverages, this highlights a potentially serious oral and general health risk. Given the decline in sales of sugar-sweetened beverages yet increase in sales of "zero sugar" alternatives,[1,2] attention should be given to the impact, these beverages have on individuals dental and holistic health beyond sugar content, particularly in terms of their erosive potential. In addition to the already acidic nature of these beverages, the consumption of sugar-sweetened acidic beverages

**Table 3: Comparison of beverage pH measurements between published studies**

| Beverage | Study | Year | Location | °C | pH |
|---|---|---|---|---|---|
| Coca-Cola® | This study | 2018 | Australia | 22 | 2.61 |
| | Reddy *et al*.[28] | 2016 | United States | 25 | 2.37 |
| | Cochrane *et al*.[19] | 2012 | Australia | * | 2.46 |
| | Cochrane *et al*.[18] | 2009 | Australia | ** | 2.39 |
| | Hara *et al*.[17] | 2008 | United States | 23 | 2.45 |
| | Seow and Thong[30] | 2005 | Australia | 22 | 2.6 |
| | Larsen and Nyvad[16] | 1999 | Denmark | ** | 2.4 |
| Red Bull® | This study | 2018 | Australia | 22 | 3.42 |
| | Reddy *et al*.[28] | 2016 | United States | 25 | 3.43 |
| | Seow and Thong[30] | 2005 | Australia | 22 | 3.1 |
| Pepsi® | This study | 2018 | Australia | 22 | 2.56 |
| | Reddy *et al*.[28] | 2016 | United States | 25 | 2.39 |
| | Cochrane *et al*.[18] | 2009 | Australia | ** | 2.36 |
| | Seow and Thong[30] | 2005 | Australia | 22 | 2.3 |
| | Larsen and Nyvad[16] | 1999 | Denmark | ** | 2.53 |
| Schweppes Tonic Water® | This study | 2018 | Australia | 22 | 2.63 |
| | Reddy *et al*.[28] | 2016 | United States | 25 | 2.54 |
| | Larsen and Nyvad[16] | 1999 | Denmark | * | 2.48 |
| Mount Franklin Water® | This study | 2018 | Australia | 22 | 4.38 |
| | Cochrane *et al*.[18] | 2012 | Australia | * | 7.56 |
| | Cochrane *et al*[19] | 2009 | Australia | ** | 4.65 |

*Room temperature, **Not stated

has been found to be associated with the occurrence of laryngopharyngeal reflux.[33] This may result in a synergistic acid attack on the teeth prolonging their exposure. Unexpectedly, several types of bottled water measured were also acidic. This is of concern given the established 18% increase in consumption of bottled water.[2] While not being acidic enough to cause significant DE, their pH would be low enough to cause demineralization to tooth enamel.[7] This is likely due to the reverse osmosis filtration process that is carried out, increasing the water's uptake of $CO_2$ and subsequently leading to the waters acidification.[34] Some of the identified acidic bottled waters include Mount Franklin® Water, Balance Cleanse® Water, Pump® Water, and Cool Ridge® Water. Further research into the effects these bottled waters may have on dental health is indicated.

Using the method in this and previous studies is impractical, expensive and time consuming. Further consideration should be undertaken to establish inexpensive and predictable models of determining beverage's erosive potential. While pH may currently be the best predictor to determine erosive potential of beverages, there are several other factors influencing it.[6] These factors, coupled with the complex, multifactorial process of DE, play key roles in influencing an individual's susceptibility.[20] This data should serve as a reference for future investigations and an immediate resource to health practitioners and individuals to facilitate dietary counseling and healthy dietary decisions among consumers.

## CONCLUSIONS

This study identified that a high percentage of non-alcoholic commercially available beverages in Australia has the potential to cause DE. Most non-alcoholic beverages, including some bottled water, have been found acidic. The risk of DE by the consumption of the tested beverages poses an oral and general health risk for the public. Further investigation is indicated.

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