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Alkaloids from the native flora of Chile: a review

[Alcaloides de la flora nativa de Chile: una revisión]

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Abstract:

In spite of the high degree of endemism of the native vascular flora of Chile (*ca.* 52%) and predictions based on the frequency of occurrence of alkaloids in the world flora (they have been found in 40.4% of the families, 13.1% of the genera and 2.7% of the species), alkaloids have been isolated from only 12.5% of families, 3.9% of genera and 1.7% of species of the native flora of Chile. The slope of the linear correlation between these two sets of figures suggests that the alkaloid potential of the native Chilean flora has been exploited to the extent of only 29%. Currently known alkaloid-containing species from the native flora of Chile are listed in this review together with pertinent references. The distribution of alkaloids was compared between the native flora of Chile and the world flora; this led to the identification of several families with good potential as sources of alkaloids.

Keywords: Alkaloids; native flora of Chile; potential sources of alkaloids; alkaloid distribution in floras; alkaloid distribution in ecosystems

Resumen:

A pesar del alto grado de endemismo de la flora vascular nativa de Chile (*ca.* 52%) y predicciones basadas en la frecuencia con que se encuentran alcaloides en la flora del mundo (en 40.4% de las familias, 13.1% de los géneros y 2.7% de las especies), se han aislado alcaloides solo desde 12,5% de las familias, 3,9% de los géneros y 1,7% de las especies de la flora nativa de Chile. La pendiente de la correlación entre estos dos conjuntos de datos sugiere que el potencial de la flora nativa de Chile como productora de alcaloides ha sido explotado solo en un 29%. En esta revisión se entrega una lista de las especies de la flora nativa de Chile que contienen alcaloides y las referencias pertinentes. La distribución de alcaloides fue comparada entre la flora nativa de Chile y la flora del mundo, lográndose identificar varias familias con un buen potencial como fuentes de alcaloides.

Palabras Clave: Alcaloides; flora nativa de Chile; fuentes potenciales de alcaloides; distribución de alcaloides en floras; distribución de alcaloides en ecosistemas

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INTRODUCTION

The continental territory of Chile is a long (18° to 56°S) and narrow stretch of land lying between the Andes range and the Pacific Ocean. Within this area, vegetational zones may be distinguished which encompass one of the driest deserts on earth, the Atacama desert, and cool temperate rain forests with average annual rainfall in excess of 4.5 m (Gajardo, 1994). The geographical isolation of the country as well as the variety of vegetational zones given by its latitudinal and altitudinal expanses has produced a unique land flora with a notably high degree of endemism (51.8%) in relation to its relatively meager surface area (Major, 1988). This flora comprises 184 families of vascular plants (18 Pteridophyta, 4 Gymnospermae, 132 Dicotyledoneae and 30 Monocotyledoneae) subdivided into 1008 genera, with a total of 5739 species, including 5082 native species of which 2630 are endemic (Marticorena, 1990). The uniqueness of the Chilean flora is also exceptional, with 496 monotypic genera, some families with higher than 80% endemism (i.e., Cactaceae) and some genera with higher than 70% endemism [i.e., *Neoporteria* (Cactaceae), *Cristaria* (Malvaceae) and *Haplopappus* (Asteraceae)] (Niemeyer 1995).

Alkaloids are widespread in Nature; they show a wide range of pharmacological activities and many

of them are used as drugs (Cordell *et al.*, 2001). In spite of the uniqueness of the native flora of Chile, predictions based on the frequency of occurrence of alkaloids in the world flora, and their interesting pharmacological activities, studies on alkaloids from the native Chilean flora have been rather scarce. This review gathers information on the alkaloid-containing taxa of the native Chilean flora and compares it with data for the world flora.

RESULTS AND DISCUSSION

Table 1 lists the alkaloid-containing taxa from the native Chilean flora. The data for Lorantheaceae and Cuscutaceae deserve a special comment. *Tristerix verticillatus* (Lorantheaceae) and *Cuscuta chilensis* (Cuscutaceae) are hemiparasitic and holoparasitic plants, respectively, whose compositions depend on the host. Thus, Cabezas *et al.* (2009) found alkaloids in *T. verticillatus* parasitizing *Berberis montana*, an alkaloid-rich species, but not *Schinus molle*, a species lacking alkaloids; moreover, the alkaloids in *T. verticillatus* were either the same as those found in *B. montana* or biosynthetically derived from them. The qualitative pattern of alkaloids found in *C. chilensis* was the same as that found in the host, *Sophora macrocarpa* (García *et al.*, 1995).

TABLE 1

Studies on the isolation of alkaloids from the native flora of Chile.

Currently accepted botanical names are used

(<http://www2.darwin.edu.ar/Proyectos/FloraArgentina/BuscarEspecies.asp>); they may be different from those used in the papers cited. Intraspecific taxa have not been considered independently.

| Family | Species | Alkaloid-type | Reference |
|--------------------|-------------------------------|---|---|
| Amaryllidaceae | <i>Rhodophiala ananuca</i> | Phenanthridine | Pacheco <i>et al.</i> , 1978, 1982. |
| Apocynaceae | <i>Skytanthus acutus</i> | Monoterpene alkaloids | Adolphsen <i>et al.</i> , 1967. |
| Aristolochiaceae | <i>Aristolochia bridgesii</i> | Nitrophenanthrene | Urzúa <i>et al.</i> , 2009 |
| Aristolochiaceae | <i>Aristolochia chilensis</i> | Nitrophenanthrene, aporphine, proaporphine | Urzúa <i>et al.</i> , 1982, 1983, 1987; Urzúa and Rojas, 1990 |
| Asteraceae | <i>Chersodoma jodoppapa</i> | Secopyrrolizidine | Morales <i>et al.</i> , 1986. |
| Asteraceae | <i>Senecio erraticus</i> | Pyrrolizidine | Reina <i>et al.</i> , 1993. |
| Asteraceae | <i>Senecio glaber</i> | Pyrrolizidine | Reina <i>et al.</i> , 1993. |
| Asteraceae | <i>Senecio illinitus</i> | Pyrrolizidine | González <i>et al.</i> , 1986. |
| Asteraceae | <i>Senecio microphyllus</i> | Pyrrolizidine | Reina <i>et al.</i> , 1993. |
| Asteraceae | <i>Senecio miser</i> | Pyrrolizidine | Reina <i>et al.</i> , 2001. |
| Asteraceae | <i>Senecio murorum</i> | Pyrrolizidine | Villarroel <i>et al.</i> , 1988. |
| Asteraceae | <i>Senecio patagonicus</i> | Pyrrolizidine | Villarroel <i>et al.</i> , 1985, 1997. |
| Asteraceae | <i>Senecio phillipicus</i> | Pyrrolizidine | González <i>et al.</i> , 1986. |
| Asteraceae | <i>Senecio portalesianus</i> | Acylpyrrolizidine | Jakupovic <i>et al.</i> , 1991. |
| Atherospermataceae | <i>Laurelia sempervirens</i> | Bisbenzylisoquinoline, seco-bisbenzylisoquinoline | Bianchi <i>et al.</i> , 1962; Urzúa <i>et al.</i> , 1975; Cassels and Urzúa, 1985; Urzúa and Vásquez, 1993; Schmeda-Hirschman <i>et al.</i> , 1996. |

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| Atherospermataceae | <i>Laureliopsis philippiana</i> | Aporphine, isoquinoline, benzyltetrahydroisoquinoline, bisbenzylisoquinoline | Urzúa and Cassels, 1975, 1978, 1982; Zabel <i>et al.</i> , 1979; Staerk <i>et al.</i> , 2009. |
| Berberidaceae | <i>Berberis actinacantha</i> | Pseudobenzylisoquinoline, bisbenzylisoquinoline, isoindolobenzazepine, protoberberine, benzylisoquinoline dimer | Fajardo <i>et al.</i> , 1979a; Weiss <i>et al.</i> , 1984; Valencia <i>et al.</i> , 1984a, 1984b; Urzúa <i>et al.</i> , 1985; Fajardo <i>et al.</i> , 1986. |
| Berberidaceae | <i>Berberis chilensis</i> | Bisbenzylisoquinoline | Torres, 1989; Torres <i>et al.</i> , 1979a,b. |
| Berberidaceae | <i>Berberis darwinii</i> | Pseudobenzylisoquinoline, isoindolobenzazepine, protoberberine, isoindolobenzazocine, isoindoloisoquinoline | Valencia <i>et al.</i> , 1984a, 1984b, 1984c, 1985. |
| Berberidaceae | <i>Berberis empetrifolia</i> | Proaporphine-benzylisoquinoline dimer, aporphine-benzylisoquinoline dimer, | Shamma <i>et al.</i> , 1973; Fajardo <i>et al.</i> , 1981, 1982a, 1982b, 1982d, 1983; 1985b 1985c, Guinaudeau <i>et al.</i> , 1982 Hussain <i>et al.</i> , 1989. |
| Berberidaceae | <i>Berberis ilicifolia</i> | Benzylisoquinoline dimer | Fajardo <i>et al.</i> , 1996. |
| Berberidaceae | <i>Berberis microphylla</i> | Pavine, benzylisoquinoline, bisbenzylisoquinoline, seco-bisbenzylisoquinoline | Fajardo <i>et al.</i> , 1979a, 1979b, 1981, 1987; Leet <i>et al.</i> , 1983, 1984. |
| Berberidaceae | <i>Berberis montana</i> | Protoberberin, benzylisoquinoline, proaporphine, aporphine | Fajardo <i>et al.</i> , 1986; Fajardo, 1992; Fajardo <i>et al.</i> , 2009; Cabezas <i>et al.</i> , 2009. |
| Berberidaceae | <i>Berberis valdiviana</i> | Isoquinoline (cularine), isoindolobenzazepine, protoberberine, proaporphine-benzylisoquinoline dimer, aporphine-benzylisoquinoline dimer, noraporphine-benzylisoquinoline dimer | Shamma <i>et al.</i> , 1973; Weiss <i>et al.</i> , 1984; Firdous <i>et al.</i> , 1984, 1985; Guineadeau <i>et al.</i> , 1982; Valencia <i>et al.</i> , 1984b. |
| Bignoniaceae | <i>Argylia radiata</i> | Monoterpene alkaloid | Bianco <i>et al.</i> , 2002. |
| Boraginaceae | <i>Heliotropium floridum</i> | Pyrrolizidine | Reina <i>et al.</i> , 1997. |
| Boraginaceae | <i>Heliotropium megalanthum</i> | Pyrrolizidine | Reina <i>et al.</i> , 1998. |
| Cactaceae | <i>Browningia candelaris</i> | β -Phenethylamine | Echeverría and Niemeyer, 2012. |
| Cactaceae | <i>Trichocereus chiloensis</i> | β -Phenethylamine | Cortés <i>et al.</i> , 1972. |
| Campanulaceae | <i>Lobelia bridgesii</i> | Pyridyl-pyrrolidine | Marambio <i>et al.</i> , 1999 |
| Campanulaceae | <i>Lobelia polyphylla</i> | Norlobelanidine | Weinges <i>et al.</i> , 1972 |
| Campanulaceae | <i>Lobelia tupa</i> | Pyridyl-pyrrolidine | Marambio <i>et al.</i> , 1999 |
| Celastraceae | <i>Maytenus disticha</i> | Nicotinoyl sesquiterpene | Alarcón <i>et al.</i> , 1998. |
| Celastraceae | <i>Maytenus magellanica</i> | Nicotinoyl sesquiterpene | Kennedy <i>et al.</i> , 2001. |
| Cuscutaceae | <i>Cuscuta chilense</i> | Quinolizidine | García <i>et al.</i> , 1995. |
| Elaeocarpaceae | <i>Aristolotelia chilensis</i> | Indolenine, quinoline | Torres and Comin, 1975; Gopalakrishna <i>et al.</i> , 1978; Bhakuni <i>et al.</i> , 1976; Bittner <i>et al.</i> , 1978 ; Zabel <i>et al.</i> , 1980; Watson <i>et al.</i> , 1989; Céspedes <i>et al.</i> , 1990, 1993; Silva and Bittner, 1992; Silva <i>et al.</i> 1997; He <i>et al.</i> , 1997. |
| Ephedraceae | <i>Ephedra gracilis</i> | Ephedra | Hegnauer, 1962. |
| Euphorbiaceae | <i>Croton chilensis</i> | Morphine, aporphine | Bittner <i>et al.</i> , 2001. |
| Fabaceae | <i>Lupinus microcarpus</i> | Quinolizidine | Wink <i>et al.</i> , 1995. |
| Fabaceae | <i>Prosopis alba</i> | β -phenethylamine, piperidine | Astudillo <i>et al.</i> , 1999. |
| Fabaceae | <i>Prosopis chilensis</i> | β -phenethylamine, tryptamine | Astudillo <i>et al.</i> , 2000. |
| Fabaceae | <i>Prosopis tamarugo</i> | β -phenethylamine, pyrrolizine, tryptamine | Astudillo <i>et al.</i> , 2000; Schmeda-Hirschmann and Jakupovic, 2000. |
| Fabaceae | <i>Sophora fernandeziana</i> | Quinolizidine, piperidine | Hoeneisen <i>et al.</i> , 1993. |
| Fabaceae | <i>Sophora macrocarpa</i> | Quinolizidine | Negrete <i>et al.</i> , 1982, 1983; Hoeneisen <i>et al.</i> , 1993. |
| Fabaceae | <i>Sophora masafuera</i> | Quinolizidine, piperidine | Hoeneisen <i>et al.</i> , 1993. |
| Fabaceae | <i>Sophora microphylla</i> | Quinolizidine, piperidine | Urzúa and Cassels, 1970; Hoeneisen <i>et al.</i> 1993. |

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| Fabaceae | <i>Sophora tetraptera</i> | Quinolizidine | Urzúa <i>et al.</i> , 1970. Reyes <i>et al.</i> , 1988. |
| Lauraceae | <i>Cryptocarya alba</i> | Benzyltetrahydroisoquinoline | Urzúa <i>et al.</i> , 1975. |
| Loranthaceae | <i>Tristerix verticillatus</i> | Isoquinoline | Cabezas <i>et al.</i> , 2009. |
| Lycopodiaceae | <i>Lycopodium confertum</i> | Paniculine | Garland and Muñoz <i>et al.</i> , 1982; Muñoz <i>et al.</i> , 1990. |
| Lycopodiaceae | <i>Lycopodium magellanicum</i> | Paniculine | Castillo <i>et al.</i> , 1976a; Loyola <i>et al.</i> , 1979. |
| Lycopodiaceae | <i>Lycopodium paniculatum</i> | Paniculine | Castillo <i>et al.</i> , 1975, 1976b; Morales <i>et al.</i> 1979. |
| Monimiaceae | <i>Peumus boldus</i> | Aporphine, benzylisoquinoline | Hughes <i>et al.</i> , 1968a,b; Genest <i>et al.</i> , 1969; Urzúa and Acuña, 1983, Urzúa and Torres, 1984, Asencio <i>et al.</i> , 1993. |
| Rhamnaceae | <i>Colletia hystrix</i> | Benzylisoquinoline | Sánchez and Torres <i>et al.</i> , 1971. |
| Rhamnaceae | <i>Colletia spinosissima</i> | Quaternary aporphine | Sánchez and Comin, 1967 |
| Rhamnaceae | <i>Discaria chacaye</i> | Aporphine, benzylisoquinoline, cyclopeptide | Pacheco <i>et al.</i> , 1973; Silva <i>et al.</i> , 1974; Rivera <i>et al.</i> , 1984; Torres <i>et al.</i> , 1984; Correa <i>et al.</i> , 1987. |
| Rhamnaceae | <i>Retanilla ephedra</i> | Cyclopeptide | Bhakuni <i>et al.</i> 1974. |
| Rhamnaceae | <i>Trevoa quinquenervia</i> | Benzylisoquinoline, benzyltetrahydroisoquinoline | Torres and Piña, 1989; Alarcón <i>et al.</i> , 2011. |
| Rutaceae | <i>Fagara mayu</i> | β -Carboline, Benzyltetrahydroisoquinoline, furoquinoline, benzophenanthridine, ephedra | Benages <i>et al.</i> 1974; Torres and Cassels, 1978. Assem <i>et al.</i> , 1979, 1983; |
| Rutaceae | <i>Pitavia punctata</i> | Furoquinoline | Silva <i>et al.</i> 1971. |
| Solanaceae | <i>Cestrum parqui</i> | Steroidal | Silva <i>et al.</i> , 1962. |
| Solanaceae | <i>Dunalia spinosa</i> | Amine-whitanolide, pyridyl-pyrrolidine | Espinoza <i>et al.</i> , 2012. |
| Solanaceae | <i>Fabiana imbricata</i> | Tetrahydroquinoline | Edward and Elmore, 1962. |
| Solanaceae | <i>Latua pubiflora</i> | Tropane | Silva and Mancinelli, 1959; Muñoz and Casale, 2003. |
| Solanaceae | <i>Nicotiana acuminata</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana corymbosa</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana longibracteata</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana miersii</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana pauciflora</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana petunoides</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana solanifolia</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Nicotiana undulata</i> | Pyridyl-pyrrolidine | Saitoh <i>et al.</i> , 1985. |
| Solanaceae | <i>Schizanthus grahamii</i> | Tropane | San Martín <i>et al.</i> , 1987; Hartmann <i>et al.</i> , 1990; Muñoz <i>et al.</i> , 1991; Humam <i>et al.</i> , 2005; Bieri <i>et al.</i> , 2006; Cretton <i>et al.</i> , 2011. |
| Solanaceae | <i>Schizanthus hookerii</i> | Tropane | Gambaro <i>et al.</i> , 1983; San Martín <i>et al.</i> 1980. |
| Solanaceae | <i>Schizanthus integrifolius</i> | Tropane | Muñoz <i>et al.</i> , 1994. |
| Solanaceae | <i>Schizanthus litoralis</i> | Tropane | Muñoz <i>et al.</i> , 1996. |
| Solanaceae | <i>Schizanthus tricolor</i> | Tropane | Humam <i>et al.</i> , 2006, 2007, 2011; Cretton <i>et al.</i> , 2010. |
| Solanaceae | <i>Solanum chilense</i> | Glycoesteroid | Schreiber, 1979. |
| Solanaceae | <i>Solanum crispum</i> | Steroidal | Bianchi <i>et al.</i> , 1965; Sato <i>et al.</i> , 1969; Schreiber, 1979; Reyes <i>et al.</i> , 1988. |
| Solanaceae | <i>Solanum furcatum</i> | Glycoesteroid | Briggs <i>et al.</i> , 1961. |
| Solanaceae | <i>Solanum ligustrinum</i> | Glycoesteroid | Delporte <i>et al.</i> , 1998. |
| Solanaceae | <i>Solanum lycopersicoides</i> | Glycoesteroid | Oleszek <i>et al.</i> , 1986. |
| Solanaceae | <i>Solanum marginatum</i> | Steroidal | Schreiber, 1979. |
| Solanaceae | <i>Schizanthus pinnatus</i> | Tropane, glycoesteroid | Urzúa and Cassels, 1972; Ripperger, 1979; De la Fuente <i>et al.</i> , 1988. |
| Solanaceae | <i>Schizanthus porrigens</i> | Tropane | Muñoz and Cortés, 1998. |

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|------------|----------------------------|--------------------|-----------------------------------|
| Solanaceae | <i>Solanum valdiviense</i> | Steroidal | Reyes <i>et al.</i> , 1988. |
| Solanaceae | <i>Vestia foetida</i> | β -Carboline | Faini <i>et al.</i> , 1978, 1980. |

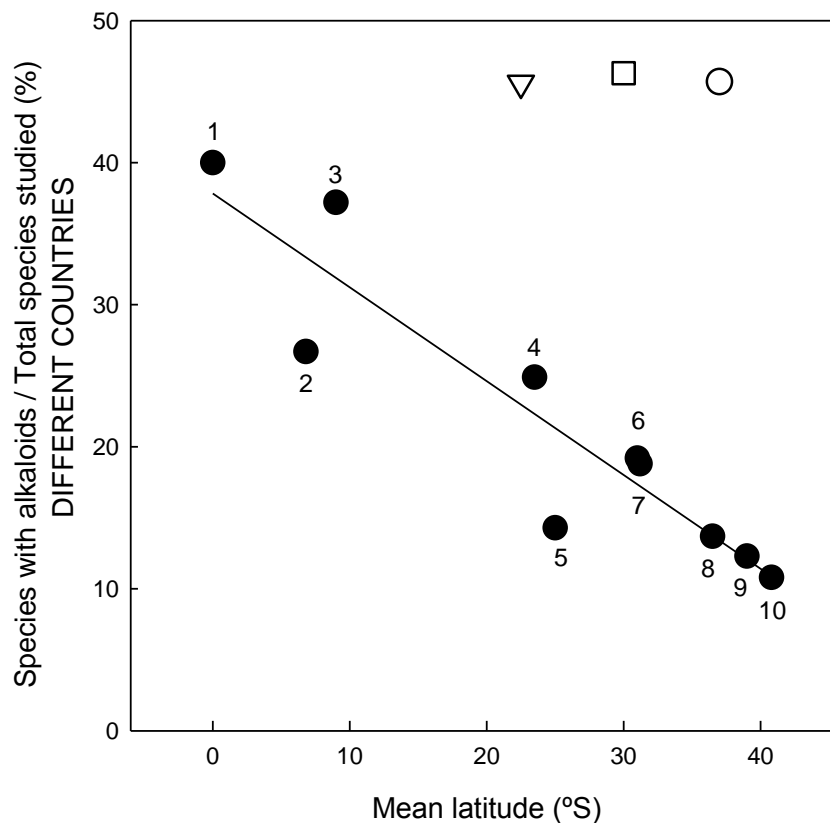
The occurrence of alkaloids in the Chilean native flora was analyzed using two different metrics: i) the proportion of alkaloid-containing species in relation to the total number of species analyzed, and ii) the proportion of alkaloid-containing species in relation to the total number of species in the flora examined.

A screening of the Chilean native flora for alkaloids showed that 45.7% of the species analyzed contained them (Bustamante *et al.*, 2006). Similar studies have been performed with the floras of other

countries and a significant and negative linear correlation has been found between the percentage of alkaloid bearing species in relation to species analyzed and mean latitude of the country (Levin 1976). Figure 1 shows such data and includes the point for Chile; this point clearly deviates from the line, as do the points for India and Pakistan. These three countries share a particularly wide range of ecosystems, mainly on account of extreme altitudinal and latitudinal gradients.

FIGURE 1

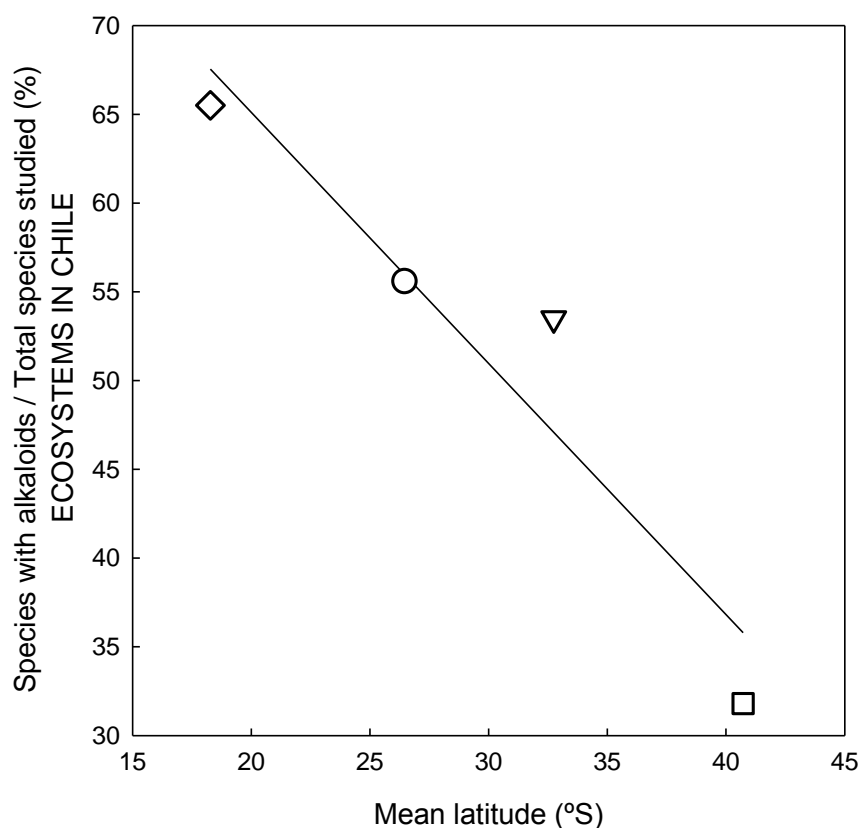
Latitudinal effect on alkaloid richness of the flora of different countries: 1 = Kenya, 2 = New Guinea, 3 = Ethiopia, 4 = Mexico, 5 = Australia, 6 = Uruguay, 7 = Israel, 8 = United States, 9 = Turkey, 10 = New Zealand, triangle = India, square = Pakistan, circle = Chile. Data from Levin (1976) and this work.



A further analysis of the latitudinal effect on alkaloid richness of the flora of Chile was performed by considering different ecosystems which occur at different mean latitudes. The results, presented in figure 2, show a negative linear relationship between

the proportion of alkaloid-containing species in relation to the total number of species analyzed, and the mean latitude of the respective ecosystem. These two analyses show the consistency of the data on the Chilean flora with data from the world flora.

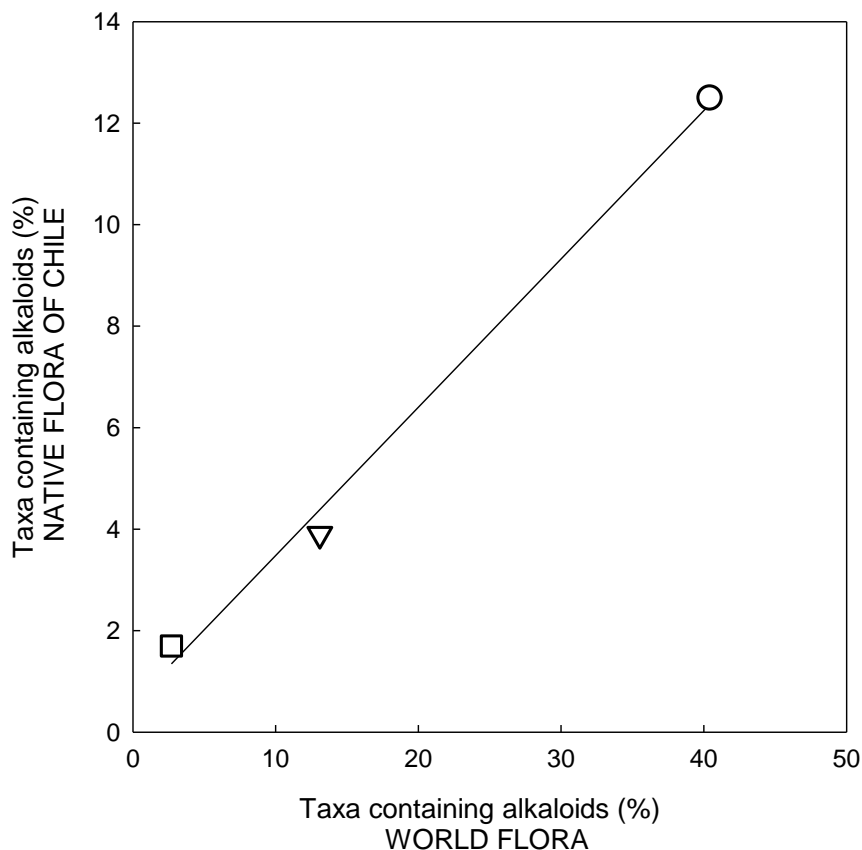
FIGURE 2
Effect of latitude on alkaloid richness of different ecosystems in Chile: rhomboid = Andean tropical, circle = desert, inverted triangle = mediterranean, square = oceanic



The number of alkaloid-containing taxa, as judged by published reports, represents a low proportion of the Chilean flora; thus, alkaloids have been reported in only 12.5% of the families, 3.9% of the genera and 1.7% of the native species occurring in Chile. When these figures are compared with corresponding values at the world scale, *i.e.*, 40.4% of

the families, 13.1% of the genera and 2.7% of the species (Cordell *et al.*, 2001; Stevens, 2008), a proportionality between the two sets of data is revealed, the slope of the correlation being 0.29. This suggests that the alkaloid potential of the Chilean native flora has been exploited to the extent of only 29%.

FIGURE 3
Comparison of flora of the world and native flora of Chile in terms of percentage of alkaloid-containing taxa at family (circle), genera (triangle) and species (square) levels



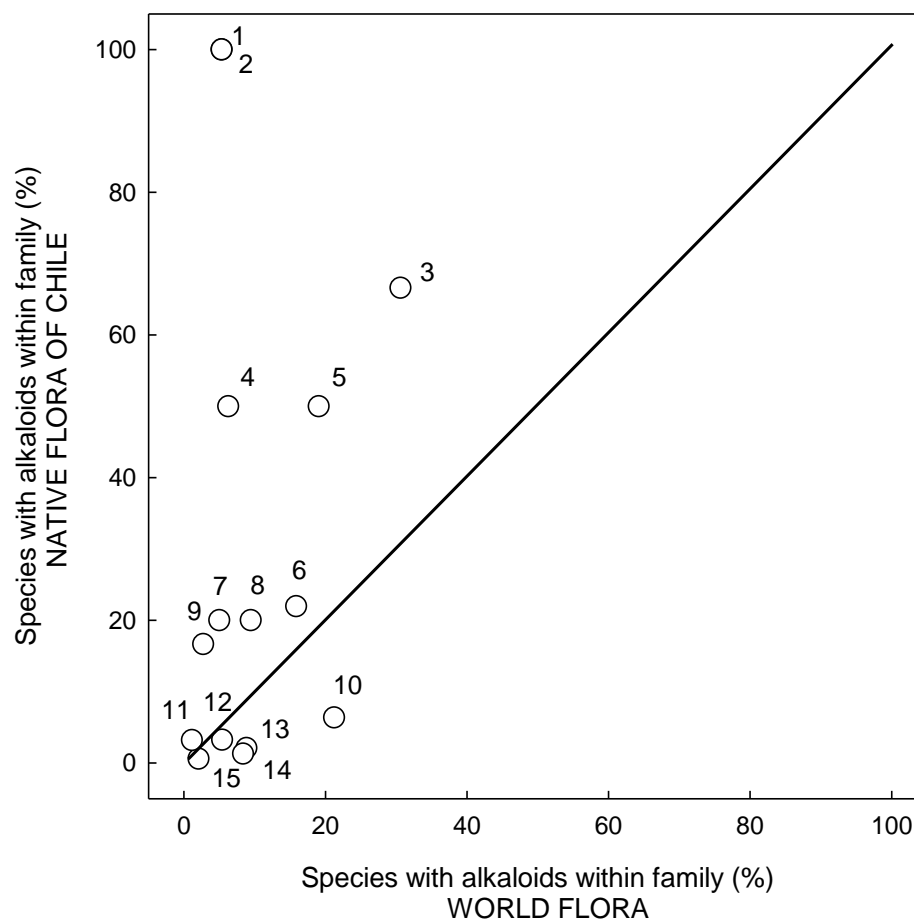
Cordell *et al.* (2001) have made a thorough analysis of the occurrence of alkaloids in the world flora, on the basis of NAPRALERT, the largest database on natural products chemistry and pharmacology (<http://www.napralert.org/>). Their results can be used as a standard for comparison for the distribution of alkaloids in the Chilean flora. Such comparison is presented in figure 4, which shows the percentage of alkaloid-containing species within families in both floras. The line drawn in the figure, with a slope equal to 1, represents the hypothetical situation if alkaloids were equally frequent in families of the floras of Chile and the world.

In families situated above the line in figure 4, a higher proportion of alkaloid-containing species occurs in the Chilean flora than in the world flora, *i.e.* in such families the Chilean flora appears richer in alkaloids than the flora of the world. However, such conclusion should be treated with caution because

most of those families contain very few species (families numbered 1-6, 8 and 9 in figure 4 have between 2 and 8 species, whereas families numbered 7 and 10-15 in figure 4 have between 34 and 837 species), thus making their apparent richness in alkaloids more a matter of chance. This point may be illustrated with the former family Monimiaceae. While worldwide 24 out of 450 (5.3%) species have been shown to contain alkaloids (Cordell *et al.*, 2001), in Chile all three species (now assigned to the Monimiaceae and Atherospermataceae), *i.e.* 100% of the species, contained alkaloids. While the former proportion can be thought of as a fair representation of alkaloid richness in the family, the second is a more discrete and hence volatile figure. Another clear example is the Rutaceae: 459 out of 1500 species contain alkaloids worldwide (30.6%), whereas 2 of 3 species in Chile (66.7%) contain them.

FIGURE 4

Percentage of alkaloid-containing species in families of the flora of Chile and the world [in parenthesis, the number of species of the flora of Chile (Marticorena and Quezada, 1985) and of the flora of the world (Cordell *et al.*, 2001). Families are: 1,2 = Monimiaceae (1,450 including Atherospermataceae) and Atherospermataceae (2); 3 = Rutaceae (3,1500); 4 = Celastraceae (4,800); 5 = Apocynaceae (2,2100); 6 = Rhamnaceae (20,900); 7 = Solanaceae (134,2800); 8 = Lauraceae (5,2000); 9 = Loranthaceae (8,700); 10 = Berberidaceae (50,650); 11 = Euphorbiaceae (34,7500); 12 = Fabaceae (293,16400); 13 = Boraginaceae (97,2000); 14 = Cactaceae (174,1650) 15 = Asteraceae (837,21000)



On the other hand, in families situated below the line of figure 4 a lower proportion of alkaloid-containing species is found in the Chilean flora than in the world flora, *i.e.* in these families the Chilean flora appears as poorer in alkaloids than the flora of the world. The families below the line (families numbered 11-15 in figure 4) are all more biodiverse than families above the line (with the exception of family numbered 7, the Solanaceae, discussed below). Hence, the frequency of occurrence of alkaloids can be more accurately compared with the situation worldwide. The

Solanaceae appears above the line on account of the poor generical representation in the Chilean flora reported, *i.e.* 22 of the 27 alkaloid-containing species belong to only three genera, *Nicotiana*, *Schizanthus* and *Solanum*. The data suggests that families falling below the line should be studied further because they should include numerous species with alkaloids.

The reports on the Chilean flora suggest that the analytical efforts have not been distributed homogeneously. Thus, reports on alkaloid-containing taxa from Chile are concentrated in a few families and

genera, *i.e.* out of the 87 species where alkaloids have been found, 27, 9, and 8 were found in the families Solanaceae, Asteraceae, and Fabaceae, respectively (the rest being distributed among 20 families), and 8, 8, 7 and 7 in the genera *Berberis*, *Nicotiana*, *Solanum* and *Schizanthus*, respectively (the rest being distributed among 35 genera).

The report on the distribution of alkaloids in the world flora showed that several families, present also in Chile, are particularly rich in alkaloids, *e.g.* Convolvulaceae, Ephedraceae, Lamiaceae, Liliaceae, Papaveraceae, Phytolaccaceae, Ranunculaceae and Zygophyllaceae (Cordell *et al.*, 2001). If the percentage of occurrence of alkaloids in those families in the world flora is multiplied by the number of species in each family in Chile, it is predicted that at least 18 species from these families should contain alkaloids.

Most work on alkaloids in Chilean species has been published by Chilean researchers with occasional collaboration of foreign colleagues, and most reports have been published more than 10 years ago; in other words, the interest in isolating new alkaloids from native Chilean plants seems to be vanishing. Given the importance of alkaloids in the cure of widespread diseases, the isolation, structural characterization and biological activity of alkaloids from the native flora of Chile should be pursued.

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REFERENCES

- Adolph G, Appel HH, Overton KH, Warnock WDC. 1967. Hydroxyskytanthines I and II: Two minor alkaloids of *Skytanthus acutus* Meyen. **Tetrahedron** 23: 3147 - 3150.
- Alarcón J, Becerra J., Silva M. 1998. Further information on the chemistry of Chilean Celastraceae. **Bol Soc Chil Quím** 43: 65 - 71.
- Alarcón J, Molina S, Villalobos N, Lillo L, Lamilla C, Céspedes CL, Seigler D. 2011. Insecticidal activity of Chilean Rhamnaceae: *Talguenea quinquenervis* (Gill. et Hook). **Bol Latinoam Caribe Plant Med Aromat** 10: 389 - 394.
- Assem EM, Benages IA, Albonico SM. 1979. A new benzophenanthridinic base from *Fagara mayu*. **Phytochemistry** 18: 511 - 512.
- Assem EM, Benages IA, Albonico SM. 1983. Further alkaloids from bark of *Fagara mayu*. **Planta Med** 48: 77 - 80.
- Asencio M, Cassels BK, Speisky H, Valenzuela A. 1993. (*R*)- and (*S*)-coclaurine from the bark of *Peumus boldus*. **Fitoterapia** 64: 455 - 458.
- Astudillo L, Jurgens K, Schmeda-Hirschmann G, Griffith GA, Holt DJ, Jenkins PR. 1999. DNA binding alkaloids from *Prosopis alba*. **Planta Med** 65: 161 - 162.
- Astudillo L, Schmeda-Hirschmann G, Herrera JP, Cortés M. 2000. Proximate composition and biological activity of Chilean *Prosopis* species. **J Sci Food Agric** 80: 567 - 573.
- Benages IA, De Juárez MEA, Albónico SM, Urzúa A, Cassels BK. 1974. Alkaloids from *Fagara mayu* bark. **Phytochemistry** 13: 2891 - 2892.
- Bhakuni D, González C, Sammes PG, Silva M. 1974. The alkaloids of *Retanilla ephedra* (Vent) Brogh. **Rev Latinamer Quím** 5: 158 - 162.
- Bhakuni DS, Silva M, Matlin SA, Sammes PG. 1976. Aristoteline and aristotelone, unusual indole alkaloids from *Aristolelia chilensis*. **Phytochemistry** 15: 574 - 575.
- Bianchi E, Djerassi C, Budzikiewicz H, Sato Y. 1965. Structure of tomatillidine. **J Org Chem** 30: 754 - 760.
- Bianchi E, Garbarino JA, Gioria F. 1962. Gli alcaloidi del la *Laurelia sempervirens* (R. e Pav.). **Gazz Chim Ital** 92: 818 - 822.
- Bianco A, Bonadies F, Cianciolo V, Melchioni C, Ramunno A, Dezzi S, Nicoletti M, Serafini M, Ballero, M. 2002. Monoterpene alkaloids from *Argylia radiata*. **Nat Prod Lett** 16: 77 - 80.
- Bieri S, Muñoz O, Veuthey JL, Christen P. 2006. Analysis of isomeric tropane alkaloids from *Schizanthus grahamii* by very fast gas chromatography. **J Sep Sci** 29: 96 - 102.
- Bittner M, Alarcón J, Aqueveque P, Becerra J, Hernández V, Hoeneisen M, Silva M. 2001. Chemical study of the Euphorbiaceae family species of Chile. **Bol Soc Chil Quím** 46: 419-432.
- Bittner M, Silva M, Gopalakrishna EM, Watson WH, Zabel V, Matlin SA, Sammes PG. 1978. New alkaloids from *Aristolelia chilensis* (Mol.) Stuntz. **J Chem Soc Chem Commun** 79 - 80.
- Briggs LH, Cambie RC, Hoare JL. 1961. *Solanum* alkaloids. Part XV. The constituents of some *Solanum* species and a reassessment of solasodamine and solauricine. **J Chem Soc** 4645 - 4649.

- Bustamante RO, Chacón P, Niemeyer HM. 2006. Chemical defences in plants: an analysis of the vascular flora of Chile. **Chemoecology** 16: 145 - 151.
- Cabezas NJ, Urzúa AM, Niemeyer HM. 2009. Translocation of isoquinoline alkaloids to the hemiparasite, *Tristerix verticillatus* from its host, *Berberis montana*. **Biochem Syst Ecol** 37: 225 - 227.
- Cassels BK, Urzúa A. 1985. Bisbenzylisoquinoline alkaloids of *Laurelia sempervirens*. **J Nat Prod** 48: 671.
- Castillo M, Loyola L, Morales G. 1976a. The alkaloids of *L. magellanicum* and the structure of magellanine. **Can J Chem** 54: 2893 - 2899.
- Castillo M, Morales G, Loyola L. 1976b. The alkaloids of *L. paniculatum* and the structure of paniculatine. **Can J Chem** 54: 2900 - 2908.
- Castillo M, Morales G, Loyola LA, Singh I, Calvo C, McLean DB. 1975. Paniculatine. A New alkaloid from *L. paniculatum* Desvaux. **Can J Chem** 53: 2513 - 2514.
- Céspedes C, Jakupovic J, Silva M, Tschritzis F. 1993. A quinoline alkaloid from *Aristolelia chilensis*. **Phytochemistry** 34: 881 - 882.
- Céspedes C, Jakupovic J, Silva M, Watson W. 1990. Indole alkaloids from *Aristolelia chilensis*. **Phytochemistry** 29: 1354 - 1356.
- Cordell GA, Quinn-Beattie ML, Farnsworth NR. 2001. The potential of alkaloids in drug discovery. **Phytother Res** 15: 183 - 205.
- Correa C, Urzúa A, Torres R. 1987. 1,2,11-Trimethoxynoraporphine from *Discaria chacaye* (G. Don). **Bol Soc Chil Quim** 32: 105 - 106.
- Cortés M, Garbarino JA, Cassels BK. 1972. Isolation of candicine from *Trichocereus chiloensis*. **Phytochemistry** 11: 849 - 850.
- Cretton S, Bartholomeusz T, Humam M, Marcourt L, Allenbach Y, Jeannerat D, Muñoz O, Christen P. 2011. Grahamines A-E, cyclobutane-centered tropane alkaloids from the aerial parts of *Schizanthus grahamii*. **J Nat Prod** 74: 2388 - 2394.
- Cretton S, Glauser G, Humam M, Jeannerat D, Muñoz O, Maes L, Christen P, Hostettmann K. 2010. Isomeric tropane alkaloids from the aerial parts of *Schizanthus tricolor*. **J Nat Prod** 73: 844 - 847.
- De la Fuente G, Reina M, Muñoz O, San Martín A, Girault JP. 1988. Tropane alkaloids from *Schizanthus pinnatus*. **Heterocycles** 27:1887 - 1897.
- Delporte C, Backhouse N, Negrete R, Salinas P, Rivas P, Cassels BK, San Feliciano A. 1998. Antipyretic, hypothermic and antiinflammatory activities and metabolites from *Solanum ligustrinum* Lood. **Phytother Res** 12: 118 - 122.
- Echeverría J, Niemeyer HM. 2012. Phenylethylamines from *Browningia candelaris*. **Bol Latinoam Caribe Plant Med Aromat** 11: 341 - 344.
- Edwards OE, Elmore NF. 1962. Fabianine. **Can J Chem** 40: 256 - 264.
- Espinoza J, Echeverría J, Urzúa A, Niemeyer HM. (2012) Withanolid amine and nicotine from *Dunalia spinosa* (Solanaceae). **Bol Latinoam Caribe Plant Med Aromat** 11: 278 - 284.
- Faini F, Castillo M, Torres R. 1978. A new [beta]-carboline alkaloid from *Vestia lycioides*. **Phytochemistry** 17: 338.
- Faini F, Torres R, Delle Monache F, Marini-Bettolo GB, Castillo M. 1980. 1-Acetyl-3-carboxy-beta-carboline, a new acid and other constituents of *Vestia lycioides*. **Planta Med** 38: 128 - 132.
- Fajardo V. 1987. Estudio químico de las especies chilenas del género *Berberis*. **Rev Latinamer Quim** 18: 46 - 50.
- Fajardo V. 1992. Alcaloides en especies del género *Berberis* de Chile, pp. 215-240. In: Muñoz O: **Química de la Flora de Chile**, Ed. Universidad de Chile, Santiago, Chile.
- Fajardo V, Araya M, Cuadra P, Oyarzún A, Gallardo A, Cueto M, Díaz-Marrero AR, Darias J, Villarroel L, Alvarez C, Mora-Pérez Y, Joseph-Nathan P. 2009. Pronuciferine N-oxide, a proaporphine N-oxide alkaloid from *Berberis coletiioides*. **J Nat Prod** 72: 1355 - 1356.
- Fajardo V, Cárcamo C, Moreno B. 1996. Illicifoline: new berbine dimer alkaloid from *Berberis illicifolia*. **Heterocycles** 43: 949 - 951.
- Fajardo V, Elango V, Cassels BK, Shamma M. 1982a. Chilenine: an isoindolobenzazepine alkaloid. **Tetrahedron Lett** 23: 39 - 42.
- Fajardo V, Elango V, Chattopadhyaya S, Jackman LM, Shamma M. 1983. Puntarenine: an unusual isoquinoline alkaloid. **Tetrahedron Lett** 24: 155 - 158.
- Fajardo V, Garrido M, Cassels BK. 1981. Calafatimine, a new imino

- bisbenzylisoquinoline alkaloid. **Heterocycles** 15: 1137 - 1139.
- Fajardo V, Guidaudeau H, Elango V, Shamma M. 1982a. Coyhaiquina: an oxidized proaporphine-benzylisoquinoline alkaloid. **J Chem Soc Chem Commun** 1350 - 1352.
- Fajardo V, León A, Loncharic A, Elango, Shamma M, Cassels B. 1982b. Alcaloides presentes en *Berberis empetrifolia*. **Bol Soc Chil Quim** 27: 159 - 164.
- Fajardo V, Podesta F, Garrido M, Urzúa A. 1985b. Coyhaiquina: un alcaloide proaporfínico-bencilisoquinolínico oxidado. **Bol Soc Chil Quim** 30: 51 - 53.
- Fajardo V, Podesta F, Shamma M, Hussain SF. 1985a. Natalinina: un nuevo alcaloide isoquinolinico dimerico oxidado. **Rev Latinamer Quim** 16: 59 - 61.
- Fajardo V, Podesta F, Urzúa A. 1986. Reseña de los alcaloides encontrados en el género *Berberis* de Chile. **Rev Latinamer Quim** 16: 141 - 156.
- Fajardo V, Urzúa A, Cassels B. 1979a. Calafatine, an unusual bisbenzylisoquinoline alkaloid. **Heterocycles** 12: 1559 - 1562.
- Fajardo V, Urzúa A, Torres R, Cassels B. 1979b. Secondary metabolites from *Berberis buxifolia*. **Rev Latinamer Quim** 10: 131-134.
- Firdous S, Freyer AJ, Shamma M, Urzúa A. 1984. (+)-Linaresine and (+)-dihydrolinaresine. The natural conversion of protoberberinium salts into cularine alkaloids. **J Am Chem Soc** 106: 6099 - 6101.
- Firdous S, Valencia E, Shamma M, Urzúa A, Fajardo V. 1985. Three New Dimeric Aporphinoids from *Berberis* Species. **J Nat Prod** 48: 664 - 666.
- Gajardo R. 1994. **La Vegetación Natural de Chile. Clasificación y Distribución Geográfica**. Editorial Universitaria, Santiago, Chile.
- Gambaro V, Labbé C, Castillo M. 1983. Angeloyl, tigloyl and seneciolyoxytropene alkaloids from *Schizanthus hookerii*. **Phytochemistry** 22: 1838 - 1839.
- García R, Erazo S, Peña RC. 1995. Flavonoids and alkaloids from *Cuscuta* (Cuscutaceae). **Biochem Syst Ecol** 23: 571 - 572.
- Garland MT, Muñoz O. 1982. Crystal data for deacetylpaniculine. **J Appl Crystallogr** 15: 112-114.
- Genest K, Lowry LJ, Hughes DW. 1969. Microcrystallophic test for some minor alkaloids of *Peumus boldus*. **Microchem J** 14: 249 - 260.
- González AG, De la Fuente G, Reina M, Loyola LA. 1986. Pyrrolizidine alkaloids from *Senecio phillicus* and *Senecio illinitus*. **Planta Med** 52: 160.
- Gopalakrishna EM, Watson WH, Silva M, Bittner M. 1978. Aristotelinine. **Acta Crystallogr B** 34: 3778 - 3780.
- Guinaudeau H, Cassels B, Shamma M. 1982. The use of nuclear magnetic resonance nuclear Overhauser enhancements in the structural elucidation of bisbenzylisoquinoline alkaloids **Heterocycles** 19: 1009 - 1012.
- Hartmann R, San Martín A, Muñoz O, Breitmaier E. 1990. Grahamine, an unusual tropane alkaloid from *Schizanthus grahamii*. **Angew Chem Int Ed Engl** 29: 385 - 386.
- He K, Valcic S, Timmermann BN, Montenegro G. 1997. Indole alkaloids from *Aristotelia chilensis* (Mol.) Stuntz. **Pharm Biol** 35: 215 - 217.
- Hegnauer R. 1962. **Chemotaxonomie Der Pflanzen**: Band 1: Thallophyten, Bryophyten, Pteridophyten Und Gymnospermen, Volumen 1, Basel-Boston-Stuttgart: Birkhauser Verlag, p 464.
- Hoeneisen M, Silva M, Wink M. 1993. Alkaloids of *Sophora* of Juan Fernández Islands and related taxa. **Bol Soc Chil Quim** 38: 167 - 171.
- Hughes DW, Genest K, Skakum W. 1968a. Alkaloids of *Peumus boldus*. Isolation of (+) reticuline and isoboldine. **J Pharm Sci** 57: 1023 - 025.
- Hughes DW, Genest K, Skakum W. 1968b. Alkaloids of *Peumus boldus*. Isolation of laurotetanine and lauroitsine. **J Pharm Sci** 57: 1619-1620.
- Humam M, Bieri S, Geiser L, Muñoz O, Veuthey J L, Christen P. 2005. Separation of four isomeric tropane alkaloids from *Schizanthus grahamii* by non-aqueous capillary electrophoresis. **Phytochem Anal** 16: 349 - 356.
- Humam M, Kehrli T, Jeannerat D, Muñoz O, Christen P, Hostettmann, K. 2006. Two new isomeric tropane alkaloids from *Schizanthus tricolor* identified by capillary NMR. **Planta Med** 72: 969.
- Humam M, Kehrli T, Jeannerat D, Muñoz O, Hostettmann K, Christen, P. 2011. Schizanthines N, O, and P, tropane alkaloids from the aerial parts of *Schizanthus tricolor*. **J Nat Prod** 74: 50 - 53.

- Humam M, Muñoz O, Christen P, Hostettmann K. 2007. Tropane alkaloids of the aerial parts of *Schizanthus tricolor*. **Nat Prod Commun** 2: 743 - 747.
- Hussain SF, Fajardo V, Shamma M. 1989. (-)-Natalamine, an aporphinoid alkaloid from *Berberis empetrifolia*. **J Nat Prod** 52: 644 - 645.
- Jakupovic J, Grenz M, Bohlmann F, Niemeyer HM. 1991. Furoremophilanes and other constituents from Chilean *Senecio* species. **Phytochemistry** 30: 2691 - 2693.
- Kennedy ML, Cortés-Selva F, Pérez-Victoria JM, Jiménez IA, González AG, Muñoz OM, Gamarro F, Castanys S, Ravelo AG. 2001. Chemosensitization of a multidrug-resistant *Leishmania tropica* line by new sesquiterpenes from *Maytenus magellanica* and *Maytenus chubutensis*. **J Med Chem** 44: 4668 - 4676.
- Leet JE, Fajardo V, Freyer AJ, Shamma M. 1983. Some dimeric benzylisoquinoline alkaloids with an unusual oxygenation pattern. **J Nat Prod** 46: 908 - 912.
- Leet JE, Freyer AJ, Minard RD, Shamma M, Fajardo V. 1984. Stereochemistry of bisbenzylisoquinoline N-oxides. Calafatine 2 α -N-oxide and calafatine 2 β -N-oxide. **J Chem Soc Perkin** 1 651 - 652.
- Levin DA. 1976. Alkaloid-bearing plants: an ecogeographical perspective. **Am Nat** 110: 261 - 284.
- Loyola LA, Morales G, Castillo M. 1979. Alkaloids of *Lycopodium magellanicum*. **Phytochemistry** 18: 1721-1723.
- Major J. 1988. Endemism: a botanical perspective. In: **Analytical Biogeography** (A.A. Myers, P.S. Giller, eds.), Chapman and Hall, London, New York, pp. 117 - 146.
- Marambio O, Monsalve E, Schmeda-Hirschmann G. 1999. DNA binding alkaloids from *Lobelia bridgesii* Hook et Arn and *Lobelia Tupa* L. **Bol Soc Chil Quim** 44: 1 - 5.
- Martcorena C. 1990. Contribución a la estadística de la flora vascular de Chile. **Gayana Botanica** 47: 85 - 113.
- Martcorena C, Quezada M. 1985. Catálogo de la flora vascular de Chile. **Gayana** 42: 3 - 155.
- Morales G, Bórquez J, Mancilla A, Pedreros S, Loyola LA. 1986. Constituents of *Chersodoma jodoppa*. **J Nat Prod** 49: 1140 - 1141.
- Morales G, Loyola LA, Castillo M. 1979. Alkaloids of *Lycopodium paniculatum*: the structure of paniculine. **Phytochemistry** 18: 1719 - 1720.
- Muñoz O. & Casale J. 2003. Tropane alkaloids from *Latua pubiflora*. **Z Naturforsch C** 58: 626 - 628.
- Muñoz OM, Castillo M, San Feliciano A. 1990. High resolution NMR studies of paniculine and related *Lycopodium* compounds. **J Nat Prod** 53: 200 - 203.
- Muñoz O. & Cortés S. 1998. Tropane alkaloids from *Schizanthus porrigens*. **Pharm Biol** 36: 162 - 166.
- Muñoz O, Hartmann R, Breitmaier E. 1991. Schizanthine X, a new alkaloid from *Schizanthus grahamii*. **J Nat Prod** 54: 1094 - 1096.
- Muñoz O, Piovano M, Garbarino J, Hellwig V, Breitmaier E. 1996. Tropane alkaloids from *Schizanthus litoralis*. **Phytochemistry** 43: 709 - 713.
- Muñoz O, Schneider C, Breitmaier E. 1994. A new pyrrolidine alkaloid from *Schizanthus integrifolius* Phil. **Liebigs Ann Chem** 5: 521 - 522.
- Negrete R, Backhouse N, Cassels BK. 1982. Leaf alkaloids of *Sophora macrocarpa*. **J Nat Prod** 45: 652.
- Negrete R, Cassels BK, Eckhardt G. 1983. (+)-9 α -Hydroxymatine from *Sophora macrocarpa*. **Phytochemistry** 22: 2069 - 2072.
- Niemeyer HM. 1995. Biologically active compounds from Chilean medicinal plants. In: **Recent Advances in Phytochemistry; Vol. 29, Phytochemistry of Medicinal Plants**, Arnason, J.T., Matta, R. & Romeo, J.T., eds., Plenum Press, New York, USA.
- Oleszek W, Shannon S, Robinson RW. 1986. Steroidal alkaloids of *Solanum lycopersicoides*. **Acta Soc Bot Pol** 55: 653 - 657.
- Pacheco P, Albónico SM, Silva M. 1973. Alkaloids, triterpenes and other constituents of *Discaria crenata*. **Phytochemistry** 12: 954 - 955.
- Pacheco P, Silva M, Sammes PG, Watson WH. 1982. Estudio químico de las Amaryllidaceae chilenas. Nuevos alcaloides de *Hippeastrum ananuca*. **Bol Soc Chil Quim** 27: 289.
- Pacheco P, Silva M, Steglich W, Watson WH. 1978. Alkaloids of Chilean Amaryllidaceae I. hippeastidine and epi-homolycorine two novel alkaloids. **Rev Latinamer Quim** 9: 28 - 32.

- Reina M, De la Fuente G, Villarroel L, Torres R. 1993. Pyrrolizidine alkaloids from *Senecio erraticus*, *S. glaber* and *S. microphyllus*. **An Quim** 89: 387 - 390.
- Reina M, González-Coloma A, Gutiérrez C, Cabrera R, Henríquez J, Villarroel L. 1997. Bioactive saturated pyrrolizidine alkaloids from *Heliotropium floridum*. **Phytochemistry** 46: 845 - 853.
- Reina M, González-Coloma A, Gutiérrez C, Cabrera R, Henríquez J, Villarroel L. 1998. Pyrrolizidine alkaloids from *Heliotropium megalanthum*. **J Nat Prod** 61: 1418 - 1420.
- Reina M, González-Coloma A, Gutiérrez C, Cabrera R, Rodríguez M, Fajardo V, Villarroel L. 2001. Defensive chemistry of *Senecio miser*. **J Nat Prod** 64: 6 - 11.
- Reyes A, Cuesta F, Gómez M. 1988. Escopoletina y escopoletin-7-0-glucósido en *Solanum valdiviense* y *Solanum gayanum*. **Rev Latinamer Quim** 19: 33.
- Reyes A, Miranda M, Martínez R. 1988. Constituents of *Sophora tetraptera* sensu reiche. **Rev Latinamer Quim** 19: 32.
- Ripperger H. 1979. Schizanthin A und B, zwei neue tropanalkaloide aus *Schizanthus pinnatus*. **Phytochemistry** 18: 171 - 173.
- Rivera A, Urzúa A, Torres R. 1984. 1,2-Dimethoxy-11-hydroxyaporphine from *Discaria serratifolia* var *montana*. **J Nat Prod** 47: 1040 - 1041.
- Saitoh F, Noma M, Kawashima N. 1985. The alkaloid contents of sixty *Nicotiana* species. **Phytochemistry** 24: 477 - 480.
- Sánchez E, Comin J. 1967. Studies on argentine plants—XXIII : Quaternary bases from *Colletia spinosissima* Gmel. **Tetrahedron** 23: 1139-1143.
- Sánchez E, Torres R. 1971. Alkaloids and friedelin from several Chilean Rhamnaceae species. **An Asoc Quim Argent** 59: 343.
- San Martín A, Labbé C, Muñoz O, Castillo M, Reina M, De la Fuente G, González AG. 1987. New tropane alkaloids from *Schizanthus grahamii*. **Phytochemistry** 26: 819 - 822.
- San Martín A, Roviroso J, Gambaro V, Castillo M. 1980. Tropane alkaloids from *Schizanthus hookeri*. **Phytochemistry** 9: 2007 - 2008.
- Sato Y, Kaneko H, Bianchi E, Kataoka H. 1969. Alkaloids from *Solanum congestiflorum*. **J Org Chem** 34: 1577 - 1582.
- Schmeda-Hirschmann G, Dutra-Behrens M, Habermehl G, Jakupovic J. 1996. Secoisotetrandrine from *Laurelia sempervirens*. **Phytochemistry** 41: 339 - 341.
- Schmeda-Hirschmann G, Jakupovic J. 2000. A DNA binding compound from *Prosopis tamarugo* pods. **Bol Soc Chil Quim** 45: 645 - 647.
- Schreiber K. 1979. The steroid alkaloids of Solanum, pp. 193-202. In Hawkes JE, Lester RN, Skelding AD: **The Biology and Taxonomy of the Solanaceae**, Ed. Academic Press for the Linnean Society, London, UK.
- Shamma M, Moniot JL, Yao SY, Miana GA, Ikram M. 1973. Pakistanine and pakistanamine, two new dimeric isoquinoline alkaloids. **J Am Chem Soc** 95: 5742 -5747.
- Silva M, Bhakuni D, Sammes PG, Pais M, Jarreau FX. 1974. A new peptide alkaloid from *Discaria crenata*. **Phytochemistry** 13: 861 - 863.
- Silva M, Bittner M. 1992. **Estudio químico de las especies de la familia Eleocarpaceae que crecen en Chile**, pp. 153-166. In: Muñoz O: Química de la Flora de Chile. Ed. Universidad de Chile, Santiago, Chile,
- Silva M, Bittner M, Céspedes C, Jakupovic J. 1997. The alkaloids of the genus *Aristolelia*. *Aristolelia chilensis* (Mol.) Stuntz. **Bol Soc Chil Quim** 42: 39 - 47.
- Silva M, Cruz MA, Sammes PG. 1971. Some constituents of *Pitavia punctata*. **Phytochemistry** 10: 3255 - 3258.
- Silva M, Mancinelli P. 1959. Atropina en *Latua pubiflora* (Griseb.) Phil. **Bol Soc Chil Quim** 9: 49 - 50.
- Silva M, Mancinelli P, Cheul M. 1962. Chemical study of *Cestrum parqui*. **J Pharm Sci** 51: 289.
- Staerk D, Pham Thi L, Bonde Rasmussen H, Guzmán A, Mølgaard P. 2009. New bisbenzylisoquinoline alkaloid from *Laureliopsis philippiana*. **Fitoterapia** 80: 112 - 114.
- Stevens PF. 2008. Angiosperm Phylogeny Website. Version 9. <http://www.mobot.org/MOBOT/research/APweb/> Accessed 14 april 2012.
- Torres R. 1984. Alcaloides en variedades de *Discaria serratifolia*. **Bol Soc Chil Quim** 29: 215 - 217.
- Torres R. 1989. 12-O-Desmetillauberina, un nuevo dímero bencilisoquinolínico de *Berberis chilensis*. **Bol Soc Chil Quim** 34: 11 - 14.

- Torres R, Cassels BK. 1978. Leaf alkaloids of *Fagara mayu*. **Phytochemistry** 17: 838 - 839.
- Torres R, Comin JH. 1975. Some constitutives of the leaves of *Aristolochia chilensis* (Mol.). **Cont Cient Tec** 16: 25 - 30.
- Torres R, Delle Monache F, Marini-Bettolo GB. 1979a. Bisbenzylisoquinoline alkaloids from *Berberis chilensis* Gillies ex Hook. **Gazz Chim Ital** 109: 567 - 569.
- Torres R, Delle Monache F, Marini-Bettolo, GB. 1979b. Biogenetic relationships between lignans and alkaloids in *Berberis* genus. Lignans and berbamine from *Berberis chilensis*. **Planta Med** 37: 32 - 36.
- Torres R, Piña M, Thakur RS. 1989. Further benzylisoquinidine alkaloids from *Talguenea quinquenervia*. **Fitoterapia** 60: 283 - 284.
- Urzúa A, Acuña P. 1983. Alkaloids from the bark of *Peumus boldus*. **Fitoterapia** 54:175 - 177.
- Urzúa A, Cassels BK. 1970. Alkaloids of *Sophora tetraptera* sensu Reiche. **Phytochemistry** 9: 2365 - 2367.
- Urzúa A, Cassels BK. 1972. Solasodine glycosides and diosgenin from *Solanum pinnatum*. **Phytochemistry** 11: 3548 - 3549.
- Urzúa A, Cassels BK. 1978. 4-hydroxynornantenine, a 4-hydroxylated noraporphine. **Tetrahedron Lett** 30: 2649 - 2652.
- Urzúa A, Cassels BK. 1982. Additional alkaloids from *Laurelia philippiana* and *L. novae-zelandiae*. **Phytochemistry** 21: 773 - 776.
- Urzúa A, Rojas V. 1990. Constituents of *Aristolochia chilensis*. **Fitoterapia** 61: 190 - 191.
- Urzúa A, Cassels B, Sánchez E, Comin J. 1975. Alcaloides de *Laurelia sempervirens* y *Laurelia philippiana*. **An Asoc Quim Argent** 63: 259 - 264.
- Urzúa A, Freyer AJ, Shamma M. 1987. Aristolodione, a 4, 5-dioxoaporphine from *Aristolochia chilensis*. **J Nat Prod** 50: 305 - 306.
- Urzúa A, Salgado G, Cassels BK, Eckhardt G. 1982. Aristolochic acids in *Aristolochia chilensis*. **Planta Med** 45: 51 - 52.
- Urzúa A, Salgado G, Cassels BK, Eckhardt G. 1983. Aristolochic acids in *Aristolochia chilensis* and the *Aristolochia*-feeder *Battus archidamas* (Lepidoptera). **Collect Czechoslov Chem Commun** 48: 1513 - 1519
- Urzúa A, Santander R, Sotes G. 2009. Aristolochic acids from *Aristolochia bridgesii*, a host-plant of *Battus polydamas archidamas*. **J Chil Chem Soc** 54: 437 - 438.
- Urzúa A, Torres R. 1984. 6a,7-Dehydroboldine from the bark of *Peumus boldus*. **J Nat Prod** 47: 525 - 526.
- Urzúa A, Torres R, Cassels BK. 1975. (+)-Reticulina en *Cryptocarya alba*. **Rev Latinamer Quím** 6: 102 - 103.
- Urzúa A, Torres R, Cassels BK., Fajardo V. 1985. Dímeros de proaporfina-1-benciltetrahydroisoquinolina en tallos de *Berberis hakeoides*. **Rev Latinamer Quím** 16: 66 - 68.
- Urzúa A, Vásquez L. 1993. Alkaloids from *Laurelia sempervirens* Wood. GLC-MS analysis of trifluoroacetil derivatives. **Bol Soc Chil Quím** 38: 35 - 37.
- Valencia E, Fajardo V, Freyer AJ, Shamma M. 1985. Magallanesine: an isoindolobenzazocine alkaloid. **Tetrahedron Lett** 26: 993 - 996.
- Valencia E, Freyer AJ, Shamma M, Fajardo V. 1984c. (±)-Nuevamine, an isoindoloisoquinoline alkaloid, and (±)-lennoxamine, an isoindolobenzazepine. **Tetrahedron Lett** 25: 599 - 602.
- Valencia E, Weiss I, Firdous S, Freyer AJ, Shamma M, Urzúa A, Fajardo V. 1984b. The isoindolobenzazepine alkaloids. **Tetrahedron** 40: 3957 - 3962.
- Valencia E, Weiss I, Shamma M, Urzúa A, Fajardo V. 1984a. Dihydrorugosinone, a pseudobenzylisoquinoline alkaloid from *Berberis darwinii* and *Berberis actinacantha*. **J Nat Prod** 47: 1050 - 1051.
- Villarroel L, Torres R, Navarro J, Fajardo V. 1985. Senecionine and seniciphylline from *Senecio patagonicus*. **Fitoterapia** 56: 250.
- Villarroel L, Torres R, Urzúa A, Modak B, Henríquez J, Salgado I. 1997. Secondary metabolites from genus *Senecio* and *Heliotropium*. **Rev Latinamer Quím** 25: 109 - 116.
- Villarroel L, Varea P, Cáceres R. 1988. Intergerrimine and usaramine alkaloids from *Senecio murorum*. **Bol Soc Chil Quím** 33: 107 - 109.
- Watson WH, Nagl A, Silva M, Céspedes C, Jakupovic J. 1989. A new indole alkaloid from *Aristolochia chilensis*. **Acta Crystallogr C** 45: 1322 - 1324.
- Weinges K, Bähr W, Ebert W, Kloss P. 1972. Norlobelanidine, das Hauptalkaloid aus *Lobelia polyphylla* Hook und Arn.. **Justus Liebigs Ann Chem** 756: 177 - 180.
- Weiss I, Freyer AJ, Shamma M, Urzúa A. 1984. The Stereochemistry at C-13 for the Proaporphine-

- benzylisoquinoline Alkaloids. **Heterocycles** 22: 2231 - 2235.
- Wink M, Meißner C, Witte L. 1995. Patterns of quinolizidine alkaloids in 56 species of the genus *Lupinus*. **Phytochemistry** 38: 139 - 153.
- Zabel V, Watson WH, Bittner M, Silva M. 1980. Structure of aristone, a unique indole alkaloid from *Aristotelia chilensis* (mol.) Stuntz, by X-ray crystallographic analysis. **J Chem Soc Perkin 1** 2842 - 2844.
- Zabel V, Watson WH, Urzúa A, Cassels BK. 1979. N, O-Diacetyl-4-hydroxynornantenine. **Acta Crystallogr B** 35: 3126 - 3129.