

Chapter

Representative Species of the Cucurbitaceae Family: Valuable Phytochemicals and Properties for Food and Medicine

Anna Busuioc, Bianca Furdui, Andreea-Veronica Botezatu and Rodica-Mihaela Dinică

Abstract

Recent research regarding various species from the Cucurbitaceae family, which are used in traditional medicine, has highlighted remarkable chemical composition and therapeutic properties with possible applications in modern alternative medicine and food field. The species mentioned in this chapter are *Cucumis metuliferus*, *Benincasa hispida*, and *Trichosantes cucumerina*, as well as a more studied and used species among them, *Momordica charantia*. This chapter correlates the phytochemical composition of these species (primary and secondary metabolites) with their biological potential, which confers therapeutic and nutritional properties. This chapter aims to highlight the importance of the four mentioned species belonging to the Cucurbitaceae family, along with their wide range of applications and also correlated with the different classes of phytochemical compounds.

Keywords: Cucurbitaceae family, phytochemical composition, therapeutic properties, food, representative species

1. Introduction

Since ancient times, people around the world have used plants as valuable sources of food and medicines [1]. In Europe, plant chemistry and the isolation of biologically active compounds developed rapidly after the influence of Paracelsus (sixteenth century), who claimed that “*All meadows and pastures, all mountains and hills are pharmacies*” [1], that is, nature is a supplier of natural products and medicines. After decades of research and evolution, scientific research is still exploring traditional medicine, and attempts are being made to elucidate the power and benefits that nature offers to integrate it into conventional medicine.

The world's biggest challenges, in recent years, have been the growth of the human population and the depletion of natural resources, which have led to hunger, malnutrition, and poor human health [2]. Other important aspects of today's life are

the increase in the number of human diseases, the development of resistance of some diseases to classical treatments, as well as the toxic side effects of synthetic drugs [3, 4]. The Food and Agriculture Organization of the United Nations (FAO) estimated that approximately 9.1% of the global population suffered from chronic malnutrition in 2023. Most of the malnourished people live in low and sub-middle-income regions [5]. Africa has the highest prevalence of undernutrition, but Asia, being the most densely populated region of the world, has the highest percentage of undernourished people [6]. In the current conditions of climate change and the underlying impact on agriculture and horticulture, underutilized plants are valuable alternatives for cultivation and use for various purposes.

Nowadays, in agriculture, grains, vegetables, and fruits are produced by using traditional or genetically modified plants and modern agricultural practices, while attempts are made to adapt various plant species to new growing environments. However, there are many plant species still underutilized or underexploited, including plant species that thrive in extreme environmental conditions and threatened habitats, possessing genetic tolerance to survive in harsh conditions and that also have important nutritional, phytochemical, and therapeutic qualities [7]. Various research has made significant advancements in demonstrating that many compounds isolated from plants are biologically active and important in the prevention of chronic conditions such as cancer, diabetes, and coronary heart disease. Phytochemical compounds have demonstrated numerous bioactivities that include antioxidant, antitumoral, antimicrobial, antihypertensive, anti-inflammatory, and hepatoprotective properties [6, 8]. Vegetables from the Cucurbitaceae family are commonly known as cucumbers. The oldest species of this plant family, first described in 1924 by paleobotanist Frank Hall Knowlton and identified to date, is *Cucurbitaciphyllum lobatum* from the Paleocene epoch in Shirley Canal, Montana [9]. Cucumbers are believed to have their origin in India and some areas from Western Asia [10]. Some species used as natural remedies in traditional medicine grow in the foothills of the Himalayas, but they are not cultivated at large scale because of their bitter fruits, dormant seeds, or late maturity [9].

Other related species in the Cucurbitaceae family were cultivated in China and the Middle East. According to available data, originally from India, the cucumber was spread to Greece and Italy, where, through the Roman Empire, it was cultivated in other regions from Europe [8, 11]. Other records of cucumber cultivation were found in France in the ninth century and in Britain in the fourteenth century, while varieties more closely related to the pumpkin and cantaloupe were first cultivated in America, successfully cultivated later in Southern Mexico since 8000 BC, in the Illinois region around 5000 BC, and in Europe during the exploration of Columbus [12].

Cucurbitaceae is a diverse plant family currently cultivated worldwide in a variety of environmental conditions. Optimal cultivation conditions are tropical and subtropical, but it can be easily adapted to cultivation in other continents. Over 300 plant species are used by humans, but only 150 species are cultivated extensively, from which only 30 are crucial for global food production. The main producers of Cucurbitaceae are countries such as India, Turkey, China, and the United States [11]. From the multitude of known and used species, in this chapter, four species of therapeutic and nutritional interest have been selected: *Momordica charantia*, *Benincasa hispida*, *Trichosantes cucumerina*, and *Cucumis metuliferus*.

The Cucurbitaceae family has an important economic role because the vegetables and fruits of this family are used in various food, cosmetic or pharmaceutical products, or for other purposes (**Figure 1**). Edible plants, derived from the Cucurbitaceae

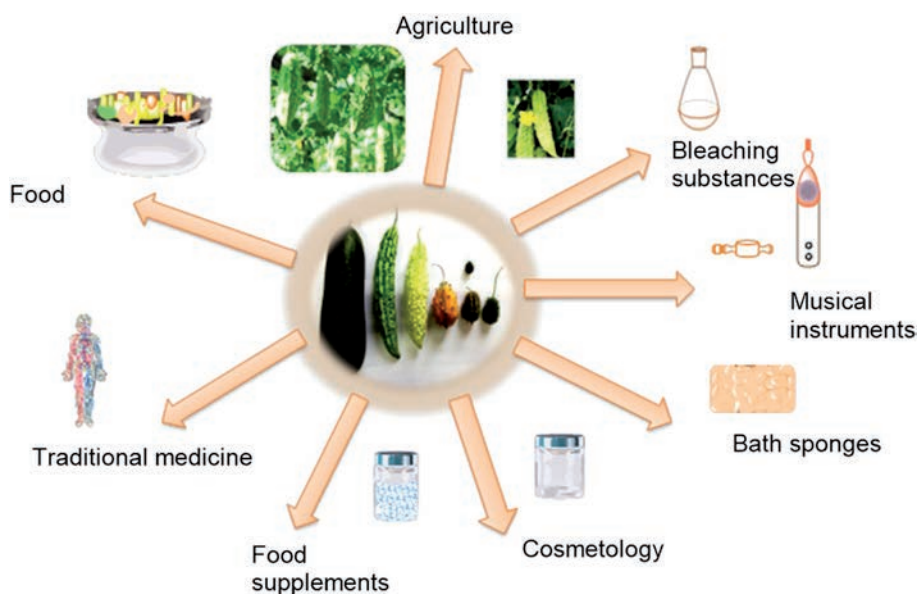


Figure 1.
 Various uses of plant species from Cucurbitaceae family.

family, belong to a group that includes five genera: *Cucurbita*, *Cucumis*, *Citrullus*, *Legenaria*, and *Sechium* [13]. This family with characteristic seeds, peel deposits, a specific chemical composition, and diverse applications, can be easily identified throughout the plant kingdom [14, 15].

2. Important classes of organic compounds identified in the studied plants

Plants can be compared to “factories” that, under the action of solar energy, consume CO₂ and water and then produce oxygen, energy, and basic compounds, such as proteins, carbohydrates, vitamins, and lipids, which are necessary for the survival of living organisms [16]. Plant metabolism consists of numerous chemical reactions catalyzed by enzymes, which take place in various plant cell structures and the production of a variety of chemical molecules from the category of primary metabolites [17]. Primary metabolites play a major role in maintaining the viability of the plant (proteins, sugars, vitamins, and lipids). In addition, plants also synthesize a series of other compounds in the chemical processes of secondary metabolism such as terpenes, phenolic, nitrogen (alkaloids, cyanogenic glycosides, and nonprotein amino acids), and sulfur compounds [18]. Secondary metabolites are biosynthesized by plants and specific to each species, often manifesting functions characteristic of some plant organs or tissues; can be identified only in a certain period of growth and development within a species; or can be activated only under certain stress factors such as the attack of microorganisms, insects or the lack of nutrients [19]. Secondary metabolites are considered compounds of interest for various reasons, such as their structural diversity and their potential as drug candidates [18].

In general, secondary metabolites are produced by biosynthetic modifications of primary metabolites, including methylation, glycosylation, and hydroxylation. Plants contain highly specific secondary metabolites, sometimes toxic at high concentration,

and represent a valuable library of bioactive compounds with broad activity on human cells, bacteria, fungi, and parasites [20].

2.1 Primary metabolites

The main primary metabolites, namely, saccharides, lipids, proteins, and vitamins, and their distribution in plant species from the Cucurbitaceae family are briefly characterized. Primary metabolites fulfill essential metabolic roles by participating in plant growth, nutrition, and reproduction.

2.1.1 Saccharides

Saccharides, also known as carbohydrates or sugars, are natural compounds synthesized by plants in the process of photosynthesis [15, 21]. It is known that saccharides fulfill various functions in plants, among them being energy sources for vital processes and important precursors in the biosynthesis of other chemical molecules [22]. This class of compounds acts as nutrients, plays an important role as signaling molecules, and regulates vital functions, that is, growth processes, metabolism, and stress tolerance response [23]. Low molecular mass saccharides, such as sucrose, trehalose, or raffinose, are involved in plant immunity as signaling molecules, which has led to the concept of “sweet immunity” [24]. These compounds are able to activate defenses and resistance-enhancing responses to pathogens [25]. Polysaccharides are widespread in plants and perform various functions such as structural (cellulose), nutritional reservoir (starch), or specific roles such as anticoagulant (heparin) [26].

In the fruits of *Momordica charantia*, various mono- and disaccharides such as arabinose, galactose, glucose, mannose, ribose, xylose, and rhamnose have been identified [27]. Studies carried out on the species of *M. charantia* from Nigeria have shown that, depending on the part of the analyzed plant, the carbohydrate content differs. Thus, similar values were found in leaves, $32.34 \pm 0.24\%$, and fruits, $34.31 \pm 0.30\%$, close also to those obtained from another study of $39 \pm 3\%$ [28], while the seeds were twice as poor in sugars with $9.18 \pm 0.86\%$ [29]. Analyses carried out on the seeds of a local variety of *M. charantia* collected from an agricultural research institute in Pakistan presented a higher concentration of soluble carbohydrates, $28.43 \pm 3.11\%$, compared to previous studies [30]. In fresh *M. charantia* fruits from the local market in Penang, Malaysia, a percentage of $45.4 \pm 0.9\%$ maltose equivalents was quantified, while in freeze-dried fruits the following saccharides and their derivatives were identified: glucose ($0.383 \pm 0.004\%$), galactose ($0.306 \pm 0.002\%$), mannose ($0.010 \pm 0.001\%$), galacturonic acid ($0.145 \pm 0.003\%$), rhamnose ($0.021 \pm 0.000\%$), arabinose ($0.086 \pm 0.000\%$), xylose ($0.049 \pm 0.000\%$), as well as very small concentrations of ribose and fructose [31].

Fresh fruits of *Cucumis metuliferus* have been found to have a low carbohydrate content of 5.55 g/100 g fresh fruit [32], and in dried fruits, 7.56 g/100 g fruit [33] or in another study, 62.25 + 1.95 mg/kg [34]. Studies on aqueous extracts from the peel of fruits grown in China have shown the predominant presence of galacturonic acid, 45.93%, with higher amounts of rhamnose (13.50%), arabinose (10.37%), glucose (5.54%), and smaller amounts of fructose (2.51%), xylose (4.24%), and mannose (0.17%) [35].

Although carbohydrates play an important role in a wide range of biological processes, carbohydrate-derived drugs cover only a limited area of therapeutic actions [36]. Many pathophysiological important carbohydrate-protein interactions

have not yet been exploited due to their high polarity. Saccharides cannot passively cross the enterocyte layer of the small intestine (a prerequisite for oral availability), and if systemically available by parenteral administration, these compounds undergo a process of rapid renal excretion. In addition to a lack of affinity, saccharides present low tissue permeability, short plasma half-life, and poor stability [36].

Medicines with compounds derived from saccharides in their structure, currently approved for human use, include benefits such as the treatment of diabetes mellitus due by the inhibition of glycosidase that prevent the digestion of carbohydrates (voglibose, miglitol and acarbose), the prevention of influenza virus infections (zanamivir and oseltamivir), anticoagulant properties by binding to antithrombin III for the treatment of sulfated glycosaminoglycan thrombosis (fondaparinux, dalteparin, ardeparin, nardoparin and enoxaparin), treatment of Gaucher disease (miglustat), epilepsy (topiramate), and osteoarthritis (sodium hyaluronate) (**Figure 2**) [36–38]. As examples of saccharide-derived drugs emerge, the strategies developed for their design will pave the way to harness the potential of this class of compounds in various therapies [39]. In addition to their therapeutic potential, sugars are present in most food products.

2.1.2 Lipids

A class of compounds that include glycerides, phospholipids, waxes, or fatty acids, lipids play an important role in living organisms, being an essential component of the homeostatic function of the human body. Lipids contribute to some vital processes, having main biological functions in plants and human health [40].

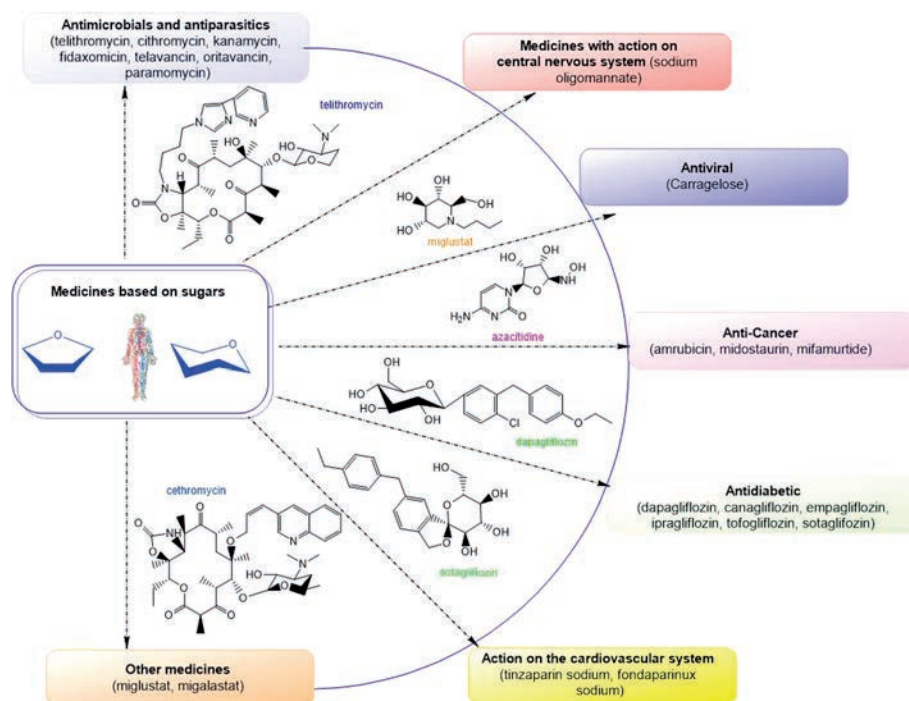


Figure 2.
Various applications of carbohydrates from plants.

Plants contain various types of lipids, including fatty acids, phospholipids, glycolipids, sterol lipids, sphingolipids, and waxes [41]. Lipids are usually extracted with organic solvents, which allow the removal of many hydrophilic components such as carbohydrates and proteins.

In higher plants, lipids are distributed in various parts, such as extrachloroplasts, where phosphatidylcholine and phosphatidylethanolamine are in higher concentrations, while thylakoids from chloroplasts usually contain three glycosylglycerides (monogalactosyl, digalactosyl, and sulfoquinovosyl diacylglycerols) and phosphatidylglycerol. The acyl-lipid composition of higher plant tissues depends on their metabolism, the plant species, and cultivation environment [42].

The seeds of buffalo gourd (*Cucurbita foetidissima*), from the Cucurbitaceae family, that grows in the semiarid regions of the USA, Mexico, Lebanon, and India, contain a high amount of fats (32–39%) and also proteins [43]. Pumpkin seeds (*Cucurbita pepo*) are rich in linoleic acid, as well as in palmitic, stearic, oleic acid, and a wide range of other fatty acids in moderate concentrations [44]. Their chemical composition has attracted attention due to its beneficial properties in the early treatment of prostate cancer. Microwave-assisted and supercritical carbon dioxide extraction revealed the triacylglycerols, sterols, and tocopherols due to which the seeds have this beneficial effect [45, 46].

Benincasa hispida seeds presented different content of saturated and unsaturated fatty acids such as myristic acid, palmitoleic acid, oleic acid, linoleic acid, stearic acid, α -linolenic acid, palmitic acid, and others [47]. In one of the more detailed studies in which a supercritical fluid extraction method was optimized, the total content of saturated fatty acids (myristic acid, palmitic acid, and stearic acid) was 15.97%, compared to palmitic acid, which was identified in a higher concentration of $9.83 \pm 0.33\%$. Unsaturated fatty acids were determined in the highest concentration in percentage of 83.53% of the total fatty acids, these being represented by palmitoleic acid, oleic acid, linoleic acid, and linolenic acid, especially α -linolenic acid, an omega-3 type acid [48]. In addition to fatty acids, sterols such as β -sitosterol and stigmast-5-ene-3-p-ol have also been identified [47]. In the edible part of the winter cucumber, a fat content of 0.02–0.20/100 g was determined [49], a content of $0.60 \pm 0.10/100$ g in the pulp, and $1.25 \pm 0.06/100$ g [50] in the peel.

The highest content of lipids is mostly found in the seeds of plants. Thus, in bitter cucumber, about 64.3% are polyunsaturated fatty acids and 20.1% are mono-unsaturated fatty acids of the total fatty acids. The oil of these seeds is unique due to its high content of conjugated 9-cis, 11-trans, 13-trans linolenic acid [51]. Another study demonstrated high concentrations of stearic acid (62.31% of total fatty acids), oleic acid (12.53%), and linoleic acid (10.40%), as well as in smaller concentrations arachidic acid (5.3%), palmitic acid (4.72%), capric acid (0.53%), and lauric acid (0.45%) [49].

In the case of kiwano fruits, the seeds showed the highest lipid concentration, 15.4 g/100 g, followed by the fruit peel, 8.89 g/100 g, and a small content in the fresh pulp [52]. Another study showed a higher value for lipid and protein in seeds (23.8 and 23.2 g/100 g, respectively) [53]. The seeds contain fatty acids in different proportions, such as linoleic acid (56.21%) and oleic acid (18.6%), followed by palmitic acid (16.2%) and stearic acid (7.65%) [54, 55].

It has been demonstrated that the chemical composition of fresh and dried fruits differs. Thus, fresh *Cucumis metuliferus* fruits presented a low lipid content of 0.7 g/100 g [8] and the dried ones of 1.26 g/100 g fruit [56]. In another study, a lipid content of 7.8 ± 0.76 mg/kg was determined for dried fruits [57]. The scientific

literature illustrates the fact that lipids are also found in the leaves of some cucumber species, with 2.6 ± 0.30 mg/kg, these values being higher than those found in the fresh fruit [31, 58].

The fruits of *Trichosanthes cucumerina* presented a small percentage of lipids, $0.47 \pm 0.03\%$ [59]. Instead, a special composition was identified in seeds of this plant, its oil containing medium concentrations of octanoic acid, dodecanoic acid, tetradecanoic acid, n-hexadecanoic acid, oleic acid, and octadecanoic acid [14]. In another study, a different composition was found rich in lauric acid ($10.28 \pm 0.01\%$), myristic acid ($6.54 \pm 0.01\%$), palmitic acid ($11.87 \pm 0.01\%$), stearic acid ($15.54 \pm 0.01\%$), oleic acid ($26.51 \pm 0.01\%$), linoleic acid ($0.75 \pm 0.01\%$), and palmitoleic acid ($0.45 \pm 0.01\%$) [60].

Global awareness of the concept of studying a group of molecules with lipid structures with therapeutic and prophylactic applications in promoting health and treating various ailments, supported by progressive research efforts to identify the properties and potential applications of such bioactive food constituents and together with consumer demand, has led to the development of a new food category commonly referred to as “functional foods” or “nutraceuticals” [42, 61]. Among the multitude of promising functional lipids that are known to date, it should be noted that the scope of functional lipids involves both bioactive lipids of natural and synthetic origin [62]. Functional lipid supplementation in the human diet can act as either an alternative therapy or an adjunctive therapy to conventional medicinal practices. Their importance increases in the current context, because nowadays, conventional therapies have many side effects and the diseases are more and more difficult to treat [42, 63]. Species in the Cucurbitaceae family have a varied lipid content, which can be useful in preventing or combating certain conditions.

2.1.3 Proteins

Proteins are another class of primary metabolites that are indispensable for living organisms. Proteins are polypeptides with a molecular weight greater than 10,000, which are made up of four basic elements, namely, carbon 50–55%, oxygen 20–23%, nitrogen 12–19%, and hydrogen 6–7%, as well as other elements in smaller amounts such as phosphorus, sulfur, copper, zinc, and others [14]. The main sources of proteins are from animals, but they are also found in smaller amounts in plants, being considered incomplete or low-quality proteins because their structures lack some of the essential amino acids. Proteins from oilseeds and legumes are generally soluble in aqueous media, and those from cereals are insoluble; therefore, it is necessary to use suitable extraction solvents. The separation of proteins is a difficult process due to their sensitivity, which takes into account temperature, degree of ionization, as well as extreme pH values, which can cause protein denaturation [64].

The protein content for the fruit of *Cucumis metuliferus* was found to be between 1.78 and 1.80 g/100 g, for the peel 2.95 g/100 g, and for the seeds, 2.63 g/100 g [56, 65, 66]. A study carried out on plant materials from Nigeria, Africa, presented a protein content in fruits of 9.04 ± 0.13 mg/kg, and of 9.77 ± 0.30 mg/kg in leaves [31]. Fresh fruits have a high concentration of proteins, of about 4 g/100 g [67]. The most recent studies highlight this class of compounds in kiwano fruits, varying between 6.22% and 6.29% [68].

The preliminary phytochemical screening of the extract from the dried seeds of *Benincasa hispida* highlights, in addition to the presence of carbohydrates, phenolic compounds, amino acids, flavonoids and sterols, the presence of proteins [56], such

as trigonelline and osmorin, known for their antibacterial properties [69]. The highest protein content was found in the seeds of winter cucumber, 0.58 ± 0.02 g/100 g, followed by the edible part of the plant, 0.49 ± 0.02 g/100 g, and finally the peel of the fruit, 0.37 ± 0.03 g/100 g [50]. Studies in the literature have shown that *Trichosanthes cucumerina* seeds have a rich protein content of 26.2–26.6 g/100 g [70]. *Momordica charantia* fruits showed a protein content of $0.71 \pm 0.13\%$ [14], including polypeptide-P, lectin, and MAP30 with anti-HIV properties [64, 71]. Proteins have also been isolated from the seeds of *M. charantia* [72–74]. In addition, the crude protein content of the fruit was found to be 11.4–20.9 g/kg, which is higher than that of ripe or common cucumbers [75]. Although it has many culinary uses, especially in South, Southeast, and East Asia, and is also cultivated for ornamental purposes, *M. charantia* is widespread in traditional medicine [76]. Fruits, flowers, and young shoots are also used as flavoring agents in various Asian dishes. The young shoots and leaves of *M. charantia*, as well as leaf and fruit extracts, are used in the preparation of teas and dietary supplements [77]. The protein content and implicitly amino acid composition of plants vary considerably by family, genus, species, and cultivar. The role of some proteins in plants includes storage functions for lectins, enzymes, and enzyme inhibitors, and structural functions for ribosomal, chromosomal, and membrane proteins [78].

Proteins are considered valuable molecules due to their applications in the fields of food and medicine. Recently, therapeutic proteins have emerged as a promising option in treating various diseases, such as diabetes, cancer, cardiovascular diseases, and others. Finally, proteins can be used in combination with small molecular weight drugs to provide synergistic benefits in modern medicine [79].

2.1.4 Vitamins

Vitamins are considered primary metabolites of plants, being able to be further used in the synthesis of secondary metabolites [14, 80]. In general, vitamin biosynthetic pathways have been elucidated in various research [81, 82]. Vitamins, whether water-soluble or fat-soluble, play an important role in supporting the health of the human body by preventing and treating various conditions such as bone homeostasis, cancer, or other diseases of the immune, digestive, skin, and cardiovascular systems [14, 81, 83–85].

Vitamins are compounds sensitive to different factors such as heat, light, oxygen, and the pH of the environment in which they are stored. There are 13 compounds recognized so far as vitamins that have been detected in plants, which are important for living organisms. Thus, fruits and vegetables, as well as various cereals and nuts, can provide in the human diet approximately 92% ascorbic acid, 69% folic acid, 64% thiamine, 49% vitamin A, 49% niacin, 46% vitamin B6, and 33% riboflavin [81]. The concentration of vitamins differs considerably in the leaves, fruits, stems, and roots of plants. It has been observed that certain parts of plant tissues located toward the outside usually contain higher concentrations of vitamins, especially ascorbic acid. Cucumbers, for example, contain a higher concentration of ascorbic acid, riboflavin, niacin, pantothenic acid, and tocopherol in the skin than in the inner part of the fruit [84].

Momordica charantia fruits are rich in various vitamins of major importance, especially vitamin C [86, 87], vitamin A, vitamin B complex [75], and vitamin E [88]. Vitamin A, vitamin E, vitamin C, vitamin B12, and folic acid have been identified in small amounts in the dried leaves of this plant, and very small concentrations of vitamin B3, vitamin B6, vitamin D, and vitamin K [89]. The main vitamin identified from

the pulp of kiwano fruits was vitamin C in variable concentration of 15.5–27.5 g/100 g dry matter or, according to other studies, 5.3 mg/g dry matter [50], followed by vitamin E (13.5–8.3 g/100 g dry matter), folic acid (0.003 mg/g dry matter), vitamin A (0.007 mg/g dry matter), riboflavin (0.015 mg/g dry matter), thiamine (0.025 mg/g dry matter), niacin (0.56 mg/g dry matter), and pantothenic acid (0.18 mg/g dry matter) [90]. Vitamin C was found in large amounts of 625.12 ± 11.17 mg/100 g [50] and vitamin K in a proportion of 1.69 mg/g dry matter from the peel of *Cucumis metuliferus* [84]. This content is higher than the recommended daily intake, which is from 70 to 140 µg for an adult [87]. Vitamins B1 were quantified in the peel of *C. metuliferus* at a concentration of 1.69 mg/g dry matter, along with vitamin B9 (1.93 mg/g dry matter) and vitamin B2 (1.74 mg/g dry matter), vitamins D (2.28 mg/g dry matter), and vitamin E (2.92 mg/g dry matter), vitamins that were not identified in the pulp of the same species. Fat-soluble vitamins were found in the seeds, such as vitamins D (1.86 mg/g dry matter), vitamin E (2.05 mg/g dry matter), vitamin K (2.58 mg/g dry matter), and vitamin A (2.22 mg/g dry matter). Among the water-soluble vitamins, the complex of B vitamins was identified (thiamine 2.20 mg/g dry matter, folic acid 2.20 mg/g dry matter, and riboflavin 1.72 mg/g dry matter), these being present in higher concentrations than vitamin C (1.72 mg/g dry matter), vitamin that was not identified in seeds [50].

Vitamin C (1.35–0.68 mg/g dry matter), thiamin (0.02–0.04 mg/g dry matter), riboflavin (0.02–0.31 mg/g dry matter), niacin (0.20–0.46 mg/g dry matter), and vitamin E were identified in *Benincasa hispida* [14, 69]. A comparative study of fruits from different countries demonstrated the presence of vitamins in different proportions; thus, the highest concentrations of vitamin C (68 mg/100 g dry matter), thiamine (0.02 mg/100 g dry matter), riboflavin (0.31 mg/100 g dry matter), and niacin (0.2 mg/100 g dry matter) were quantified in plants from Malaysia, while those from Australia had a different composition of 27 mg/100 g dry matter of vitamin C, 0.4 mg/100 g dry matter of niacin, 0.05 mg/100 g dry matter of riboflavin, and 0.02 mg/100 g dry matter of thiamine. Another study on *Benincasa hispida* from China presented the poorest vitamin content of 1.35 mg vitamin C/100 g plant, 0.02 mg riboflavin/100 g, 0.46 mg niacin/100 g, and a lack of thiamine [91].

A comparative study highlighted the fact that chemical composition is influenced by the harvesting period of plants. Thus, it was demonstrated that the highest concentration of vitamin C in the fruits of *T. cucumerina* is found in the late harvest period (0.94 g/100 g), being higher than in the crops at the beginning of the season (0.252 g/100 g) [11, 92]. In another study in which the edible part of the fruit was analyzed, 30.5% vitamin C, 11.3% vitamin B6, 3% pantothenic acid, and less than 1.1% of vitamin E were present, while vitamins B12 and D were not identified [93].

Finally, vitamins are indispensable in the functioning processes of the human body, and the lack of vitamins leads to the impairment of metabolism. Some vitamins are very unstable and can be easily lost, especially in food processing and storage, so processing methods and storage conditions are very important to maintain vitamin content. In addition, the content and variety of vitamins in food are different, and sometimes vitamin supplements are recommended to meet the needs of the human body [73].

2.2 Secondary metabolites

Secondary metabolites are important compounds in plant growth and development, with numerous applications in various industrial, food, and therapeutic fields,

and have been increasingly researched in recent years to discover potential therapeutic targets [16]. There are various classifications of these secondary metabolites. Some of these classify secondary metabolites in pigments, glycosides, lignins, tannins, resins, balms, alkaloids, antibiotics, phytoncides, vegetable insecticides, and others [24]. The presence of secondary metabolites in plants contributes to their pollination, which is carried out with the help of insects and is due to different classes of compounds that influence the color, fragrance, or nectar of these plants [86, 94].

In general, secondary metabolites are generated by biosynthetic modifications of primary metabolites. For economic reasons, the study of secondary metabolites has been the subject of research in recent years, contributing to the development of several fields of phytochemistry. Studies have identified over a 1000 new chemical compounds from different plant species annually. According to literature data, approximately 25% of drugs used to prevent and treat various ailments contain compounds of plant origin [18, 20, 95].

Secondary metabolites have important roles in plants as biologically, physiologically, and ecologically active compounds, but they are also important in various domains such as food, pharmaceutical, technical, industrial, or agricultural fields.

2.2.1 Polyphenols

Phenolic compounds are secondary metabolites of plants, characterized by the presence of an aromatic ring and several hydroxyl groups. Probably the largest group of secondary metabolites, phenolic compounds range from simple (with a single aromatic ring) to complex structures. Their primary role in plants is to protect the plant from being attacked by pathogens, free radicals, or UV rays [96].

According to specialized studies, *Benincasa hispida* has an increased content of flavonoids in the peel, 1.13 ± 0.15 g/100 g, while in the seeds, they were not identified [44]. The contents of phenolic acids and flavonoids in the dried fruit were 81.3 ± 1.4 mg GAE/g and 486.8 ± 4.0 mg CE/g dry product, respectively [97]. By another method of isolation and investigation, values of 193.77 ± 2.86 µg in 10 mg of aqueous extract were determined [98].

In *Momordica charantia*, flavonoid compounds were found in two forms, namely, as free aglycones or glycosides. Depending on the type of extract, the concentration of polyphenols and flavonoids was found to vary, with the ethanolic and aqueous extracts showing a content of 44.0 mg and 62.0 mg EqQ/g extract, respectively, while the concentration of polyphenols was 68.8 and 51.6 mg EqAG/g extract [99]. The main phenolic compounds isolated from bitter cucumber were gallic acid, chlorogenic acid, caffeic acid, p-coumaric acid, syringic acid, vanillic acid, p-methoxybenzoic acid, protocatechuic acid, catechin, rutin, and myricetin. Glycosides such as apigenin-7-O-glycoside (1955.55 ng/mg) and luteolin-7-O-glycoside (725.50 ng/mg) were also identified [100], and other hydroxy acids such as ferulic, malic, malonic, salicylic, tartaric, and cinnamic acids. Phenolic acids such as caffeic, *o*-, *m*-, and *p*-coumaric acids were isolated from the roots of the plant, too [101, 102]. Other studies revealed chlorogenic, ferulic, p-hydroxybenzoic, gallic, β-resorcylic, vanillic, syringic, salicylic, cinnamic, veratric, homogentisic acids, and vanillin, as well as flavonoids such as myricetin, kaempferol, quercetin, catechin, rutin, hesperidin, naringenin, biocyanin A, and naringin, in *Momordica charantia* [103]. The leaves have a different phytochemical profile, which contain polyphenols such as 4-hydroxybenzoic acid, derivatives of 4-O-caffeoylquinic acid, 4-O-feruloylquinic acid, 5-O-feroylquinic acid, sinapinic acid, 2,4-bis(2-phenylpropan-2-yl)phenol and the

acids found in other parts of the plant (caffeic acid, cinnamic acid, ferulic acid, and p-coumaric acid) [104], and flavonoids (isorhamnetin-3-O-glucoside, isorhamnetin-O-acetylhexoside, kaempferol-3-O-glucoside, kaempferol-3-O-rutinoside, kaempferol-O-acetylhexoside, kaempferol-O-pentosylhexoside, quercetin-3-O-glucoside, quercetin-3-O-rutinoside, quercetin-O-acetylhexoside, quercetin-O-dihexoside, quercetin-O-pentosylhexoside, and rutin) [105, 106]. The flowers, the less studied part of these plants, contain flavonoids that are represented by kaempferol and rutin and polyphenols such as 4-hydroxybenzoic acid, caffeic acid, epicatechin, catechin, chlorogenic acid, ferulic acid, gallic acid, and p-coumaric acid [107]. Studies in the literature showed that the seeds contain some phenolic compounds known and isolated in plants from other geographical areas, such as gallic acid, caffeic acid, epicatechin, catechin, chlorogenic acid, gentisic acid, o-coumaric acid, p-coumaric acid, sinapic acid, protocatechuic acid, syringic acid, cinnamic acid, ferulic acid, and vanillic acid [107, 108].

The presence of polyphenols and flavonoids in *T. cucumerina* fruit was initially highlighted by specific identification reactions. Subsequently, secondary metabolite contents were determined by spectrophotometric and chromatographic methods. Thus, from the most recent studies, the total polyphenol content was between 3.1 and 5.8 EqAG/g dry matter [90]. The peels of the fruit are rich in both polyphenols, 500 mg EqAG/100 g dry matter, and flavonoids, 171 mg EqQ/100 g [109]. The compounds isolated from the pulp were rutin, quercetin, quercetin-3-d-galactoside, kaempferol-3-glucoside, kaempferol [109], gallic acid, catechin, epicatechin, neochlorogenic acid, caffeic acid, and p-coumaric acid [90]. The studies that were carried out on the aerial part of *T. cucumerina* plants showed that they have a total content of polyphenols and flavonoids of 38.82 ± 0.45 mg EqAG/g extract and 26.30 ± 0.45 mg EqQ/g extract, respectively.

Phytochemical screening of the studied plant materials from the Western Province of Sri Lanka highlighted the presence of polyphenols, flavonoids, steroids, and tannins [110]. A total content of 4.64 ± 0.3 mg EqAG/g of polyphenols and 0.77 ± 0.1 mg Eq. Q/g of flavonoids was determined for the fruits of the snake cucumber. A higher content was determined in the plant's flowers (19.97 ± 1.6 mg EqAG/g and 4.46 ± 0.1 mg Eq. Q/g), while the richest content was in the leaves, which presented 27.39 ± 1.2 mg EqAG/g polyphenols and 6.05 ± 0.1 mg Eq. Q/g flavonoids [111]. For the aqueous extracts of the ripe fruits, 65.8 ± 0.50 mg EqAG/g total polyphenols and 45.4 ± 0.76 mg Eq. Q/g total flavonoids were quantified [112].

Polyphenols detected in species of the Cucurbitaceae family play a crucial role due to their potent antioxidant, antimicrobial, and anti-inflammatory activities, which contribute to reducing oxidative stress, modulating cell signaling pathways and preventing the onset and progression of various chronic diseases, including cardiovascular diseases, neurodegenerative diseases, and certain types of cancer.

2.2.2 Alkaloids

Alkaloids represent a large group of nitrogen compounds with a basic character, which are found in plants as secondary metabolites, with more than 40,000 such compounds identified (**Figure 3**) [113].

Alkaloids play important roles in plant metabolism, catabolism, or plant physiology. They can act as nitrogen storage reservoirs, are protective agents against predator attack, growth regulators, or substitutes for plant minerals such as potassium and calcium [114].

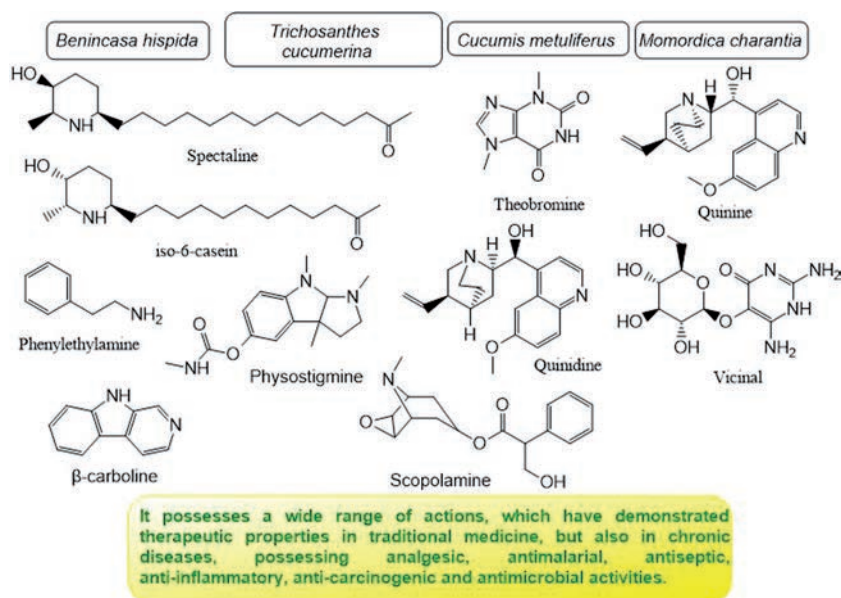


Figure 3. Alkaloids with biological properties identified in Cucurbitaceae family.

Cucumis metuliferus has been found to be a rich source of alkaloids, at a concentration of 106 mg/g in the fruit peel, 1.06 mg/g in the bark, and up to 2.54 mg/g in the seeds [90].

In the *Benincasa hispida* species, alkaloids such as 5-methylcytosine and citrulline were identified, with a total content in the peel of 4.20 ± 0.10 mg/100 g, in the pulp 4.35 ± 0.05 mg/100 g, and no compounds of this class were identified in the seeds [44].

High concentrations of vicin were quantified in *Momordica charantia* fruits (0.210 ± 0.010 pg/100 pg), in fruit pulp (0.131 ± 0.005 pg/100 pg), and in peel (0.114 ± 0.006 pg/100 pg) [115, 116].

Some alkaloids have antibacterial, antifungal and antiviral, and anticancer properties. They also help reduce blood pressure, relieve pain and spasm, and stimulate circulation and breathing. These properties may extend to toxicity to animals, microorganisms, and viruses, and administered in an appropriate dose, some alkaloids are pharmacologically active [117].

Some alkaloids, such as spectaline, theobromine, quinine, quinidine, scopolamine, and physostigmine, with biological properties identified in the Cucurbitaceae family [70, 118–120] are presented in **Figure 3**.

The therapeutic properties of alkaloids are important in the current context, in which diseases are increasingly numerous and resistant to classical treatments. Therefore, additional research will be generated to discover new drugs based on natural compounds with reduced side effects compared to classical drugs.

2.2.3 Terpenes

Terpenes, as well as their oxygenated derivatives (terpenoids), are important plant metabolites. More than 40,000 terpenoids that have been identified share a common structural feature of being obtained by the repetitive fusion of branched five-carbon units based on the isoprene backbone. These monomers are generally referred to as

isoprene units because the thermal decomposition of many terpenoid substances produces isoprene as a product [121].

Several compounds specific to this species have been isolated from the fruits and leaves of *M. charantia*, many of them being identified only in this plant species. Thus, until now, almost 204 triterpenoids have been isolated and identified from different parts of the *M. charantia* plant, most of which belong to the cucurbitan and oleanane-type terpenes [122]. Some of the most representative compounds from the terpenoid class isolated from the roots, flowers, and leaves of the *Momordica charantia* are α -carotene, lutein, β -carotene, β -ryptoxanthin, zeaxanthin, antheraxanthin, violaxanthin, squalene, and amyirin [123, 124]. Kuguacina P, a compound that has so far only been identified and isolated in bitter cucumber, was isolated from leaves in a proportion of 66.7%, in fruits 25.0%, and a smaller percentage in roots 8.3%. It was obtained by extraction using two basic solvents, ethanol with a yield of 58.3% and methanol with a yield of 25.0% [125].

A valuable compound from the terpenoid class that is more widespread in Cucurbitaceae species is carotene. Thus, the presence of β -carotene was identified in various parts of the species *Cucumis metuliferus* in the seeds in a proportion of 0.13 ± 0.06 mg/100 g seeds [54]. According to other studies, fruits contain between 1.5 and 88 μ g β -carotene/100 g of fruit [90]. Other isolated compounds from *Cucumis metuliferus* plants were isovitexin, cucurbitacin C, lutein [126], cucurbitacin B [127], oleanolic acid, and ursolic acid [128].

T. cucumerina contains, in addition to β -carotene, lutein, and cucurbitacins, other compounds such as 23, 24-dihydrocucurbitacin D, 3- β -hydroxyoleic acid identified in the fruit, isocucurbitacin B, 23,24-dihydroisocucurbitacin B, 23,24-dihydrocucurbitacin E, and lycopene [129]. A comparative study on fresh and dry samples of plant material highlighted the presence of some compounds in different proportions, such as lycopene in the fresh pulp (18 mg/100 g), and in the dry pulp (165.3 mg/100 g), lutein (18.4 mg/100 g dry plant), α -carotene (10.7 mg/100 g dry plant), and β -carotene (2.8 mg/100 g dry plant) [130]. The dry plant material contains various concentrations of the same compounds (191.7 mg lutein/100 g, 101.5 mg α -carotene/100 g, and 29.2 mg β -carotene/100 g, respectively) [130]. Cucurbitacin B [131] and cucurbitacin E have been identified in the seeds of these species, too. Terpenoids specific to the Cucurbitaceae family, such as isornultiflorenol and cucurbitacin B, have been identified in the seeds of *B. hispida* [48].

Terpenes, a widespread class of natural plant compounds found abundantly in species of the Cucurbitaceae family, are of major importance for human health and well-being due to their diverse properties, including anti-inflammatory, antimicrobial, antioxidant, and antitumor activities. In addition to their therapeutic role, terpenes are the compounds that contribute to the aroma, taste, and smell of plants, having valuable applications in the food, pharmaceutical, cosmetic, and aromatherapy industries, thus strengthening the essential link between plants and the quality of human life.

2.2.4 Saponins

Saponins are a heterogeneous group of glycosides that contain at least one glycosidic bond and are characterized by their structure containing a triterpene or steroid aglycone and one or more monosaccharide units. They are widespread in the plant kingdom, especially in legumes [132]. These compounds are secondary plant metabolites that are stored in plant cells as inactive precursors but can be easily transformed into biologically active substances by plant enzymes in response to pathogen attack.

In several studies, the presence of saponins in *C. metuliferus* fruits is demonstrated, but their chemical composition has not been studied in detail [133].

Phytochemical screening on *T. cucumerina* species revealed the presence of various classes of compounds, including saponins [90].

Extracts from *M. charantia* seeds presented saponins such as goiaglycoside A, goiaglycoside B, goiaglycoside C, goiaglycoside D, momordicoside F2, momordicoside I, and momordicoside K [76].

Consumer demand for natural products, together with their physicochemical (surfactant) properties and increasing evidence of their biological activity, has led to the study of saponins as commercially significant compounds with expanding applications in the food, cosmetic, and pharmaceutical fields. Increasing their commercial potential requires the development of new processes, processing strategies to address the processing challenges generated by their complex structure.

3. Conclusions

Plants have always been an indispensable source for human life and evolution, providing not only essential nutrients but also a wide range of bioactive compounds with remarkable therapeutic value. The evaluation of the chemical composition of plants, such as the analysis of important classes including polyphenols, terpenoids, or alkaloids, has allowed the elucidation of the mechanisms by which these compounds contribute to maintaining health, the prevention of diseases, and the improvement of various chronic conditions. This chapter highlights the importance and usefulness of some plant species from the Cucurbitaceae family. The study of the chemical composition, as well as the therapeutic potential of four species from this plant family, and of the ways of integrating them into food products, supports the development of a balanced diet, rich in natural antioxidants and anti-inflammatory compounds, with protective effects against oxidative stress, and metabolic imbalances. Finally, recent research has demonstrated once again that plants have not only a fundamental nutritional role but also a true therapeutic potential, directly contributing to improving the quality of life and supporting health.

Acknowledgements

This work was partially supported by Internal Grant 2025 no. 7956/31.03.2025 of Department of Chemistry, Physics and Environment, Faculty of Sciences and Environment, “Dunărea de Jos” University of Galați, “Targeted therapeutic molecules, anti-inflammatory and antitumor, isolated from exotic plants acclimatized in Romania” and ADER grant 5.2.1. no 521/18.07.2023, “Conservation and valorization of the genetic heritage of aromatic and medicinal species that can be cultivated on the territory of Romania.”

Author details

Anna Busuioc, Bianca Furdui, Andreea-Veronica Botezatu
and Rodica-Mihaela Dinică*

Department of Chemistry, Physics and Environment, Faculty of Science and
Environment, “Dunărea de Jos” University of Galați, Galați, Romania

*Address all correspondence to: rodica.dinica@ugal.ro

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