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The pH of beverages available to the American consumer

Avanija Reddy, DMD, MPH¹, Don F. Norris, DMD², Stephanie S. Momeni, MS, MBA¹, Belinda Waldo, DMD³, and John D. Ruby, DMD, PhD¹

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Abstract

Background—Dental erosion (DE) is the chemical dissolution of tooth structure in the absence of bacteria when the environment is acidic (pH < 4.0). Recent studies indicate that low pH is the primary determinant of beverage erosive potential although citrate chelation of calcium ions may contribute to erosion at higher pH. The purpose of this study was to determine the erosive potential measured by the pH of commercially available beverages.

Methods—A total of 380 beverages were purchased from stores in Birmingham, Alabama, categorized (e.g. juices, sodas) and assessed for pH. An Accumet AR 15 pH meter was used to measure the pH of each beverage in triplicate immediately after opening at 25°C. The pH data were recorded as mean ± standard deviation.

Results—The majority (93%, 355/380) of beverages had a pH below 4.0 and 7% (25/380) had a pH 4. Relative beverage erosivity zones based on previous studies of apatite solubility in acid indicated: 39% (150/380) of the beverages were considered extremely erosive (pH <3.0); 54% (205/380) were considered erosive (pH 3.0 to 3.99); 7% (25/380) were considered minimally erosive (pH 4.0).

Conclusions—This comprehensive pH assessment of beverages available for human consumption found that the majority are potentially erosive to the dentition. This study will provide dental clinicians and hygienists information regarding the erosive potential (pH) of commercially available beverages.

Practical Implications—Specific dietary recommendations for the prevention of dental erosion may now be developed based on the patient’s history of beverage consumption.

Corresponding Author: Stephanie S. Momeni, MS, MBA; The University of Alabama at Birmingham, LHRB Room 238, 1720 2nd Avenue South, Birmingham, AL 35294-0007. Phone: 1-205-934-9190. sks@uab.edu.

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Keywords

Erosive potential; commercial beverages; pH; dental erosion

INTRODUCTION

Sweetened beverage consumption has increased dramatically over the past 35 years in America with carbonated soft drinks being consumed the most frequently; children, teens, and young adults are the main consumers.^{1–3} In 1942 the annual production of soft drinks was about 60 12-ounce servings per person, and that number has increased almost 10-fold since 2005.⁴ Between 1999–2002 daily carbonated soft drink/fruit drink consumption by 13- to 18-year-olds was 26 ounces, and the Center for Science in the Public Interest has reported that in 2004 total consumption of these drinks for every man, woman and child was approximately 68 gallons per year.⁴ The prevalence of dental erosion in the 21st century has also increased due to our enhanced preference for sweet and sour.⁵ The consumption of acidic beverages contributes to an erosive oral milieu, and should be of concern to the dental practitioner.^{6–9}

The pH of commercial non-dairy beverages range from 2.1 (lime juice concentrate) to 7.4 (spring water).¹⁰ Commercially available beverages with a pH < 4.0 are potentially damaging to the dentition.¹¹ Acids are added to beverages and compose a flavor profile giving the beverage a distinctive taste. Acids provide a tartness and tangy taste that helps to balance the sweetness of sugar present in the beverage; they are key factors in the taste of the beverage. Phosphoric acid is added to cola drinks to impart tartness, reduce growth of bacteria and fungi, and improve shelf-life. Citric acid, a substance naturally occurring in citrus drinks and added to many others, imparts a tangy flavor and functions as a preservative. Malic acid occurs naturally in apples, pears and cherries, and is added to many non-carbonated beverages such as fruit drinks, fortified juices, sports drinks and iced teas because it enhances the intrinsic flavor. Malic acid is added to artificially sweetened carbonated beverages to intensify taste and reduce the amount of other added flavorings. These additives give the beverage its distinctive sugar/acid signature taste.

Dental erosion is the irreversible acidic dissolution of surface tooth structure by chemical means in the absence of microorganisms. It primarily occurs when hydrogen ions [H⁺] interact with the surface fluoroapatite and hydroxyapatite crystals after diffusion through plaque-pellicle biofilm—a process termed proton-promoted dissolution.¹² Erosion may initially progress through the enamel lamellae exposing dentinal tubules leading to dentinal sensitivity, however, with continuous erosive insult to the surface enamel, larger areas of the enamel-dentin junction will eventually become exposed, leading to enhanced sensitivity.^{7,13,14} As the oral cavity pH drops below 4.0, the tooth surface erodes and with each unit of decrease in pH there is a ten-fold increase in enamel solubility resulting in a 100 fold increase in enamel demineralization as the pH approaches 2.0 from 4.0.¹¹ Importantly, the consumption of beverages with higher concentrations of available hydrogen ions (pH < 4.0) results in the immediate softening of the tooth surface that becomes quite susceptible to removal by abrasion and attrition.¹⁵

The frequent consumption of acidic beverages is a developing problem for children, teenagers, and adults. The dramatic increase in consumption of acid soft drinks, fruit juices, fruit drinks, sports drinks and carbonated beverages is now thought to be the leading cause of dental erosion observed among children and adolescents.^{16–18} A recent report of dental erosion in children indicates its prevalence may range from 10% to 80%.¹⁹ Deciduous teeth, having a thinner enamel layer, are more prone to rapid erosion into dentin leading to exposure of the dental pulp.¹⁹ It is evident that erosion causes many clinical problems with restorative treatment being necessary to replace lost tooth structure, eliminate dental pain and restore functional esthetics.

Previous investigations have indicated pH, not titratable acidity, is the critical determinant of beverage erosive potential.^{10,19–24} Citrate may also contribute to dental erosion by removing $[Ca^{++}]$ through ligand-promoted dissolution (chelation) at a higher pH approaching 6.¹² The purpose of this study is to determine the hydrogen ion concentration (pH) of beverages including new products that are commercially available in stores, gas stations and vending machines. Information obtained from this study will enable dental care practitioners to make appropriate dietary beverage suggestions when counseling patients about the damaging effects of acid in drinks.

METHODS

Beverages were purchased from convenience stores, grocery stores, gas stations and vending machines in the Birmingham, Alabama area. A total of 380 beverages were studied and categorized. Groups included: waters and sport drinks (Table 1); juices and fruit drinks (Table 2); sodas (Table 3); energy drinks, teas and coffee (Table 4). An Accumet AR 15 pH meter (Fisher Scientific, Pittsburgh, PA) was used to measure the pH of each beverage in triplicate immediately after opening at 25 °C. The pH data were recorded as range and mean \pm standard deviation. Nutritional information labels on the containers were used to determine the type of acid(s) added to the beverages.

RESULTS

All pH data is expressed as: range and mean \pm standard deviation. Seventy waters and sports drinks had a pH range of 2.67 – 7.40 and a mean of 3.31 ± 0.77 (Table 1). Fifty-one juices had a pH range of 2.25 – 4.69 and a mean of 3.48 ± 0.47 (Table 2A). Seventy-eight fruit drinks had a pH range of 2.43 – 3.87 and a mean of 2.99 ± 0.31 (Table 2B). Ninety-five sodas had a pH range of 2.32 – 5.24 and a mean of 3.12 ± 0.52 (Table 3). Sixty-eight energy drinks had a pH range 2.47 – 3.97 and a mean of 3.13 ± 0.29 (Table 4A). Seventeen teas had a pH range of 2.85 – 5.18 and a mean of 3.48 ± 0.77 ; coffee had a pH of 5.11 (Table 4B). The majority of beverages tested had a pH < 4.0 (355/380 = 93%) (Tables 1–4). Relative beverage erosivity zones based on previous studies of apatite solubility in acid indicated: 39% (150/380) of the beverages tested were considered extremely erosive (pH < 3.0); 54% (205/380) were considered erosive (pH 3.0 to 3.99); 7% (25/380) were considered minimally erosive (pH = 4.0)(Fig. 1). The most acidic beverages tested with a pH < 2.4 were: lemon juice (pH 2.25), RC Cola (pH 2.32), Coca-Cola Classic (2.37), Coca-Cola

Cherry (pH 2.38), Pepsi (pH 2.39). Citric > phosphoric > malic acids were the most frequently added acids to the drinks.

DISCUSSION

Previous laboratory studies have determined the pH of beverages for human consumption.^{6,10,22,24–28} Our study determined the pH of 380 beverages available to the American consumer and is the most comprehensive in terms of beverage numbers and diversity. Recently, there has been an increase in beverage diversity in the marketplace that probably accounts for the large number of beverages procured. Our results are consistent with reported beverage pH values by other investigators; for examples, we determined the pH of Coca Cola was 2.37 (Table 3) as compared to (2.46)²¹, (2.45)²⁴, (2.48)²⁵, (2.53)²⁹, (2.39)²², (2.40)³⁰, (2.49)³¹, (2.53)²⁷, the pH of Schweppes Tonic Water was 2.54 (Table 3) as compared to (2.50)⁶, (2.48)³⁰, the pH of Gatorade Lemon Lime was 2.97 (Table 1) as compared to (2.93)³¹, (2.95)²⁶, (3.01)²¹, (2.90)¹⁰, (3.08)²⁸, (3.17)²⁴, (3.29)²², the pH of Pepsi was 2.39 (Table 3) as compared to (2.53)³⁰, (2.36)²², (2.39)²⁴, (2.30)¹⁰, (2.46)²⁵, (2.53)²⁷, and the pH of apple juice was 3.57 and 3.66 (Table 2A) as compared to (3.60)¹⁰, (3.41)²⁴ and (3.60)³².

The pH of extrinsic solutions (dietary beverages) coming into contact with the dentition appears to be the major determinant of dental erosion; the hydrogen ion concentration [H⁺] or acidity, as measured in pH, is primarily responsible for the immediate dissolution and softening of surface tooth structure (erosive potential) by acidic beverages composed of weak acids, e.g. citric and phosphoric acid.^{10,12,19–24} The titratable acidity or buffer capacity, intrinsic to these acids, does not play as critical a role in dental erosion as pH due the limited time exposure the dentition has with ingested liquids during each drinking and swallowing episode.^{19,20,22,33,34} Therefore, pH or [H⁺] at the time of dental exposure is the important chemical parameter to assess when determining the erosive potential of beverages.

Teeth erode in the pH range of 2.0 to 4.0, although surface enamel starts to demineralize as the pH drops below 5.5 when the external milieu of the oral cavity becomes under-saturated for hydroxyapatite.³⁵ Apatite solubility studies indicate a logarithmic increase in apatite solubility as pH drops under laboratory equilibrium conditions as can be seen in the solubility curve (Fig. 1).^{30,36} Apatite solubility above pH 4.0 is minimal; a drop of 1 unit to 3.0 results in a 10 fold increase in apatite solubility. Moreover, as pH drops from 3.0 to 2.0 there is an increase in apatite solubility that approaches 1000 g/l (Fig. 1). Based on the apatite solubility curve in Fig. 1, we propose that the chemical erosive potential of beverages be segregated into 3 zones: extremely erosive— pH < 3.0 (red); erosive—pH 3.0 to 3.99 (yellow); minimally erosive—pH 4.0 (green). The relative erosivity zones (extremely erosive, erosive, minimally erosive) of 380 beverages as determined by pH indicated: 39% (150/380) were extremely erosive (pH < 3.0); 54% (205/380) were erosive (pH 3.0 to 3.99); 7% (25/380) were minimally erosive (pH 4.0). Although apatite solubility as a function of pH is a continuum, the segregation of erosive potential into 3 discrete zones would be helpful to the dental clinician when providing a dietary guide of relative beverage erosivity to the patient. The prevailing paradigm for dental erosion remains: as the pH of the oral milieu decreases, the solubility of apatite on the tooth surface increases logarithmically.¹¹

Dental erosion from beverages is primarily caused by either phosphoric acid and/or citric acid, and both are triprotic acids with 3 available $[H^+]$ enabling proton-promoted dissolution.^{12,37} Chelation or ligand-promoted dissolution by anionic citrate contributes to enamel demineralization by the removal of Ca^{++} at a higher pH range approaching 6.¹² At the erosive pH 3 only 3% of citrate ions are appropriately ionized to chelate Ca^{++} , indicating their contribution to the erosive process at this pH is minimal.³⁸ However, if anionic citrate were to remain within the oral cavity for extended time intervals allowing the pH to rise to 6, chelation could play a contributing role in the erosive process; for example the eating of citrus fruits more than twice a day has been associated with dental erosion⁴³. Nevertheless, high concentrations of $[H^+]$ reflected by low pH from citric and/or phosphoric acid result in undersaturation for both fluor- and hydroxyapatite leading to dental erosion. Hence, pH is the controlling parameter in determining the erosive potential of beverages.^{11,19-24}

Knowledge of beverage pH is essential for the development of preventive strategies for patients with clinical erosion.^{7,39,40} The elimination of extremely erosive drinks (pH < 3.0), minimizing erosive drinks (pH 3.0 – 3.99), and substituting drinks with a (pH 4.0) would be prudent advice for the prevention of erosion. Fluoride does not prevent erosion since highly acidic environments solubilize fluorapatite and calcium fluoride.^{35,41,42} Xerostomic conditions exacerbate the erosive process due to lack of saliva essential for the dilution and buffering of $[H^+]$ in the oral cavity.^{43,44} The primary dentition of children is highly susceptible to the erosive process and low pH beverages should not be placed in a baby bottle, especially at sleep time when the mouth is xerostomic. Athletes may have decreased salivary flow rates due to dehydration from profuse sweating after prolonged, intense physical activity and should re-hydrate with water.⁴⁵ Geriatric patients on medications with xerostomic side effects are vulnerable to erosion, and the exposure of cementum and dentin due to gingival recession allow for root demineralization and hypersensitivity from contact with erosive drinks.^{7,14,46} Obviously, saliva is an important ameliorating milieu for the abrogation of dental erosion by not only diluting and buffering extrinsic acids, but also providing the source of glycoproteins that coat the tooth surface as the protective acquired pellicle.^{20,43,44} However, when acidic beverage consumption is excessive, saliva may offer the dentition limited protection from erosion.⁴⁷

CONCLUSION

Studies suggest that the pH or $[H^+]$ is the primary determinant of beverage erosive potential. The pH of 380 beverages was determined and assessed for relative erosivity. Relative beverage erosivity zones based on previous studies of apatite solubility in acid indicated: 39% (150/380) of the beverages tested were considered extremely erosive (pH < 3.0); 54% (205/380) were considered erosive (pH 3.0 to 3.99); 7% (25/380) were considered minimally erosive (pH 4.0). The most acidic beverages tested with a pH < 2.4 were: lemon juice (pH 2.25), RC Cola (pH 2.32), Coca-Cola Classic (2.37), Coca-Cola Cherry (pH 2.38), Pepsi (pH 2.39). Information obtained from this study will enable dental care practitioners to make appropriate dietary suggestions when counseling patients about the damaging dental effects of acid(s) in the beverages they drink.

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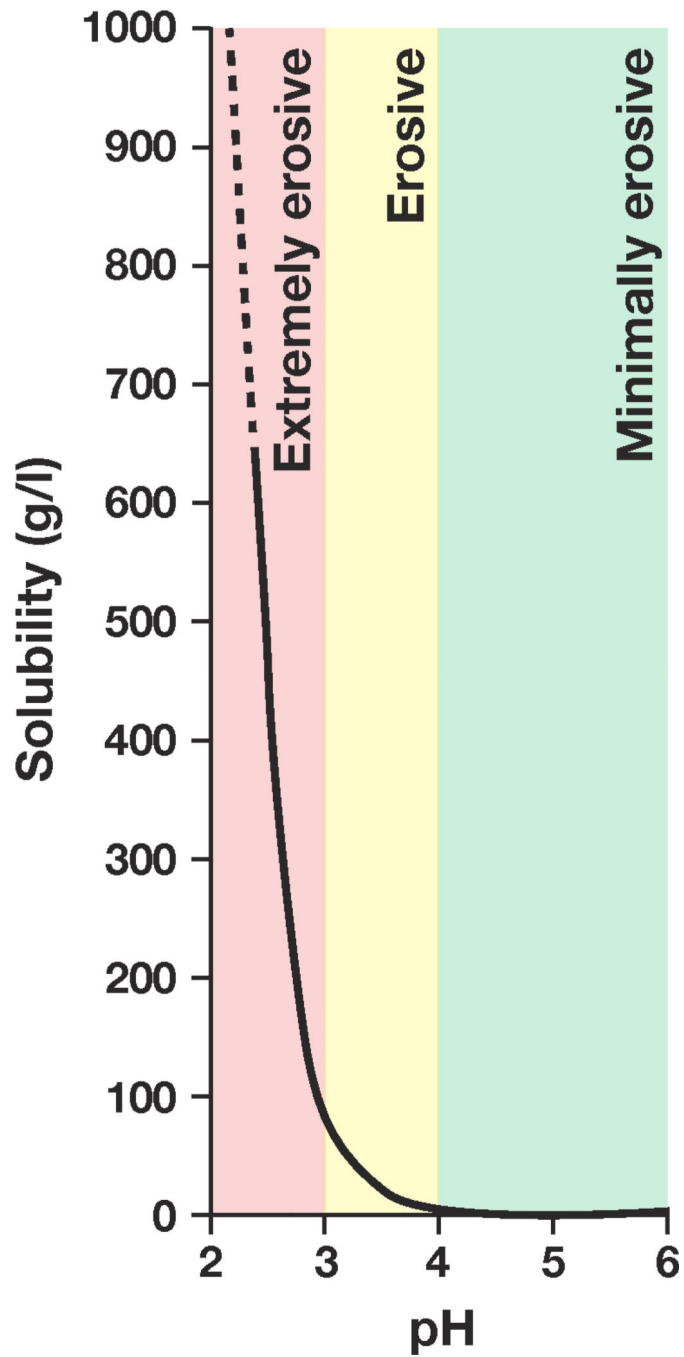


Fig 1. Erosion zones based on theoretical solubility of apatite as a function of pH; adapted with permission from Larsen and Nyvad³⁰

Table 1pH of waters and sports drinks (pH \pm standard deviation, n = 3).

Active Water® Focus Dragonfruit	2.82 \pm 0.04	Powerade® Zero – Orange	2.93 \pm 0.01
Active Water® Power Strawberry Kiwi	3.38 \pm 0.03	Propel® Berry	3.01 \pm 0.00
Active Water® Vigor Triple Berry	2.67 \pm 0.01	Propel® Grape	3.10 \pm 0.01
Aquafina® regular	6.11 \pm 0.23	Propel® Kiwi Strawberry	3.17 \pm 0.00
Birmingham Municipal Water	7.20 \pm 0.05	Propel® Lemon	3.03 \pm 0.00
Clear American® (flavored water) Kiwi Strawberry	3.70 \pm 0.01	S. Pellegrino® sparkling natural mineral water	4.96 \pm 0.09
Clear American® (flavored water) Pomegranate Blueberry Acai	3.24 \pm 0.01	Skinny Water® Acai Grape Blueberry	3.81 \pm 0.02
Clear American® (flavored water) Tropical Fruit	3.07 \pm 0.01	Skinny Water® Goji Fruit Punch	3.67 \pm 0.01
Clear American® (flavored water) White Grape	3.43 \pm 0.01	Skinny Water® Raspberry Pomegranate	3.68 \pm 0.01
Dasani® Grape	3.05 \pm 0.01	Sobe Life Water® Acai Fruit Punch	3.22 \pm 0.01
Dasani® Lemon	3.03 \pm 0.01	Sobe Life Water® Blackberry Grape	3.15 \pm 0.01
Dasani® Strawberry	3.03 \pm 0.01	Sobe Life Water® Cherimoya Punch	3.28 \pm 0.00
Dasani® regular	5.03 \pm 0.04	Sobe Life Water® Strawberry Dragonfruit	3.32 \pm 0.01
Gatorade® Frost Riptide Rush	2.99 \pm 0.01	Sobe Life Water® Fuji Apple Pear	3.53 \pm 0.01
Gatorade® Rain Lime	3.19 \pm 0.01	Sobe Life Water® Mango Melon	3.29 \pm 0.01
Gatorade® Rain Strawberry Kiwi	3.17 \pm 0.01	Vidration Vitamin Enhanced Water® Defense Pomegranate Acai Blueberry	2.92 \pm 0.01
Gatorade® Blueberry Pomegranate Low Calorie	3.21 \pm 0.01	Vidration Vitamin Enhanced Water® Energy Tropical Citrus	2.91 \pm 0.01
Gatorade® Fierce Grape	3.05 \pm 0.00	Vidration Vitamin Enhanced Water® Multi V-Lemon Lime	3.59 \pm 0.01
Gatorade® Fierce Melon	3.05 \pm 0.00	Vidration Vitamin Enhanced Water® Recover Fruit Punch	3.61 \pm 0.01
Gatorade® Fruit Punch	3.01 \pm 0.01	Vitamin Water® Connect Black Cherry Lime	2.96 \pm 0.01
Gatorade® Lemon Lime	2.97 \pm 0.01	Vitamin Water® Dwnld Berry Cherry	3.04 \pm 0.01
Gatorade® Orange	2.99 \pm 0.00	Vitamin Water® Energy Tropical Citrus	3.15 \pm 0.01
Gatorade® Rain Berry	3.17 \pm 0.01	Vitamin Water® Essential orange orange	3.23 \pm 0.00
Perrier® carbonated mineral water	5.25 \pm 0.10	Vitamin Water® Focus Kiwi Strawberry	3.04 \pm 0.01
Powerade® Fruit Punch	2.77 \pm 0.01	Vitamin Water® Multi-V lemonade	3.19 \pm 0.01
Powerade® Grape	2.77 \pm 0.01	Vitamin Water® Power C Dragonfruit	3.05 \pm 0.00
Powerade® Lemon Lime	2.75 \pm 0.01	Vitamin Water® Revive Fruit Punch	3.65 \pm 0.01
Powerade® Mountain Berry Blast	2.82 \pm 0.01	Vitamin Water® Spark Grape Blueberry	3.19 \pm 0.01
Powerade® Orange	2.75 \pm 0.02	Vitamin Water® XXX Acai Blueberry Pomegranate	2.98 \pm 0.01
Powerade® Sour Melon	2.73 \pm 0.00	Vitamin Water® Zero Mega C Grape Raspberry	3.05 \pm 0.00
Powerade® Strawberry Lemonade	2.78 \pm 0.01	Vitamin Water® Zero Recoup Peach Mandarin	3.01 \pm 0.01
Powerade® White Cherry	2.81 \pm 0.01	Vitamin Water® Zero Rise Orange	3.46 \pm 0.00
Powerade® Zero Grape	2.97 \pm 0.01	Vitamin Water® Zero Squeezed Lemonade	3.19 \pm 0.00
Powerade® Zero -Lemon Lime	2.92 \pm 0.00	Vitamin Water® Zero XXX Acai Blueberry Pomegranate	3.05 \pm 0.01
Powerade® Zero -Mixed Berry	2.93 \pm 0.01	Vitamin Water® Zero-Go Go Mixed Berry	3.08 \pm 0.01

Red = extremely erosive, Yellow = erosive, Green = minimally erosive.

Table 2pH of (A) fruit juices, (B) fruit drinks (pH \pm standard deviation, n = 3).

A			
Amp® Energy juice-Mixed Berry	3.62 \pm 0.01	Ocean Spray® Pineapple Peach Mango Juice Blend	3.64 \pm 0.01
Amp® Energy juice-Orange	3.60 \pm 0.01	Ocean Spray® Ruby Red	3.07 \pm 0.01
Barber's® Orange Juice	3.81 \pm 0.01	Ocean Spray® Strawberry Kiwi Juice Cocktail	2.90 \pm 0.01
Campbell's® Tomato Juice	4.01 \pm 0.01	Ocean Spray® Orange Juice	3.83 \pm 0.01
Dole® Pineapple Juice	3.40 \pm 0.01	Simply® Apple	3.67 \pm 0.01
Juicy Juice® Apple	3.64 \pm 0.01	Simply® Orange Orange Juice	3.78 \pm 0.00
Juicy Juice® Berry	3.78 \pm 0.01	Tango® energy juice	3.47 \pm 0.00
Juicy Juice® Sparkling Apple	3.47 \pm 0.01	Tropicana® 100% Juice-Apple Juice	3.50 \pm 0.02
Juicy Juice® Sparkling Berry	3.50 \pm 0.01	Tropicana® 100% Juice-Orange Juice	3.80 \pm 0.01
Juicy Juice® Sparkling Orange	3.49 \pm 0.01	Tropicana® Apple Orchard Style Juice	3.57 \pm 0.00
Lemon Juice	2.25 \pm 0.01	Tropicana® Grape Juice	3.29 \pm 0.01
Minute Maid® Apple Juice	3.66 \pm 0.01	Tropicana® Orange Juice (with Calcium)	4.09 \pm 0.01
Minute Maid® Cranberry Apple Raspberry	2.79 \pm 0.01	V8 Fusion® Cranberry Blackberry	3.56 \pm 0.01
Minute Maid® Cranberry Grape	2.71 \pm 0.01	V8Fusion® Pomegranate Blueberry	3.66 \pm 0.00
Minute Maid® Natural Energy Mango Tropical	3.34 \pm 0.02	V8 Fusion® Strawberry Banana	3.66 \pm 0.00
Minute Maid® Natural Energy Pomegranate Berry	3.33 \pm 0.01	V8 Splash® Berry Blend	2.94 \pm 0.01
Minute Maid® Natural Energy Strawberry Kiwi	3.40 \pm 0.01	V8 Splash® Strawberry Kiwi	2.99 \pm 0.01
Minute Maid® Orange Juice	3.82 \pm 0.01	V8 Splash® Tropical Blend	2.93 \pm 0.00
Minute Maid® Pineapple Orange	3.71 \pm 0.01	V8 Vegetable Juice® low sodium	4.17 \pm 0.01
Minute Maid® Ruby Red Grapefruit Juice	3.07 \pm 0.03	V8 Vegetable Juice®	4.23 \pm 0.01
Naked® Blue Machine	3.81 \pm 0.01	V8 Vegetable Juice Spicy Hot®	4.19 \pm 0.00
Naked® Orange Mango	3.75 \pm 0.01	Very Fine® Grapefruit Juice	3.22 \pm 0.03
Naked® Protein Zone	4.69 \pm 0.01	Welch's® Apple Juice	3.57 \pm 0.01
Ocean Spray® Cranberry	2.56 \pm 0.00	Welch's® Orange Juice	3.73 \pm 0.00
Ocean Spray® Cran-Grape	2.79 \pm 0.01	Welch's® 100% Grape Juice	3.38 \pm 0.00
Ocean Spray®Cran-Pomegranate	2.72 \pm 0.01		
B			
Barber's® Fruit Punch	3.15 \pm 0.00	Minute Maid® Pink lemonade	2.59 \pm 0.00
Barber's® Lemonade	2.69 \pm 0.00	Mondo® (Legendary Berry)	3.07 \pm 0.01
Barber's® Orange Drink	2.96 \pm 0.00	Mondo® (primo punch)	3.10 \pm 0.01
Bug Juice® Berry Raspberry	2.99 \pm 0.01	Sesame Street® Elmo's Punch	3.87 \pm 0.01
Bug Juice® Fruity Punch	3.09 \pm 0.00	Simply® Lemonade	2.61 \pm 0.01
Bug Juice® Grapey grape	2.83 \pm 0.00	Snapple® Kiwi Strawberry	2.77 \pm 0.01
Bug Juice® Leapin Lemonade	3.06 \pm 0.00	Snapple® Mango Madness	2.89 \pm 0.01
Bug Juice® Whistlin Watermelon	3.40 \pm 0.01	Sobe® Black and Blueberry Brew	2.69 \pm 0.00
CapriSun® Surfer Cooler	3.08 \pm 0.00	Sobe® Citrus Energy	2.63 \pm 0.00
Country Time® Lemonade	2.72 \pm 0.01	Sobe® Fuji Apple Cranberry (Low Calorie)	3.16 \pm 0.01
Crystal Lite® Fruit Punch	2.96 \pm 0.02	Sobe® Orange Carrot	3.34 \pm 0.00
Crystal Lite® Green Tea Raspberry Mix	3.11 \pm 0.02	Sobe® Pina Colada	3.25 \pm 0.01

Crystal Lite® Raspberry Ice	2.77 ± 0.01	Sobe® Power Fruit Punch	2.43 ± 0.02
Fuze® Banana Colada	3.45 ± 0.03	Sobe® Strawberry Banana	2.62 ± 0.01
Fuze® Blueberry Raspberry	3.20 ± 0.01	Sun Fresh® Lemonade	2.68 ± 0.01
Fuze® Green Tea-Honey and Ginseng	3.28 ± 0.02	Sunny D® Smooth	2.92 ± 0.01
Fuze® Orange Mango	3.34 ± 0.02	Sunny D® Tangy Original	2.86 ± 0.01
Fuze® Peach Mango	3.53 ± 0.01	Tahitian Treat® Fruit Punch	3.01 ± 0.01
Fuze® Strawberry Banana	3.54 ± 0.01	Tropicana® Cranberry Cocktail	2.70 ± 0.01
Fuze® Strawberry Guava	3.55 ± 0.02	Tropicana® Juice Beverage Cranberry	2.59 ± 0.00
Fuze® Strawberry Melon	3.18 ± 0.01	Tropicana® Juice Beverage-Grape	2.58 ± 0.00
Fuze® Tropical Punch	3.17 ± 0.01	Tropicana® Lemonade	2.70 ± 0.01
HiC® Tropical	2.81 ± 0.03	Tropicana Twister® Blue Raspberry Rush	2.62 ± 0.00
Jumex® Guava	3.38 ± 0.02	Tropicana Twister® Cherry Berry Blast	2.63 ± 0.00
Jumex® Mango	3.41 ± 0.01	Tropicana Twister® Orange Strawberry Banana Burst	2.89 ± 0.01
Jumex® Peach	3.33 ± 0.02	Tropicana Twister® Strawberry Kiwi Cyclone	2.59 ± 0.01
Jumex® Strawberry Banana	3.68 ± 0.01	TumE Yummies® Fruitabulous Punch	3.35 ± 0.00
Kool Aid® Burst (Tropical)	3.07 ± 0.01	TumE Yummies® Orangearific	3.34 ± 0.01
Kool Aid® Mix- Lemon Lime	Kool Aid® Mix- Lemon Lime	TumE Yummies® Soursational Raspberry	3.18 ± 0.00
Kool Aid® Mix- Pink Lemonade	2.66 ± 0.01	TumE Yummies® Very Berry Blue	3.33 ± 0.00
Kool Aid® Mix- Pink Lemonade	2.66 ± 0.01	TumE Yummies® Very Berry Blue	3.33 ± 0.00
Kool Aid® Mix- Tropical Punch	2.69 ± 0.00	Vitamin Stix® Dragonfruit Acai	3.11 ± 0.01
Kool Aid® Mix-Cherry	2.71 ± 0.00	Vitamin Stix® Passonfruit Citrus	3.19 ± 0.01
Kool Aid® Mix-Grape	2.83 ± 0.01	Vitamin Stix® Strawberry kiwi	3.06 ± 0.01
Kool Aid® Mix-Orange	2.77 ± 0.01	Welch's® Blueberry Kiwi Blast	2.57 ± 0.01
Little Hug® Grape	3.09 ± 0.01	Welch's® Cranberry	2.59 ± 0.02
Little Hug® Orange	3.00 ± 0.01	Welch's® Grape juice cocktail	2.92 ± 0.01
Minute Maid® Fruit Punch	2.86 ± 0.00	Welch's® Orange Pineapple	3.20 ± 0.01
Minute maid® Lemonade	2.57 ± 0.01	Welch's® Ruby Red Grapefruit Juice	2.97 ± 0.01
Minute Maid® Orangeade	2.85 ± 0.00	Welch's® Strawberry Kiwi	3.03 ± 0.01

Red = extremely erosive, Yellow = erosive, Green = minimally erosive.

Table 3pH of sodas (pH \pm standard deviation, n = 3).

7up®	3.24 \pm 0.02	Hansen's® Cane Soda-Pomegranate	2.55 \pm 0.00
7up® Cherry	2.98 \pm 0.01	Hawaiian Punch® (fruit Juicy Red)	2.87 \pm 0.01
7up® Diet	3.48 \pm 0.00	IBC® Rootbeer	4.10 \pm 0.02
A&W® Cream Soda	3.86 \pm 0.01	Izze® Sparkling Blackberry	3.28 \pm 0.01
A&W® Rootbeer	4.27 \pm 0.02	Izze® Sparkling Clementine	3.27 \pm 0.01
A&W® Rootbeer-Diet	4.57 \pm 0.00	Izze® Sparkling Pomegranate	3.01 \pm 0.01
Ale 8-One®	3.13 \pm 0.01	Jolly Rancher® Orange	2.88 \pm 0.01
Barq's® Rootbeer	4.11 \pm 0.02	Jolly Rancher® Grape	2.60 \pm 0.01
Boylan's® Black Cherry	2.76 \pm 0.02	Jones® Blue Bubblegum	2.99 \pm 0.01
Boylan's® Crème Soda	4.17 \pm 0.02	Jones® Cream Soda	3.04 \pm 0.01
Boylan's® Diet Black Cherry	4.00 \pm 0.01	Jones® Green Apple Soda	2.65 \pm 0.01
Boylan's® Diet Rootbeer	4.05 \pm 0.02	Jones® M.F. Grape	2.89 \pm 0.02
Boylan's® Grape	2.91 \pm 0.01	Jones® Mandarin Orange	2.93 \pm 0.00
Boylan's® Orange Cream	3.59 \pm 0.01	Jones® Orange & Cream Soda	2.79 \pm 0.01
Boylan's® Orange Soda	3.22 \pm 0.00	Jones® Red Apple	3.40 \pm 0.02
Boylan's® Original Birch Beer	3.80 \pm 0.00	Jones® Root Beer	3.42 \pm 0.02
Boylan's® Rootbeer	4.01 \pm 0.01	Jones® Strawberry Lime	2.81 \pm 0.02
Boylan's® Sugar Cane Cola	2.54 \pm 0.01	Maine® Root Beer	4.36 \pm 0.02
Buffalo Rock® Ginger Ale	3.23 \pm 0.01	Mellow Yellow®	3.03 \pm 0.00
Canada Dry® Club Soda	5.24 \pm 0.03	Mountain Dew® (regular)	3.22 \pm 0.07
Canada Dry® Ginger Ale	2.82 \pm 0.01	Mountain Dew® Code Red	3.27 \pm 0.01
Coca-Cola® Classic	2.37 \pm 0.03	Mountain Dew® Diet	3.18 \pm 0.01
Coca-Cola® Zero	2.96 \pm 0.03	Mountain Dew® Voltage	3.05 \pm 0.01
Coca-Cola® Caffeine Free Diet	3.04 \pm 0.01	Mr. Pibb® xtra	2.80 \pm 0.01
Coca-Cola® Caffeine Free	2.34 \pm 0.03	Mug® Rootbeer	3.88 \pm 0.02
Coca-Cola®Cherry	2.38 \pm 0.03	Natural Brew Draft® Root Beer	2.90 \pm 0.00
Coca-Cola® Cherry Zero	2.93 \pm 0.01	Pepsi®	2.39 \pm 0.03
Coca-Cola® Diet	3.10 \pm 0.05	Pepsi®-Wild Cherry	2.41 \pm 0.03
Coca-Cola® Lime Diet	2.96 \pm 0.03	Pepsi Diet®	3.02 \pm 0.01
Crush® Grape	2.76 \pm 0.01	Pepsi Max®	2.74 \pm 0.01
Crush® Orange	2.87 \pm 0.01	Pepsi Max® Ceasefire	2.70 \pm 0.01
Crush® Orange	2.93 \pm 0.03	RC Cola®	2.32 \pm 0.02
Dr Pepper® Diet Cherry	3.32 \pm 0.01	Schweppes® Tonic Water	2.54 \pm 0.03
Dr. Pepper® Cherry	3.06 \pm 0.02	Sierra® Mist Diet	3.31 \pm 0.01
Dr. Pepper® Diet	3.20 \pm 0.00	Sierra® Mist	3.09 \pm 0.02
Dr. Pepper®	2.88 \pm 0.04	Sprite®	3.24 \pm 0.05
Fanta® Grape (2 liter)	2.67 \pm 0.02	Sprite® zero	3.14 \pm 0.01
Fanta® Pineapple (2 liter)	2.79 \pm 0.02	Sunkist® -Solar Fusion -Tropical Mandarin	3.02 \pm 0.01
Fanta® Orange	2.82 \pm 0.02	Sunkist® – Strawberry	2.99 \pm 0.01
Fanta® Strawberry	2.84 \pm 0.01	Sunkist® Diet	3.49 \pm 0.01

Fresca® (1 liter)	3.08 ± 0.01	Sunkist® Orange	2.98 ± 0.01
Grapico® Diet	3.04 ± 0.01	Sunkist® Peach	2.89 ± 0.01
Grapico®	2.77 ± 0.03	Tab®	2.72 ± 0.01
Hansen's® Cane Soda-Black Cherry Diet	3.47 ± 0.02	Vault®	2.77 ± 0.02
Hansen's® Cane Soda-Cherry Vanilla Crème	2.91 ± 0.01	Vault® Red Blitz	2.80 ± 0.01
Hansen's® Cane Soda-Creamy Rootbeer Diet	3.73 ± 0.01	Vault®	2.89 ± 0.03
Hansen's® Cane Soda-Kiwi Strawberry	2.59 ± 0.01	Welch's® grape soda	3.11 ± 0.02
Hansen's® Cane Soda-Mandarin Lime	2.57 ± 0.01		

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Table 4pH of (A) energy drinks, (B) teas and coffee (pH \pm standard deviation, n = 3).

A			
24:7® Energy Cherry Berry	2.61 \pm 0.01	Monster® low carb	3.60 \pm 0.01
180 Blue® Orange Citrus Blast	2.82 \pm 0.00	Monster® M-80	3.29 \pm 0.00
180 Blue® with Acai	2.82 \pm 0.01	Monster® MIXXD	3.35 \pm 0.00
5 hour energy® Berry	2.81 \pm 0.03	Monster Hitman® energy shot	3.44 \pm 0.01
5 hour energy® extra strength	2.82 \pm 0.00	Nitrous Monster® Anti-gravity	3.64 \pm 0.01
5 hour energy® Lemon-Lime	2.81 \pm 0.00	Nitrous Monster® Killer B	3.31 \pm 0.00
Amp energy® Elevate	2.79 \pm 0.01	Nitrous Monster® Super Dry	3.46 \pm 0.00
Amp energy® Overdrive	2.78 \pm 0.01	No Fear® regular	2.97 \pm 0.02
Amp energy® regular	2.81 \pm 0.01	No Fear® sugar free	3.06 \pm 0.01
Amp energy® sugar free	2.86 \pm 0.01	NOS® fruit punch	3.32 \pm 0.00
Crunk® Citrus	3.20 \pm 0.01	NOS® grape	3.27 \pm 0.01
Crunk® Energy Drink	3.31 \pm 0.01	NOS® high performance energy drink	3.31 \pm 0.01
Crunk® Grape Acai energy drink	3.30 \pm 0.01	Nos® power shot	3.03 \pm 0.02
Crunk® Low Carb Sugar Free	3.34 \pm 0.00	Orange County Choppers®	2.78 \pm 0.02
Drank®	3.09 \pm 0.01	Purple Stuff Lean®	2.87 \pm 0.01
Fuel Energy Shots® Lemon Lime	3.97 \pm 0.01	Redbull® regular	3.43 \pm 0.01
Fuel Energy Shots® Orange	3.44 \pm 0.01	Redbull® shot	3.25 \pm 0.03
Full Throttle® Blue Agave	3.10 \pm 0.01	Redbull® sugar free	3.39 \pm 0.00
Full Throttle® Citrus	3.09 \pm 0.01	Redbull® sugar free shot	3.28 \pm 0.02
Full Throttle® Red Berry	3.08 \pm 0.01	Redline® Peach mango	2.74 \pm 0.02
Hydrive® Blue Raspberry	3.45 \pm 0.01	Redline® Princess exotic fruit	2.85 \pm 0.01
Hydrive® Citrus Burst	3.03 \pm 0.01	Redline® Triple Berry	2.77 \pm 0.01
Hydrive® Lemon Lime	3.42 \pm 0.01	Redline Xtreme® Grape	3.23 \pm 0.01
Hydrive® Triple Berry	3.15 \pm 0.01	Redline Xtreme® Triple Berry	3.24 \pm 0.01
Jolt® Blue Bolt	2.96 \pm 0.00	Redline Xtreme® Watermelon	3.41 \pm 0.00
Jolt® Passion Fruit	2.82 \pm 0.01	Rhinos® Energy Drink	3.51 \pm 0.01
Jolt® Power Cola	2.47 \pm 0.01	Rhinos® Sugar Free Energy Drink	3.32 \pm 0.01
Jolt® Ultra: Sugar Free	3.14 \pm 0.00	Rockstar® Energy Cola	3.14 \pm 0.01
Killer Buzz®	3.23 \pm 0.01	Rockstar® Energy Drink	2.74 \pm 0.01
Killer Buzz® sugar free	3.36 \pm 0.00	Rockstar® Juiced -energy + guava	3.16 \pm 0.01
Meltdown® Energy Peach Mango	2.77 \pm 0.00	Rockstar® Juiced -energy + juice-Mango Orange Passion	3.05 \pm 0.01
Monster® Assault	3.58 \pm 0.01	Rockstar® Punched (Energy + Punch)	2.83 \pm 0.01
Monster® Energy	3.48 \pm 0.01	Rockstar® Recovery	2.84 \pm 0.01
Monster® Khaos	3.47 \pm 0.01	Rockstar® Sugar Free	3.15 \pm 0.03
B			
Admiral® Iced Tea Green Tea	3.72 \pm 0.01	Milos® No Calorie Famous Sweet Tea	5.18 \pm 0.03
Admiral® Iced Tea Mango	3.41 \pm 0.00	Nestea® Iced Tea with natural Lemon flavor	2.94 \pm 0.01
Admiral® Iced Tea Raspberry	2.94 \pm 0.00	Nestea® Red Tea pomegranate and passion fruit	2.87 \pm 0.01
Admiral® Iced Tea Sweet Tea	3.76 \pm 0.01	Red Diamond® Tea Fresh Brewed Sweet Tea	5.04 \pm 0.02

Arizona® Diet Green tea + Ginseng	3.29 ± 0.01	Snapple® Diet Raspberry Tea	3.39 ± 0.02
Arizona® Iced Tea	2.85 ± 0.03	Snapple® Diet Peach Tea	3.32 ± 0.01
Lipton® Green Tea with Citrus	2.93 ± 0.00	Snapple® Peach Tea	2.94 ± 0.01
Lipton® Green Tea with Citrus-Diet	2.92 ± 0.00	Snapple® Raspberry Tea	2.92 ± 0.00
Milos® Famous Sweet Tea	4.66 ± 0.02	Starbucks® Medium Roast	5.11 ± 0.05

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