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Introductory Chapter: Carboxylic Acids - Key Role in Life Sciences

Georgiana Ileana Badea and Gabriel Lucian Radu

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<http://dx.doi.org/10.5772/intechopen.77021>

1. Introduction

Carboxylic acids or organic acids are the compounds containing in the molecule the carboxyl functional group attached to the hydrocarbon radical. They are largely distributed in nature and are intermediates in the degradation pathways of amino acids, fats, and carbohydrates.

The carboxyl group consisting of a carbonyl (C=O) with a hydroxyl group (O-H) attached to the same carbon atom and is usually written as -COOH or CO₂H. The compounds presenting two or more carboxylic groups are called dicarboxylic, tricarboxylic acids, while their salts and esters are called carboxylates. By the nature of the radical, they can be classified into saturated, unsaturated, or aromatic acids. In the International Union of Pure and Applied Chemistry (IUPAC) nomenclature, carboxylic acids have an “-oic acid” suffix added to hydrocarbons having the same number of carbon atoms. Still, some organic acids are called by their common name, for example, formic acid and acetic acid.

The molecular weight of organic acids varies widely from relatively small compounds such as formic and acetic acids to much larger compounds (fatty acids) with higher numbers of carboxylic and phenolic functional groups. Monocarboxylic acids with 5–10 carbon atoms in the chain are colorless liquids with unpleasant smells. As the carbon chain length increases (>10 carbon atoms) the acids are waxlike solids, and their smell diminishes with increasing molar mass and decreasing volatility.

Organic acids are weak acids with pK_a values ranging from 3 (carboxylic) to 9 (phenolic) meaning that they do not dissociate totally in a neutral aqueous solution to produce H⁺ cations. The representative low molecular weight organic acids (formic, oxalic, and malic) have a relatively low pK_a (<4.0).

Due to the presence of both hydroxyl and the carbonyl groups in the molecule, the carboxylic acids can exhibit hydrogen bonding with themselves leading to increased stabilization of the compounds and show elevated boiling points. They are polar molecules soluble in polar solvents, but as the alkyl chain increases their solubility decreases due to the hydrophobic nature of the carbon chain. In non-polar media, carboxylic acids exist as dimeric pairs due to their capacity to form hydrogen bonds [1].

2. Applications in Life Sciences

Carboxylic acids are compounds occurring naturally in different stages of life cycles (living organism-Krebs cycle; fermentation processes, and geological processes) or can be produced in the laboratories or at large scale (synthesis) from oxidation reactions of aldehydes, primary alcohols, and hydrocarbons, oxidative cleavage of olefins, base catalyzed dehydrogenation of alcohols or through the hydrolysis of nitriles, esters, or amides. The organic acids play significant and varied roles in our contemporary society as evidenced by multiple applications in the field of medicine, agriculture, pharmaceuticals, food, and other industries.

Carboxylic acids and their derivatives are used in the production of polymers, biopolymers, coatings, adhesives, and pharmaceutical drugs. They also can be used as solvents, food additives, antimicrobials, and flavorings.

Organic acids have important roles in the **food industry**, since they affect the organoleptic properties (e.g. taste, aroma, and color) and the stability of food items. They can be present as natural food components, for example, the acids present in fruits and vegetables (citric acid in citrus fruits, malic acid in grapes and apples, oxalic acid salts in parsley, broccoli), or added artificially, as acidulants (citric acid), preservatives (lactic acid), emulsifiers (tartaric acid), antioxidants (ascorbic acid), or flavors (propionic acid) in a wide variety of products for human consumption (foods and beverages). The level and nature of organic acids present in foods and drinks provide relevant information for monitoring the fermentation processes, control the production, storage, and distribution stages or identify possible adulteration actions. Precisely for this purpose, analytical methods need to be continuously developed and applied in order to identify and quantify the amounts of different acids present in food and beverages. The beverage industry (juices and drinks) is one of the most controlled and regulated industries in terms of composition and authenticity of products. Organic acids are well-known as effective preservatives, and their antimicrobial action is due to the ability to change from undissociated to dissociated form, depending on the environmental pH, making them effective antimicrobial agents. An example, some organic salts (calcium and sodium propionate) prevent spoilage by inhibiting the growth of bacteria and fungi and are used as preservatives in dairy and bakery food products. However, there are carboxylic acids that have a beneficial effect on micro-organisms, helping their growth by acting as vitamins for microbial nutrition (e.g. folic acid, nicotinic acid, or p-aminobenzoic acid). Several studies on the inhibitory effect of various organic acids (oxalic, citric, and malic acids) on polyphenol oxidase (PPO), the enzyme responsible for the browning of damaged fruits and vegetables, have been conducted over the years. The successful results of these studies have had

a positive economic impact in the food industry, where maintaining the quality and extending the products shelf-life represents a necessity [2].

Carboxylic acids also play significant roles in the **medicinal fields**. Since organic acids are intermediate metabolites of all major groups of organic cellular components, it has been repeatedly proven that their presence in excess in various fluids of the human body is linked to the manifestation of certain diseases. Organic acids are indicators of organic acidurias associated with various inborn errors of protein metabolism. More than 65 disorders well-known these days are due to enzyme deficiency in the amino acids degradation pathways (leucine, isoleucine, valine, homocysteine, tyrosine, methionine, threonine, lysine, and tryptophan) resulting in an increase of the organic acid concentration in circulation or excreted urine [3]. This toxic accumulation of metabolites, which are not present under physiological conditions in the organism, causes an intoxication-like clinical condition. The urinary organic acid pattern yielded from these metabolic abnormalities is essential for diagnosis. For example, the levels of homovanillic acid (HVA) and vanillylmandelic acids (VMAs) in body fluids are used in the diagnosis of neurological diseases and disorders. Studies of the metabolic fingerprints associate the alternative less efficient degradation pathways of fatty acids (leading to increased levels of adipic and suberic acids in urinary excretion) with disorders like autism. The levels of succinic acid in clinical samples indicate the occurrence of a bacterial infection without the possibility of differentiation between aerobic and anaerobic bacteria type. The quantification of organic acids levels in body fluids can provide useful information in critical areas of metabolism: neurotransmitter metabolism, gastrointestinal function, cellular energy and mitochondrial metabolism, and amino acid/organic acid balance with the purpose of an early diagnosis of various diseases.

The **pharmaceutical industry** benefits as well from the presence and the functions of carboxylic acids. Explaining the importance of carboxylic acids and their derivatives in the pharmaceutical industry rely on the chemical nature of the functional group. The most important roles that carboxylic functions play in pharmaceuticals are:

- Solubilizer acting in modulating solubility, lipophilicity, and cell permeation (e.g. antibiotic or antihistaminic drug classes);
- Prodrug and/or bioprecursor acting as compounds not biologically active but converted into active ones in specific conditions (e.g. drugs from antihypertensive, antithrombotic, or antiviral classes);
- Pharmacophore providing specific interactions with an enzyme, triggering, or blocking its biological response (e.g. blood cholesterol-reducing drugs, nonsteroidal anti-inflammatory drugs).

Carboxylic acid-containing drugs play a major role in the medical treatment of pain and diseases [4].

They are also used in a wide variety of applications as ingredients in cosmetics. A class of organic acids with an important contribution in the cosmetic field is the alpha hydroxy acids (AHAs).

Citric, malic, tartaric, and lactic and glycolic acids are part of this category and are extensively used in cosmetics for purposes such unblock/clean pores, improve the skin texture, whitening, anti-wrinkle, or acne treatment. Also, carboxylic acids represented by aldobionic acids (ABAs), retinoic acids, vitamin C, and azelaic acid are most effective in providing antioxidant and anti-aging protection, as well as improving moisture-retention [5, 6]. The carboxylic acid-based esters are the derivatives most well-known for their flavors and fragrances and are widely used in various applications including perfumes, deodorant, and air fresheners.

Fatty acids represent the class of carboxylic acids recognized for its utility in the cosmetic industry since their water-soluble salts (soaps) have been used as cleansers, since antiquity and are the most useful surfactants known.

Although is a controversy issue about the role of organic acids in **geological processes**, a collection of studies and data provide insights and research directions concerning their influence on geological processes. Many reports suggested that organic acids have participated in soil formation, surface weathering, subsurface porosity generation, and ore formation. Also, studies described the significant and varied roles of organic acids played in rhizosphere acidification and mineral weathering. Literature data list the important roles of organic acids in rhizosphere processes such as mobilization of nutrients (Fe, phosphates), protection against aluminum toxicity, increasing the weathering rate of primary minerals, and participating in translocation of Fe and Al. Other classes of carboxylic acids such as phenolic and fatty acids inhibit the normal growth of plants and algae, acting as allelochemicals, resulting in adverse impacts on the physiological and ecological environment (changed microflora) [7].

One chapter of this book offers, the detailed discussion of mechanisms of organic acid on the acquisition of soil phosphate in the fields of plant physiology, plant nutrition, and soil chemistry. Some plant species strongly mobilize soil phosphate by carboxylates improving this macronutrient acquisition.

3. Conclusions

The carboxylic acid compounds still may find applications that cannot be fully covered in this chapter. As conclusion, starting from food to medicine, from the human body to earth and environment, the production, destruction, absorption, or release of these compounds show a strong impact on all the processes/reactions that take place.

As a final conclusion, this subject is an endless one and the classes of compounds that contain the carboxyl functional group, along with all their derivatives, are inseparable from everything that life means on this earth.

Conflict of interest

Replace the entirety of this text with the “conflict of interest” declaration.

Author details

Georgiana Ileana Badea^{1*} and Gabriel Lucian Radu²

*Address all correspondence to: truicageorgiana@yahoo.com

1 National Institute of Research and Development for Biological Sciences, Bucharest, Romania

2 Polytechnic University of Bucharest, Bucharest, Romania

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