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EVALUATION OF THE EROSION POTENTIAL OF FOURTEEN COMMERCIAL BEVERAGES BY MEASURING PH AND DETERMINING TITRATABLE ACIDITY

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Chemical factors that determine the erosive potential of food and beverages include pH value, mineral content, buffer properties (titratable acidity and buffer capacity), etc. The goal was to determine the pH and titratable acidity (TA) in fourteen commercially available beverages. Five carbonated soft drinks (among them two energy), two sports drinks, two fruit juices, two teas and three alcoholic drinks were evaluated. The initial pH was measured using a pH meter, and TA was determined by titration with NaOH. The pH and TA data were recorded as mean values of triplicate measurements ± standard deviation. The pH values ranged from 2.51 (Guarana No Sleep) to 6.64 (green tea), and TA ranged from 0.54 ml (Coca-Cola) to 4.28 ml (orange juice) of NaOH to reach pH 5.5, and 1.08 ml (chokeberry juice) to 5.83 ml (orange juice) to reach pH 7.0. Literature data suggest that unsaturated substances with low pH and high TA have a high erosive potential. Drinks such as Guarana No sleep, Schweppes Bitter Lemon, Coca Cola and Sprite were found to have a pH below 3.0 and can be extremely erosive (Guarana have the highest TA) if consumed frequently, and with the habit of holding in the mouth. Also, regular and large consumption of drinks with a high TA (orange juice and Red Bull) could increase the risk of dental erosion, regardless of their pH above 3.0. *Acta Medica Medianae 2023;62(3): 24-31.*

Key words: *dental erosion, commercial beverages, erosive potential, pH, titratable acidity*

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Introduction

Tooth erosion, which implies the demineralization of teeth without the participation of bacteria (1), has become a real challenge for both researchers and clinicians in recent years. The complexity of erosive damage requires constant scientific and professional analysis from multiple aspects in order to prevent disease and preserve dental health in the long term.

Acidic substances, which may have an internal or external origin, or both at the same time, are mainly responsible for tooth erosion. The most common external factors of dental erosion are fruit juices, carbonated drinks, sports and energy drinks (2–4) whose consumption has increased sharply in recent decades. According to the latest data, the leading consumers of soft drinks (especially carbonated) are the United States of America with 154 liters of annual consumption per inhabitant. In Europe, the leading countries in the consumption of soft drinks are Belgium with 109, followed by Germany and Norway with 98 liters of annual consumption per capita. Europe tops the consumption of energy drinks, while in the USA sports drinks are the most popular (5).

Acidic foods, as well as acidic dietary supplements (acidic fruits, pickled vegetables, salad dressings, acidic candies, chewable vitamin C tablets, etc.) can also have an erosive effect (2). Apart from the fact that it can occur in chronic alcoholics, tooth erosion can be a problem for people who are involved in wine tasting, because the prolonged contact of acidic drinks and enamel can result in its damage (6, 7). In endogenous erosions, the main reasons for gastric acid reaching the oral cavity are gastroesophageal reflux disease (GERD), vomiting during pregnancy, bulimia, anorexia nervosa, xerostomia and malabsorption syndrome (7).

The erosive potential of a substance (ability to cause dental erosion) depends on several chemical parameters, such as pH and buffer properties (titratable acidity -TA and buffer capacity, acid type, calcium and phosphate concentration (degree of saturation) and fluoride content (8). The pH value is an indicator of the initial concentration of hydrogen ions in the solution. Although it affects the degree of saturation (by determining the activity of PO43- and OH- ions), it represents an important independent factor of dissolution (9). According to many data from the literature, pH is a critical determinant of the erosive potential of beverages (10-12). Consumption of beverages with a higher concentration of available hydrogen ions (pH < 4.0) leads to an immediate softening of the tooth surface, which becomes susceptible to removal by abrasion and wear (8).

All acids, potential causes of erosive damage, are weak acids (except HCl) that are in an undissociated form at low pH values, but gradually dissociate with increasing pH (8). The following acids are found in food and drinks: phosphoric (cola drinks), citric (fruit, fruit juices, sports and energy drinks), acetic (vinegar, salad dressings, pickles), malic (apples, pineapples, grapes, orange juice, white wine), tartaric (grapes, champagne, red wine), lactic (cheese, yogurt, red wine) and ascorbic acid (vitamin C as a supplement to food and drink, some carbonated drinks - Sinalco, Izostar, etc.). Due to their gradual dissociation, weak acids act as buffers and thus oppose changes in pH value (13).

Although the pH value is an important factor of erosive potential, it does not provide information about the total acidity of the solution (drink or food), ie. about on the presence of undissociated acids. Titratable acidity, as a measure of solution buffering, is a strong indicator of higher concentrations of undissociated acid species in the erosive substance (8). The undissociated form of the acid is of great importance, because it has no charge and can diffuse more easily into the subsurface enamel layer ("near surface" layer). Once there, this species dissociates by acting as a proton (H+) carrier in the enamel mineral and maintains an acidic (unsaturated) state that promotes further dissolution. This means that the pH of the environment will remain low for longer, and enamel dissolution will continue to progress (14).

In this research, the goal was to measure the pH and TA of fourteen beverages, which are commercially available to the Serbian consumer, based on which certain recommendations would be given regarding the consumption of beverages that can cause erosive damage to teeth.

Material and methods

To test the erosive potential of beverages, by measuring pH and determining TA, 12 commercially available beverages and two types of tea were used: five carbonated soft drinks (Coca-Cola, Schweppes, Sprite and two energy drinks: Guarana and Red Bull), two fruit juices (orange and aronia), two sports drinks (Aqua Viva Recharge Strong and Isodrinx isotonic Sports Drink), two teas (green and black) and three alcoholic drinks (beer, white and red wine). Four commercial packages were used for each drink. Table 1 shows the compositions of the tested beverages as listed on their packaging.

In line with the published protocol (3, 15), the pH was measured using a previously calibrated multifunctional electronic device CONSORT C830 (Consort bvba, Belgium), with the 50 ml of beverage placed in a beaker and stirred using a non-heating magnetic stirrer until a reaching stable reading. TA was calculated as the volume of a 0.9613 M NaOH solution required to increase the pH of each beverage to 5.5 and 7.0. The solution was added in aliquot of 0.3 ml while stirring with a non-heating magnetic stirrer until a stable pH reading was achieved. The values of pH and TA, respectively, were determined three times for each drink and an average value was calculated.

The pH was measured immediately after opening the packaging (bottle or can) at room temperature, while the prepared teas were cooled to a temperature of 22 ºC.

Results

Initial pH values of the analyzed beverages and titratable acidity are expressed as mean values of triplicate measurements ± standard deviation (Table 2).

Four drinks (Guarana No sleep, Schweppes Bitter Lemon, Coca Cola and Sprite) had a pH below 3.0. Seven drinks had a pH range of 3.0−4.0 (including Riesling white wine with a pH of 3.02) and three drinks had a pH above 4.0 (chokeberry juice pH=4.04). Green and black tea showed not much lower pH values than neutral (6.64±0.02 and 6.61±0.04).

Coca-Cola showed a rapid response when adding only 0.54 ml of NaOH to reach a pH of 5.5, which is the lowest TA value measured, and 1.73 ml to reach a pH of up to 7.0. Orange juice had the highest TA, with 4.28 or 5.83 ml of NaOH to reach equivalent pH values, followed by Red Bull (3.27 and 5.21). Due to the high pH of teas (above 5.5), their TA was calculated only up to pH 7.00 and was 0.13±0.03 for green and 0.12±0.02 for black tea.

Table 1. Compositions of the tested drinks as listed on their respective packaging

	Beverages / Manufacturer	Composition
1.	**Coca-Cola** HBC – Srbija A.D. Zemun, Serbia	Water, sugar, carbon dioxide, caramel color (E150d), phosphoric acid, natural flavors including caffeine
2.	**Schweppes Bitter Lemon** HBC – Srbija A.D. Zemun, Serbia	Water, high fructose syrup, lemon juice, carbon dioxide, lemon extract, citric acid, flavors, preservative potassium sorbate, antioxidant ascorbic acid, stabilizers E 1450 and E 445, color carotene.
3.	**Sprite** HBC – Srbija A.D. Zemun, Srbija	Water, high fructose syrup, carbon dioxide, citric acid, acidity regulator sodium citrate, natural lemon and lime flavors, preservative sodium benzoate.
4.	**Guarana No Sleep** Knjaz Miloš A.D., Aranđelovac, Serbia	Water, sugar, carbon dioxide, citric acid, taurine, guarana aroma, caffeine, vitamin mixture, preservative: sodium benzoate, color: E150d
4.	**Red Bull** Red Bull, GmbH Fuschl am See, Austria	Water, sucrose, glucose, citric acid, carbon dioxide, taurine, acidity regulators, caffeine, vitamins, flavors, colors (caramel, riboflavin)
5	**Isodrinx Isotonic Sports Drink** Nutrend, D.S.Chvalkovice, Czech Republic	Water, sugar, glucose, acidity regulator, citric acid, sodium chloride, sodium citrate, white emulsion (stabilizers E1450 and E445), calcium gluconate, preservative potassium sorbate, potassium gluconate, preservative sodium benzoate, magnesium citrate, aroma, color brilliant blue
6.	**Aqua Viva Recharge** Knjaz Miloš, A.D., Aranđelovac, Serbia	Water, fructose, dextrose, citric acid, sodium citrate, potassium phosphate, magnesium carbonate, table salt, preservatives: E202 and E211, stabilizers E414 and E445, red orange flavor, sweetener E960 - steviol glycosides, colors E110 and E122
7.	**Life Premium 100% voćni sok pomarandža** Nectar D.O.O. Bačka Palanka, Serbia	Water, concentrated orange juice, citric acid
8.	**Chokeberry juice** Loveberry, Valjevo, Serbia	Anthocyanins, proanthocyanidins, phenolic acids, flavanols, pectins, organic acids, proteins, carbohydrates, vitamin C, vitamin E, carotenoids, iodine, potassium, calcium and magnesium
10.	**Zaječarsko Pivo** Heineken Srbija D.O.O. Zaječar, Serbia	Water, barley malt, corn grits, hop extract
11.	**Crnogorski Vranac Red Wine** 13. Jul Plantaže A.D., Podgorica, Montenegro	Water, alcohol 12%, glycerol, organic acids, tannins, phenols, anthocyanins, flavan-3-ols, flavonols
12.	**Royal Grozd – Rizling** dry white wine Vinarija Levač D.O.O Rekovac, Serbia	Water, alcohol 10.5%, lactic acid, malic acid, tartaric acid, citric acid, succinic acid, acetic acid and sulfates
13.	Green tea in filter bags Adonis pharmacy, Soko Banja Niš, Serbia	Caffeine, theophylline, theobromine, kaempferol, quercetin, chlorogenic acid, caffeic acid, gallic acid, catechin tannins, heterosides of terpene alcohols, fats, proteins, minerals, vitamin C, vitamin B
14.	Black tea In filter bags Adonis pharmacy Soko Banja Niš, Serbia	Caffeine, theophylline, theobromine, kaempferol, quercetin, caffeic acid, gallic acid, fats, proteins, minerals, fluorine, vitamin C, vitamin E

pH and titratable acidity (TA) measurement

Table 2. Initial pH and TA of the beverages

	Beverages	Initial pH±s.d.	TA±s.d. up to pH	
			5,5	7,0
1.	Coca Cola	2.56±0.06	0.54±0.05	1.73±0.07
2.	Schweppes Bitter Lemon	2.54±0.03	2.72±0.05	4.37±0.05
3.	Sprite	2.71±0.04	1.87±0.03	2.85±0.06
4.	Guarana No Sleep	2.51±0.03	3.24±0.03	4.96±0.05
5.	Red Bull	3.32±0.08	3.27±0.05	5.21±0.04
6.	Isodrinx Isotonic Sports Drink	3.43±0.02	1.55±0.03	2.41±0.05
7.	Aqua Viva Recharge (red orange) Strong	3.18±0.03	1.84±0.06	3.14±0.04
8.	Life Premium 100% orange juice	3.82±0.04	4.28±0.03	5.83±0.05
9.	Chokeberry juice	4.04±0.04	0.71±0.03	1.08±0.05
10.	Zaječar light beer	3.96±0.05	0.64±0.05	1.59±0.07
11.	Red wine *Kratošija*	3.49±0.05	1.82±0.04	2.34±0.03
12.	White wine *Rizling*	3.02±0.06	2.69±0.03	3.18±0.05
13.	Green tea	6.64±0.02	/	0.13±0.03
14.	Black tea	6.61±0.04	/	0.12±0.02

Discussion

Many authors pointed out the complexity of the erosive process in which, in addition to chemical parameters, physical factors are also important (flow rate - swishing or holding the drink in the mouth, frequent consumption - numerous short periods of acid exposure, temperature of the drink, adhesive ability). In addition, three biological factors are of great importance: the structure of the teeth, the influence of saliva, and the acquired pellicle. Whether the erosive potential of the beverage will succeed in manifesting itself through erosive damage to the teeth will depend on host factors and exposure conditions (2, 5, 16-18).

The pH measure of the substance acidity is an important indicator of dental erosion: as pH decreases, erosive damage increases, regardless of the way erosion is measured (9). At low pH, it is possible that some other influences are strong enough to prevent erosion, but also, erosion can progress in a solution with a relatively high pH in the absence of facilitating factors. This means that calcium and phosphate concentration, in combination with pH, determine the degree of saturation with respect to tooth minerals. It has therefore been suggested that there is no fixed critical pH for tooth erosion (9). This value is calculated based on the concentration of calcium and phosphate in the erosive solution. Lussi et al. published critical pH values (pHc) in relation to hydroxyapatite for various beverages, acidic food supplements and medications and found that they ranged from 3.9 to 6.5. From these data, the critical pH values of several beverages, whose erosive potential was determined in this paper, were extracted (Coca Cola 5.1; Sprite 6.5; orange juice 3.6; beer 5.0; red wine 5.1; white wine 5.1; and black tea 5.6) (19). Nevertheless, in this study the aim was to measure the initial pH and determine the TA, while the measurement of the concentration of calcium and phosphate was not in its focus.

The range of pH values was from 2.51±0.03 (Guarana No Sleep) to 6.64±0.02 (green tea). The obtained pH results for individual beverages are similar to reports of pH values of beverages published by other researchers, for example, pH of Coca Cola drink 2.56 compared to 2.45 (2), 2.67

(3), 2.55 (4); Red Bull energy drink pH was 3.32 compared to 3.30 (2), 3.81 (20), 3.35 (4); orange juice pH 3.82 compared to 3.56 (2), 3.60 (21); red wine pH 3.49 compared to 3.48 (21); white wine 3.02 compared to 3.60 (2).

Other authors, examining the erosive potential of the same beverage of different brands, found that the range of beer pH is 4.26–4.34 (22) (in the present study 3.96), white wine is 2.99–3.56 (23) (in the present study 3.02), red wine 3.43–3.68 (2) and 3.75–4.02 (23) (in the present study 3.49).

There was a smaller or larger difference in the pH values of the teas compared to the literature data, which can be explained by the differences in the type of tea (ready-made teas or those that are prepared immediately before consumption). In the present study green tea had a pH of 6.64 compared to 5.4 (24) and 6.75 (25) and black tea 6.61 compared to 5.0 (24) and 7.02 (25).

As for sports drinks, this study included domestic brands - Isodrinks Isotonic Sports Drink (pH 3.43) and Aqua Viva Recharge (pH 3.18), which could only be compared with sports drinks of those brands that are published in the literature, such as Gatorade with pH 3.17 (2) and 2.89 (4) or Isostar (pH 3.87) (2). Also, there are no data on testing the erosive potential of chokeberry juice.

Reddy et al. published an extensive study on calculating the pH of 380 commercially available soft drinks in the US (10). Based on a study of apatite solubility (11) indicating a logarithmic increase in apatite solubility as pH decreases under laboratory equilibrium conditions, Reddy et al. proposed to separate the chemical erosive potential of beverages into 3 zones: the zone of highly erosive beverages with pH <3, the zone of erosive beverages (pH from 3.0 to 3.99) and the zone of minimally erosive beverages (pH ≥4.0) (10). According to this recommendation, in present paper, all carbonated drinks except Red Bull would belong to highly erosive drinks, the erosive zone would include orange juice, sports and alcoholic drinks, as well as Red Bull, and minimally erosive drinks such as chokeberry juice, green and black tea.

According to Redi et al., knowledge of beverage pH is essential for the development of prevention in patients prone to erosive tooth damage. Their advice for erosion prevention is 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) (10).

Regardless of this emphasized theoretical approach to the solubility of apatite as a function of pH, a low pH value of an erosive substance (drink) does not necessarily mean enamel dissolution. As already mentioned, the erosive potential of the drink will also depend on the content of calcium and phosphate ions, which can be considered protective factors (2, 4, 20). One example is yogurt, which has a pH of around 4, but is not erosive due to the high concentrations of these ions (2, 4).

From a chemical point of view, the type of acid in the erosive solution (drink) is also important. Apart from mono (acetic and lactic) and diprotic (malic and tartaric) acids, triprotic acids, which include citric and phosphoric, are particularly noteworthy. Citric acid can produce three hydrogen ions from each molecule that directly dissolves enamel minerals by reacting with carbonate or phosphate ions. Apart from hydrogen ions, the aqueous solution of citric acid contains acidic anions (citrates) and undissociated acid molecules. Given the number of hydrogen ions in the molecule, this acid will dissociate in three phases. On the other hand, the citrate anion can form complexes with calcium, removing it from the crystal surface. The activity of citric acid also depends on the pH. At lower pH values, this acid dissociates to provide hydrogen ions that directly attack the surface of the mineral, and at higher pH, the citrate ion extracts calcium from the surface of the crystal. At medium pH values, both mechanisms function. Citric acid thus shows a double harmful effect by demineralizing the tooth surface (8). Similar to citric acid, phosphoric acid also belongs to the class of triprotic, with three values of the dissociation constant, providing hydrogen ions at a lower pH and bonding with calcium in solution at a higher pH value. The difference is in the formation of complexes with calcium, which are stronger with citrate and have a three-dimensional shape of the molecule (8, 14).

The buffer properties of an aqueous solution represent a measure of resistance to pH changes and can be expressed through titratable acidity (the amount of base in mmol/L, required to raise the pH to a defined level of 5.5 and/or 7.0) and buffer capacity (determining how much base can withstand a solution without changing the pH value) (12, 14). This study focused on the determination of titratable acidity, a parameter of erosive potential that is considered more suitable than buffering capacity because it maintains longer the concentration of hydrogen ions available for interaction with the tooth surface, i.e. has a "closer" relationship with the concentration of undissociated acid (14). In relation to pH, Jensdottir et al. found a significant correlation between TA and dental tissue dissolution after long-term exposure to soft drinks (24 hours), while after short-term exposure (3 min) erosion was related to pH and not to TA. Therefore, it has been suggested that TA is a better indicator of erosive potential during longer erosive challenges and pH is more accurate for short exposure (26).

The TA values measured in this study were similar to the results of other authors (15, 27, 28), when comparing the values in milliliters of added base until reaching pH 5.5 or 7, 0. Contemporary literature suggests that TA should be calculated as a concentration in mmol/L, which is more chemically correct and allows for easier comparison (5, 8, 9). Therefore, the value levels of this erosive potential parameter in the present research did not always correspond to the data from studies that used the recommended units (2, 4, 29, 30).

Conclusion

Although erosion is a multifactorial condition, which depends on many risk and protective factors, this research has pointed out some chemical aspects that are important for the erosive potential of some commercially available beverages. Literature data suggest that unsaturated substances with low pH and high titratable acidity have a high erosive potential. Drinks such as Guarana No sleep, Schweppes Bitter Lemon, Coca Cola and Sprite were found to have a pH below 3.0 and can be extremely erosive (among them is Guarana with the highest TA) if consumed frequently, and, for example, with the habit of holding in the mouth. Also, regular and large consumption of drinks with a high TA (orange juice and Red Bull) could increase the risk of dental erosion, regardless of the fact that their pH is above 3.0. Therefore, knowledge of the beverages/food erosive potential (pH and TA) is very important and should be an integral part of the preventive strategy of erosive dental damage.

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EVALUACIJA EROZIVNOG POTENCIJALA ČETRNAEST KOMERCIJALNIH NAPITAKA PREMA PH VREDNOSTI I TITRABILNOJ KISELOSTI

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Hemijski faktori koji određuju erozivni potencijal hrane i pića uključuju pH vrednost, sadržaj minerala, puferska svojstva (titrabilnu kiselost i puferski kapacitet) itd. Cilj ovog rada bio je da se odrede pH vrednost i titrabilna kiselost (TK) četrnaest komercijalno dostupnih napitaka. Procenjivano je pet gaziranih bezalkoholnih pića (među njima dva energetska), dva sportska napitka, dva voćna soka, dva čaja i tri alkoholna pića. Početna pH vrednost napitaka merena je pH metrom, a TK je određena titracijom sa NaOH. Podaci o pH i TK zabeleženi su kao srednje vrednosti trostrukih merenja ± standardna devijacija. Vrednosti pH kretale su se od 2,51 (Guarana No Sleep) do 6,64 (zeleni čaj), a TK od 0,54 ml (Coca-Cola) do 4,28 ml (sok od pomorandže) NaOH da bi se pH dovela do pH 5,5 i od 1,08 (sok od aronije) do 5,83 (sok od pomorandže) do dostizanja neutralne vrednosti pH. Podaci iz literature sugerišu da nezasićene supstance sa niskom pH vrednosti i visokom TK imaju visok erozivni potencijal. Ustanovljeno je da pića Guarana No sleep, Schweppes Bitter Lemon, Coca-Cola i Sprite imaju pH vrednost ispod 3,0 (među njima Guarana ima najveću vrednost TK), te mogu biti izuzetno erozivna ako se konzumiraju često i uz naviku zadržavanja u ustima. Takođe, redovna i u velikim količinama konzumacija pića sa visokom TK (sok od pomorandže i Red bull) mogla bi povećati rizik od dentalne erozije, bez obzira na to što je njihova pH vrednost iznad 3,0. Poznavanje erozivnog potencijala (pH i TK) pića/hrane veoma je važno i treba da bude sastavni deo preventivne strategije erozivnih oštećenja zuba. *Acta Medica Medianae 2023;62(3):24-31.*

***Ključne reči**: erozija zuba, komercijalna pića, erozivni potencijal, pH, titrabilna kiselost*