7 pH

pH is defined as "the negative log of the hydrogen ion (H^+) activity," although "concentration" is often substituted for "activity" in a working definition.[385] In other words, if the pH is 7.0, the H^+ concentration ($[H^+]$) is 10^{-7} moles per L; if the pH is 3, the concentration is 10^{-3}. Water with a pH below 7 is "acidic," and water with a pH above 7 is "basic" or "alkaline." The definition of "normal" water pH varies between authorities, but it is usually described as somewhere between 5.5-6.5 and 8-9. By comparison, vinegar is pH 3, colas are between 3-4, beer is between 4-5, and milk is around pH 6.4. A related measurement, alkalinity, is based upon the capacity of a water sample to resist a change in pH and is usually reported as mg/L of $CaCO_3$. The pH controls solubility and concentrations of elements in water. For example, many metals precipitate out of alkaline water, whereas many dissolve in acidic water.

Water pH impacts the effectiveness of various water treatments and its palatability for animals. For example, the effectiveness of chlorination is reduced at a high pH. Low pH may precipitate or inactivate medications commonly delivered in drinking water. Sulfonamides are a particular concern in this respect as precipitated medication may leach back into the water after treatment has ended, contributing to potential drug residues in food animals. Acidic water tends to have a sour taste; basic is described as metallic. The taste threshold for hydrochloric acid is as low as 0.0001 mol/L.[385] Acid water also tends to dissolve metals from plumbing and soil it contacts, further impacting palatability.

Function

In the body, extracellular fluid (ECF) is normally maintained within a very narrow range centered around pH 7.4.[385,386] A number of critical physiological processes are pH-dependent, thus any significant departure from "normal" may be harmful to the organism.[386]

Metabolism

The acid-base balance in mammals represents a dynamic equilibrium between metabolic acid production and its elimination. As such, it is influenced by a number of interdependent processes, especially respiration and urine production, chemical buffering by bone and other tissues, and several dietary elements. A comprehensive review of these processes is beyond the scope of this report, but, in brief, a decrease in plasma pH from normal (acidosis) stimulates increased respiration, decreasing the blood concentration of CO_2 that would otherwise react with water to form carbonic acid (H_2CO_3). It also stimulates the kidney to produce urine that is more acidic. It does this by increasing elimination of the H^+ ion. The net result is an active elimination of acid and an increase in plasma pH back towards normal.[385,386] The H^+ ion may also react chemically with buffering molecules in bone, minimizing the magnitude of any pH change.[387,388]

Certain nutrients, referred to as "strong ions," while not acidic or basic in the chemical sense, influence animals' acid-base balance by shifting the equilibrium of internal homeostatic processes to enhance or inhibit the elimination of H^+ from the body. For example, diets rich in Na^+ and K^+ tend to "push" the body in the alkaline direction, whereas Cl^-, as ammonium chloride (NH_4Cl), is used clinically to move the balance in an acidic direction. Dairy nutritionists compound rations on the basis of the "strong ion difference" equation $((Na^++K^+)-(Cl^-+S^{2-}))$.[386] Diets with a negative strong ion difference produce mild acidosis shortly before lactation, which decreases the incidence of milk fever.[389-391]

Toxicity

Excessively acid or basic drinking water can theoretically affect animals in four ways. First, extremes of pH may result in tissue damage to the mouth and oropharynx, causing irritation and refusal to drink. Second, unusual extremes of pH may dissolve materials from pipes, ditches, etc., which are toxic or impart an unpleasant taste to the water. For example, Cu, Fe, and Pb concentrations have all been shown to increase in acidic water as a result of leaching the metals from plumbing.[392-395] Consumption of acidic drinks *may* dissolve dental enamel and weaken teeth.[396,397] Finally, consumption of a large amount of excessively acid or basic water could theoretically shift the body's acid-base balance.

We were unable to find any reports detailing acute toxicity as a result of drinking extremely acid or basic water, although co-author Merl Raisbeck has investigated field cases in which cattle drank extremely basic solutions (pH 12-14) resulting in erosions and hemorrhage in the mouth and esophagus.

"Acid rain," precipitation rendered acidic by atmospheric pollution, is a well-recognized problem in aquatic organisms because toxic elements, especially Al, are leached from solids that come in contact with the acidic water. It is especially problematic in poorly buffered surface waters of northeastern North America.[398] Mammals are considerably less sensitive to the effects of dissolved metals than fish, but acidic water supplies have been suggested as contributing to the presence of Pb and Cu in domestic drinking water, a possible concern for human health.[392,393,395] Even if not present at toxic concentrations, many elements impart a repellent taste to water.

Despite the hypothetical potential of acidic (pH < 5.5) water to cause acidosis in animals, water systems in laboratory animal colonies and, to a lesser extent, swine facilities, are commonly acidified to minimize bacterial infections.[396,399-401] It is thought the acidified environment protects the intestinal epithelial barrier from bacterially-mediated disruption as well as reducing bacterial contamination in the water itself.[399]

Some effects have been observed in ruminants and monogastrics due to the ingestion of acidic feed and water. Acidogenic rations are fed to dairy cattle during late pregnancy to prevent milk fever. For example, the addition of NH_4Cl and ammonium sulfate ($(NH_4)_2SO_4$) at 98 g apiece/head/day to the diet of lactating dairy cows lowered blood pH, increased blood calcium (Ca^{2+}), and increased excretion of urinary Ca^{2+} and the ammonium ion (NH_4^+).[390] The same amount of these salts added to drinking water would result in a pH of approximately 5.5. Mineral acids (HCl and H_2SO_4) have been fed to prevent milk fever.[402] Dairy cows given rations containing 0.65% or 1.8% hydrochloric acid (HCl) (equivalent to pH 2-3, respectively, if added to drinking water) had increased blood Ca^{2+}, a small (0.05) decrease in blood pH, acidic urine, and a decreased incidence of milk fever.[391] Rats given water acidified to pH 2.0 with HCl or H_2SO_4 for six weeks exhibited somewhat decreased feed intake and water intake, and weight loss compared to those fed pH 2.5 or pH 7.0 water; however, stomach pH values were not statistically different amongst treatment groups.[403] Rats consuming water acidified to pH 2.5 with HCl for six to 11 months showed no changes in weight and "negligible" damage to tooth enamel.[397] Rats drinking water with pH 2 for 21 weeks drank slightly less than controls, while those consuming pH 3 water showed no measurable effects in any health parameter.[404] Water with a pH of 2.5 given to rats for 30 days resulted in decreased water intake, while water with pH 3 given to rats produced no growth deficits.[396] Rats drinking water with a pH of 1.4-3.5 for 42-84 days showed accelerated erosion on the tooth surface; however, oral cavity pH was unchanged.[405] Mice consuming acidified water (pH 2.0) for 120 days had slightly decreased reticuloendothelial clearance rates when compared to controls, possibly as a result of decreased growth and smaller spleens.[406] It is questionable if the physiologic effects in these reports are a direct result of acidic water on systemic acid-base status, *per se*. Even a study that reported some relatively subtle effects (decreased gains) in rats at pH 2.5 or less, gastric pH was unchanged,[403] and rats and rabbits fed pH 2.3-2.5 water for seven months maintained normal blood pH.[401]

Several experiments reported no effects when acidic water was fed, and it is commonly believed that acidifying water to approximately pH 3 is beneficial in rodent colonies. Rats consuming water with pH of 2.5 gave birth to and weaned more pups than control animals.[407] Rats and rabbits ingesting water at pH 2.3-2.5 for seven months showed no affect on health as measured by growth and multiple blood parameters.[401]

Summary

Existing human drinking water standards (pH 6.5-8.5) were established decades ago for aesthetic reasons (especially taste) and to protect plumbing from corrosion, rather than upon health-based criteria.[392,408] Although a number of Cooperative Extension Service Web sites suggest water below this range will produce pathologic acidosis in cattle, none we examined offered hard evidence. Nor were we able to find any references to direct health effects of moderately acidic or basic water in animals. There *are* a number of references to the beneficial effects of acidifying laboratory animal and swine water with mineral acids to pH 3. The only adverse effects in these reports were relatively subtle and occurred at pH < 3.0. The only example of feeding a pure mineral acid to ruminants (equivalent to approximately pH 2-3) resulted in acidified urine, but there were no adverse health effects over a several week period. There is no equivalent data for basic drinking water. From a purely pathophysiological standpoint, it seems unlikely that water with a pH between 3.0 and 7.0 would cause health problems in otherwise normally managed animals. An exception might be feedlot ruminants, which are often marginally acidotic as a metabolic consequence of the high soluble carbohydrate rations they receive. In this case, acid water might be sufficient to trigger a crisis.

The other potential adverse effects of basic or acidic water involve mobilization of potentially toxic substances (e.g. metals) from plumbing or soils. While it seems unlikely the amounts mobilized would be sufficient to actually cause poisoning under most conditions, it is quite probable they would be large enough to cause water refusal. Because the effect of any given pH on palatability depends upon what the water contacts, there is no way to make any wide-reaching recommendation in this regard.

We suspect the commonly touted acceptable ranges for drinking water pH (a low of 5.5-6.5 and a high of 7.5-9.0) are excessively conservative from a strictly animal health standpoint, at least on the acid side, but there are not sufficient experimental and/or clinical data to offer a specific alternative.