Medicinal and Aromatic Plants of the World

Ulysses Paulino Albuquerque
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Ákos Máthé *Editors*

Medicinal and Aromatic Plants of South America

Brazil

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Medicinal and Aromatic Plants (MAPs) have been utilized in various forms since the earliest days of mankind. They have maintained their traditional basic curative role even in our modern societies. Apart from their traditional culinary and food industry uses, MAPs are intensively consumed as food supplements (food additives) and in animal husbandry, where feed additives are used to replace synthetic chemicals and production-increasing hormones. Importantly medicinal plants and their chemical ingredients can serve as starting and/or model materials for pharmaceutical research and medicine production. Current areas of utilization constitute powerful drivers for the exploitation of these natural resources. Today's demands, coupled with the already rather limited availability and potential exhaustion of these natural resources, make it necessary to take stock of them and our knowledge regarding research and development, production, trade and utilization, and especially from the viewpoint of sustainability. The series Medicinal and Aromatic Plants of the World is aimed to look carefully at our present knowledge of this vast interdisciplinary domain on a global scale. In the era of global climatic change, the series is expected to make an important contribution to the better knowledge and understanding of MAPs. The Editor of the series is indebted for all of the support and encouragement received in the course of international collaborations started with his ISHS involvement, in 1977. Special thanks are due to Professor D. Fritz, Germany for making it possible. The encouragement and assistance of Springer Editor, Mrs. Melanie van Overbeek, has been essential in realizing this challenging book project. Thanks are due to the publisher - Springer Science+Business Media, The Netherlands - for supporting this global collaboration in the domain of medicinal and aromatic plants. We sincerely hope this book series can contribute and give further impetus to the exploration and utilization of our mutual global, natural treasure of medicinal and aromatic plants. Budapest, Prof. Dr. Ákos Máthé.

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Preface

This book gathers information about a small variety of medicinal and aromatic plants that spontaneously grow or are cultivated in South America, and it is part of the series Medicinal and Aromatic Plants of the World, conceived by Prof. Dr. Ákos Máthé. The plants are described in the form of short monographs and were selected according to the following criteria: (1) plants that are widely used in South America, and preferentially but not exclusively included in official programs of primary health care or (2) plants that are being investigated in the laboratories of researchers who accepted our invitation to collaborate on the present volume.

We tried to present state-of-the-art information for each of the 43 species included in this book. The reader will realize that although some species were extensively studied, several popular claims about their therapeutic potential have not been scientifically determined. In South America, we only study a very small fraction of the available plants with alleged medicinal properties and do not even exhaust all of the research possibilities in these cases, which is likely true in other continents as well.

We believe that several actions are required to change this scenario, including performing ethnobotanical and ethnopharmacological studies that are more theoretically and methodologically rigorous and performing systematic long-term studies of the species that exhibit at least one interesting biological activity. In the meantime, the present book, together with the remaining volumes of this series, may constitute a reference guide for future research and public health professionals.

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Part I
Medicinal and Aromatic Plants of South America

South American Biodiversity and Its Potential in Medicinal and Aromatic Plants

Alissandra Trajano Nunes and Ulysses Paulino Albuquerque

Abstract The Americas are characterized by an array of ecosystems and are home to one of the most biologically diverse areas in the world, in addition to a vast cultural diversity represented by different ethnic groups. Historically, South American peoples have shown a high degree of dependence on natural resources, especially on plants, which are used for a variety of purposes. This relationship has resulted in potential sources for new natural products, possibly including the extraction of plant-derived chemical compounds for medicinal and aromatic purposes. The global herbal market is worth billions of dollars, but in South American countries, incentives for research and the development of bioproducts by domestic companies are lacking. Moreover, a lack of scientific knowledge on these resources causes native plants to be undervalued, and the high degree of environmental degradation threatens the biological diversity and associated traditional knowledge.

Keywords Ethnobotany · Sociobiodiversity · Traditional ecological knowledge · Diversity of useful plants

1 South American Sociobiodiversity

South America, whose wealth in biological and cultural diversity is distributed across a large area of the Americas (40%), is considered to be the largest territory in the Southern Hemisphere (Gardi et al. 2014). Its geography features a variety of environments, ranging from mountainous areas with high elevations, such as the

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Andes (Aconcágua reaches 6961 m), to plains and the basins of the Amazon, Orinoco and Paraná Rivers (Gardi et al. 2014).

Due to the changes in terrain, the climate changes dramatically, ranging from tropical humid to dry and cold, resulting in irregular rainfall, which in very dry areas of Chile, Bolivia and Argentina reaches only 250 mm annually; a complete contrast to this climate type is the wettest region on the planet, located in Colombia, where the greatest annual rainfall is recorded, approximately 8000 mm (Gardi et al. 2014). South America's soils form a mosaic of more than 30 types, directly affecting biodiversity and ecosystem function (Gardi et al. 2014).

Such environmental variations generate diverse landscape units, with forest formations ranging from Araucaria forests in colder regions (Paraná, Brazil and southern Chile) to shrub formations and grasslands in dry and arid regions in northern Chile, such as in the Atacama Desert, which is considered the driest place in the world (Prado 2003; PRHS 2006; Echeverria et al. 2007; Rey-Benayas et al. 2007; Gardi et al. 2014). The other formations in South America include savannas, *cerrados*, the Pantanal, tropical rainforests (Amazon rainforest) and the pampas and steppes found in the highlands of Ecuador and Peru (Prado 2003; PRHS 2006; Salazar et al. 2007; Gardi et al. 2014).

South America comprises biomes that are home to a large diversity of plants, estimated at 81000 species (Mittermeier et al. 2003; Myers et al. 2000). Of these, approximately 50,000 angiosperms are found in Brazil, representing 22% of the global species richness (MMA 2002; Giulietti et al. 2005; FAO 2011). Colombia, Peru, Ecuador and Venezuela, and Brazil form one of the most megadiverse region in the world (Table 1) (MMA 2002; Fioravanti 2013). It is estimated that half of all plant species worldwide occur in the Amazon Basin, which spans 6.9 million square kilometers across nine countries (Brazil, Bolivia, Peru, Colombia, Ecuador, Venezuela, Guyana, Suriname and French Guiana).

Bolivia has 12,000 native plant species, and the total diversity of angiosperms is distributed among 286 families, comprising 16% of the endemic flora of the country (Meneses et al. 2015). Although the countries in northern South America, namely, Guyana, French Guiana and Suriname, are small in area, they are home to a high diversity of plants (Boggan et al. 1997; Jørgensen et al. 2014).

Uruguay is an outlier among South American countries in that it has the lowest diversity of angiosperms. Finally, Chile has a high degree of endemism despite the low number of species (Zuloaga and Belgrano 2015) and also contains very rich sites, such as the Juan Fernández Archipelago National Park, whose flora includes 137 endemic and 213 native species (CONAF 2016).

The biodiversity of a region extends far beyond the variability of living organisms (Brasil 2000); it also includes a set of social and cultural activities associated with the knowledge, use and management of natural resources (Diegues and Arruda 2001). Thus, the diversity of plants in South America is certainly part of the life history of the inhabitants of this continent. This strong relationship between local populations and the environment is manifested in changes in landscape units for animal husbandry and crop cultivation, such as those performed by indigenous peoples such as the Incas, the oldest civilization on this continent, who lived in the Andes

Table 1 Diversity and endemism of South American angiosperm plant species

Country	Diversity	Endemism	Source
Brazil	50,000–56,000	33%	Mittermeier et al. (1997)
			MMA (2002)
			Giulietti et al. (2005)
Colombia	45,000–51,000	33%	Mittermeier et al. (1997)
			Giam et al. (2010)
			Fonnegra and Jiménez (2007)
Peru	18,000–20,000	29.8%	Mittermeier et al. (1997)
Ecuador	17,600–21,100	22,7–23,7%	Mittermeier et al. (1997)
			Jørgensen and León-Yánez (1999)
Venezuela	15,000–21,070	33.3–38%	Mittermeier et al. (1997)
Bolivia	15,345	15.3%	Davis et al. (1997)
			Jørgensen et al. (2014)
			Meneses et al. (2015)
Argentina	10,944	17.5%	Zuloaga and Belgrano (2015)
French Guiana and Guyana	8507	23,5%	Boggan et al. (1997)
			Davis et al. (1997)
Suriname	5000	–	Boggan et al. (1997)
			Davis et al. (1997)
Paraguay	6500–7000	24.6%	Basualdo et al. (1991)
			Zuloaga and Belgrano (2015)
Chile	4672	16.6%	Davis et al. (1997)
			Massardo and Rozzi (1996) and Gardner et al. (2015)
Uruguay	313	–	Haretche et al. (2012)

(Peru, Bolivia, Chile and Ecuador) and essentially dominated South America for centuries (Beyhaut 1994).

After the arrival of European colonists in the sixteenth century, the native people lost their territory, and the exploitation of natural resources expanded (Todorov 1993; Bueno and Dias 2015). Immense areas were devastated across the continent, and many biomes were degraded, with only small forest remnants remaining as environmental protection units, such as, for example, in Brazil (MMA 2002). Despite this destruction and the continuing deforestation, South America remains one of the most biologically diverse places on the planet.

Along with the loss of biological diversity, many ethnic groups have vanished, but there are still some ethnic remnants, such as in Colombia (120 indigenous groups), Peru (55 indigenous groups), Bolivia (35 indigenous groups), Venezuela (28 recognized ethnic groups), Ecuador (22 indigenous groups, Afro-Ecuadorians, Mestizos and Whites) and Paraguay (19 indigenous groups) (Vilca 2008; ACNUR 2009; DGEEC 2013; Zarur 2000; MIDIC 2016). In Brazil, there are more than 200 indigenous groups and many riverside, hinterland and *quilombola* (Maroon) communities, among others, bringing together an invaluable wealth of traditional knowledge of biodiversity (Diegues and Arruda 2001; Bosi 2000).

Colonization had a strong negative impact on native populations, consequently representing a strong threat to local knowledge. However, it resulted in a complex multicultural mosaic, in which different cultures and knowledge are interconnected. This knowledge may be a valuable tool in the struggle for biodiversity conservation (Diegues 2000), as many different groups of people depend on these resources (Posey 1984; Diegues and Arruda 2001; MMA 2002; Nogueira et al. 2010). The process of cultural exchange is dynamic and active in South America due to the contact among different groups of people through various types of migratory events (Neves et al. 2007). These processes enrich both the local biodiversity and the knowledge associated with it.

The importance of local knowledge of South American biological diversity is also evident in its contribution to advancing the field of bioprospecting. In this context, there is growing interest on ethnopharmacological research, as most manufactured drugs have a natural origin that often relies on information corresponding to the traditional uses of plants (Patwardhan 2005; Moore et al. 2017).

2 The Medicinal and Aromatic Plants of South America

Considering global biodiversity, it is estimated that there are between 50,000 and 70,000 medicinal and aromatic plants (MAPs) used worldwide by a majority of the planet's population. For example, in some South American countries, approximately 80% of the population uses medicinal plants (Firmo et al. 2011). Based on this estimate, it is clearly necessary to better understand the diversity of MAPs, especially given the lamentable destruction of ecosystems worldwide, which has resulted in approximately 15,000 species being threatened with extinction, according to the International Union for Conservation of Nature (IUCN 2000).

According to the World Health Organization (WHO 2007), more than 21,000 species are used worldwide for medicinal purposes, but there is no systematic data for South America (IUCN 2000). Another important aspect is that the uncontrolled exploitation of these countries has reduced biodiversity every year and many plant species are disappearing and with them, their associated traditional knowledge.

The study of MAPs allows the improved understanding of the local medical systems and thus the elucidation of gaps in the development of herbal medicines, contributing to the search for active compounds to develop drugs and increase therapeutic options for healthcare professionals (Elisabetsky and Moraes 1990; Klein et al. 2009; Tavares et al. 2013).

Despite the importance of the study of MAPs, the data in the literature are scattered and limited to a specific sector of the public. Further, even when information is gathered, as in one of the largest databases available on the Internet, "Plants for the future", with approximately 7000 useful species, the available information covers a limited number of plants (PFAF 2016). This database provides the scientific name and common name and information on the geographic distribution and uses of plants (PFAF 2016).

Table 2 Articles published on plants in the indicated Latin American countries during the period 1984–2004

South American countries	Year of publication							
	1984–1986	1987–1989	1990–1992	1993–1995	1996–1998	1999–2001	2002–2004	Total
Brazil	24	34	252	378	622	981	1431	3722
Argentina	15	15	98	176	339	495	603	1741
Chile	4	5	51	75	100	144	194	573
Venezuela	0	10	31	64	89	99	101	394
Colombia	1	2	28	39	48	72	75	265
Peru	5	5	27	24	39	43	71	214
Uruguay	1	1	1	5	13	22	26	69

Source: Adapted from Calixto (2005)

Most of the information available is primarily concentrated in books. Small percentages of the medicinal flora of some South American countries, such as Colombia, Venezuela, Chile, Ecuador, Bolivia and Peru, are described in books on medicinal plants of South America (see, for example, Roth and Lindorf 2002), which provide an overview of the phytochemistry of the plants common to these countries (Roth and Lindorf 2002). In Brazil, a considerable number of articles and books provide information on the use of and specific properties for very few species, usually the most common species or those with the most widespread use.

Calixto (2005) analyzed 25 years of research on the medicinal plants of Latin America (Table 2), finding records for seven of the 13 South American countries. In the last decade, the number of studies in Brazil has increased, and in the Scopus database alone, more than 1967 publications are found for this country when conducting a search using a combination of the keywords "medicinal plants" and Brazil. Research involving the MAPs in South American countries is of interest for pharmaceutical companies that seek to find active ingredients with the potential for the production of phytomedicines (Calixto 2005).

Table 3 presents records of native and exotic plants per country. Colombia, Brazil and Argentina are exceptional in that more than 1000 plant species in each country are recorded as being used for medicinal purposes (Table 3). In Peru, 4000 plant species used for medicinal and aromatic purposes have been recorded (Sanz-Biset et al. 2009; Gupta et al. 2014). A critical feature of these listings is that the records are incomplete regarding the origin of the species; therefore, the estimates are inaccurate regarding the diagnostic of the potential of the continent's native flora.

Despite South America's rich biodiversity and its pharmacological potential, there is a clear need to invest in research on plant species (Heinzmann and Barros 2007; Simões and Schenkel 2002). According to Calixto (2005), natural products originating from the continent's flora have been rapidly developed as a result of combined efforts between universities and the pharmaceutical industry to produce new effective and safe drugs. However, great effort is needed to establish the rational and sustainable exploitation of South American biodiversity in order to sustain-

Table 3 Estimated numbers of plant species used for medicinal purposes in South America

Country	Year/Period	No. of maps	Source
Brazil	2016	3000	MIDIC (2016)
Argentina	2009	1529	Barboza et al. (2009)
Chile	1996	469	Massardo and Rozzi (1996)
Peru	2009–2010	1500–4000	Sanz-Biset et al. (2009), Bussmann and Glenn (2010), and Gupta et al. (2014)
Colombia	2013–2015	5000	Fonnegra and Jiménez (2007), Cadena-González et al. (2013), and Jiménez et al. 2015
Uruguay	1993	22	González et al. (1993)
Venezuela	2002–2009	700	Giraldo et al. (2009)
Paraguay	1991	1500–3500	Basualdo et al. (1991)
Guyana			DeFilipps et al. (2004)
French Guiana	2004	1000–1200	DeFilipps et al. (2004)
Suriname	1982–2007	138	Verpoort and Dihal (1987), Hasrat et al. (1997), and Andel et al. (2007)
Ecuador	2006–2016	275	Torre et al. (2006) and Tinitana et al. (2016)

ably meet the needs of pharmaceutical companies and local people in these countries while also respecting the intellectual property rights that include the traditional knowledge associated with these plants.

The use of medicinal plants by people from different parts of South America is not random. The variety of medicinal plants reported is related to the richness within each botanical family, with different evidence from Brazil (Medeiros et al. 2014), Bolivia (Thomas et al. 2009) and Ecuador (Bennett and Husby 2008). These data reinforce the fact that the biodiversity in South America may mask the real abundance of MAPs. Despite these findings, there is also evidence for some plants, such as ferns and lycophytes, that, although used in accordance with their existing availability, are used less and less in local communities because they are perceived as inferior therapeutic resources (Reinaldo et al. 2015). This phenomenon suggests the need for detailed ethnobiological and ethnopharmacological studies to understand the roles of plants in different local medical systems in South America.

Notably, despite the high biodiversity in South America, few phytomedicines have been developed from the flora. This anomaly may be explained by the following criticisms of several researchers: a lack of systematic and continued studies with promising plants; a lack of collaboration among researchers; limitations related to research methods and misinterpretations of pharmacological tests; and confusing, misleading and limited procedures for collecting ethnobotanical data, which are often the basis for other research fields (Houghton et al. 2007; Gertsch 2009; Albuquerque et al. 2014). For example, Medeiros et al. (2014) found problems in several published studies on medicinal plants that were based on surveys of information from the local populations, which compromises the quality, reliability and clarity of the findings.

In the case of phytomedicines, one-quarter of products sold in pharmacies are manufactured from materials extracted from tropical plants (Abranches 2015). Thus, some researchers consider the value of natural products for society and the economy incalculable (Abranches 2015) and the losses of genetic resources through biopiracy also incalculable. To minimize these risks, the Interministerial Group on Industrial Property (Grupo Interministerial de Propriedade Industrial, or GIPI, appointed by the Brazilian Ministry of Development, Industry and Foreign Trade/2006), produced a "Non-Exhaustive List of Customary Names Used in Brazil Associated with Biodiversity" to track native species patented by other countries (GIPI 2016).

3 The Treasures of South America

South America's biodiversity is a valuable source of active ingredients that can be used as medicines, with only a few products that are currently commercially available, such as pilocarpine, which is extracted from the leaves of *Pilocarpus microphyllus* Stapf. (jaborandi), a native plant from Brazil (Valdez et al. 1993; Wynn 1996; Pinheiro 2002). Pilocarpine has been used for decades in the preparation of medication indicated for glaucoma (Merck 1998) and is also used to relieve some side effects of radiotherapy, such as dry mouth (xerostomia), by stimulating the secretion of saliva (Valdez et al. 1993; Wynn 1996).

An important contribution of medicinal flora is d-tubocurarine, a substance known as "curare", which is a preparation made with the species *Chondrodendron tomentosum* Ruiz and Pavon (Menispermaceae). Curare is used as poison by indigenous peoples and was introduced into the market for anesthesiology in 1940 due to its relaxant effect on skeletal muscles (Nogueira et al. 2010). Another phytomedicine recently introduced to the market is derived from the medicinal plant known as cordia, *Cordia verbenacea* DC. (Boraginaceae), which has anti-inflammatory activity with indications for tendonitis and muscle pain and is produced by a major Brazilian pharmaceutical company (Calixto 2005).

Myracrodruon urundeuva Allemão is one of the primary plants used in traditional medicine in northeast Brazil and in other South American countries, including Bolivia (Deharo et al. 2004). It is indicated as antimicrobial, anti-inflammatory and healing in the treatment of wounds, gastritis, gastric ulcers, cervicitis, vaginitis and hemorrhoids (Lorenzi and Matos 2002; Botelho et al. 2007; Bianco 2004). With properties similar to the Brazilian peppertree (*Schinus terebinthifolius* Raddi), it has antimicrobial, healing and anti-inflammatory indications. *M. urundeuva* is used as a drug in the treatment of cervicitis, vaginitis and cervical vaginitis in the form of gynecological gel and vaginal ovules (Brasil 2016).

As in the previous examples, in recent decades, research on medicinal plants has confirmed some traditional indications, but there is an urgent need to determine the actual diversity of medicinal plants and to protect and regulate access to the biological resources of South America (Marques 2000). Aiming to regulate the use of some species, the Brazilian National Health Surveillance Agency (Agencia Nacional de Vigilância Sanitária do Brasil – ANVISA 2011) published a list of the phytomedicines of the Brazilian pharmacopoeia, containing information on 47 plant species and their derivatives as phytomedicines for infusions and decoctions, tinctures, syrup, gels, ointment, soap and creams. Despite the important ANVISA initiative, this list is only a sample of all medicinal plants, many of which are exotic (Brasil 2011).

Unfortunately, the technological state of the products marketed by the pharmaceutical industry in Brazil, which may be one of the few South American countries with major advances in this area, is based on the popular use of plants rather than with pre-clinical proof of biological activities (Yunes et al. 2001; Firmo et al. 2011). To improve this situation, a policy committed to the development of scientific studies and incentives for the pharmaceutical industry is needed (Rates 2001; Yunes et al. 2001; Calixto 2005). In Brazil, for example, 74 native species are used by the industry in 300 diverse types of products, but "the lack of quantitative data indicating where these plants are harvested, the quantities involved, and their harvesting capacity will limit any attempts at establishing conservation strategies at a national level" (Melo et al. 2009).

The generation of patents requires additional attention, considering that in South America, there seems to be no effective culture or stimulus toward generating patents arising from scientific studies, which is also a concern with regard to biopiracy, as it endangers the genetic heritage of the continent (Marques 1999; Moreira et al. 2004).

Finally, South America has a valuable assortment of plant resources with the potential for bioprospecting and conservation (see Gonzales and Valerio 2006; Sülsen et al. 2011; Cruz et al. 2013) despite high levels of degradation and the improper exploitation of MAPs. In addition, it is necessary to gather information in a systematic way to advance analysis and propose strategic actions for development and research.

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Chemical Diversity and Ethnopharmacological Survey of South American Medicinal and Aromatic Plant Species

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Abstract The present chapter is a short review providing information about the chemical constituents of some South American plant species used by local communities in countries of this continent except the Falkland Islands and Surinam. Many plants found in the countries of Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Uruguay, and Venezuela have valuable phytotherapeutic applications in alternative medicine. This chapter presents information reported in the scientific literature concerning the most significant plant families used in folk medicine, considering their chemical compositions and highlighting the following categories: alkaloids, an important class of biologically active compounds; phenolics, especially flavonoids; and essential oils.

Keywords South American countries · Chemical composition · Ethnopharmacology · Traditional medicine · Phytotherapy · Medicinal and aromatic species · Biodiversity · Alkaloids · Phenolic compounds · Essential oils · Flavonoids

1 Introduction

The use of herbs as medicinal plants by humanity, as an alternative therapy for the treatment of diseases, has been commonplace for thousands of years. More recently, herbs have been used as models for novel therapeutic agents. Medicinal plants provided the basis for modern traditional medicine, with the earliest records, dating from 2600 BC, documenting the use of almost 1000 plant-derived substances in Mesopotamia and ancient Egypt, the region now known as the Middle East.

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The secondary metabolites of plants are an economically important source of pharmaceuticals and can serve as models for synthetic drugs. They play vital roles in the physiology of plants, helping to protect against unexpected environmental hazards. Studies in this area have increased over the last decades, with many compounds being isolated and their chemical structures discovered.

The biodiversity of the terrestrial ecosystems of South America constitutes one of its essential features, and most important is the fact that this region still contains vast intact wild areas, where new chemical molecules can be discovered. The South American biosphere therefore has an enormous potential to provide phytochemicals with active components that can be used in industrial products.

2 Ethnopharmacological Overview and Chemical Compositions

Below we have compiled some of the scientific research from South American countries related to species of recognized importance in folk medicine, describing a great diversity of chemical compounds and their known and potential uses.

Among many applications of plants, Gonzales and Valerio Junior (2006) specifically considered the anti-cancer properties of species used in folk medicine by Peruvian populations from the Andean and Amazonian regions. The authors found evidence of the beneficial use of *cat's claw*, also known as *uña de gato* (*Uncaria tomentosa* (Willd.) DC.), *maca* (*Lepidium meyenii* Walp.), and *dragon's blood* (*Croton lechleri* Müll. Arg.). Major constituents identified in *cat's claw* include alkaloids, organic acids, anthocyanins, sterols, and triterpenes. The major constituents reported in *maca* include tannins, saponins, sterols, polyunsaturated fatty acids, β-carbolines, uridine, malic acid, prostaglandins, flavonoids, and anthocyanins. *Dragon's blood* contains alkaloids, phenolic compounds such as proanthocyanidins and flavonoids, and tannins such as catechin-(4α→8)-epigallocatechin, gallocatechin-(4α→8)-epicatechin, gallocatechin-(4α→6)-epigallocatechin, catechin-(4α→8)-gallocatechin-(4α→8)-gallocatechin, and gallocatechin-(4α→8)-gallocatechin-(4α→8)-epigallocatechin.

Bixa orellana L., known by its folk name *urucum*, has been used by native people in Brazil because of its food and biological uses. Its widespread dissemination, evidenced by crops grown in other South American countries including Colombia, Paraguay, Venezuela, Bolivia, Argentina, Peru, Guyana, and Ecuador, is due to the demand for its natural dye (bixin) by the food and pharmaceutical industries (Vilar et al. 2014).

Considering species found in Colombia, studies have listed 254 plants, including 127 wild species, used in the northwest Antioquia region for various medicinal purposes. The species in this list belong to 193 genera of 79 families, notably the Asteraceae, Lamiaceae, Poaceae, Apiaceae, and Solanaceae, and their uses have been divided into 131 categories (Fonnegra-Gómez and Villa-Londoño 2011). The Asteraceae family was also studied by Ribeiro et al. (2010), who investigated the uses of 102 species, as well as their chemical constitutions, in a phytochemical screening approach using crude extracts of the plants.

Chemical evaluation was made of species of the *Eremanthus* genus collected in an ecological reserve in Brazil. The chemical screening of *E. erythropappus* (DC.) Macleish, *E. incanus* (Less.) Less., and *E. glomerulatus* Less. revealed the presence of reducing sugars, carbohydrates, amino acids, tannins, flavonoids, glycosides, cardiotonics, carotenoids, steroids, triterpenoids, coumarin and its derivatives, saponins, alkaloids, purines, polysaccharides, and anthraquinones. The *Eremanthus* genus contains several species that are known by their folk name *candeia* and are mostly exploited for the production of an essential oil, whose main component, α-bisabolol, has antiphlogistic, antibacterial, antimycotic, dermatological, and spasmodic properties.

Alviz et al. (2013) studied *Ceratopteris pteridoides* (Hook) Hieron. and found evidence of its diuretic activity, corroborating the popular use of this plant in the northern districts of Colombia. Major components found in *C. pteridoides* were aromatic amines and tryptamines, esters, aldehydes, and ketones, with smaller amounts of tannins and cardiotonics. Lagos-López (2007) studied ethnobotanical aspects of species with medicinal properties in six municipalities of the Department of Boyacá, in a survey of 600 people who claimed to have knowledge of the use of these plants. The species most commonly used for stomach ache (employed by 80% of the population) was *Cape gooseberry* (*Physalis peruviana* L.), a member of the Solanaceae family. Franco et al. (2007) also studied *Cape gooseberry*, due to its high commercial value and medicinal properties including anticancer, antimycobacterial, antipyretic, diuretic, immunomodulatory, and anti-inflammatory activities. Its anti-inflammatory activity was confirmed and validated, and the compound 12-*O*-tetradecanoylphorbol-13-acetate was isolated and tested, showing statistically significant activity.

Quintero et al. (2015) studied herbs collected from eight different local markets in the Colombian capital and conducted semi-structured interviews with 16 sellers of medicinal plants. In these interviews, the herb vendors mentioned species such as *chitato* (*Muntingia calabura* L.), *alfalfa* (*Medicago sativa* L.), *laurel* (*Morella pubescens* Willd), *suelda consuelda* (*Symphytum officinale* L.), and *paico* (*Chenopodium ambrosioides* L.), which were not found in the National Colombian Formulary. *Alfalfa* is rich in nutrients such as provitamin A and vitamins B, C, D, and K, and is used to combat scurvy and rickets. The herbs mentioned were found in folk medicine, and their efficacy and safety of use have not been established scientifically (Lorenzi and Matos 2008).

Folk knowledge is a consistent theme in this review, and according to Quintero et al. (2015) the vendors showed little knowledge about possible side effects of the medicinal plants, which could be indicative of unsatisfactory practices in the community. Ignorance of the differences between the decoction and infusion forms of preparation was also evident. Plants that could be promising for new therapeutic uses were identified, including *albahaca* (*Ocimum basilicum* L., also *Ocimum campechianum* Mill.), *calendula* (*Calendula officinalis* L.), *cidrón* (*Aloysia triphylla* Royle), *cola de caballo* (*Lasiacis sorghoidea* (Desv. ex Ham.) Hitchc &

Chase, also *Equisetum arvense* L. or *Equisetum bogotense* Kunth.), and *manzanilla* (*Matricaria chamomilla* L.) (Quintero et al. 2015). Eleven herbs with essential oils in their composition were collected and investigated by Bueno-Sánchez et al. (2009) for their anti-tubercular activity. The authors concluded that the essential oils from *Achyrocline alata* (Kunth) DC., which contains 24.0% thymol, and *Swinglea glutinosa* (Blanco) Merr., which contains 49.6% α-pinene as well as other identified compounds, are candidates as potential phytotherapeutic agents against tuberculosis in humans. *Macela* is one of several popular names of *A. satureioides* (Lam.) DC., and this name is also used to describe *A. alata*, a typical species from southern Brazil, which also occurs in Uruguay, Paraguay, and Argentina. *A. satureioides* is used as an anti-inflammatory, antispasmodic, digestive, sedative, and carminative (Lorenzi and Matos 2008). Chemical investigations of *A. alata* and other species of *Achyrocline* collected in Argentina and Uruguay showed similar profiles in terms of their phenolic constituents, flavonoids, and quinic acid derivatives, compounds that justify the folk uses of these plants. The main compounds found were chlorogenic acid, isoquercitrin, 3,4-dicaffeoyl quinic acid, 3,5-dicaffeoyl quinic acid, 4,5-dicaffeoyl quinic acid, quercetin, 3-*O*-methylquercetin, 4,2′,4′-trihydroxy-6′-methoxychalcone, and gnaphalium (Grassi-Zampieron et al. 2010).

Arias (2012) investigated herbs used to treat common diseases in the vicinity of the Colombian city of Leticia, in the Amazon region, during the years 2008 and 2009. A total of 115 herbs with medicinal uses were reported, comprising 109 genera and 99 species. It was concluded that the families Arecaceae, Bignoniaceae, and Rubiaceae, and species such as *yarumo* (*Cecropia sciadophylla* Mart.), *carambolo* (*Averrhoa carambola* L.), *cat's claw* (*Uncaria tomentosa* Willd. DC.), *acapu* (*Minquartia guianensis* Aubl.), *lancetilla* (*Alternanthera brasiliana* (L.) Kuntze), and *amacizo* (*Erythrina fusca* Lour.) had considerable cultural value within this specific Amazon community. Carvajal-De Pabón et al. (2014) assessed different parts of *Passiflora ligularis* Juss., locally known as *granadilla*, including the pulp, flowers, leaves, flower cores, and stems. Substances detected in different proportions in the various plant tissues included phenolic compounds, coumarins, anthocyanins, saponins, tannins, flavonoids, triterpenes/steroids, quinones, alkaloids, and lactones. This information served as a starting point for a basic qualitative procedure to describe the biological activity of this species, including phytochemical, bromatological, and mineral analyses.

Lorenzi and Matos (2008) described the *Drimys* genus in Brazil, where *Drimys brasiliensis* Miers is used against dyspepsia, dysentery, nausea, intestinal pain and cramping, fever, and anemia. This plant, which is recognized worldwide as a carminative, stomachic, and tonic, contains tannins and sesquiterpenoids in its composition.

Hajdu and Hohmann (2012) described two species of the genus *Triplaris*, namely *T. peruviana* Fisch. & Meyer ex C.A. Meyer and *T. pavonii* Meisn., used for the treatment of dysentery and burns by the Bolivian Kallawaya ethnic group. A close relative, *Triplaris americana* L., whose local name is *palo santo*, was studied by Oliveira et al. (2008), who identified the chemical compounds present as triterpenes (friedeline and friedelinol), flavonoids (quercetin and quercetin-3-*O*-α-L-arabinofuranoside), a phenylpropanoid glycoside (vanicoside), an amide (moupamide), and gallic acid. Its application for the treatment of malaria in Peru is supported by the detected high in vivo activity of the ethanol extract of the bark against *Plasmodium vinckei petteri*, as well as its in vitro activity against *Plasmodium falciparum*.

Brazil has a broad and rich biodiversity, which is accompanied by a long-standing acceptance of medicinal plants and traditional knowledge by the population. Herbal medicines are regulated by the National Health Surveillance Agency (ANVISA) and by the Brazilian Agricultural Ministry. Since 2006, Brazil has two current public policies favoring the widespread use of herbal medicines, namely the National Policy on Integrative and Complementary Practices in the Public Health System, and the National Policy on Medicinal Plants and Herbal Medicines. Compounded herbal medicines are prepared in pharmacies according to good manufacturing practices, under authorization by the Health Surveillance secretariats (Carvalho et al. 2014). Despite the wide biodiversity of higher plants native to Brazil, with over 45,000 species, or 20–22% of the total global diversity, Brazil has hardly any medicines near the top of the list of commercially available herbal products. In fact, this market is still only worth about 260 million US dollars, which represents less than 5% of the medicines sold in this country (Dutra et al. 2016). Species such as *Cordia verbenacea* DC. (also named *Varronia verbenacea* (DC.) Borhidi), *Euphorbia tirucalli* L., *Mandevilla velutina* K. Schum., *Phyllanthus spp*., *Euterpe oleracea* Mart., *Vitis labrusca* L., *Hypericum caprifoliatum* Cham. & Schltdl., *Hypericum polyanthemum* Klotzsch ex Reichardt, *Maytenus ilicifolia* Mart. ex Reissek, *Protium kleinii* Cuatrec., *Protium heptaphylium* (Aubl.) Marchand, *Myracrodruon urundeuva* Allemão, and *Trichilia catigua* A. Juss. were selected for evaluation by Dutra et al. (2016). It was concluded that very few studies have been dedicated to investigation of the mode of action of isolated compounds, with most studies being based on the in vitro and in vivo effects of crude extracts. The authors described the use of *Myracrodruon urundeuva* Allemão, popularly known as *aroeira*, which presents an anti-colitis effect and includes in its composition the compounds β-caryophyllene, euphol, and α,β-amyrin, responsible for this action in mice. Also reported was *Trichilia catigua* A. Juss., a native Brazilian plant commonly used as a neurostimulant and aphrodisiac, known by its folk name *catuaba*, whose chemical composition includes the presence of alkaloids, lactones, β-sitosterol, stigmasterol, and flavalignans.

The following section describes important classes of chemical compounds found in plant species from South America.

3 Important Chemical Groups Found in South American Plant Species

3.1 Alkaloids

The term alkaloid, meaning alkali-like substance, was introduced in 1819 by the pharmacist W. Meissner to describe nitrogenous compounds derived from plants. Alkaloids are a very large and heterogeneous group of compounds that are not only derived from plants, but also from microorganisms, insects, and animals. They are usually basic and often cause a physiological response (Ebadi 2006; Yang and Ren-Sheng 2011).

In plants, alkaloids generally act as a defense against predators, due to their toxicity, bitter flavor, and action on the central nervous system, resulting in improved species survival rates (Matsuura and Fett-Neto 2015). Interestingly, these toxic properties have been useful to indigenous South American populations, who employ a mixture of *Strychnos* species to make curare, a poison used in hunting and warfare (Silva et al. 2005).

Alkaloids have been used in medicine since ancient times to treat a variety of ailments, and remain the subject of research today. Some examples of alkaloids with medicinal properties are morphine (analgesic), derived from *Papaver somniferum* L., ephedrine (anti-asthma), from *Ephedra sinica* Stapf, and vincristine (antitumor), from *Catharanthus roseus* (L.) G. Don.

A variety of alkaloids with pharmacological and economic importance can be found in South America. One example is quinine, obtained from the dried bark of the *Cinchona* tree (Rubiaceae family), which has been used for centuries to treat malaria. In combination with other drugs, quinine is still used to treat uncomplicated malaria, and is also employed as a muscle relaxant and as a flavoring agent in foods and beverages (Achan et al. 2011; Schardein and Macina 2006).

Lycopodium clavatum (L.) and *Lycopodium thyoides* (Humb. & Bonpl. ex Willd) are species from the Lycopodiaceae family that are rich in alkaloids and are used popularly in South America to treat gastrointestinal disorders and to stimulate the central nervous system (Navarrete et al. 2006; Øllgaard and Windisch 2014). Konrath et al. (2012) isolated alkaloids from these two species and observed antioxidant effects and significant inhibition of acetylcholinesterase in *in vitro* and *ex vivo* experiments, making these species candidates for the treatment of neurodegenerative disorders such as Alzheimer's disease.

The roots from the species *Psychotria ipecacuanha* Standl., native to Brazil, mainly contain the alkaloids emetine, cephaeline, and psychotrine. This species, known as *ipecac*, is used in folk medicine as an emetic, amebicide, and expectorant (Daniel 2006). Studies also suggest anti-HIV activity (Valadão et al. 2015) and antitumor activity (Uzor 2016), among other biological effects (Akinboye and Bakare 2011).

Another important alkaloid is pilocarpine, isolated from the leaves of jaborandi (*Pilocarpus microphyllus* Stapf), native to the Amazon region of Brazil. This alkaloid