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A review of phototoxic plants, their phototoxic metabolites, and possible developments as photosensitizers.

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1 Review

2 A review of phototoxic plants, their phototoxic metabolites, and possible developments as
3 photosensitizers.

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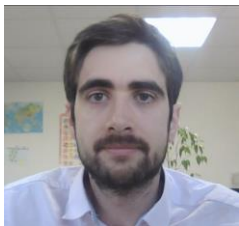
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31 This article is based on her Master's thesis work.

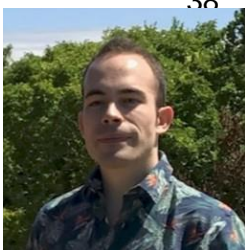


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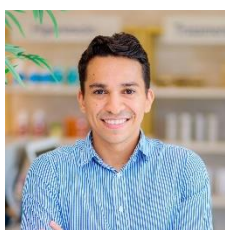
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86 different macrocycles but also the extraction of photosensitizers from natural compound. He
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88 (PDT) against cancer cells and bacteria strains.

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166

167 Abstract

168 This study provides a comprehensive overview of the current knowledge regarding phototoxic
169 terrestrial plants and their phototoxic and photosensitizing metabolites. Within the 435,000
170 land plant species, only around 250 vascular plants have been documented as phototoxic or
171 implicated in phototoxic occurrences in humans and animals. This work compiles a
172 comprehensive catalog of these phototoxic plant species, organized alphabetically based on
173 their taxonomic family. The dataset encompasses meticulous details including taxonomy,
174 geographical distribution, vernacular names, and information on the nature and structure of
175 their phototoxic and photosensitizing molecule(s). Subsequently, this study undertook an in-
176 depth investigation into phototoxic molecules, resulting in the compilation of a comprehensive

177 and up-to-date list of phytochemicals exhibiting phototoxic or photosensitizing activity
178 synthesized by terrestrial plants. For each identified molecule, an extensive review was
179 conducted, encompassing discussions on its phototoxic activity, chemical family, occurrence
180 in plant families or species, distribution within different plant tissues and organs, as well as the
181 biogeographical locations of the producer species worldwide. The analysis also includes a
182 thorough discussion on the potential use of these molecules for the development of new
183 photosensitizers that could be used in topical or injectable formulations for antimicrobial and
184 anticancer phototherapy as well as manufacturing of photoactive devices.

185

186 Abbreviations

187 GBIF Global Biodiversity Information Facility

188 INPI French Institute for Intellectual Property

189 PACT Photodynamic antimicrobial therapy

190 PDT Photodynamic Therapy

191 PS Photosensitizer

192 ROS Reactive Oxygen Species

193 USA United States of America

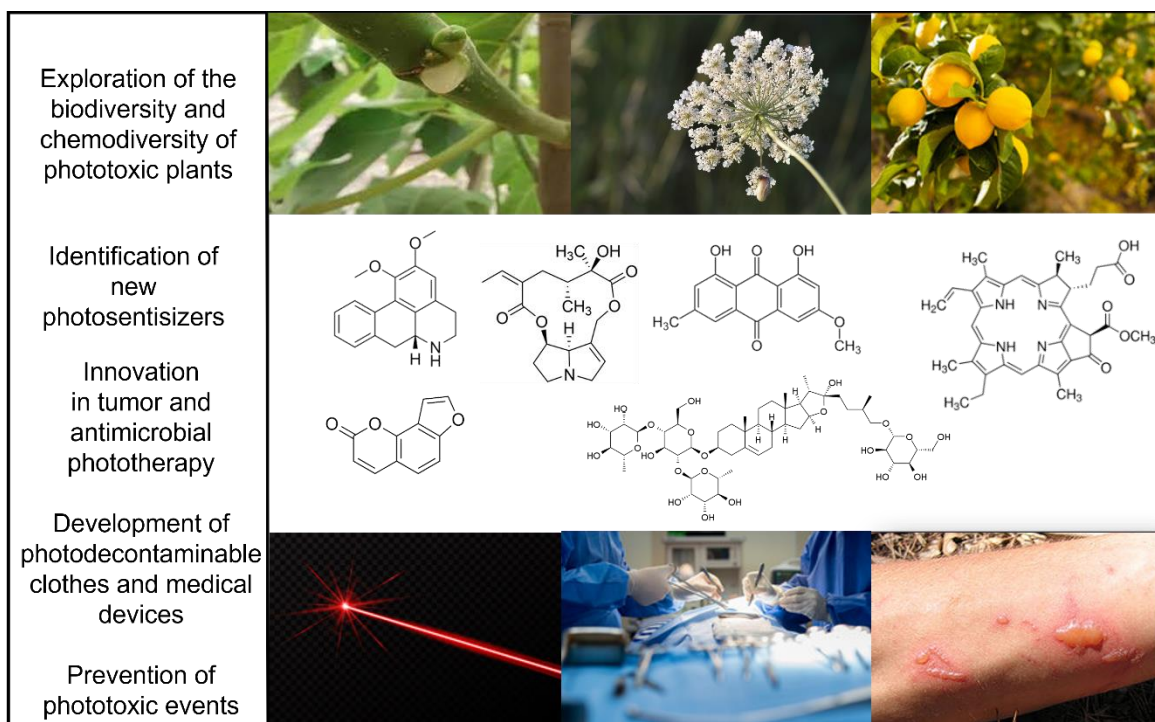
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195 Highlights

- 196 • Complete list of phototoxic and photosensitizing plant species of the world
- 197 • Complete list of plant phototoxic metabolites (Type I and Type II photosensitizations)
- 198 • Chemodiversity of phototoxic molecules in relation to botanical families
- 199 • Discussion on the possible use of plant phototoxic molecules for phototherapy

200

201 Graphical abstract



202

203 1.Introduction

204 Natural products and their structural analogues play a key role in drug discovery, particularly
 205 for the treatment of cancer and infectious diseases ^[1]. They are more than ever a major source
 206 of inspiration for researchers to develop innovative therapies and their interest is currently
 207 revitalised in the face of chemoresistance of cancer cells and microorganisms ^[2]. Among the
 208 alternative strategies to chemotherapy, photodynamic therapy (PDT) and Photodynamic
 209 antimicrobial therapy (PACT) have emerged as efficient treatments to destroy cancer cells,
 210 tumour vasculature and microorganisms. PDT and PACT are based on the use of a
 211 photoactivatable molecule, the photosensitizer (PS), light, and oxygen naturally present in the
 212 biological medium. After light excitation of the PS, an energy transfer to oxygen generates a
 213 high burst of reactive oxygen species (ROS), such as singlet oxygen and superoxide radical
 214 anion. These highly oxidative species induce amino acid oxidation, proteins fragmentation,
 215 peroxidation of membrane lipids and oxidation of nucleic acids in the immediate biological
 216 environment, leading to rapid cancer cell death through necrosis, apoptosis, necroptosis or
 217 autophagy and destruction of viruses, bacteria, parasites and fungi ^[3]. This strategy has proven
 218 very efficient to treat solid tumors and for the eradication of pathogenic microorganisms ^[3-6],
 219 that represent a major public health threat in regard to the emergence of new viruses (Ebola,
 220 coronavirus, etc.), spread of resistant bacteria and fungi, and the growing public distrust of
 221 vaccines. As compared to conventional chemotherapeutic treatments, phototherapy offers

222 many advantages as PS usually show a low intrinsic toxicity and can be delivered easily and
223 precisely to tumour microenvironments or infection zones. Accurate definition of the photo-
224 irradiation area limits adverse phototoxic effects and the fast and non-specific mode of action
225 of PS avoids the development of chemoresistance, as the life time of singlet oxygen is very
226 short and tumor cells or microorganisms have no possibility to develop chemoresistance in
227 response to the lethal ROS release. Additionally, the possible vectorization and targeted
228 delivery of PS to cell and bacterial membranes, cell walls or cell organites can further improve
229 the selectivity of PDT.

230 2. Clinical applications of photosensitizers (PS)

231 The first uses of light as a therapeutic agent date back to ancient times as Egyptians, Chinese
232 and Indians were trying to treat vitiligo, psoriasis and even skin cancer using light. However,
233 it was not until the end of the 19th century that phototherapy became a science and was
234 popularized by the Danish physician Niels Finsen who initiated the use of concentrated light
235 radiation for the treatment of lupus vulgaris. During this same period, the use of PS for
236 therapeutic purposes also began to be studied. In 1898, the concept of photosensitization
237 emerged when Oscar Raab first observed the toxicity of acridine in the presence of light on
238 paramecia. This finding led to extensive studies by Tappeiner, Jodl-bauer and collaborators and
239 to the introduction of the term "photodynamic action," used by Tappeiner in 1904. In 1900,
240 Prime, a French neurologist, observed that epileptic patients treated with oral eosin developed
241 dermatitis in areas exposed to the sun. In 1908, Hausmann demonstrated that hematoporphyrin
242 is a photosensitizer. He reported the destruction of paramecia and red blood cells and described
243 in detail the symptoms of sensitized mice after exposure to light. In 1913, Friedrich Meyer-
244 Betz performed the first human trial of hematoporphyrin, injecting himself with 200 mg of the
245 product. As long as he remained unexposed to the sun, nothing happened, but upon exposure
246 to sunlight, he observed a photosensitization that resulted in hyperpigmentation of the skin and
247 generalized edema, from which he suffered for two months. Following these pioneering
248 discoveries, PDT was progressively developed as an efficient and innovative method to treat
249 tumors and infections, and natural or synthetic phototoxic molecules were developed as PS.
250 The range of PS applications has expanded considerably in recent years, and they are now
251 commonly used for the phototherapy of tumours, destruction of tumour vasculature, as well as
252 the treatment of viral, bacterial and fungal infections of the skin, nails, wounds and mucous
253 membranes. Some examples of routine use of PS include the treatment of acne and keratosis,

254 chronic and acute wound infections, burn infections, and solid topical and internal tumors. PS
255 have also been more recently proposed and developed for the photo-decontamination of
256 hospital equipment and manufacture of photodecontaminable surfaces to prepare clothing,
257 laboratory coats and dressings for hospital and hygiene equipment. For example, a large
258 number of surfaces and materials (cellulose, cellulose nanocrystals, nanocellulose,
259 hemicellulose, ...) can be ionically or covalently grafted with natural or synthetic PS and
260 developed for antimicrobial applications [7-12]. Lignin and chitosan nanoparticles grafted with
261 PS have also been developed to obtain photoantimicrobial surfaces [13-15]. Several research
262 groups have also carried out the functionalization of different polymers like Nylon-6,
263 polyacrylonitrile, polyurethane, polylactic or polyolefin with different PS including cationic
264 porphyrin, protoporphyrin IX, Bodipy, ruthenium complexes, ... [16-20]. These polymers
265 functionalized with PS are very effective for antibacterial PDT on *S.aureus*, *E. Coli*, *P.*
266 *aeruginosa*, for antifungal PDT and for antiviral PDT on the human coronavirus strain HCoV-
267 229E [19]. However, despite the numerous benefits of phototherapy, only few phototoxic drugs
268 are currently indicated for clinical use, because of pharmacokinetics limitations or preparation
269 difficulties.

270 3. Searching for new phototoxic chemical scaffolds to stimulate innovation in phototherapy

271 In the seventies, Dr Thomas Dougherty, continuing and expanding upon the work of
272 phototherapy pioneers, played a major role in the development of PS and modern
273 photodynamic therapy (PDT) for cancer therapy [21]. The first generation of PS were porphyrins
274 and hematoporphyrins with long clearance time, low chemical purity and short excitation
275 wavelength [22]. Photofrin®, the first clinically approved PS for the treatment of cancer, is a
276 complex mixture of oligomers, which makes its clinical use poorly reproducible. In addition,
277 it has a relatively low quantum fluorescence yield and a low efficiency for ROS generation.
278 The second generation of PS includes clinically approved or under-clinical trials drugs such as
279 Porfimer sodium (Photofrin®), Temoporfin (Foscan®), Motexafin lutetium, Palladium
280 bacteriopheophorbide, Purlytin®, Verteporfin (Visudyne®) and Talaporfin (Laserphyrin®). In
281 this second generation, introduction of heavy atoms (halogens and metals) enhanced the singlet
282 oxygen production yield and prevented PS aggregation in the bloodstream and physiological
283 fluids. Additionally, expansion of the PS' conjugating systems increased their light absorption
284 efficiency at wavelengths better penetrating human skin and tissues (650-700 nm).
285 Pharmacomodulation of PS also increased their bioavailability, lipophilicity and cellular

286 uptake. Despite these improvements, most current PS still do not meet the requirements of
287 optimal drugs. For example, Foscan® has an enhanced absorption in the near infrared, is very
288 efficient, but has the disadvantage of being relatively toxic and difficult to eliminate from the
289 body, resulting in undesirable residual phototoxicity. Visudyne® and Verteporfin®, two
290 benzoporphyrin-derived PS, have the advantage of not causing skin photosensitivity but are
291 relatively difficult to prepare ^[22,23]. Most current PS are macrocyclic tetrapyrrolic derivatives
292 (porphyrins and their chlorine and bacteriochlorine derivatives), with high absorbency in the
293 far-red spectral range (650-750 nm), and thus comparable fields of application for phototherapy
294 because of their chemical homology. These gaps justify the importance of exploring new
295 natural PS and synthetic routes, not only in order to develop drugs with improved
296 pharmacokinetics, selectivity and reduced toxicity or systemic phototoxicity, but also to
297 identify novel molecular scaffolds with attractive physicochemical characteristics allowing the
298 development of innovative PS.

299 4. Chemical ecology as a source of inspiration to identify new photosensitizers: screening 300 phototoxic plants

301 A lot of terrestrial plants are known to synthesize phototoxic phytochemicals that are released
302 and triggered in response to predation by herbivores or attack by infectious pathogens and
303 parasites ^[24-30]. However, the total number of phototoxic species and metabolites has never
304 been explored in detail although previous attempts to write comprehensive reviews on the
305 subject are available in the literature ^[31,32]. Moreover, for some molecules like coumarins,
306 hundreds have been described but many of them have never been evaluated for possible
307 phototherapy applications ^[33]. Plant phototoxic molecules are synthesized as natural secondary
308 metabolites, produced and possibly induced in response to predation, invasion or infection.
309 Contact with the tissues of predators, invaders or pathogens, followed by sunlight photo-
310 activation eventually kills the pathogens or burns the predators to protect the plant and exert an
311 allelopathic effect ^[34-37]. This defence system is highly effective not only to repel grazers or
312 invaders, but also to kill microorganisms that could attack the plant tissues using cell wall
313 disrupting enzymes. The existence of this chemistry defence system has been demonstrated in
314 diverse plants from various taxonomic groups, biomes and ecoregions of the world, supporting
315 the hypothesis of a convergent adaptive evolutionary process that has led to a high
316 chemodiversity of phototoxic molecules ^[27]. In line with these data, many wild and cultivated
317 phototoxic plants have been reported to cause contact photodermatitis in humans. In particular,

318 phototoxic events are regularly reported in gardeners, farmers, children, employees of plants
319 processing companies and consumers in contact with wild species, horticultural, agricultural
320 or ornamental plants and essential oils. Phototoxic plants are also responsible for episodes of
321 livestock phototoxicity, with a strong impact on the health and survival of animals, especially
322 in countries where animals are kept in natural areas ^[38,39]. It is important to consider two
323 possible mechanisms of phototoxicity ^[32,40]. Primary phototoxicity is induced by molecules
324 that are directly photosensitive and will generate the production of ROS when exposed to
325 light. The phototoxic agent contained in the plant may be phototoxic when in contact with the
326 skin (e.g. furanocoumarins) or may reach the skin when ingested, with or without any chemical
327 modification. The photophysical, photochemical and biochemical processes involved in the
328 primary phototoxicity of these natural products has been described in detail in a previous
329 review ^[41] and rely on the photooxidation of intracellular and membrane biomolecules ^[41]. In
330 contrast, secondary phototoxicity is caused by molecules that are not directly phototoxic but
331 can lead to the production of phototoxic compounds through liver damage when ingested. For
332 example, phylloerythrin is produced by microbial degradation of chlorophyll in ruminant
333 stomachs. Phylloerythrin is normally excreted in bile but accumulates in the blood and skin
334 when hepatic damage interferes with the phylloerythrin conjugating and excreting mechanisms.
335 In the superficial layers of the skin, phylloerythrin is phototoxic because it absorbs ultraviolet
336 radiation of the sun. Hepatogenous sensitization can be observed for example with triterpenes
337 and monoterpenes that are not directly phototoxic as they do not contain light-absorbing
338 chromophores. As such, compounds considered to be photoprotective such as flavonoids or
339 betalaines can also be responsible for secondary photosensitization after ingestion ^[32,42-44].

340 5. Objective of the study

341 In this work, our objective was to highlight the potential of plant phototoxic molecules as
342 possible candidates to develop new PS. For this purpose, we achieved an inventory of the
343 biodiversity of phototoxic terrestrial plants and described the structures of phototoxic or
344 photosensitizing molecules identified so far in terrestrial plants. First, it appeared essential to
345 estimate the number of phototoxic plants in relation to the biodiversity of terrestrial plants, and
346 we therefore listed all plants reported to contain phototoxic natural products or to be phototoxic
347 in humans and livestock, detailing their taxonomy and geographical distribution worldwide. In
348 the next section, we listed all phototoxic plant natural products, indicating, when available,
349 their activity in various model studies, their chemical family, their physicochemical

350 characteristics, the species in which they can be found and the geographical distribution of
351 these species. We discriminated phototoxic molecules involved in primary photosensitization
352 from molecules involved in secondary photosensitization after ingestion by ruminants. In
353 some cases, molecules may be phototoxic through both photosensitization processes. This
354 analysis made it possible to highlight the chemodiversity of phototoxic molecules synthesized
355 by terrestrial plants and to link the presence of specific phototoxic chemical families to
356 botanical families. The described plants and phototoxic natural products reveal promising
357 prospects for the further development of new photosensitizers, for the phototherapy of tumors
358 and infections.

359

360 6. Methods

361 A literature search was conducted to include scientific publications published since 1989 in
362 five specialised databases (ScienceDirect, Scopus, PubMed, Google Scholar, MDPI) using
363 different combinations of keywords, the main ones being plant names but also family names
364 of molecules, as well as other terms such as natural molecule, natural product, plant,
365 photosensitizer, photosensitization, phototoxic and phototoxicity. A few previous studies,
366 considered as fundamental pioneer research on phototoxicity and phototherapy were also
367 included. A total of 84 non-redundant publications and 8 book chapters were found and kept
368 for the review after checking that their scientific content was relevant to the scope and provided
369 they met a sufficient scientific quality. Only publications with title, abstract and content in
370 English were selected. Selected publications were mainly articles, but journals, book chapters
371 or short communications were also evaluated for inclusion in the study. Articles dealing with
372 natural photoprotective products were excluded. Information about molecules, including their
373 chemical family, structure and molecular formula, was checked on the PubChem database and
374 cross-checked independently by 2 chemists. The taxonomic classification of each plant and
375 location was checked with the GBIF biodiversity database (<https://www.gbif.org/>). Wherever
376 the presence of a plant species in a country or biome was reported in our paper, we checked
377 that the validity of the data was supported by rigorous scientific observation or report.

378 7. Results

379 7.1. Inventory of phototoxic plants

380 To date about 435,000 land plant species, including 391,000 vascular plants, have been
 381 identified on Earth (Figure 1.) Vascular plants include angiosperms, gymnosperms, filices
 382 (ferns) and lycophytes while bryophytes (non-vascular seedless plants) include mosses,
 383 hornworts and liverworts (Figure 1.). The exact number of world plants species is for certain
 384 underestimated as botanists discover and document about 2,000 new species of flowering
 385 plants every year ^[45]. Among these species, no phototoxic plant was reported in the subgroup
 386 of bryophytes. Within the 391,000 vascular plant species, only around 250 species were
 387 documented as phototoxic or involved in phototoxic occurrences in humans (Figure 1.). The
 388 inaccurate number of phototoxic species is explained by the fact that in some reports, only the
 389 plant genus was described without specifying the species. Additionally, some species that
 390 contain phototoxic metabolites have not necessarily been the subject of phototoxicity reports
 391 in humans or animals.

KINGDOM PLANTAE ~ 435 000 species



Subgroup VASCULAR PLANTS
 391 000 species: Angiosperms,
 gymnosperms, filices (ferns) and
 lycophytes

Subgroup BRYOPHYTES
NON VASCULAR
SEEDLESS PLANTS
 44 000 species: Mosses,
 hornworts, liverworts
0 phototoxic species

392 **~250 phototoxic species**

393 Figure 1. Repartition of the 435,000 world plant species in taxonomic subgroups and
 394 distribution of phototoxic world plant species. Only around 250 plant species belonging to the
 395 subgroup of vascular plants have been identified as phototoxic.

396 Table 1. presents the complete inventory of phototoxic plants of the world, listed in alphabetical
397 order within their taxonomic family. All species were catalogued with their taxonomy, location,
398 vernacular name and, when known, the nature and structure of their phototoxic molecule(s). In
399 several phototoxic plants, the molecule(s) responsible for the activity are still unidentified
400 (indicated as “Unknown” in Table 1.). Phototoxic plants include species which have been
401 known for a long time for their phototoxicity but also lesser described species that have not
402 been studied in detail for the characterization of phototoxic molecules and represent a potential
403 source of new molecules. The presence of phototoxic compounds was reported in a wide
404 diversity of plant families present in different biomes of the world (Figure 2.). In particular, a
405 large number of phototoxic species were documented in the families Apiaceae, Asteraceae,
406 Fabaceae, Rutaceae, and Poaceae (Table 1. and Figure 2.).

Family	Plant name	Vernacular name, local name	Location	Molecule(s) responsible for phototoxicity	Chemical family	References
Acanthaceae	<i>Strobilanthes sp.</i>	Lidah Jin/Pecah biling (Malaysia)	Malaysia	Unknown	Report of flavonoids, alkaloids, triterpenoids, porphyrins and derivatives in the taxonomic family.	[46]. This paper discusses the phototoxicity of Malaysian plant extracts screened in HL60 promyelocytic leukemia cells.
Actinidiaceae	<i>Actinidia chinensis</i> Planch.	Kiwi	East Asia, Europe, New-Zealand, USA	Unknown	Unknown	[47]
Aizoaceae	<i>Tetragonia tetragonoides</i> (Pall.) Kuntze	Tetragone	Littorals, including Brazil	Chlorophylls, pheophorbide <i>a</i> , pheophorbide <i>b</i>	Porphyrins and derivatives	[48]
Amaranthaceae	<i>Alternanthera maritima</i> (Mart.) A.St.-Hil.	Seaside joyweed	East of South America, including	Unknown	Report of Flavonoids, saponins, steroids	[49]

Amaranthaceae	<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	Alligator weed	Brazil, West of Africa USA, South America (littoral), France and East Asia	Rubiadin, rubiadin-1- methyl ether	Anthraquinones	[47,50,51]
Amaranthaceae	<i>Froelichia floridana</i> (Nutt.) Moq.	Florida snakecotton	USA, Australia	3,4-dihydroxyphenyl polyphenolic caffeate	Polyphenols	[52]
Amaranthaceae	<i>Froelichia humboldtiana</i> (Roem. & Schult.) Seub.		Brazil	Naphodianthrone(s)	Naphodianthrone(s)	[47,52–54]
Amaranthaceae	<i>Kochia scoparia</i> (L.) Schrad. = <i>Bassia scoparia</i> subsp. scoparia		Europe, USA Asia, Mexico	Unknown	Unknown	[55]
Amaryllidaceae	<i>Cooperia pedunculata</i>	Rain lily	Mexico, USA	Unknown	Unknown	[54]
Amaryllidaceae	<i>Zephyranthes drummondii</i> D.Don	Prairie lily	U.S.A., Mexico	Unknown	Report of Furanocoumarins	[50]
Anacardiaceae	<i>Mangifera indica</i> L.	Mango mangueira	South hemisphere, including Brazil	Unknown	Report of catechols, triterpenoids,	[56]

Anacardiaceae	<i>Pentaspadon motleyi</i> <i>Hook.fil.</i>		Asia Pacific	Pheophorbide <i>a</i> , pheophorbide <i>b</i>	Porphyrins and derivatives	[57]
Anacardiaceae	<i>Rhus succedaneum</i> = <i>Rhus</i> <i>succedanea</i> L. = <i>Toxicodendron</i> <i>succedaneum</i> (L.) Kuntze	Unknown	Asia, Brazil	Unknown	Report of catechols	[58]
Anacardiaceae	<i>Rhus verniciflua</i> Stokes = <i>Toxicodendron</i> <i>vernicifluum</i> (Stokes) F.A.Barkley		China, Korea and Japan	Unknown	Report of catechols	[56]
Anacardiaceae	<i>Schinopsis brasiliensis</i> Engl.	Baraúna	South America, including Brazil	Unknown	Report of Tannins	[59]
Anacardiaceae	<i>Schinus terebinthifolius</i> = <i>Schinus terebinthifolia</i> Raddi	Aroeira	Littorals, including Brazil	Unknown	Report of catechols	[56]
Anacardiaceae	<i>Semecarpus anacardium</i> L.fil.	Oriental cashew	India	Unknown	Report of catechols	[56]
Annonaceae	<i>Annona purpurea</i> Moç. & Sessé ex Dunal		Central America	Berberine	Isoquinoline alkaloid	[47,60]
Annonaceae	<i>Guatteria blepharophylla</i> Mart.	Envireira	South hemisphere,	Berberine, isomoschatoline, lysicamine	Oxaporphine	[61,61]

Annonaceae	<i>Guatteria ferruginea</i> A.St.-Hil.	including Brazil North of Southern America, including Brazil	3-hydroxy- nornuciferine, isomoschatoline, liriodenine, lysicamine, nornuciferine, o- methyloschatoline	Aporphine alkaloids	[61,62]
Annonaceae	<i>Guatteria latifolia</i> (Mart.) R.E.Fr.	Brazil	3-hydroxy- nornuciferine, isomoschatoline, liriodenine, lysicamine, nornuciferine, o- methyloschatoline	Aporphine alkaloids	[61-63]
Annonaceae	<i>Guatteria sellowiana</i> Schtdl.	Brazil	3-hydroxy- nornuciferine, isomoschatoline, liriodenine, lysicamine, nornuciferine, o- methyloschatoline	Aporphine alkaloids	[61,62]

Apiaceae	<i>Ammi majus L.</i>	Bishop's weed	Southern Europe, Northern and Western Africa, Central Asia, Brazil	3,4-dihydroxyphenyl polyphenolic caffeate, 7-Methoxycoumarin, 8-Methoxypsoralen, alloimperatorin, ammirin, angelicin, archangelicin, bergapten, bergaptol, imperatorin, isobergapten, isopimpinellin, marmesin, marmesinin, methoxsalen, oxypeucedanin, sphondin, xanthotoxin	Furanocoumarins, polyphenols	[38,39,47,50,52,54,64-68]
Apiaceae	<i>Ammi visnaga (L.) Lam</i>	Khella	Argentina, Europe, Mediterranean basin	7-Methoxycoumarin, 8-hydroxybergapten,, 8-Methoxypsoralen, archangelicin, imperatorin, khellin, marmesin, methoxsalen, visnagin, xanthotoxin	Furanocoumarins	[47,50,69-71]

Apiaceae	<i>Anethum graveolens</i> L.	Dill	Worldwide, reported in Europe, North America, Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten, methoxsalen, isobergapten, sphondin	Furanocoumarins	[67]
Apiaceae	<i>Angelica archangelica</i> L.	Angelica	Europe + cold climates	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergaptol, isobergapten, isopimpinellin, oreoselone, sphondin, steroid sapogenins 3- spirostanols	Furanocoumarins	[47,50,54,64–67]

Apiaceae	<i>Angelica dahurica</i> (Fisch. ex Hoffm.) Benth. & Hook.fil. ex Franch. & Sav.		East Asia	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, imperatorin, methoxsalen, xanthotoxin	Furanocoumarins	[66]
Apiaceae	<i>Angelica lucida</i> L.	Angelica	North hemisphere	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, isoimperatorin, methoxsalen, xanthotoxin	Furanocoumarins	[66]
Apiaceae	<i>Angelica sinensis</i> (Oliv.) Diels (scientific name) = <i>Angelicae tuhou radix</i> (chinese medicinal herb)	Chinese angelica	China	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, methoxsalen, xanthotoxin	Furanocoumarins	[66]

Apiaceae	<i>Angelica sylvestris</i> L.	Wild angelica	USA, Iceland, Eurasia	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, methoxsalen, xanthotoxin	Furanocoumarins	[67]
Apiaceae	<i>Anthriscus cereifolium</i> (L.) Hoffm.		Europe, USA, New Zealand	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergaptol, isobergaptin, methoxsalen, sphondin	Furanocoumarins	[67]
Apiaceae	<i>Anthriscus sylvestris</i> (L.) Hoffm.	Cow parsley (EN)	Africa, New Zealand, Europe, Asia and USA	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergaptol, isobergaptin, methoxsalen, sphondin	Furanocoumarins	[67]

Apiaceae	<i>Apium graveolens</i> L.	Celery	Worldwide, including Brazil	4,5',8- trimethylpsoralen (Trioxsalen), 7- Methoxycoumarin, 8- Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten, isoimperatorin, isopimpinellin, methoxsalen, sphondin, xanthotoxin	Furanocoumarins	[50,66,67]
Apiaceae	<i>Cnidium monnieri</i> (L.) Cusson	Monnier's snowparsley	East Asia	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Coriandrum sativum</i> L.	Coriander	Worldwide, including Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, methoxsalen	Furanocoumarins	[66]

Apiaceae	<i>Cymopterus watsonii</i> (J.M.Coult. & Rose) M.E.Jones = <i>Aulospermum ibapense</i> (M.E.Jones) J.M.Coult. & Rose	Spring parsley	North America	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, bergapten, methoxsalen, xanthotoxin	Furanocoumarin	[47,50,54,64-67]
Apiaceae	<i>Daucus carota</i> L.	Wild carrot	North hemisphere, South Africa, Oceania, South America, some occurences reported in Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergaptol, isobergapten, methoxsalen, sphondin	Furanocoumarins	[67]
Apiaceae	<i>Foeniculum vulgare</i> Mill.	Fennel	Worldwide, including Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten,	Furanocoumarins	[67]

Apiaceae	<i>Glehnia littoralis</i> (A.Gray) F.Schmidt = <i>Radix glehniae</i> as chinese traditional medicine	USA and East Asia	methoxsalen sphondin 7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, isoimperatorin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Heracleum candicans</i> Wall. ex DC. = <i>Semenovia candicans</i> (Wall. ex DC.)	China	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, bergapten, heraclenin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Heracleum laciniatum</i>	Norway	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten, isopimpinellin, methoxsalen, sphondin	Furanocoumarins	[67]

Apiaceae	<i>Heracleum lanatum Michx.</i>		North hemisphere	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, isobergaptin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Heracleum mantegazzianum</i> Sommier & Levier	Giant hogweed	Europe, USA	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergaptin, bergaptol, isobergaptin, methoxsalen, sphondin	Furanocoumarins	[54,66,67]
Apiaceae	<i>Heracleum sibiricum L.</i>		Eurasia	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, bergaptin, methoxsalen	Furanocoumarins	[66]

Apiaceae	<i>Heracleum sphondylium</i> L.	Hogweed	North hemisphere, New Zealand	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol isobergapten, isopimpinellin, methoxsalen, sphondin	Furanocoumarins	[66,67]
Apiaceae	<i>Heracleum thomsonii</i> C.B.Clarke = <i>Semenovia thomsonii</i> (C.B.Clarke) Manden.		Asia	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, methoxsalen, sphondin	Furanocoumarins	[66]
Apiaceae	<i>Imperatoria ostruthium</i> L. = <i>Peucedanum ostruthium</i> (L.) Koch		Europe	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, isobergapten, methoxsalen, oxypeucedanin, sphondin	Furanocoumarins	[66,67]

Apiaceae	<i>Levisticum officinale</i> Koch	Lovage	Europe, USA, Korea, Japan, New Zealand	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten, methoxsalen, sphondin	Furanocoumarins	[66,67]
Apiaceae	<i>Pastinaca sativa</i> L.	Wild parsnip	North hemisphere, Australia, New Zealand	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, imperatorin, isobergapten, isopimpinellin, methoxsalen, xanthotoxin, sphondin	Furanocoumarins	[47,50,66,67]
Apiaceae	<i>Petroselinum crispum</i> (Mill.) Fuss	Parsley	Europe, Americas, including	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin,	Furanocoumarins	[50]

		Brazil, South of Africa, Australia, New Zealand	methoxsalen, oxypeucedanin		
Apiaceae	<i>Petroselinum sativum</i> Hoffm. = <i>Petroselinum crispum</i> subsp. <i>crispum</i>	Europe and Central America	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, archangelicin, bergapten, bergaptol, isobergapten, isopimpinellin, methoxsalen, oxypeucedanin, sphondin, xanthotoxin	Furanocoumarins	[50,66,67]
Apiaceae	<i>Peucedanum alsaticum</i> L. = <i>Xanthoselinum alsaticum</i> (L.) Schur	Europe	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, methoxsalen	Furanocoumarins	[66]

Apiaceae	<i>Peucedanum cervaria</i> Linnaeus, 1753		Europe	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Peucedanum tauricum</i> M. Bieb Also known as <i>Peucedanum</i> <i>ruthenicum</i> M.Bieb.		Balkans (Eastern Europe)	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, bergapten, bergaptol	Furanocoumarins	[66]
Apiaceae	<i>Pimpinella magna</i> L.		Europe	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin, bergaptol, isobergaptent, methoxsalen, sphondin	Furanocoumarins	[66]
Apiaceae	<i>Pimpinella major</i> (L.) Huds.		Europe	7-Methoxycoumarin, archangelicin, bergapten, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Pimpinella saxifraga</i> L.		North hemisphere	7-Methoxycoumarin, archangelicin, isopimpinellin, methoxsalen	Furanocoumarins	[66]
Apiaceae	<i>Sphenosciadium capitellatum</i> A.Gray	Whiteheads, ranger's buttons	West USA	7-Methoxycoumarin, 8-Methoxypsoralen, archangelicin,	Furanocoumarins	[54]

	also known as <i>Angelica capitellata</i> (A.Gray) Spalik, Reduron & S.R.Downie			bergapten, methoxsalen		
Araceae	<i>Aglaonema simplex</i> (Blume) Blume	Malayan sword	South East Asia	20 ¹ -Hydroxypurpurin-7 delta-lactone ethyl methyl diester, hydroxypurpurin-7-lactone ethyl methyl diester, methyl phytyl diester, pheophorbide <i>a</i>	Porphyrins and derivatives	[47,72,73]
Araceae	<i>Dieffenbachias maculata</i> (Lodd.) G.Don = <i>Dieffenbachia seguine</i> (Jacq.) Schott		Tropics, no occurrence reported in Brazil	Unknown	Unknown	[74]
Arecaceae	<i>Euterpe oleracea</i> Mart.	Açaí	Brazil and Colombia	Pheophorbide <i>a</i>	Porphyrins and derivatives	[75,76]
Asparagaceae	<i>Agave lecheguilla</i> Torr.		Mexico	Unknown	Report of saponins	[50,52,54]
Asparagaceae	<i>Agave lechuguilla</i> Torr.		Mexico	Unknown	Report of Porphyrins and derivatives	[50]
Asparagaceae	<i>Nolina texana</i> S. Watson	Texas sacahuista	USA, Mexico	Unknown	Unknown	[50,52]

Asphodelaceae	<i>Aloe vera</i> (L.) Burm. f.	Aloe vera	Worldwide, including Brazil	Aloe-emodin, anthraquinone, fagopyrin, emodin, rhein	Naphthodianthrones, Anthraquinones	[47,67,77]
Asteraceae	<i>Artemisia scoparia</i>		Eurasia	Scoparone	Coumarin	[78]
Asteraceae	<i>Brachyglottis adamsii</i> (Cheeseman) B.Nord.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Brachyglottis hectori</i> (Buchanan) B.Nord.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Brachyglottis huntii</i> (F.Muell.) B.Nord.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Brachyglottis kirkii</i> (Hook.fil. ex Kirk) C.J.Webb = <i>Urostemon kirkii</i> (Hook.fil. ex Kirk) B.Nord.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Brachyglottis perdicoides</i> (Hook.fil.) Hook.fil.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Brachyglottis sciadophila</i> (Raoul) B.Nord.		New Zealand	Retorsine, senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]

Asteraceae	<i>Chrysanthemum segetum</i> L. = <i>Glebionis segetum</i> (L.) Fourr.		Europe	Unknown	Reports of Furanocoumarins	[54,66] [80,81] see also [80-82]
Asteraceae	<i>Cineraria maritima</i> L. = <i>Jacobaea maritima</i> subsp. maritima		Mediterranean basin	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Echinops latifolius</i> Tausch.		Russia, China	Thiophene	Thiophene and derivatives	[47]
Asteraceae	<i>Leuzea carthamoides</i> Willd (= <i>Rhaponticum</i> <i>carthamoides</i>)		Russia	Thiophene	Thiophene and derivatives	[83]
Asteraceae	<i>Parthenium hysterophorus</i> L.	Santa Maria feverfew	USA, Central and South Americas including Brazil, East Africa, Oceania, East Asia, India	Unknown	Unknown	[84]
Asteraceae	<i>Pittocaulon bombycophole</i> (Bullock) H.Rob. & Brettell		Mexico	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Pittocaulon filare</i> (Mc Vaugh) H.Rob. & Brettell		Mexico	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]

Asteraceae	<i>Pittocaulon hintonii</i> H.Rob. & Brettell		Mexico	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Pittocaulon praecox</i> (Cav.) H.Rob. & Brettell		Mexico	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Pittocaulon velatum</i> (Greenm.) H.Rob. & Brettell		Mexico	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Porophyllum obscurum</i> (Spreng.) DC.		South America, including Brazil	Thiophene	Thiophene and derivatives	[41]
Asteraceae	<i>Senecio brasiliensis</i> (Spreng.) Less.	Flor das almas	Brazil	Senecionine	Pyrrolizidine Alkaloids	[85]
Asteraceae	<i>Senecio carpathicus</i> Herbich = <i>Jacobaea abrotanifolia</i> subsp. <i>carpathica</i> (Herbich) B.Nord. & Greuter		East Europe	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio cineraria</i> DC.	Silver ragwort	North hemisphere	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio douglasii</i> DC.		USA	Retorsine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio erucifolius</i> L.		Eurasia	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio gibbosus</i> subsp. <i>bicolor</i> (Willd.) Peruzzi, N.G.Passal. & Soldano = <i>Jacobaea maritima</i> subsp.		Europe, Mediterranea n basin	Senecionine	Pyrrolizidine Alkaloids	[79]

	<i>bicolor</i> (Willd.) B.Nord. & Greuter					
Asteraceae	<i>Senecio jacalensis</i> Greenm. & Greenm.		Mexico	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio jacobaea</i> Brot. ex Willk. & Lange, 1865	Tansy ragwort	North America, Europe, Australia	Retorsine	Pyrrolizidine Alkaloids	[54]
Asteraceae	<i>Senecio othonnae</i> M.Bieb. = <i>Jacobaea othonnae</i> (M.Bieb.) C.A.Mey.		East Europe, Middle East	Senecionine, senkirkine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio paludosus</i> L. = <i>Jacobaea paludosa</i> subsp. <i>paludosa</i>		Europe	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio riddellii</i> Torr. & A.Gray		USA	Pyrrolizidine alkaloids, riddelliine, retorsine	Pyrrolizidine Alkaloids	[79,86]
Asteraceae	<i>Senecio rupestris</i> Waldst. & Kit. = <i>Senecio squalidus</i> subsp. <i>rupestris</i> (Waldst. & Kit.) Greuter		East Europe	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio stibianus</i> Lacaita		Italy	Senecionine	Pyrrolizidine Alkaloids	[79]

Asteraceae	<i>Senecio subalpinus</i> Koch = <i>Jacobaea subalpina</i> (W.D.J.Koch) Pelser & Veldkamp	East Europe	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Senecio vulgaris</i> L.	North America, Eurasia, West of South America, Australia, New Zealand	Retorsine	Pyrrolizidine Alkaloids	[54]
Asteraceae	<i>Senecio wagneri</i> Degen = <i>Tephrosieris papposa</i> subsp. wagneri (Degen) B.Nord.	Bulgaria	Senecionine	Pyrrolizidine Alkaloids	[79]
Asteraceae	<i>Tagetes erecta</i> L.	Worldwide	Thiophene	Thiophene and derivatives	[41]
Bignoniaceae	<i>Oroxylum indicum</i>	Malaysia	Unknown	Report of Chrysin, baicalein, baicalin, flavonoids, iridoids in the Bignoniaceae family. Phototoxicity was demonstrated in leaf extracts.	[46]

Boraginaceae	<i>Anchusa strigosa</i> Banks & Sol.		Arabian peninsula, Middle East, Israel	Retronecine	Pyrrolizidine Alkaloids	[79]
Boraginaceae	<i>Cynoglossum officinale</i> L.	Houndstoungue	North hemisphere	Unknown	Report of Pyrrolizidine alkaloids	[54,64]
Boraginaceae	<i>Echium plantagineum</i> L.	Borragem / Paterson's curse (purple viper's-bugloss)	Europe, South Africa, Oceania, South America (some occurrences in Brazil)	Unknown	Report of Pyrrolizidine alkaloids	[38,54]
Brassicaceae	<i>Brassica napus</i> L.	Rapeseed / Canola	Europe, Brazil	Unknown	Unknown	[47]
Brassicaceae	<i>Brassica rapa</i> L.	Turnip rape / mustard	Europe, Brazil	Unknown	Reports of Saponins	[47,50,54]
Bromeliaceae	<i>Ananas comosus</i> (L.) Merr.	Pineapple	Mostly Central and South America, including	Unknown	Unknown	[56]

			Brazil, also reported in Africa and Asia			
Bromeliaceae	<i>Bromelia antiacantha</i> Bertol.		Brazil	Unknown	Unknown	[87]
Celastraceae	<i>Kokoona reflexa</i>	Mata ulat	Malaysia	Unknown	Report of sesquiterpenes and triterpenoids. Phototoxicity was reported in the leaf extract.	[46]
Chrysobalanaceae	<i>Maranthes corymbosa</i>	Merbatu (Malaysia)	Malaysia	Unknown	Report of flavonoids. Phototoxicity was reported in the stem extract.	[46]
Clusiaceae	<i>Calophyllum inophyllum</i>	Bintangor laut (Malaysia)	South hemisphere, including Brazil	Unknown	Report of pyranocoumarins, xanthones, triterpenes, steroids, and flavonoids in the taxonomic family. Phototoxicity was reported in the leaf extract.	[46]
Clusiaceae	<i>Garcinia atroviridis</i> Griff ex T.Anderson	Asam gelugor (Malaysia)	Malaysia	Unknown		[46]

Clusiaceae	<i>Garcinia mangostana</i> L.	Mangosteen	South hemisphere, including Brazil	Mangostin (in pericarp)	Xanthone Flavonoid	[88,89]
Commelinaceae	<i>Rhoeo spathacea</i> (Sw.) Stearn also known as <i>Tradescantia spathacea</i> Sw.		Central America	Rutin	Flavonoid	[90]
Costaceae	<i>Costus speciosus</i> (J.Koenig) Sm. = <i>Hellenia speciosa</i> (J.Koenig) S.R.Dutta	Canereed	Pacific Asia, Central America	Dioscin, diosgenin	Saponins	[91]
Euphorbiaceae	<i>Hevea brasiliensis</i> (Willd. ex A.Juss.) Müll.Arg.	Hevea	South Asia, West Africa, Central and South Americas including Brazil	Unknown	Unknown	[56]
Euphorbiaceae	<i>Ricinus communis</i> L.		Worldwide, including Brazil	<i>Ricinus communis</i> agglutinin (RCA)	Lectin	[92]
Fabaceae	<i>Arachis hypogaea</i> L.	Peanut	Worldwide, including Brazil	<i>Arachis hypogaea</i> Lectin (PNA)	Lectin, Report of Furanocoumarins,	[92]
Fabaceae	<i>Bauhinia forficata</i> Link	Cow's foot	South America,	<i>Bauhinia forficata</i> Lectin (BfL)	Lectin, Report of Furanocoumarins,	[92]

Fabaceae	<i>Biserrula pelecinus</i> L.		including Brazil Mediterranean basin	Unknown	Reports of Furanocoumarins	[47]
Fabaceae	<i>Bituminaria bituminosa</i> (L.) C.H. Stirt.		Europe	Angelicin	Furanocoumarins	[47,50,66]
Fabaceae	<i>Cassia alata</i> (L.) = <i>Senna alata</i> (L.) Roxb.	Gelenggang daun besar (Malaysia)	South Asia, West Africa, Central and South Americas including Brazil, USA	Unknown	Reports of alkaloids, flavonoids, coumarins, anthraquinones in the taxonomic family. Report of phototoxicity in the leaf extract.	[46]
Fabaceae	<i>Chamaecrista nictitans</i> (L.) Moench	Sensitive pea	Central America and South America, including Brazil	Unknown	Reports of Furanocoumarins	[93]
Fabaceae	<i>Chamaecrista serpens</i> (L.) Greene	Slender sensitive pea	Central America and South America,	Unknown	Reports of Furanocoumarins	[93]

Fabaceae	<i>Crotalaria retusa</i> L.	Rattleweed	including Brazil Tropical belt, including Brazil	Unknown	Reports of Furanocoumarins, pyrrolizidine alkaloids	[36,52,85]
Fabaceae	<i>Cullen cinereum</i> (Lindl.) J.W.Grimes		Australia	Unknown	Reports of Furanocoumarins	[47,50]
Fabaceae	<i>Dipteryx odorata</i> (Aubl.) Forsyth f.	Cumaru / tonka	North of South America, including Brazil	Nodakenetin	Furanocoumarins	[66,94]
Fabaceae	<i>Entada phaseoloides</i> (L.) Merr.	Beluru/akar sintok (Malaysia)	South Asia, Africa, Central Americ	Unknown	Unknown. Report of phototoxicity in stem extract.	[46]
Fabaceae	<i>Enterolobium contortisiliquum</i> (Vell.) Morong	Pacara earpod tree	Brazil	Unknown	Reports of porphyrin and derivatives, Furanocoumarins, Saponins	[85,93,95]
Fabaceae	<i>Erythrina variegata</i> L.	Tiger's claw	India, Oceania, South East Asia, Pacific ocean	Unknown	Reports of Carotenoids, furanocoumarins	[96]

Fabaceae	<i>Glycine max (L.) Merr.</i>	Soybean	islands, Central and South Americas including Brazil	Lectin (glycine max)	Lectin, report of Furanocoumarins	[92]
Fabaceae	<i>Griffonia simplicifolia</i> (Vahl ex DC.) Baill.		West Africa	Griffonia simplicifolia Lectin (GSAIA4)	Lectin, Report of Furanocoumarins,	[92]
Fabaceae	<i>Holocalyx balansae</i> Micheli	Alecrim	South America, including Brazil	Unknown	Reports of Furanocoumarins, porphyrins and derivatives	[50]
Fabaceae	<i>Lotus corniculatus</i> L.	Bird's-foot trefoil	Europe, Brazil	Unknown	Reports of Furanocoumarins	[47]
Fabaceae	<i>Medicago denticulata</i> Willd. also known as <i>Medicago polymorpha</i> L.	Burr trefoil	Colombia, Mexico, Europe, USA and China	Unknown	Reports of Furanocoumarins	[54,64]

Fabaceae	<i>Medicago lupulina</i> L.	Black medic / Alfafa-lupulina	North hemisphere, Australia, New Zealand, South America including Brazil	Unknown	Reports of Furanocoumarins	[54]
Fabaceae	<i>Medicago nigra</i> L.		Worldwide, including Brazil	Unknown	Reports of Furanocoumarins	[47,54]
Fabaceae	<i>Medicago sativa</i> L.	Alfafa	Worldwide, including Brazil	Unknown	Reports of Furanocoumarins	[47,54]
Fabaceae	<i>Melilotus officinalis</i> (L.) Lam.	Melilot	North hemisphere	Unknown	Reports of coumarins and furanocoumarins	[33,66]
Fabaceae	<i>Mimosa pteridifolia</i> Benth.	Jurema-cor-de- rosa	Brazil	Flobabenic tannins, pyrogalllic tannins	Tannins	[97]
Fabaceae	<i>Mimosa tenuiflora</i> (Willd.) Poir.	Jurema preta, calumbi (Brazil)	Central America and Brazil	Flobabenic tannins, pyrogalllic tannins	Tannins Reports of Furanocoumarins and saponins	[97]
Fabaceae	<i>Mimosa verrucosa</i> Benth.	Jurema-branca, jurema-de- oeiras	Brazil	Flobabenic tannins, pyrogalllic tannins	Furanocoumarins	[97]

Fabaceae	<i>Peltophorum pterocarpum</i>		South hemisphere	Unknown	Report of phototoxicity in the leaf extract.	[46]
Fabaceae	<i>Psoralea corylifolia</i> L. also known as <i>Cullen corylifolium</i> (L.) Medik.		East Asia	Angelicin, bergaptol, isobergaptol, sphondin	Furanocoumarins	[65-68]
Fabaceae	<i>Stryphnodendron fissuratum</i> E.M.O. Martins		Brazil	Unknown	Reports of Furanocoumarins	[98]
Fabaceae	<i>Trifolium hybridum</i> L.	Alsike clover	Europe, North America, Brazil	Unknown	Reports of Furanocoumarins	[54,64]
Fabaceae	<i>Trifolium pratense</i> L.	Red clover	Europe, Brazil	Unknown	Reports of Furanocoumarins	[47]
Fabaceae	<i>Trifolium repens</i> L.	White clover	Europe, Brazil	Unknown	Reports of Furanocoumarins	[47]
Fabaceae	<i>Vicia sativa</i> L.	Lentils	Worldwide, including Brazil	Bergaptol	Furanocoumarins	[50,54]
Geraniaceae	<i>Erodium cicutarium</i> (L.) L'Hér.	Alfilaria	Eurasia, North America, South of Australia, South Africa, West	Unknown	Report of Anthraquinones	[47]

Geraniaceae	<i>Erodium moschatum</i> (L.) L'Hér.	musk stork's- bill	of South America Europe, Oceania, South Africa, Japan, Western USA, South America (not Brazil)	Unknown	Unknown	[47]
Ginkgoaceae	<i>Ginkgo biloba</i> L.	Ginkgo	North hemisphere, also found in Brazil	Unknown	Report of catechols	[56]
Haemodoraceae	<i>Haemodorum</i> <i>distichophyllum</i> (Hook.)		Australia, Tasmania	Phenalenone A	aromatic ketone	[99,100]
Haemodoraceae	<i>Lachnanthes tinctoria</i>		USA Atlantic coast	lachnanthocarpone (Report of tetraoxygenated derivatives in	Phenalenone derivative	[101,102]

				<i>Wachendorfia thyrsiflora</i>)		
Heliotropiaceae	<i>Heliotropium europeum</i> L.	European heliotrope	Eurasia, Australia, USA	Heliotrine, lasiocarpine	Pyrrolizidine Alkaloids	[54,79]
Hypericaceae	<i>Hypericum maculatum</i> Crantz		Eurasia	Hypericin	Naphtodianthrones	[50]
Hypericaceae	<i>Hypericum perforatum</i> L.	St John's wort	Worldwide, including Brazil (Mostly North hemisphere)	Anthraquinone, hyperforine, hypericin	Naphtodianthrones	[47,50,52,54,57,64,67,10 3–106]
Hypericaceae	<i>Hypericum pseudomaculatum</i> Bush	False spotted St. Johnswort	USA	Anthraquinone, hypericin	Anthraquinone, naphtodianthrones	[52,54,64]
Hypericaceae	<i>Hypericum punctatum</i> Lam.	Spotted St. Johnswort	USA	Anthraquinone, hypericin	Anthraquinone, naphtodianthrones	[52,54,64]
Hypericaceae	<i>Hypericum triquetrifolium</i> Turra		Mediterranea n basin	Hypericin	Naphtodianthrones	[50]
Irvingiaceae	<i>Irvingia malayana</i>	Pauh kijang (Malaysia)	Malaysia, South-East Asia	Unknown		[46]

Lamiaceae	<i>Leonurus sibiricus</i> L.		America, Europe, Asia	Pheophorbide <i>a</i>	Porphyrins and derivatives	[73]
Lamiaceae	<i>Phlomis younghusbandii</i> Mukerjee		China	Unknown	Reports of Furanocoumarins	[66]
Lamiaceae	<i>Scutellaria barbata</i> D. Don	Barbed skullcap	Southern China	Pheophorbide <i>a</i>	Porphyrins and derivatives	[47,106]
Lamiaceae	<i>Tectona grandis</i> L.f.	Teak	Central America, Brazil, Subsaharian Africa, India and Pacific Asia	Unknown	Unknown	[107]
Lamiaceae	<i>Thymus vulgaris</i> L.	Thyme	Europa, Oceania, USA, Central and South Americas, including Brazil	Thymol	Phenol	[108]
Lauraceae	<i>Cinnamomum camphora</i> (L.) Nees & Eberm. = <i>Cinnamomum camphora</i> (L.) J.Presl	Camphor tree	Worldwide, including Brazil	Eucalyptol	Monoterpene	[108]

Lauraceae	<i>Cryptocarya griffithiana</i>	Medang (Malaysia)	Malaysia	Unknown	Report of phototoxicity in leaf extracts.	[46]
Lythraceae	<i>Lawsonia inermis</i> (L.)		South Asia, Africa, Australia, South and Central America	Unknown	Report of phototoxicity in leaf extracts.	[46]
Malvaceae	<i>Hibiscus cannabinus</i> (L.)		South hemisphere, USA, Europe	Unknown	Report of phototoxicity in leaf extracts.	[46]
Malvaceae	<i>Malachra fasciata</i> Jacq. N.V.	Roadside leafbract	Oceania, Central and South America, including Brazil	Unknown	Unknown	[36,47]
Moraceae	<i>Artocarpus integrifolia</i> L.fil. = <i>Artocarpus integer</i> (Thunb.) Merr.		Africa, Europe, South America, including Brazil	Archangelicin, bergapten, citropten, jacalin	Furanocoumarins, coumarins, lectins	[109]

Moraceae	<i>Brosimum gaudichaudii</i> Trécul		South America, Brazil	Archangelicin, bergapten, citropten, marmesin, marmesinin	Furanocoumarins	[63,66,87,110]
Moraceae	<i>Fatoua pilosa</i>		China, Indonesia, New Zealand	Rutaretin	Coumarins	[111]
Moraceae	<i>Ficus carica</i> L.	Common fig	Worldwide, including Brazil	Angelicin, archangelicin, bergapten, bergaptol, citropten, isobergapten, isopimpinellin, sphondin. Report of unidentified phototoxic molecules in the Malaysian species <i>Ficus deltoidea</i> [46]	Furanocoumarins	[56,66,67]
Myrtaceae	<i>Eucalyptus globulus</i> Labill.	Eucalyptus	Worldwide, including Brazil	Eucalyptol, thymol	Monoterpenes, Phenols	[108]
Myrtaceae	<i>Myrciaria cauliflora</i> (Mart.) O.Berg	Jaboticaba	Americas, including Brazil	Anthocyanins, coumarins, flavonoids, phenolic acids,	Coumarins, phenols and flavonoids	[112,113]

Myrtaceae	<i>Syzygium aromaticum</i> (L.) Merr. & Perry = <i>Eugenia caryophyllata</i> Thunb.	Clove	Tropical rainforest, including Brazil	p-Hydroxybenzoic acid, resorcinol Eugenol, thymol	Phenols	[108]
Nartheceaceae	<i>Nartheceum ossifragum</i> (L.) Huds.	Asphodel	Europe	Episarsasapogenin, smilagenin, yamogenin	Saponins	[50,91,114]
Papaveraceae	<i>Chelidonium majus</i> L.	Celandine	Europe, Asia and South America, including Brazil	Alkaloidal protoberberine (BBR- F), berberine, chelerythrine, chelidonine, coptisine, jatorrhizine, protopine, sanguinarine, stylophine	Protoberberine Alkaloids	[47,115]
Papaveraceae	<i>Fumaria officinalis</i> L.		North hemisphere, Australia, New Zealand, South America,	Berberine		[68]

Pittosporaceae	<i>Pittosporum eugenoides</i> A.Cunn.	Lemonwood	including Brazil Australia, New Zealand, West of USA	Bergapten	Furanocoumarin	[47]
Pittosporaceae	<i>Pittosporum tenuifolium</i> Gaertn.	Kohuhu	Western Europe, West of USA	Bergapten	Furanocoumarin	[47]
Poaceae	<i>Avena sativa</i> L.	Oat	Europe, USA, Brazil	Unknown	Unknown	[54]
Poaceae	<i>Brachiaria brizantha</i> (A.Rich.) Stapf		Central and South Americas, including Brazil, Africa, Asia Pacific	Protodioscine	Saponins	[36,54,85,114,116,117]
Poaceae	<i>Brachiaria decumbens</i> = <i>Brachiaria eminii</i> (Mez) Robyns		Central and South Americas, including Brazil, Africa	Dichotomin, dioscin, diosgenin, protodioscine, soyasapogenin, soyasapogenol, steroid sapogenins 3-	Saponins	[36- 38,54,85,91,114,116,117 1]

				spirostanols, yamogenin		
Poaceae	<i>Brachiaria humidicola</i> (Rendle) Schweick. = <i>Brachiaria dictyoneura</i> (Fig. & De Not.) Stapf = <i>Urochloa humidicola</i> (Rendle) Morrone & Zuloaga		Central and South Americas, including Brazil, Africa	Protodioscine	Saponins	[36,54,85,114,116,117]
Poaceae	<i>Brachiaria ruziziensis</i> R.Germ & C.M.Evrard		South America, including Brazil, Africa	Unknown	Reports of Saponins	[36,85,117]
Poaceae	<i>Cynodon dactylon</i> (L.) Pers.	Bermuda grass	Worldwide	Unknown	Reports of Porphyrins and derivatives	[50]
Poaceae	<i>Echinochloa crus-galli</i> (L.) P.Beauv.	Cockspur	Worldwide, including Brazil	Unknown	Reports of Anthraquinones	[47]
Poaceae	<i>Echinochloa esculenta</i> (A.Braun) H.Scholz	Japanese barnyard millet	West Asia, USA, Europe, Oceania	Unknown	Reports of Anthraquinones	[47]

Poaceae	<i>Echinochloa frumentacea</i>	Indian barnyard millet	Australia, India, Europe, USA, Africa, rare in Brazil, Asia	Unknown	Reports of Anthraquinones	[47]
Poaceae	<i>Lolium perenne</i> L.	Perennial rye grass	Europe, Brazil	Perlolone	Alkaloid	[54,64]
Poaceae	<i>Panicum antidotale</i> Retz.	Blue panicum	Australia, USA, some occurrences in Europe	Diosgenin, epismilagenin, tamagenin	Saponins, steroidal sapogenins	[54]
Poaceae	<i>Panicum coloratum</i> L.	Coolah grass	Africa, U.S.A-Mexico border, one occurrence in Brazil	Diosgenin, epismilagenin, tamagenin	Saponins	[54,91]
Poaceae	<i>Panicum dichotomiflorum</i> Michx.	Millet	Americas (including Brazil), Europe, Korea, Japan, New Zealand	Dichotomin, diosgenin, epismilagenin, tamagenin	Saponins	[37,54,91]

Poaceae	<i>Panicum maximum</i> Jacq. = <i>Megathyrsus maximus</i> (Jacq.) B.K.Simon & S.W.L.Jacobs	Guinea grass	Americas, including Brazil, Africa, East Asia, Australia	Diosgenin, epismilagenin, tamagenin	Saponins, steroidal sapogenins	[54]
Poaceae	<i>Panicum miliaceum</i> L.	Millet	North hemisphere, Australia, reports in Brazil	Diosgenin, epismilagenin, tamagenin, yamogenin	Saponins, steroidal sapogenins	[54,114]
Poaceae	<i>Panicum virgatum</i> L.	Switch grass	USA, Europe, East Asia	Diosgenin, epismilagenin, tamagenin	Saponins, steroidal sapogenins	[54]
Poaceae	<i>Phyllostachys bambusoides</i> Siebold & Zucc.	Castillon bamboo	Africa, Asia, North and South America, including Brazil	20 ¹ -hydroxypurpurin- 7 delta-lactone ethyl methyl diester, hydroxypurpurin-7- lactone ethyl methyl diester, methyl phytyl diester	Porphyrins and derivatives	[47,72]
Polygonaceae	<i>Fagopyrum esculentum</i> Moench = <i>Fagopyrum sagittatum</i> Gilib.	Buckwheat	North hemisphere, Brazil, South of Africa,	Fagopyrin E, fagopyrin F, hypericin	Coumarins, naphthodianthrones	[38,50,52,54,64]

			Australia, New Zealand			
Polygonaceae	<i>Fagopyrum tataricum</i> (L.) Gaertn	Tartarian buckwheat	North hemisphere	Fagopyrin E, fagopyrin F, hypericin	Furanocoumarins, naphthodianthrones	[47,50,54,64]
Polygonaceae	<i>Rheum palmatum</i> L.		South-East Oceania, Europe, China, USA	Anthraquinones	Anthraquinones	[47]
Polygonaceae	<i>Rumex hymenosepalus</i> , <i>Rumex sp.</i>		North America, arid and semi-arid regions	Emodine	Anthraquinone	[118,119]
Primulaceae	<i>Myrsine coriacea</i> Merr.		Vietnam	Myrsine coriacea Lectin (McL)	Lectin	[109]
Ranunculaceae	<i>Helleborus niger</i> L.	Christmas rose	Europe, USA	Berberine	Isoquinoline alkaloid	[47,60]
Rhamnaceae	<i>Rhamnus frangula</i>	buckthorn or alder buckthorn	Europe, North Africa, and western Asia	Anthraquinones including physcione (=parietin=rheochrysi	Anthraquinones	[120]

Rubiaceae	<i>Cinchona spp.</i>		Tropical regions of South America	Quinine din), chrysophanol and emodine	Alkaloid	[121]
Rubiaceae	<i>Galium odoratum</i> (L.) Scop.	Asperula odorata (FR)	North hemisphere	Anthraquinone, berberine, rubiadin, rubiadin-1-methyl ether,	Anthraquinones, coumarins, furanocoumarins	[33]
Rubiaceae	<i>Genipa americana</i> L.	Genip	Central and South America, including Brazil	Anthraquinone, berberine, rubiadin, rubiadin-1-methyl ether,	Anthraquinones	[87]
Rubiaceae	<i>Heterophyllaea lycioides</i> (Rusby) Sandwith		West of South America	5,5'-bisoranjidiol, 5-chlorosoranjidiol, 7-chlorobisoranjidiol, anthraquinone, berberine lycionine, pustuline, rubiadin,	Anthraquinones	[47,50,51,122]

				rubiadin-1-methyl ether, soranjidiol		
Rubiaceae	<i>Heterophyllaea pustulata</i> Hook. f.	Cegadera	Argentina	2-hydroxy-3-methyl anthraquinone, 5,5'-bisoranjidiol, anthraquinone, berberine, damnacanthal, damnacanthol, heterophyllin, pustuline, rubiadin-1-methyl ether, rubiadin, soranjidiol, soranjidiol-1-methyl ether	Anthraquinones	[47,51,54,122-129]
Rubiaceae	<i>Rubia cordifolia</i> L.		Africa, Asia	Anthraquinone, berberine, rubiadin, rubiadin-1-methyl ether,	Anthraquinones	[68]
Rubiaceae	<i>Rubia yunnanensis</i> Diels		China	Anthraquinone, berberine rubiadin,	Anthraquinones	[130]

Rubiaceae	<i>Sherardia arvensis</i> L.	Blue field-madder	North America, Europe, West coast of South America, Australia, New Zealand	rubiadin-1-methyl ether Anthraquinone, berberine, rubiadin, rubiadin-1-methyl ether, rubiadin, soranjidiol	Anthraquinones	[50]
Rutaceae	<i>Atalantia racemosa</i>		India	Rutaretin	Coumarins	[131]
Rutaceae	<i>Boenninghausenia albiflora</i>		Himalaya, China, Japan, Indonesia and South-east Asia	Suberenone	Coumarins	[132]
Rutaceae	<i>Citrus × limon</i> (L.) Burm.fil. = <i>Citrus × bergamia</i> Risso	Lemon	Worldwide, including Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, citropten,	Alkaloids, furanocoumarins	[56,66,67,110,133]

Rutaceae	<i>Citrus limetta</i> Risso = <i>Citrus medica</i> L.	Mousami / sweet lemon	South America, including Brazil	isobergaptin, isopimpinellin, methoxsalen, sphondin 7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergaptin, bergaptol, isobergaptin,, methoxsalen, sphondin	Alkaloids, furanocoumarins	[67,133]
Rutaceae	<i>Citrus x aurantifolia</i> (Christm.) Swingle <i>Citrus hystrix</i>	Lime	South hemisphere, including Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergaptin, bergaptol, citropten, isobergaptin, isopimpinellin, methoxsalen, sphondin, xanthotoxin	Alkaloids, furanocoumarins	[46,56,66,67,110,133]

Rutaceae	<i>Citrus maximus</i> = <i>Citrus grandis</i>		Americas, Africa, western Europe, India, China, South-east Asia, Australia and Oceania	Suberenone	Coumarin	[134]
Rutaceae	<i>Citrus x paradisi</i> Macfad.	Grapefruit / Pomelo	Americas, including Brazil, East Asia, Europe	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, citropten, isobergapten, isopimpinellin, methoxsalen, sphondin	Alkaloids, furanocoumarins	[67,84,133]
Rutaceae	<i>Citrus x sinensis</i> (Mill.) Pers., 1806 = <i>Citrus x aurantium</i> L.	Sweet orange / blood orange	Western Africa, Western Europe, Central America and South	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, citropten, isobergapten,	Alkaloids, furanocoumarins	[67,110,133]

Rutaceae	<i>Clausena anisata</i> (Willd.) Hook.fil., De Wild. & Staner	Horsewood	America, including Brazil Central and South of Africa, Sino- Indian coastline	isopimpinellin, methoxsalen, sphondin 7-Methoxycoumarin, anthranilic acid, archangelicin, bergapten, citropten, imperatorin, methoxsalen,oxypeuc edanin	Alkaloids, furanocoumarins	[66,133]
Rutaceae	<i>Dictamnus albus</i> L.	Burning bush	Europe, USA, Asia	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, citropten, isobergapten, methoxsalen, sphondin	Alkaloids, furanocoumarins	[67,133]
Rutaceae	<i>Glycosmis pentaphylla</i>	orangeberry, gin berry	South-east Asia, North of Australia	Glycoborinine, p-coumaroyltyramine	Carbazole alkaloids (betacarbolines)	[135]
Rutaceae	<i>Micromelum minutum</i>	Cemumar hitam (Malaysia)	Malaysia, Indonesia, Australia	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin,	Alkaloids, furanocoumarins	[46]

Rutaceae	<i>Pelea anisata</i> H. Mann. = <i>Melicope anisata</i> (H.Mann) T.G.Hartley & B.C.Stone	Mokihana	Hawaii	berberine, bergapten, bergaptol, citropten, isobergapten, isopimpinellin, methoxsalen, sphondin, xanthotoxin 7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, citropten, isobergapten, methoxsalen, sphondin	Alkaloids, furanocoumarins	[67,133]
Rutaceae	<i>Ruta angustifolia</i> Pers.		Europe	7-Methoxycoumarin, anthranilic acid, archangelicin, bergapten, citropten, methoxsalen, rutamarin	Alkaloids, furanocoumarins	[136]
Rutaceae	<i>Ruta chalepensis</i> L.	Fringed rue	Europe, Central America, South	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin,	Alkaloids, furanocoumarins, coumarins	[67,133,136]

			America, a few in Brazil	berberine, bergapten, bergaptol, citropten, isobergapten, methoxsalen, sphondin, rutacultin		
Rutaceae	<i>Ruta graveolens</i> L.	Rue, common rue, herb-of-grace	Eurasia, South America, including Brazil	7-Methoxycoumarin, 8-Methoxypsoralen, angelicin, anthranilic acid, archangelicin, berberine, bergapten, bergaptol, chalepentin, citropten, isobergapten, isopimpinellin, isoimperatorin, isorutarin, marmesin, methoxsalen, rutamarin, sphondin, xanthotoxin, gravelliferone, rutacultin, suberenone, rutaretin	Alkaloids, furanocoumarins, coumarins	[50,66,67,74,133,136-139]
Rutaceae	<i>Ruta montana</i> (L.) L.		Europe, Mediterranean basin	7-Methoxycoumarin, anthranilic acid, archangelicin,	Alkaloids, furanocoumarins	[136]

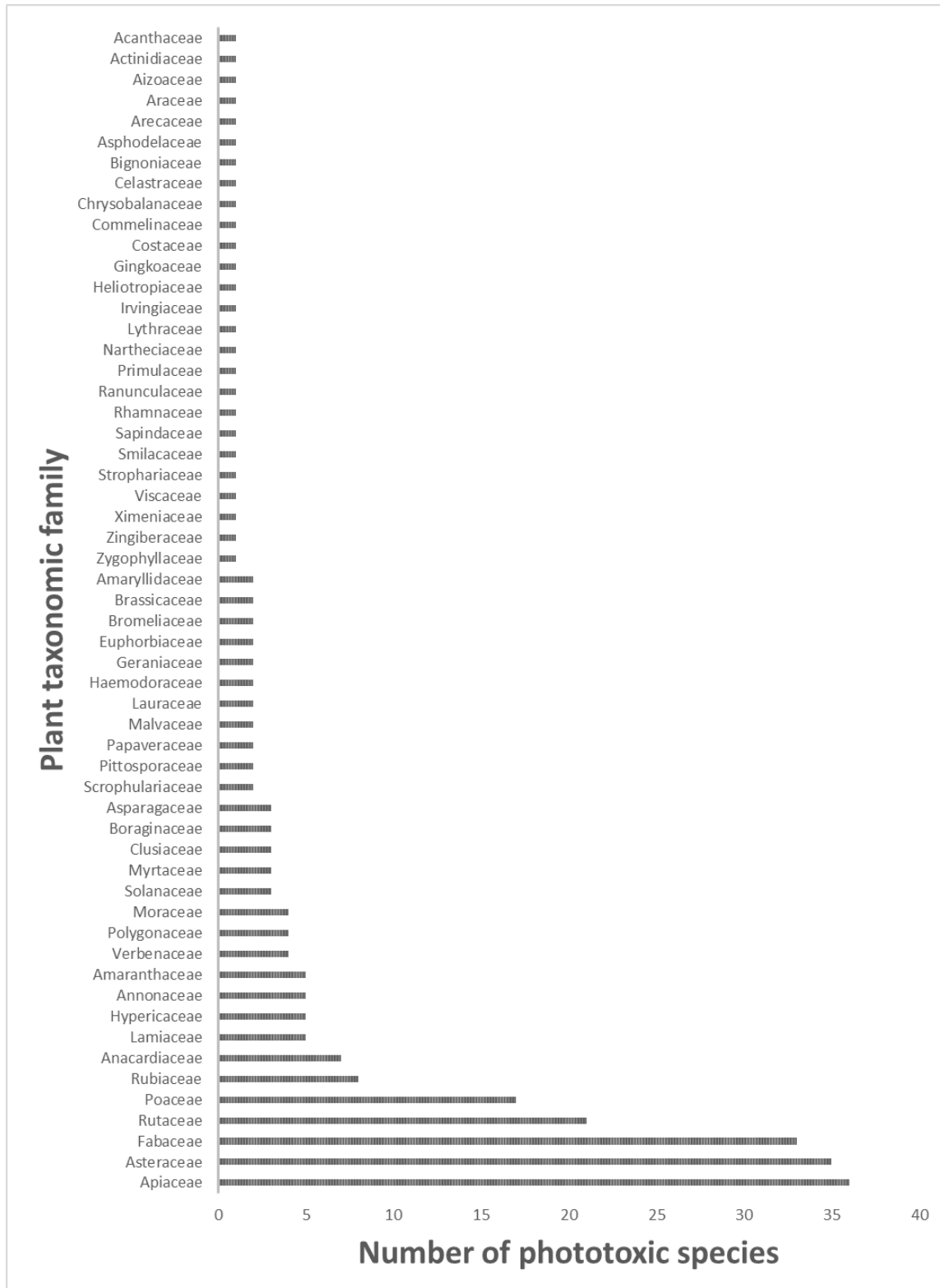
Rutaceae	<i>Ruta pinnata L.fil.</i>		Spain	bergapten, citropten, methoxsalen, sphondin	Alkaloids, furanocoumarins	[66]
Rutaceae	<i>Thamnosma montana</i> Torr. & Frem	Mojave desert rue	West of USA	7-Methoxycoumarin, 8-Methoxypsoralen, anthranilic acid, archangelicin, bergapten, citropten, methoxsalen	Alkaloids, furanocoumarins	[50,133]
Rutaceae	<i>Thamnosma texana</i> (Gray) Torr.	Dutchman's breeche	USA: Arizona (Hualapai Mountains) to Texas and N. Mexico.	7-Methoxycoumarin, 8-Methoxypsoralen, alloimperatorin, alloimperatorin methyl ether epoxide, anthranilic acid, archangelicin, berberine, bergapten, citraopten, heraclenin,	Alkaloids, furanocoumarins	[47,50,52,54,64,66,133,1 40]

				herniarin, imperatorin, isopimpinellin, methoxsalen, osthol, oxypeucedanin, thamnosmin, xanthotoxin		
Sapindaceae	<i>Talisia esculenta</i> (A.St.-Hil.) Radlk.	Pitomba	Brazil	Unknown	Unknown	[87]
Scrophulariaceae	<i>Myoporum laetum</i> G. Forst. And <i>Myoporum tenuifolium</i>	New Zealand manatoka	American and European coastlines, Brazil, New Zealand	Ngaione	Furanosesquiterpenoids	[38,50]
Smilacaceae	<i>Smilax ornata</i> Lem.		Central America, brazil	Smilagenin	Saponin	[141]
Solanaceae	<i>Lycopersicon esculentum</i> Mill. = <i>Solanum lycopersicum</i> L.	Tomato	Worldwide	Bergapten	Furanocoumarin	[50]
Solanaceae	<i>Solanum betaceum</i> Cav.	Tamarillo	Worldwide	Unknown	Reports of Anthocyanes, carotenoids, chlorophylls	[142]

Solanaceae	<i>Solanum melongena</i> L.	Eggplant	Worldwide, including Brazil	Nasunin	Anthocyanes	[143]
Strophariaceae	<i>Agrocybe aegerita</i> (V.Brig.) Singer = <i>Cyclocybe aegerita</i> (V.Brig.) Vizzini		USA, Europe	<i>Agrocybe aegerita</i> Lectin	Lectin	[109]
Verbenaceae	<i>Lantana camara</i> L.	Common lantana	Worldwide	Lantadenes	Lantadenes triterpenoids	[36,38,50,52,54]
Verbenaceae	<i>Peronema canescens</i>	Sungkai (Malaysia)	Malaysia	Unknown	Report of phototoxic molecules in leaf.	[46]
Verbenaceae	<i>Premna odorata</i>	Bebuas (Malaysia)	South-east Asia	Unknown	Report of phototoxic molecules in leaf.	[46]
Verbenaceae	<i>Verbena officinalis</i> L.	Vervain	Worldwide	Unknown	Report of Porphyrins and derivatives	[50]
Viscaceae	<i>Viscum album</i> L.	Mistletoe	Eurasia, North America	Mistletoe (<i>Viscum album</i>) Lectin (ML)	Lectin	[109]
Ximeniaceae	<i>Ximenia americana</i> L.	Tallow wood	South hemisphere, including Brazil	Riproximin	Lectin	[109]

Zingiberaceae	<i>Curcuma longa</i> L.	Curcuma	Tropical belt, including Brazil	Curcumin	Polyphenol	[41,47,144–147]
Zygophyllaceae	<i>Tribulus terrestris</i> L.	Tribulus	Worldwide	Diosgenin, Epi- sarsasapogenin	Saponins	[50,52,91,114]

408 Table 1. Phototoxic plants of the world, listed in alphabetical order of their taxonomic family.
 409 All species were catalogued with their taxonomy, location, vernacular name and, when known,
 410 the nature and structure of their phototoxic molecule(s). In several phototoxic plants, the
 411 molecule(s) responsible for the activity are still unidentified (Unknown).



412

413 Figure 2. Number and distribution of phototoxic plant species in the plant taxonomic families.

414

415 7.2. Inventory of phototoxic molecules

416 In a second step, a detailed search of phototoxic molecules was performed, providing the

417 complete updated list of phototoxic phytochemicals synthesized by terrestrial plants (Table 2.).

418 For each molecule, we reviewed all papers discussing its phototoxic activity, chemical

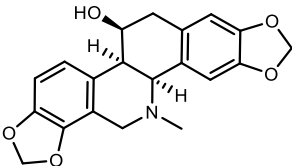
419 structure, chemical family, presence in different plant families or species, location in the

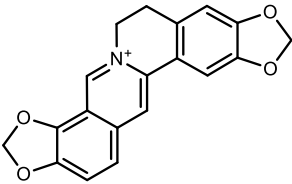
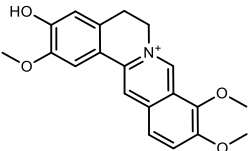
420 different plant tissues and organs, biogeographical location of the producer species in the

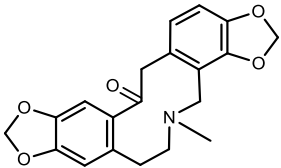
421 world, as well as a list of relevant references evidencing the phototoxic activity of the

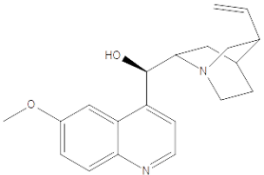
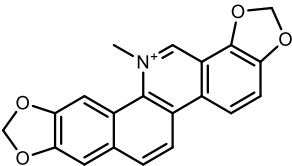
422 compound in *in vitro* or *in vivo* models. (Table 2.). For well-studied molecules, singlet-oxygen

423 yields can be found in a previous report ^[148].

Chemical Family and Photosensitization type	Molecule	Chemical structure	Producer plant(s)	Biogeographical zone of the plant(s)	Plant tissue location	Biological activity and photophysical characteristics	References
Type I Photosensitization							
Alkaloid Type I	(+)-Chelidonine (C ₂₀ H ₁₉ NO ₅)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)	Europe, Asia and South America, including Brazil	Sap, stem and bark	Pro-apoptotic in uterine cancer cells. λ_{\max} ~278 nm depending on solvent	[115]

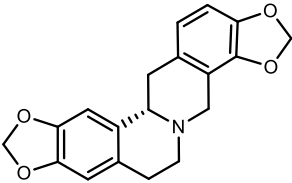
Alkaloid Type I	Coptisine (C ₁₉ H ₁₄ NO ₄ ⁺)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)	Europe, Asia and South America, including Brazil	Sap, stem and bark	Same comment as (+)- Chelidonine $\lambda_{\text{max}} \sim 325$ nm depending on solvent	[115]
Alkaloid Type I	Jatrorrhizine (C ₂₀ H ₂₀ NO ₄ ⁺)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)	Europe, Asia and South America, including Brazil	Sap, stem, bark	Same comment as (+)- Chelidonine. <i>Chelidonium majus</i> L. is rich in numerous biologically active compounds, like protoberberine	[115]

						alkaloids (e.g., berberine, coptisine, protopine, stylophine, jatrorrhizine), flavonoids, phenolic acids, saponins and defense-related proteins	
Alkaloid Type I	Protopine (C ₂₀ H ₁₉ NO ₅)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)	Europe, Asia and South America, including Brazil	Sap, stem, bark	Same comment as (+)- Chelidoneine λ_{max} ~308 nm depending on solvent	[115]

Alkaloid Type I	Quinine (C ₂₀ H ₂₄ N ₂ O ₂)		a) <i>Cinchona spp.</i> (Rubiaceae)	a) tropical regions of South America	Bark	λ _{max} ~345 nm depending on solvent	[121]
Alkaloid Type I	Sanguinarine (C ₂₀ H ₁₄ NO ₄ ⁺)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)	Europe, Asia and South America, including Brazil	Sap, stem, bark	Same comment as (+)- Chelidonine λ _{max} ~290-310 nm depending on solvent	[115]

Alkaloid
Type I

Stylophine
(C₁₉H₁₇NO₄)



Chelidonium majus L. (Celandine) -
(Papaveraceae)

Europe, Asia and
South America,
including Brazil

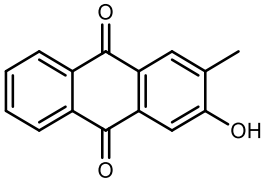
Sap, stem, bark

Same comment
as (+)-
Chelidonine.

[115]

Anthraquinone
Type I

2-Hydroxy-3 methyl
anthraquinone
(C₁₅H₁₀O₄)



Heterophyllaea pustulata Hook. f.
(Cegadera) - (Rubiaceae)

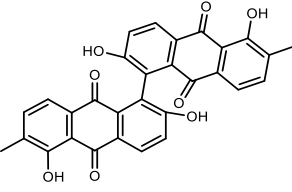
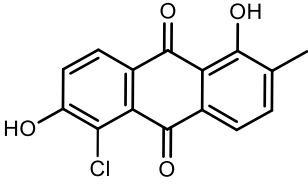
Argentina (Jujuy,
Salta and Tucuman
provinces)

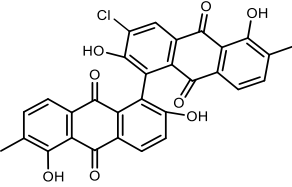
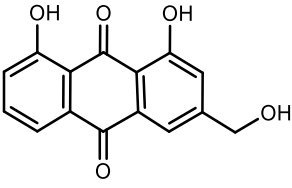
Leaves and stems

Indicated in
breast and
colorectal
cancer
phototherapy.

λ_{max}~ 430-440
nm depending
on solvent

[47]

Anthraquinone Type I	5,5'-bisoranjidiol (C ₃₀ H ₁₈ O ₈)		a) <i>Heterophyllaea pustulata</i> Hook. f. (Cegadera) - (Rubiaceae) ^[122,125-127] b) <i>Heterophyllaea lycioides</i> (Rusby) Sandwith - (Rubiaceae) ^[122]	a) Argentina (Jujuy, Salta and Tucuman provinces) b) West of South America	Antibacterial phototoxicity on <i>S.aureus</i> ^[122,125-127]
Anthraquinone Type I	5-Chloro-soranjidiol (C ₁₅ H ₉ ClO ₄)		<i>Heterophyllaea lycioides</i> (Rusby) Sandwith - (Rubiaceae)	West of South America	Aerial parts Anthraquinone derivatives similar to those found in <i>H.pustulata</i> , but <i>H.lycioides</i> contains rare chlorinated derivatives such as 7- chlorobisoranji diol and 5-

Anthraquinone Type I	7-Chloro bis soranjidiol (C ₃₀ H ₁₇ ClO ₈)		<i>Heterophyllaea lycioides</i> (Rusby) Sandwith - (Rubiaceae) ^[122]	West of South America	Aerial parts	Same anthraquinones derivatives as found in <i>H.</i> <i>pustulata</i> .	[122]
Anthraquinone Type I	Aloe-emodin (C ₁₅ H ₁₀ O ₅)		<i>Aloe vera</i> (L.) Burm. f. (<i>Aloe vera</i>) - (Asphodelaceae) ^[47]	Worldwide, including Brazil	Roots and Leaves	Used as a photosensitizer ^[47] Some non- PS natural products may potentiate phototoxicity including indole-3-acetic acid, carvacrol, β-glucans, and	[47,67,106,129]

ascorbic acid.

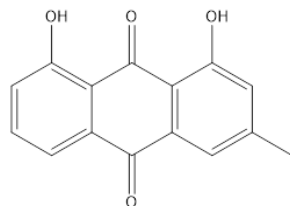
[106]

$\lambda_{\text{max}} \sim 430 \text{ nm}$
depending on
solvent

Anthraquinone

Chrysophanol

($\text{C}_{15}\text{H}_{10}\text{O}_4$)



Rhamnus frangula [120]

(Rhamnaceae)

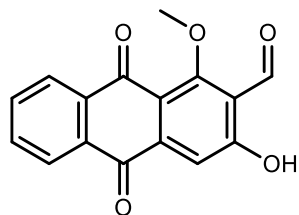
Europe, North
Africa, and western
Asia

$\lambda_{\text{max}} \sim 430\text{-}440$
nm depending
on solvent

[120]

Anthraquinone

Damnacanthal



Heterophyllaea pustulata Hook. f.

(Cegadera) - (Rubiaceae)

[50,51,123,125-127]

Argentina

Phototoxic on [50,51,123,125-127]

S.aureus

λ_{\max} ~530 nm

depending on

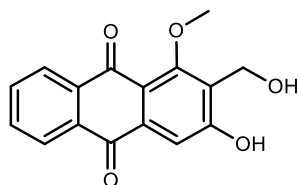
solvent

Type I

(C₁₆H₁₀O₅)

Anthraquinone

Damnacanthol



Heterophyllaea pustulata Hook. f.

(Cegadera) - (Rubiaceae)

[50,51,123,125-127]

Argentina

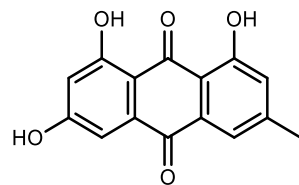
[50,51,123,125-127]

Type I

(C₁₆H₁₂O₅)

Anthraquinone

Emodin = Archin



a) *Aloe vera* (L.) Burm. f. (Aloe vera) - (Asphodelaceae) ^[67]

a) Worldwide, including Brazil

b) Latex

λ_{max} ~430 nm depending on solvent

^[67]

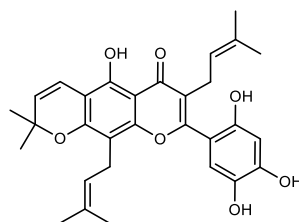
b) *Rheum spp.* (Rhubarb) - (Polygonaceae) ^[67]

c) *Rhamnus spp.* (Buckthorns) (Rhamnaceae) ^[67]

d) *Rumex sp.* (Polygonaceae) ^[118,149]

Anthraquinone

Heterophyllin



Heterophyllaea pustulata Hook. f. (Cegadera) - (Rubiaceae) ^[123,125,126]

Argentina

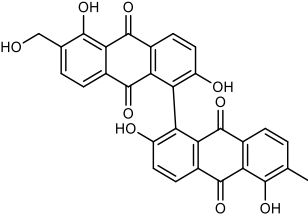
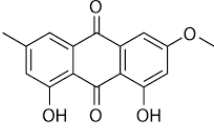
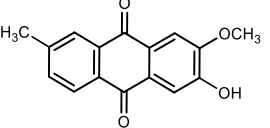
^[123,125,126]

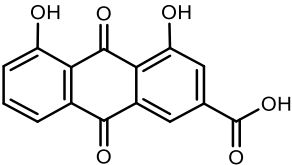
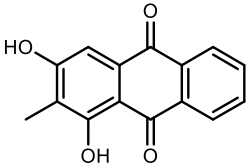
Type I

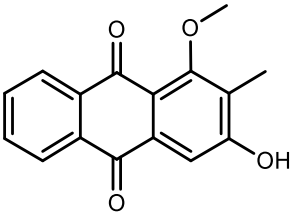
(C₁₅H₁₀O₅)

Type I

(C₂₂H₂₆N₂O₄)

Anthraquinone Type I	Lycionine (C ₃₀ H ₁₈ O ₉)		<i>Heterophyllaea lycioides</i> (Rusby) Sandwith - (Rubiaceae) ^[122]	West of South America	Aerial parts	See comment for 5-chloro- soranjidiol	^[122]
Anthraquinone Type I	Physcion=Physcione= parietin=rheochrysidin (C ₁ H ₁₂ O ₅)		<i>Rhamnus frangula</i> ^[120]	Europe, North Africa, and western Asia		λ _{max} ~365 nm depending on solvent	^[120]
Anthraquinone Type I	Pustuline (C ₁₆ H ₁₂ O ₄)		a) <i>Heterophyllaea pustulata</i> Hook. f. (Cegadera) - (Rubiaceae) ^[51,122,125,126] b) <i>Heterophyllaea lycioides</i> (Rusby) Sandwith - (Rubiaceae) ^[51,122]	a) Argentina b) West of South America			^[51,122,125,126]

Anthraquinone Type I	Rhein (C ₁₅ H ₈ O ₆)		<i>Rheum spp.</i> - (Polygonaceae) ^[67] (Rhubarb) - (Polygonaceae) ^[67] a) <i>Aloe vera</i> (L.) Burm. f. (<i>Aloe vera</i>) - (Asphodelaceae) ^[67]	a) Worldwide, including Brazil	a) Latex	$\lambda_{\text{max}} \sim 430\text{-}450$ nm depending on solvent ^[67]
			<i>Rhamnus spp.</i> - (Rhamnaceae) ^[67] b) (Nerprun) - (Rhamnaceae) ^[67]			
Anthraquinone Type I	Rubiadin (C ₁₅ H ₁₀ O ₄)		(Rubiaceae) ^[50] a) <i>Heterophyllaea pustulata</i> Hook. f. (<i>Cegadera</i>) - (Rubiaceae) ^[47,50,51,123-129] b) <i>Alternanthera philoxeroides</i> (Mart.) Griseb. (alligator weed) - (Amaranthaceae) ^[47,50]	a) Argentina b) USA, South America (coastal), France and East Asia c) North America, Europe, West coast of South America,	a) stem, leaves	Antibacterial ^[47,50,51,123-129] The phototoxic anthraquinones soranjidiol (red) and rubiadin (yellow) have absorption maxima at the

				Australia, New Zealand		interface of the UV-C and UV-B (~280 nm) and at 410–420 nm (visible light) ^[50]
			<i>Galium spp.</i> - (Rubiaceae) ^[50]			
			<i>Coprosma spp.</i> - (Rubiaceae) ^[50]			
			c) <i>Sherardia arvensis</i> - (Rubiaceae) ^[50]			
Anthraquinone Type I	Rubiadin-1-methyl ether (C ₁₆ H ₁₂ O ₄)		(Rubiaceae) ^[50] a) <i>Heterophyllaea pustulata</i> Hook. f. (Cegadera) - (Rubiaceae) ^[47,50,51,123–129] b) <i>Alternanthera philoxeroides</i> (Mart.) Griseb. (alligator weed) - (Amaranthaceae) ^[47,50]	a) Argentina b) USA, South America (coastal), France and East Asia c) North America, Europe, West coast of South America,	a) Stem, leaves	Phototoxicity ^[47,50,51,123–129] demonstrated in human breast cancer cells ^[47,50] λ_{max} ~ 530-540 nm depending on solvent

Galium spp. - (Rubiaceae) ^[50]

Australia, New
Zealand

Coprosma spp. - (Rubiaceae) ^[50]

c) *Sherardia arvensis* - (Rubiaceae)

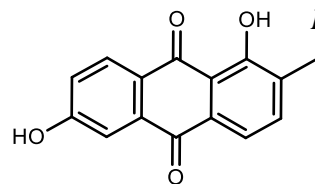
^[50]

Anthraquinone

Soranjidiol

Type I

(C₁₅H₁₀O₄)



Heterophyllaea spp. - (Rubiaceae) ^[50]

a) West of South
America

Stem, leaves

Antibacterial ^[50,51,122-129]

a) *Heterophyllaea lycioides* (Rusby)

Sandwith - (Rubiaceae) ^[50]

b) Argentina

Rubiadin is
identified as a
promising
photosensitizer

b) *Heterophyllaea pustulata* Hook. f.

(Cegadera) - (Rubiaceae) ^[50,51,122-129]

c) North America,
Europe, West coast
of South America,

Galium spp. - (Rubiaceae) ^[50]

Australia, New

Coprosma spp. - (Rubiaceae) ^[50]

Zealand

c) *Sherardia arvensis* L. -

(Rubiaceae) ^[50]

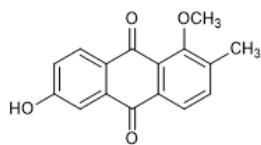
Anthraquinone

Type I

Soranjidiol-1-methyl

ether

(C₁₆H₁₂O₄)



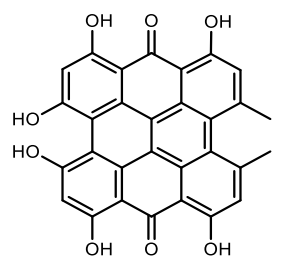
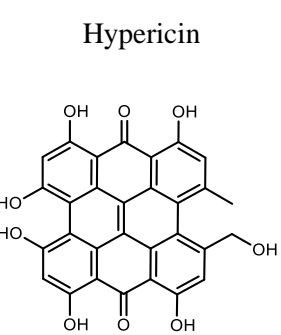
Heterophyllaea pustulata Hook.
f.(Cegadera) - (Rubiaceae) [50,51,122-
129]

Argentina

High
antiproliferativ
e activity *in*
vitro in human
breast cancer
cells

Phototoxic on
HSV-1 herpes
virus

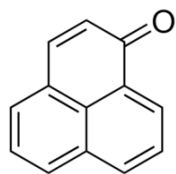
[50,51,122-129]

<p>Anthraquinone derivatives = naphthodianthrones =</p>	<p>Hypericin (C₃₀H₁₆O₈) and Pseudohypericin (C₃₀H₁₆O₉)</p>		<p><i>Hypericum spp.</i> - (Hypericaceae) ^[67] a) <i>Hypericum perforatum</i> L. (St John's wort) - (Hypericaceae) ^[41,47,50,54,64,67,103,105,146]</p>	<p>a) Worldwide, including Brazil (Mostly North hemisphere)</p>	<p>a) Pistils, fruits, stems Hypericin has absorption maxima at 236 and 592 nm ^[50]</p>
<p>Perylenequinones Type I</p>	<p>Hypericin Pseudohypericin</p>		<p>b) <i>Hypericum triquetrifolium</i> Turra - (Hypericaceae) ^[50] c) <i>Hypericum maculatum</i> Crantz - (Hypericaceae) ^[50] d) <i>Hypericum pseudomaculatum</i> Bush (False spotted St. John's wort) - (Hypericaceae) ^[54,64] e) <i>Hypericum punctatum</i> Lam. - (Hypericaceae) ^[54,54] f) <i>Fagopyrum esculentum</i> Moench - (Polygonaceae) ^[50,54] g) <i>Fagopyrum sagittatum</i> - (Polygonaceae) ^[54]</p>	<p>b) Mediterranean basin c) Eurasia d) USA e) USA f) North hemisphere, Brazil, South of Africa, Australia, New Zealand g) Balkans, Japan, Korea, USA h) North hemisphere</p>	<p>^[54] causes severe phototoxicity in grazing animals exposed to visible light (500 – 600 nm).</p>

h) *Fagopyrum tataricum* (L.) Gaertn
(Tartary buckwheat) -
(Polygonaceae) ^[47,50,54]

Aromatic ketone
(fused benzene and
naphthalene ring)

Phenalenone
(C₁₃H₈O)



Haemodorum distichophyllum
(Hook.)

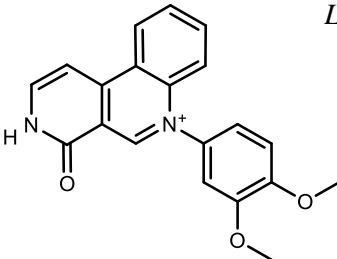
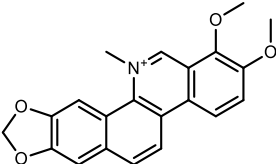
Australia, Tasmania

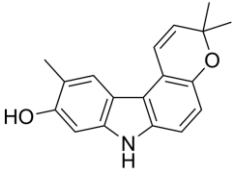
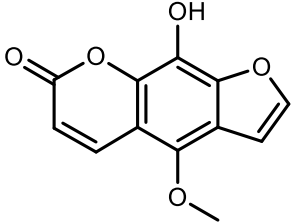
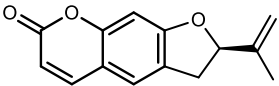
High
production
yield of singlet
oxygen

[99,100]

Type I

λ_{\max} ~ 240-260
nm and 330-
430 nm
depending on
solvent

<p>Benzo naphthyridinone alkaloid</p> <p>Type I</p>	<p>Perloline</p> <p>(C₂₀H₁₇N₂O₃⁺)</p>		<p><i>Lolium perenne</i> L. (Perennial rye grass) - (Poaceae)</p>	<p>Europe, Brazil</p>	<p>[54]</p> <p>[54,64]</p> <p>[64] Primary Photosensitizati on in horses</p>
<p>Benzophenanthridin e Alkaloid</p> <p>Type I</p>	<p>Chelerythrine</p> <p>(C₂₁H₁₈NO₄⁺)</p>		<p><i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae)</p>	<p>Europe, Asia and South America, including Brazil</p>	<p>Sap, stem and bark</p> <p>Pro-apoptotic in uterine cancer cells.</p> <p>[115]</p> <p>λ_{max}~342 nm depending on solvent</p>

Carbazole alkaloid	Glycoborinine		<i>Glycosmis pentaphylla</i> (Rutaceae)	South-east Asia, North of Australia	[135]
Type I	(C ₁₈ H ₁₇ NO ₂)				
Coumarin	7-Methoxycoumarin = herniarin		(Umbelliferae) ^[110] (Apiaceae) ^[110] (Rutaceae) ^[110]		^[110] λ _{max} ~ 330-340 nm depending on solvent
Type I	(C ₁₀ H ₈ O ₃)		<i>Thamnosma texana</i> (Gray) Torr. (Dutchman's breeche) - (Rutaceae) ^[140]		^[110,140]
Coumarin	Ammirin		<i>Ammi majus</i> L. (Bishop's weed) - (Apiaceae) ^[47,50]	Southern Europe, Northern and	Highly phototoxic ^[47,50]
Type I					

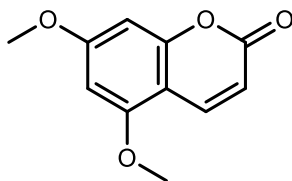
(C₁₄H₁₂O₃)

Western Africa,
Central Asia, Brazil

λ_{max}: 248, 260
and 302 nm
depending on
solvent

Coumarin
Type I

Citropten = 5,7-
dimethoxycoumarin =
Limettin



(Rutaceae) ^[56]

a) *Citrus x sinensis* (Mill.) Pers.,
1806 = *Citrus x aurantium* L.
(Orange) - (Rutaceae) ^[110]

b) *Citrus x aurantifolia* (Christm.)
Swingle (Lime) - (Rutaceae) ^[56]

c) *Citrus x limon* (L.) Burm.fil. =
Citrus x bergamia Risso (Lemon) -
(Rutaceae) ^[56]

d) *Citrus x paradisi* Macfad.
(Grapefruit / Pomelo) - (Rutaceae)

^[56]

(Moraceae) ^[56]

a) Western Africa,
Western Europe,
Central America and
South America,
including Brazil

/

Same comment
as for 7-
methoxycouma
rin

^[56,110]

b) South hemisphere,
including Brazil
c) Worldwide,
including Brazil
d) Americas,
including Brazil, East

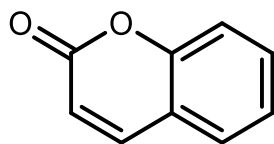
λ_{max}~ 360-365
nm depending
on solvent

e) *Ficus carica* L. (Common fig) -
(Moraceae) ^[56]

e) Worldwide,
including Brazil

Coumarin
Type I

Coumarin
(C₁₉H₁₈O₅)



Myrciaria cauliflora (Mart.) O.Berg
(Jaboticaba) - (Myrtaceae) ^[112]

Americas, including
Brazil

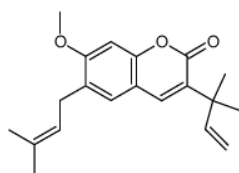
Fruits

λ_{\max} ~ 315-340
nm depending
on solvent

^[112]

Coumarin

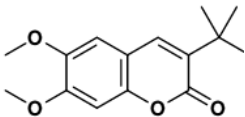
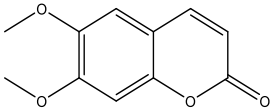
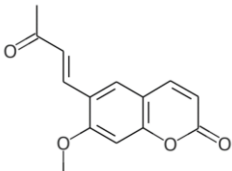
Gravelliferone (and
methyl ester)
(C₁₉H₂₂O₃)

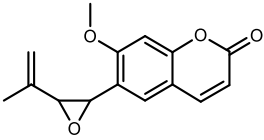
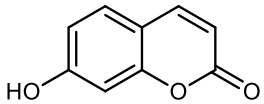


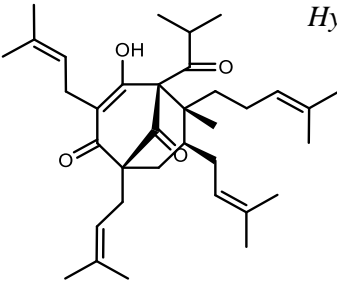
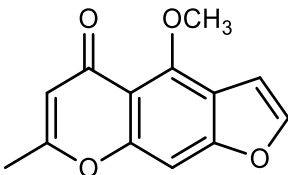
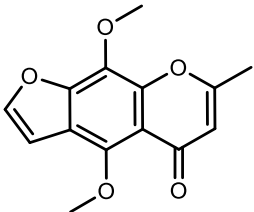
Ruta graveolens L. (Roa) -
(Rutaceae)

Eurasia, South
America, including
Brazil

^[151]

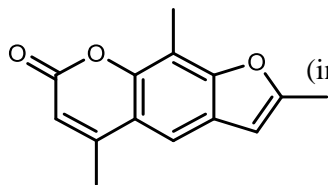
Coumarin	Rutacultin (C ₁₆ H ₁₈ O ₄)		<i>Ruta graveolens</i> L. (Rua) - (Rutaceae), <i>Ruta chalepensis</i> (Rutaceae) <i>Helietta apiculata</i> (Rutaceae)	Eurasia, South America, including Brazil	Roots	[151]
Coumarin Type I	Scoparone (=6,7- Dimethoxycoumarin) (C ₁₁ H ₁₀ O ₄)		<i>Artemisia scopariae</i> (virgate wormwood, capillary wormwood or redstem wormwood, yīn chén in Mandarin Chinese) (Asteraceae)	Eurasia		λ _{max} ~ 300-330 nm depending on solvent [152]
Coumarin	Suberenone (C ₁₄ H ₁₂ O ₄)		<i>Ruta graveolens</i> L. (Rua) (Rutaceae) also present in <i>Citrus maxima</i> (<i>Burm.</i>) Merr. = <i>Citrus grandis</i> (L.) <i>Osbeck</i> (Rutaceae)	Eurasia, South America, including Brazil Central and South America, including Brazil, India,		[153] Several minor related coumarins have been reported in the roots of <i>Ruta pinnata</i> [154]. These

			and <i>Boenninghausenia albiflora</i> (Rutaceae)	Himalaya, China and South-east Asia		include Gravelliferone methyl ether, xanthyletin, furopinnarin, pinnarin, benahorin, limettin, luvangetin, bergapten and sabandinin.
Coumarin Type I	Thamnosmin (C ₁₅ H ₁₄ O ₄)		<i>Thamnosma texana</i> (Gray) Torr. (Dutchman's breeche) - (Rutaceae) [140]	Arizona (Hualapai Mountains) to Texas and N. Mexico.	$\lambda_{\text{max}} \sim 300\text{-}330 \text{ nm}$ depending on solvent	[140]
Coumarin Type I	Umbelliferone = 7- hydroxycoumarin (C ₉ H ₆ O ₃)		(Apiaceae) [66]		$\lambda_{\text{max}} \sim 300\text{-}330 \text{ nm}$ depending on solvent	[66]

Cyclic terpene ketone Type I	Hyperforin (C ₃₅ H ₅₂ O ₄)		<i>Hypericum perforatum</i> L. (St John's wort) - (Hypericaceae) ^[155]	Worldwide, including Brazil (Mostly North hemisphere)	Pistils, fruits, stems	Plant defense molecule $\lambda_{\text{max}} \sim 272\text{-}274$ nm depending on solvent	[155]
Furanochromone Type I	Visnagin (C ₁₃ H ₁₀ O ₄)		<i>Ammi visnaga</i> (L.) Lam (Khella) - (Apiaceae) ^[69,70]	Argentina, Europe, Mediterranean basin	Seeds	$\lambda_{\text{max}} \sim 315\text{-}334$ nm depending on solvent	[69,70]
Furanochromone (=Furochromone) Type I	Khellin (C ₁₄ H ₁₂ O ₅)		<i>Ammi visnaga</i> (L.) Lam (Khella) - (Apiaceae) ^[69,71]	Argentina, Europe, Mediterranean basin	Seeds	Antifungal, antibacterial and antiviral activity. Khellin could be useful as a PS against psoriasis and	[69-71]

Furanocoumarin
(=Furocoumarin
= Psoralen)

4,5',8-
Trimethylpsoralen =
Trioxsalen



Apium graveolens L. (celery)
(infected by *Sclerotinia sclerotiorum*
(Lib.) de Bary ("pink rot") -
(Apiaceae) ^[50]

Worldwide,
including Brazil

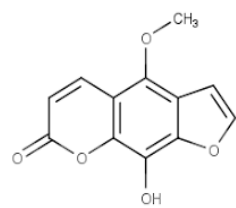
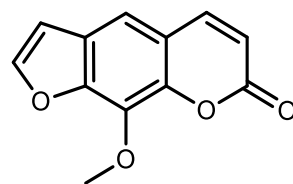
Type I

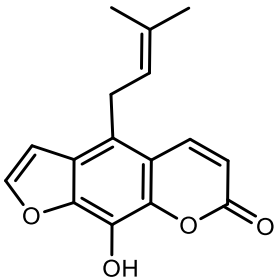
(C₁₄H₁₂O₃)

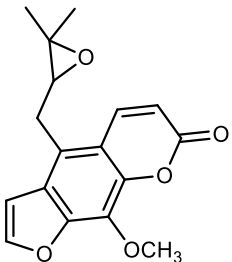
vitiligo. λ_{max}~
250-and 338
nm in alcohol

The species ^[50]
contains other
phototoxic
molecules:
Xanthotoxin,
bergapten, 8-
hydroxybergapt
en,
isopimpinellin,
isoimperatorin,
rutaretin

λ_{max}~ 360 nm
depending on
solvent

Furanocoumarin Type I	8-hydroxybergapten (C ₁₂ H ₈ O ₅)		<p>a) <i>Ammi visnaga</i> (L.) Lam - (Apiaceae) ^[47,50]</p> <p>(This molecule is also produced by b) <i>Sclerotinia sclerotiorum</i> (Lib.) de Bary ("pink rot") - (Sclerotiniaceae) ^[50]</p>	<p>a) Argentina, Europe, Mediterranean basin</p> <p>b) Europe, USA, South of Africa, East of Asia</p>	<p>Highly phototoxic ^[47,50]</p> <p>$\lambda_{\text{max}} \sim 350\text{-}360$ nm depending on solvent</p>
Furanocoumarin Type I	8-Methoxypsoralen (8- MOP) = Methoxsalen = Xanthotoxin (C ₁₂ H ₈ O ₄)		<p>(Apiaceae) ^[110]</p> <p>(Rutaceae) ^[110]</p>	<p>Phototoxic on ^[110] the plant- pathogenic fungus <i>Colletotrichum</i> <i>acutatum</i> and the ascomycete <i>Aspergillus</i> <i>nidulans</i></p> <p>$\lambda_{\text{max}} \sim 350$ nm depending on solvent</p>	

Furanocoumarin Type I	Alloimperatorin (=prangenidin) (C ₁₆ H ₁₄ O ₄)		<p>a) <i>Ammi majus</i> L. (Bishop's weed) - (Apiaceae) ^[47,50]</p> <p>b) <i>Thamnosma texana</i> (Gray) Torr. (Dutchman's breeche) - (Rutaceae) ^[140]</p>	<p>a) Southern Europe, Northern and Western Africa, Central Asia, Brazil</p> <p>b) Texas, Mexico</p>	<p>Highly phototoxic</p> <p>λ_{max}~ 290-310 nm depending on solvent</p>	[47,50,140]
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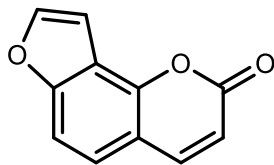
Furanocoumarin Type I	Alloimperatorin methyl ether epoxide (C ₁₆ H ₁₄ O ₄)		<p><i>Thamnosma texana</i> (Gray) Torr. (Dutchman's breeche, blisterweed) - (Rutaceae) ^[140]</p>	<p>Texas, Mexico</p>	<p>λ_{max}~ 290-310 nm depending on solvent</p>	[140]
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Furanocoumarin

Type I

Angelicin

(C₁₁H₆O₃)



Present with other furanocoumarins
in

a) *Ammi majus* L. (Bishop's weed) -
(Apiaceae) ^[66,67]

b) *Anethum graveolens* L. (Dill) -
(Apiaceae) ^[67]

Angelica spp - (Apiaceae) ^[66]

c) *Angelica archangelica* L.
(Angélique) - (Apiaceae) ^[67]

d) *Anthriscus sylvestris* (L.) Hoffm.
(Cow parsley) - (Apiaceae) ^[67]

e) *Anthriscus cereifolium* (L.) Hoffm.
- (Apiaceae) ^[67]

f) *Apium graveolens* L. (Celery) -
(Apiaceae) ^[66,67]

g) *Daucus carota* L. (Wild carrot) -
(Apiaceae) ^[67]

a) Southern Europe,
Northern and
Western Africa,
Central Asia, Brazil

b) Worldwide,
mostly Europe and
North America,
found in Brazil

c) Europe + cold
climates, very rare
cases in Brazil

d) Africa, New
Zealand, mostly in
Europe, Asia and
USA

e) Europe, USA,
New Zealand

f) Worldwide,
including Brazil

The content in
furanocoumarin
s may vary
widely
according to
geographic
location and
climate

λ_{\max} ~ 340-350
nm depending
on solvent

[66,67]

- h) *Foeniculum vulgare* Mill. (Fennel) g) North hemisphere,
 - (Apiaceae) ^[67] South Africa,
 Oceania, South
- i) *Heracleum laciniatum* auct. scand., America, some found
 non Hornem.- (Apiaceae) ^[66,67] in Brazil
- j) *Heracleum mantegazzianum* h) Worldwide,
 Sommer & Levier (Giant hogweed) including Brazil
 - (Apiaceae) ^[67]
- k) *Heracleum sphondylium* L. i) Norway
 (Hogweed) - (Apiaceae) ^[67] j) Europe, North
 America, New
 Zealand
- l) *Levisticum officinale* Koch
 (Lovage) - (Apiaceae) ^[67]
- m) *Pastinaca sativa* L. (Wild k) North hemisphere,
 parsnip) - (Apiaceae) ^[66,67] New Zealand
- n) *Petroselinum sativum* Hoffm.= l) Europe, USA,
Petroselinum crispum subsp. *crispum* Korea, Japan, New
 - (Apiaceae) ^[67] Zealand
- o) *Peucedanum ostruthium* Linnaeus, m) Eurasia, Oceania,
 1753 (Masterwort) - (Apiaceae) ^[67] North and South

- p) *Psoralea corylifolia* L. - Americas, including
 (Fabaceae) ^[67] Brazil
- q) *Bituminaria bituminosa* (L.) C.H. n) Europe and
 Stirt. - (Fabaceae) ^[66] Central America
 (only 1 occurrence in
 Brazil, does not seem
 endemic)
- r) *Ficus carica* L. (Common fig) - o) Europe
 (Moraceae) ^[66,67]
- s) *Citrus x aurantifolia* (Christm.) p) Asia, 1 occurrence
 Swingle (Citron vert) - (Rutaceae) ^[67] in North America, 1
 in Africa, 1 in Arabic
 peninsula
- t) *Citrus x limon* (L.) Burm.fil. = q) Europe
Citrus x bergamia Risso (Lemon) -
 (Rutaceae) ^[67]
- u) *Citrus limetta* Risso = *Citrus* r) Worldwide
medica L. (Mousami) - (Rutaceae) ,including Brazil
^[67]

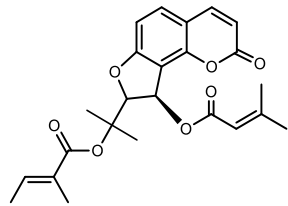
- | | |
|--|--|
| v) <i>Citrus x paradisi</i> Macfad.
(Grapefruit / Pomelo) - (Rutaceae)
[67] | s) South hemisphere,
including Brazil |
| | t) Benin |
| w) <i>Citrus x sinensis</i> (Mill.) Pers.,
1806 = <i>Citrus x aurantium</i> L.
(Orange) - (Rutaceae) [67] | u) South America,
including Brazil |
| | v) Benin |
| x) <i>Dictamnus albus</i> L. (Burning
bush) - (Rutaceae) [67] | w) Western Africa,
Western Europe,
Central America and
South America,
including Brazil |
| y) <i>Pelea anisata</i> H. Mann. =
<i>Melicope anisata</i> (H.Mann)
T.G.Hartley & B.C.Stone -
(Rutaceae) [67] | x) Europe, USA,
Asia |
| z) <i>Ruta chalepensis</i> L. (Fringed rue) -
(Rutaceae) [67] | y) Hawaii |
| aa) <i>Ruta graveolens</i> L. (Rue / Rua) -
(Rutaceae) [67] | z) Europe, Central
America, South
America, a few in
Brazil |

aa) South America,
including Brazil,
Eurasia

Furanocoumarin

Archangelicin

(C₂₄H₂₆O₇)



(Apiaceae) ^[66]

(Rutaceae) ^[66]

(Fabaceae) ^[66]

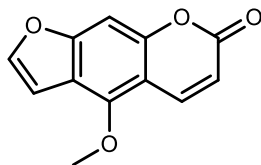
(Moraceae) ^[66]

[66]

Type I

Furanocoumarin

Bergapten



Type I

(5-methoxypsoralen)

(C₁₂H₈O₄)

- a) *Ammi majus* L. (Bishop's weed) - (Apiaceae) [38,47,50,66] a) Southern Europe, Northern and Western Africa, Central Asia, Brazil
- b) *Pastinaca sativa* L. (Wild parsnip) - (Apiaceae) [47,50,66] b) Eurasia, Oceania, North and South Americas, including Brazil
- c) *Cymopterus watsonii* (J.M.Coult. & Rose) M.E.Jones (Spring parsley) - (Apiaceae) [47,50] c) North America
- Heracleum spp.* - (Apiaceae) [50,66] d)
- d) *Heracleum laciniatum* - (Apiaceae) [50,66] e) North hemisphere, New Zealand
- e) *Heracleum sphondylium* L. (Hogweed) - (Apiaceae) [50,66] f) Worldwide, including Brazil
- f) *Foeniculum vulgare* Mill. (Fennel) - (Apiaceae) [50] g) Worldwide, mostly Europe and North America, found in Brazil
- g) *Anethum graveolens* L. (Dill) - (Apiaceae) [50]
- Angelica spp.* - (Apiaceae) [50,66]

/

Highly phototoxic in the ultraviolet A (UVA) range, 320–400 nm

[38,47,50,56,63,66,139,140]

- | | |
|--|--|
| h) <i>Petroselinum sativum</i> Hoffm.=
<i>Petroselinum crispum subsp. crispum</i>
- (Apiaceae) ^[50,66] | h) Europe and
Central America
(only 1 occurrence in
Brazil, does not seem
endemic) |
| i) <i>Pimpinella major</i> (L.) Huds. -
(Apiaceae) ^[66] | i) Europe |
| j) <i>Levisticum officinale</i> Koch
(Lovage) - (Apiaceae) ^[66] | j) Europe, USA,
Korea, Japan, New
Zealand |
| k) <i>Apium graveolens</i> L. (Celery) -
(Apiaceae) ^[66] | k) Worldwide,
including Brazil |
| l) <i>Peucedanum tauricum</i> M. Bieb
(Also known as <i>Peucedanum
ruthenicum</i> M.Bieb.) - (Apiaceae) ^[66]

(Rutaceae) ^[56] | l) Balkans (Easten
Europe)

m) Eurasia, South
America, including
Brazil |
| m) <i>Ruta graveolens</i> L. (Rue / Rua) -
(Rutaceae) ^[47,56,138] | n) Texas, Mexico |

- | | |
|--|--|
| n) <i>Thamnosma texana</i> (Gray) Torr.
(Dutchman's breeche) - (Rutaceae)
[47,50,140] | o) Worldwide,
including Brazil |
| o) <i>Citrus spp.</i> (e.g. limes, bergamot
orange, grapefruit, Earl Grey tea) -
(Rutaceae) [50,66] | p) Worldwide,
including Brazil |
| p) <i>Citrus × limon</i> (L.) Burm.fil. =
<i>Citrus × bergamia</i> Risso (Lemon) -
(Rutaceae) [50,56,66] | q) Americas,
including Brazil, East
Asia, Europe |
| q) <i>Citrus x paradisi</i> Macfad. -
(Grapefruit / Pomelo) (Rutaceae)
[50,56,66] | r) West of USA |
| r) <i>Thamnosma montana</i> Torr. &
Frem - (Mohave desertrue)
(Rutaceae) [50] | s) South hemisphere,
including Brazil |
| s) <i>Citrus x aurantifolia</i> (Christm.)
Swingle (Lime) - (Rutaceae) [56] | t) Australia, New
Zealand, West of
USA |
| Various <i>Pittosporum spp.</i> -
(Pittosporaceae) [50] | u) Western Europe,
West of USA |
| | v) Worldwide,
including Brazil |

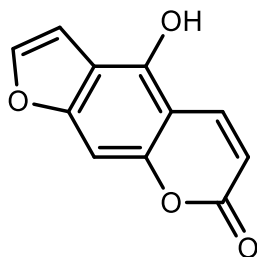
- t) *Pittosporum eugenoides* A.Cunn. - w) Worldwide,
(Pittosporaceae) ^[50] including Brazil
- u) *Pittosporum tenuifolium* Gaertn. - x) Europe, USA,
(Pittosporaceae) ^[50] South of Africa, East
of Asia
- v) *Vicia sativa* L. - (Fabaceae) ^[50] y) Brazil
- w) The cultivated tomato : z) Worldwide
Lycopersicon esculentum Mill - ,including Brazil
(Solanaceae) ^[50]
- x) *Sclerotinia sclerotiorum* (Lib.) de
Bary (“pink rot”) - (Sclerotiniaceae)
^[50]
- (Moraceae) ^[56]
- y) *Brosimum gaudichaudii* Trécul
(mamacadela or inharé) - (Moraceae)
^[63]
- z) *Ficus carica* L. (Common fig) -
(Moraceae) ^[56]

Furanocoumarin

Type I

Bergaptol

(C₁₁H₆O₄)



Reports of various furanocoumarins that may include bergaptol in:

- a) *Ammi majus* L. (Bishop's weed) - (Apiaceae) ^[67]
- b) *Anethum graveolens* L. (Dill) - (Apiaceae) ^[67]
- c) *Angelica archangelica* L. (Angélique) - (Apiaceae) ^[67]
- d) *Anthriscus sylvestris* (L.) Hoffm. (Cow parsley) - (Apiaceae) ^[67]
- e) *Anthriscus cereifolium* (L.) Hoffm. - (Apiaceae) ^[67]
- f) *Apium graveolens* L. (Celery) - (Apiaceae) ^[67]
- g) *Daucus carota* L. (Wild carrot) - (Apiaceae) ^[67]

a) Southern Europe, Northern and Western Africa, Central Asia, Brazil

b) Worldwide, mostly Europe and North America, found in Brazil

c) Europe + cold climates, very rare cases in Brazil

d) Africa, New Zealand, mostly in

Europe, Asia and USA

e) Europe, USA, New Zealand

f) Worldwide, including Brazil

Involved in photodermatitis cases in humans.

λ_{max} ~ 325-330 nm depending on solvent

[66,67]

- h) *Foeniculum vulgare* Mill. (Fennel) g) North hemisphere,
 - (Apiaceae) ^[67] South Africa,
 Oceania, South
 i) *Heracleum laciniatum* auct. scand.,
 non Hornem.- (Apiaceae) ^[67] America, some
 occurrences found in
 j) *Heracleum mantegazzianum* Brazil
 Sommer & Levier (Giant hogweed)
 - (Apiaceae) ^[67] h) Worldwide,
 including Brazil
 k) *Heracleum sphondylium* L.
 (Hogweed) - (Apiaceae) ^[67] i) Norway
 l) *Levisticum officinale* Koch
 (Lovage) - (Apiaceae) ^[67] j) Europe, North
 America, New
 Zealand
 m) *Pastinaca sativa* L. (Wild
 parsnip) - (Apiaceae) ^[67] k) North hemisphere,
 New Zealand
 n) *Petroselinum sativum* Hoffm.=
Petroselinum crispum subsp. *crispum*
 - (Apiaceae) ^[67] l) Europe, USA,
 Korea, Japan, New
 Zealand
 o) *Peucedanum ostruthium* Linnaeus,
 1753 (Masterwort) - (Apiaceae) ^[67] m) Eurasia, Oceania,
 North and South

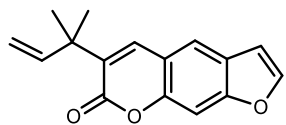
- p) *Peucedanum tauricum* M. Bieb. - Americas, including
Also known as *Peucedanum* Brazil
ruthenicum M.Bieb. - (Apiaceae) ^[67]
- q) *Psoralea corylifolia* L. - n) Europe and
(Fabaceae) ^[67] Central America
- r) *Ficus carica* L. (Common fig) - o) Europe
(Moraceae) ^[67] p) Balkans (Easten
Europe)
- s) *Citrus x aurantifolia* (Christm.)
Swingle (Lime) - (Rutaceae) ^[67]
- t) *Citrus x limon* (L.) Burm.fil. = q) East Asia
Citrus x bergamia Risso (Lemon) -
(Rutaceae) ^[67]
- u) *Citrus limetta* Risso = *Citrus* r) Worldwide,
medica L. (Mousami) - (Rutaceae) including Brazil
^[67]
- v) *Citrus x paradisi* Macfad. s) South hemisphere,
(Grapefruit / Pomelo) - (Rutaceae) including Brazil
^[67]

- | | |
|---|--|
| w) <i>Citrus x sinensis</i> (Mill.) Pers.,
1806 = <i>Citrus × aurantium</i> L.
(Orange) - (Rutaceae) ^[67] | t) Worldwide,
including Brazil |
| x) <i>Dictamnus albus</i> L. (Burning
bush) - (Rutaceae) ^[67] | u) South America,
including Brazil |
| y) <i>Pelea anisata</i> H. Mann. =
<i>Melicope anisata</i> (H.Mann)
T.G.Hartley & B.C.Stone -
(Rutaceae) ^[67] | v) Americas,
including Brazil, East
Asia, Europe |
| z) <i>Ruta chalepensis</i> L. (Fringed rue) -
(Rutaceae) ^[67] | w) Western Africa,
Western Europe,
Central America and
South America,
including Brazil |
| aa) <i>Ruta graveolens</i> L. (Rue / Rua) -
(Rutaceae) ^[67] | x) Europe, USA,
Asia |
| | y) Hawaii |
| | z) Europe, Central
America, South
America, a few in
Brazil |

aa) Eurasia, South
America, including
Brazil

Furanocoumarin

Chalepensin



Ruta graveolens L. (Rue / Rua)
(Rutaceae) and *Clausena sp.*,
(Rutaceae) ^[47,50]

Eurasia, South
America, including
Brazil

Highly
phototoxic

^[47,50,156]

λ_{\max} ~ 325-360
nm depending
on solvent

Type I

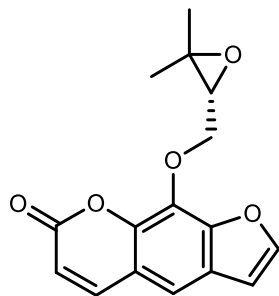
(C₁₆H₁₄O₃)

Furanocoumarin

Type I

Heraclenin

(C₁₆H₁₄O₅)



a) *Thamnosma texana* (Gray) Torr.
(Dutchman's breeche) - (Rutaceae)

[140]

a) Texas, Mexico

λ_{\max} ~ 260 nm
depending on
solvent

[66,140]

b) China

b) *Heracleum candicans* Wall. ex
DC. = *Semenovia candicans* (Wall.
ex DC.) - (Apiaceae) [66]

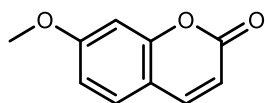
Furanocoumarin

Type I

Herniarin

= (7-Methoxycoumarin)

(C₁₀H₈O₃)



Thamnosma texana (Gray) Torr.
(Dutchman's breeche) - (Rutaceae)

[140]

Texas, Mexico

λ_{\max} ~ 358 nm
depending on
solvent

[140]

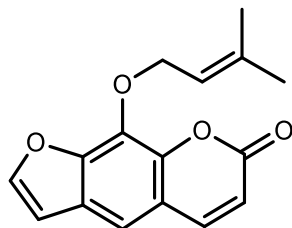
Same comment
as Heraclenin

Furanocoumarin

Type I

Imperatorin

(C₁₆H₁₄O₄)



a) *Ammi majus* L. - (Apiaceae)
[38,47,50]

b) *Ammi visnaga* (L.) Lam -
(Apiaceae) [50,157]

c) *Pastinaca sativa* L. - (Apiaceae)
[50,157]

d) *Thamnosma texana* (Gray) Torr. -
(Apiaceae) [140]

e) *Angelica dahurica* (Fisch. ex
Hoffm.) Benth. & Hook.fil. ex
Franch. & Sav. - (Apiaceae) [66]

f) *Clausena anisata* (Willd.)
Hook.fil., De Wild. & Staner -
(Rutaceae) [66]

a) Southern Europe,
Northern and
Western Africa,
Central Asia, Brazil

b) Argentina, Europe,
Mediterranean basin

c) Eurasia, Oceania,
North and South
Americas, including
Brazil

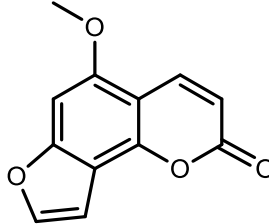
d) Arizona (Hualapai
Mountains) to Texas
and N. Mexico.

e) East Asia

λ_{\max} ~ 255, [38,50,66,67,140,157]
268 and 286
nm depending
on solvent

Highly
phototoxic

Same comment
as Heraclenin.

				f) Central and South of Africa, Sino-Indian coastline	
Furanocoumarin Type I	Isobergapten (C ₁₂ H ₈ O ₄)		<p>Reports of various furanocoumarins that may include isobergapten in :</p> <p>a) <i>Ammi majus</i> L. (Bishop's weed) - (Apiaceae) ^[67]</p> <p>b) <i>Anethum graveolens</i> L. (Dill) - (Apiaceae) ^[67]</p> <p>c) <i>Angelica archangelica</i> L. (Angélique) - (Apiaceae) ^[67]</p> <p>d) <i>Anthriscus sylvestris</i> (L.) Hoffm. (Cow parsley) - (Apiaceae) ^[67]</p> <p>e) <i>Anthriscus cereifolium</i> (L.) Hoffm. - (Apiaceae) ^[67]</p>	<p>a) Southern Europe, Northern and Western Africa, Central Asia, Brazil</p> <p>b) Worldwide, mostly Europe and North America, found in Brazil</p> <p>c) Europe + cold climates, very rare cases in Brazil</p> <p>d) Africa, New Zealand, mostly in Europe, Asia and USA</p>	<p>λ_{max}~ 340-350 nm depending on solvent</p> <p>Responsible for numerous cases of photodermatitis in humans.</p>

- f) *Apium graveolens* L. (Celery) - e) Europe, USA,
(Apiaceae) ^[67] New Zealand
- g) *Daucus carota* L. (Wild carrot) - f) Worldwide,
(Apiaceae) ^[67] including Brazil
- h) *Foeniculum vulgare* Mill. (Fennel) g) North hemisphere,
- (Apiaceae) ^[67] South Africa,
Oceania, South
i) *Heracleum laciniatum* auct. scand.,
non Hornem.- (Apiaceae) ^[67] America, some
occurrences found in
Brazil
- j) *Heracleum mantegazzianum*
Sommier & Levier (Giant hogweed)
- (Apiaceae) ^[67] h) Worldwide,
including Brazil
- k) *Heracleum sphondylium* L.
(Hogweed) - (Apiaceae) ^[67] i) Norway
- l) *Levisticum officinale* Koch
(Lovage) - (Apiaceae) ^[67] j) Europe, North
America, New
Zealand
- m) *Pastinaca sativa* L. (Wild
parsnip) - (Apiaceae) ^[66,67] k) North hemisphere,
New Zealand

- n) *Petroselinum sativum* Hoffm.= 1) Europe, USA,
Petroselinum crispum subsp. *crispum* Korea, Japan, New
- (Apiaceae) ^[67] Zealand
- o) *Peucedanum ostruthium* Linnaeus, m) Eurasia, Oceania,
1753 (Masterwort) - (Apiaceae) ^[67] North and South
Americas, including
- p) *Pimpinella magna* L. - (Apiaceae) Brazil
^[67]
- q) *Heracleum lanatum* - (Apiaceae) n) Europe and
Central America
^[66]
- o) Europe
- p) Europe
- r) *Psoralea corylifolia* L. - q) North hemisphere
(Fabaceae) ^[67]
- r) East Asia
- s) *Ficus carica* L. (Common fig) -
(Moraceae) ^[66,67]
- s) Worldwide,
including Brazil

- t) *Citrus x aurantifolia* (Christm.)
Swingle (Lime) - (Rutaceae) ^[67]
- u) *Citrus × limon* (L.) Burm.fil. =
Citrus × bergamia Risso (Lemon) -
(Rutaceae) ^[67]
- v) *Citrus limetta* Risso = *Citrus*
medica L. (Mousami) - (Rutaceae)
^[67]
- w) *Citrus x paradisi* Macfad.
(Grapefruit / Pomelo) - (Rutaceae)
^[67]
- x) *Citrus x sinensis* (Mill.) Pers.,
1806 = *Citrus × aurantium* L.
(Orange) - (Rutaceae) ^[67]
- y) *Dictamnus albus* L. (Burning
bush) - (Rutaceae) ^[67]
- e) *Pelea anisata* H. Mann. =
Melicope anisata (H.Mann)
- t) South hemisphere,
including Brazil
- u) Worldwide,
including Brazil
- v) South America,
including Brazil
- w) Americas,
including Brazil, East
Asia, Europe
- x) Western Africa,
Western Europe,
Central America and
South America,
including Brazil
- y) Europe, USA,
Asia
- z) Hawaii

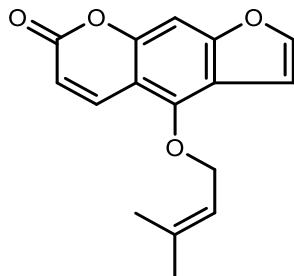
<p>T.G.Hartley & B.C.Stone - (Rutaceae) ^[67]</p>	<p>aa) Europe, Central America, South America, a few in Brazil</p>
<p>aa) <i>Ruta chalepensis</i> L. (Fringed rue) - (Rutaceae) ^[67]</p>	<p>ab) Eurasia, South America, including Brazil</p>
<p>ab) <i>Ruta graveolens</i> L. (Rue / Rua) - (Rutaceae) ^[67]</p>	

Furanocoumarin

Type I

Isoimperatorin

(C₁₆H₁₄O₄)



a) *Thamnosma montana* Torr. & Frem (Mohave desertrue) - (Rutaceae) ^[50]

b) *Ruta graveolens* L. (Rue / Rua) - (Rutaceae) ^[50,157]

c) *Apium graveolens* L. (celery) (infected by *Sclerotinia sclerotiorum* (Lib.) de Bary (“pink rot”)) - (Apiaceae) ^[50]

d) *Glehnia littoralis* (A.Gray) F.Schmidt = *Radix glehniae* - (Apiaceae) ^[66]

e) *Angelica lucida* L. (Angelica) - (Apiaceae) ^[66]

a) West of USA

b) Eurasia, South America, including Brazil

c) Worldwide, including Brazil

d) USA and East of Asia

e) North hemisphere

Highly phototoxic

λ_{\max} ~ 330-340 nm depending on solvent

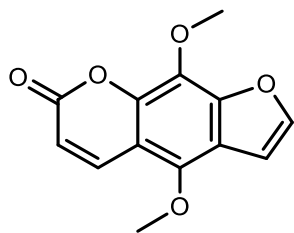
^[50,66,157]

Furanocoumarin

Isopimpinellin

Type I

(C₁₃H₁₀O₅)



(Rutaceae) ^[56]

a) *Ruta graveolens* L. (Rue / Rua) -
(Rutaceae) ^[47,50]

b) *Thamnosma texana* (Gray) Torr.
(Dutchman's breeche) - (Rutaceae)
^[47,50,140]

c) *Thamnosma montana* Torr. &
Frem (Mohave desertrue) -
(Rutaceae) ^[50]

d) *Citrus × limon* (L.) Burm.fil. =
Citrus × bergamia Risso (Lemon) -
(Rutaceae) ^[56,66]

e) *Citrus x sinensis* (Mill.) Pers.,
1806 = *Citrus × aurantium* L.
(Orange) - (Rutaceae) ^[110]

f) *Citrus x aurantifolia* (Christm.)
Swingle (Lime) - (Rutaceae) ^[56]

a) Eurasia, South
America, including
Brazil

b) Arizona (Hualapai
Mountains) to Texas
and N. Mexico.

c) West of USA

d) Worldwide,
including Brazil

e) Western Africa,
Western Europe,
Central America and
South America,
including Brazil

f) South hemisphere,
including Brazil

Highly ^{[38,50,56,66,110,140,}
phototoxic, ^{157]}
responsible for
cattle
phototoxicity,
particularly in
sheeps.

λ_{\max} ~ 330-340
nm depending
on solvent

Phototoxic on
the plant-
pathogenic
fungus
Colletotrichum
acutatum and
the ascomycete

- g) *Citrus x paradisi* Macfad. g) Americas, *Aspergillus*
(Grapefruit / Pomelo) - (Rutaceae) including Brazil, East *nidulans* ^[110]
^[56] Asia, Europe
- h) *Pastinaca sativa* L. (Wild parsnip)
- (Apiaceae) ^[50,66,157] h) Eurasia, Oceania,
- i) *Apium graveolens* L. (Celery) - North and South
(Apiaceae) ^[50,66] Americas, including
Brazil
- j) *Petroselinum sativum* Hoffm. =
Petroselinum crispum subsp. crispum i) Worldwide,
- (Apiaceae) ^[66] including Brazil
- k) *Heracleum sphondylium* L. j) Europe and Central
(Hogweed) - (Apiaceae) ^[66] America
- l) *Ammi majus* L. (Bishop's weed) - k) North hemisphere,
(Apiaceae) ^[38,66] New Zealand
- m) *Angelica archangelica* L. l) Southern Europe,
(Angelica) - (Apiaceae) ^[66] Northern and
Western Africa,
- n) *Heracleum laciniatum* - Central Asia, Brazil
(Apiaceae) ^[66]

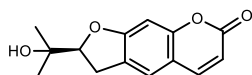
- o) *Pimpinella saxifraga* L. - m) Europe + cold
(Apiaceae) ^[66] climates
- p) *Sclerotinia sclerotiorum* (Lib.) de n) Norway
Bary (Pink rot) - (Sclerotiniaceae) ^[50]
o) North hemisphere
- (Moraceae) ^[56]
- p) Europe, USA,
q) *Ficus carica* L. (Common fig) - South of Africa, East
(Moraceae) (de Menezes *et al.*, 2014) of Asia

q) Worldwide,
including Brazil

Furanocoumarin
Type I

Marmesin =
nodakenetin

(C₁₄H₁₄O₄)



- a) *Ammi majus* L. (Bishop's weed) - a) Southern Europe,
(Apiaceae) ^[38,47,50] Northern and
Western Africa,
b) *Ammi visnaga* (L.) Lam (Khella) - Central Asia, Brazil
(Apiaceae) ^[47,71]
- b) Argentina, Europe,
Mediterranean basin

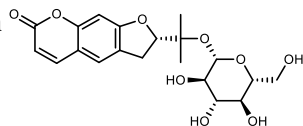
Highly
phototoxic,
responsible for
phototoxicity in
cattle

^[38,47,50,71,110]

Furanocoumarin
Type I

Marmesinin = Ammijin

(C₂₀H₂₄O₉)



a) *Ammi majus* L. (Bishop's weed) -
(Apiaceae) [38,47,50]

d) *Brosimum gaudichaudii* Trécul -
(Moraceae) [110]

a) Southern Europe,
Northern and
Western Africa,
Central Asia, Brazil

b) South America,
Brazil

c) *Ruta graveolens* L. (Rue / Rua) -
(Rutaceae) [47,50]

d) *Brosimum gaudichaudii* Trécul -
(Moraceae) [110]

c) Eurasia, South
America, including
Brazil

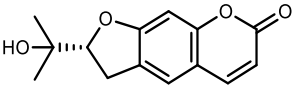
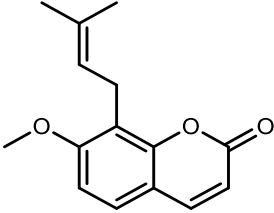
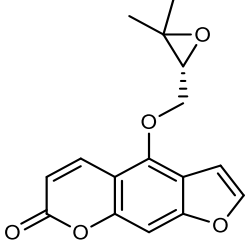
d) South America,
Brazil

λ_{\max} ~ 300-320
nm depending
on solvent

Highly
phototoxic,
responsible for
phototoxic
events in cattle

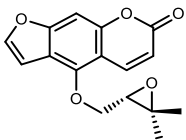
λ_{\max} ~ 330-340
nm depending
on solvent

[38,47,50,110]

Furanocoumarin Type I	Nodakenetin (C ₁₄ H ₁₄ O ₄)		<i>Dipteryx odorata</i> Willd, (<i>Coumarouna odorata</i> Aubl.) - (Fabaceae) ^[66]	North of South America, including Brazil	λ_{\max} ~ 330-340 nm depending on solvent	^[66]
Furanocoumarin Type I	Osthol (C ₁₅ H ₁₆ O ₃)		<i>Thamnosma texana</i> (Gray) Torr. (Dutchman's breeche) - (Rutaceae) ^[140]	Arizona (Hualapai Mountains) to Texas and N. Mexico.	λ_{\max} ~ 310-320 nm depending on solvent	^[140]
Furanocoumarin Type I	Oxypeucedanin = 4-[(3,3- Dimethyloxiran-2-		a) <i>Ammi majus</i> L. (Bishop's weed) - (Apiaceae) ^[47,50] b) <i>Petroselinum crispum</i> (Mill.) Fuss (Parsley) - (Apiaceae) ^[50]	a) Southern Europe, Northern and Western Africa, Central Asia, Brazil	a) Seeds, fruits λ_{\max} ~ 310-320 nm depending on solvent	Highly phototoxic ^[140] ^[47,50,66,140]

y1)methoxy]furo[3,2-g]chromen-7-one)

(C₁₆H₁₄O₅)



(-)-Oxypeucedanin

c) *Peucedanum ostruthium* Linnaeus, 1753 (Masterwort) - (Apiaceae) ^[66]

d) *Thamnosma texana* (Gray) Torr. (Dutchman's breeche) - (Rutaceae)

^[140]

e) *Clausena anisata* (Willd.) Hook.fil., De Wild. & Staner (Horsewood) - (Rutaceae) ^[66]

b) Worldwide, including Brazil

c) Europe

d) Arizona (Hualapai Mountains) to Texas and N. Mexico.

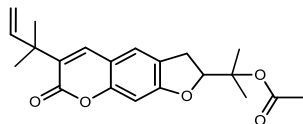
e) Central and South of Africa, Sino-Indian coastline

Furanocoumarin

Type I

Rutamarin

(C₂₁H₂₄O₅)



a) *Ruta graveolens* L. (Rue / Rua) - (Rutaceae)

b) *Ruta angustifolia* Pers. - (Rutaceae)

a) Eurasia, South America, including Brazil

b) Europe

λ_{max} ~ 310-320 nm depending on solvent

Phototoxic, antibacterial, antifungal, antiviral, antiparasitic,

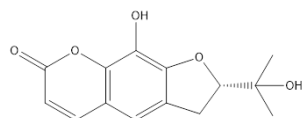
^[136]

insecticidal and
larvicidal

Furanocoumarin

Rutaretin

C₁₄H₁₄O₅



(a) *Ruta graveolens* L. (Rue)

(Rutaceae)

(a) Eurasia, South
America, including
Brazil

[151]

also present in (b) *Atalantia
racemosa* (Rutaceae),

(b) India

[131]

(c) *Fatoua pilosa* (Moraceae)

(c) China, Indonesia,
New-Zealand

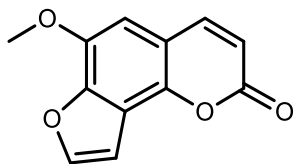
[111]

Furanocoumarin

Type I

Sphondin

(C₁₂H₈O₄)



Present with other furanocoumarins
in:

- a) *Ammi majus* L. (Bishop's weed) -
(Apiaceae) ^[67]
- b) *Anethum graveolens* L. (Dill) -
(Apiaceae) ^[67]
- c) *Angelica archangelica* L.
(Angélique) - (Apiaceae) ^[67]
- d) *Anthriscus sylvestris* (L.) Hoffm.
(Cow parsley) - (Apiaceae) ^[67]
- e) *Anthriscus cereifolium* (L.) Hoffm.
- (Apiaceae) ^[67]
- f) *Apium graveolens* L. (Celery) -
(Apiaceae) ^[67]
- g) *Daucus carota* L. (Wild carrot) -
(Apiaceae) ^[67]

a) Southern Europe,
Northern and
Western Africa,
Central Asia, Brazil

b) Worldwide,
mostly Europe and
North America,
found in Brazil

c) Europe + cold
climates, very rare
cases in Brazil

d) Africa, New
Zealand, mostly in

Europe, Asia and
USA

e) Europe, USA,
New Zealand

f) Worldwide,
including Brazil

λ_{\max} ~ 310-320
nm depending
on solvent

[66,67]

- h) *Foeniculum vulgare* Mill. (Fennel) g) North hemisphere,
 - (Apiaceae) ^[67] South Africa,
 Oceania, South
 i) *Heracleum laciniatum* auct. scand.,
 non Hornem.- (Apiaceae) ^[67] America, some
 occurrences found in
 j) *Heracleum mantegazzianum* Brazil
 Sommer & Levier (Giant hogweed)
 - (Apiaceae) ^[67] h) Worldwide,
 including Brazil
 k) *Heracleum sphondylium* L.
 (Hogweed) - (Apiaceae) ^[67] i) Norway
 l) *Levisticum officinale* Koch
 (Lovage) - (Apiaceae) ^[67] j) Europe, North
 America, New
 Zealand
 m) *Pastinaca sativa* L. (Wild
 parsnip) - (Apiaceae) ^[66,67] k) North hemisphere,
 New Zealand
 n) *Petroselinum sativum* Hoffm.=
Petroselinum crispum subsp. *crispum*
 - (Apiaceae) ^[67] l) Europe, USA,
 Korea, Japan, New
 Zealand
 o) *Peucedanum ostruthium* Linnaeus,
 1753 (Masterwort) - (Apiaceae) ^[67] m) Eurasia, Oceania,
 North and South

- p) *Pimpinella magna* L. - (Apiaceae) Americas, including
^[67] Brazil
- q) *Heracleum thomsoni* - (Apiaceae) n) Europe and
^[67] Central America
- r) *Psoralea corylifolia* L. - o) Europe
(Fabaceae) ^[67] p) Europe
q) Asia
- s) *Ficus carica* L. (Common fig) -
(Moraceae) ^[66,67] r) East Asia
- t) *Citrus x aurantifolia* (Christm.)
Swingle (Lime) - (Rutaceae) ^[67] s) Worldwide,
including Brazil
- u) *Citrus × limon* (L.) Burm.fil. =
Citrus × bergamia Risso (Lemon) -
(Rutaceae) ^[67]
- v) *Citrus limetta* Risso = *Citrus*
medica L. (Mousami) - (Rutaceae)
^[67] t) South hemisphere,
including Brazil

- | | |
|--|--|
| w) <i>Citrus x paradisi</i> Macfad.
(Grapefruit / Pomelo) - (Rutaceae)
[67] | u) Worldwide,
including Brazil |
| x) <i>Citrus x sinensis</i> (Mill.) Pers.,
1806 = <i>Citrus × aurantium</i> L.
(Orange) - (Rutaceae) [67] | v) South America,
including Brazil

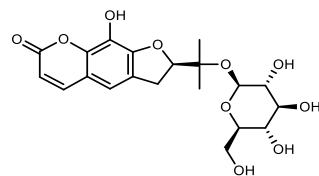
w) Americas,
including Brazil, East |
| y) <i>Dictamnus albus</i> L. (Burning
bush) - (Rutaceae) [67] | Asia, Europe |
| e) <i>Pelea anisata</i> H. Mann. =
<i>Melicope anisata</i> (H.Mann)
T.G.Hartley & B.C.Stone -
(Rutaceae) [67] | x) Western Africa,
Western Europe,
Central America and
South America,
including Brazil |
| aa) <i>Ruta chalepensis</i> L. (Fringed rue)
- (Rutaceae) [67] | y) Europe, USA,
Asia |
| ab) <i>Ruta graveolens</i> L. (Rue / Rua) -
(Rutaceae) [67] | z) Hawaii

aa) Europe, Central
America, South
America, a few in
Brazil |

ab) Eurasia, South
America, including
Brazil

Furanocoumarin
glycoside
Type I

Isorutarin
(C₂₀H₂₄O₁₀)

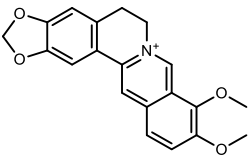


Ruta graveolens L. (Rua) -
(Rutaceae)

Eurasia, South
America, including
Brazil

Numerous
reports of
phototoxic
events with this
species.

[47,50]

<p>Isoquinoline alkaloid</p> <p>Type I</p>	<p>Berberine</p> <p>(C₂₀H₁₈NO₄⁺)</p>		<p>(Annonaceae) ^[60,157]</p> <p>a) <i>Annona purpurea</i> Moç. & Sessé ex Dunal (Sncoya) - (Annonaceae) ^[47]</p>	<p>a) Central America</p> <p>b) Europe, USA</p>	<p>a) leaves</p>	<p>λ_{max}~ 310-320 nm depending on solvent</p>	<p>Berberin is ^[60,115,157] used in Traditional Chinese Medicine because of its multiple biological activities including antidiabetic, anti-inflammatory, antimalarial, antimicrobial, anticancer and</p>
			<p>(Ranunculaceae) ^[157]</p> <p>b) <i>Helleborus niger</i> L. (Rose de Noël) - (Ranunculaceae) ^[157]</p>	<p>c) Europe, Asia and South America, including Brazil</p>	<p>b) leaves</p>		
			<p>(Berberidaceae) ^[157]</p>				
			<p>(Juglandaceae) ^[47]</p>				
			<p>(Magnoliaceae) ^[157]</p>				
			<p>(Menispermaceae) ^[157]</p>				

(Rubiaceae) ^[157]

antioxidant
activities.

(Rutaceae) ^[157]

(Papaveraceae) ^[157]

c) *Chelidonium majus* L. (Celandine)

- (Papaveraceae) ^[115]

Berberin is fluorescent and capable of producing ¹O₂ and radical species when exposed to UVA irradiation. Its phototoxicity is associated to apoptosis after ROS generation and, autophagy in cancer cell lines (« photokilling » activity).

$\lambda_{\text{max}} \sim 345 \text{ nm}$
depending on
solvent

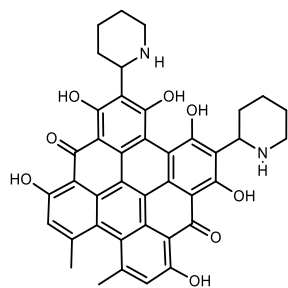
Naphthodianthrones

Fagopyrin :

Type I

E : (C₃₉H₃₂N₂O₈)

F : (C₃₈H₃₀N₂O₈)



Fagopyrin E

Fagopyrum spp.- (Polygonaceae)
[64,67]

a) North hemisphere

Leaves and flowers

[38,50,54,64,67,157]

Highly
Phototoxic^[54]

b) North hemisphere,

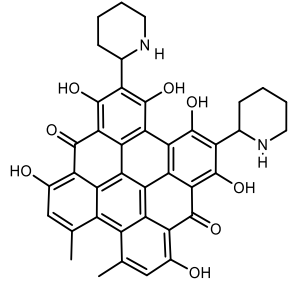
a) *Fagopyrum tataricum* (L.) Gaertn
(Tartarian buckwheat) -
(Polygonaceae)^[54,64,157]

Brazil, South of
Africa, Australia,
New Zealand

$\lambda_{\text{max}} \sim 550\text{-}590$
nm depending
on solvent

b) *Fagopyrum esculentum* Moench -
(Polygonaceae)^[38,50,54,64]

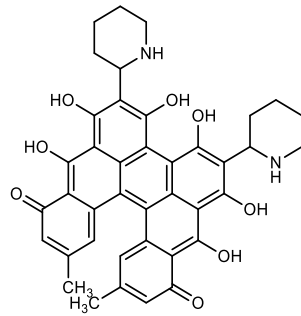
c) Balkans, Japan,
Korea, USA



c) *Fagopyrum sagittatum* -
(Polygonaceae) ^[54]

Protofagopyrin :
(C₄₀H₃₆N₂O₈)

Fagopyrin F



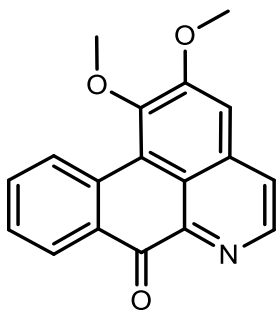
Protofagopyrin

Oxoaporphine
alkaloid

Type I

Lysicamine

(C₁₈H₁₃NO₃)



Guatteria spp. - (Annonaceae) ^[62]

a) *Guatteria blepharophylla* Mart.-
(Annonaceae) ^[61]

b) *Guatteria ferruginea* A.St.-Hil. -
(Annonaceae) ^[62]

c) *Guatteria latifolia* (Mart.) R.E.Fr.
- (Annonaceae) ^[62]

d) *Guatteria sellowiana* Schltdl. -
(Annonaceae) ^[62]

a) South hemisphere,
including Brazil

b) North of Southern
America, including
Brazil

c) Brazil

d) Brazil

Identification
of Isoquinoline
alkaloids in
aerial parts of 3
Guatteria
species found
in Brazil.

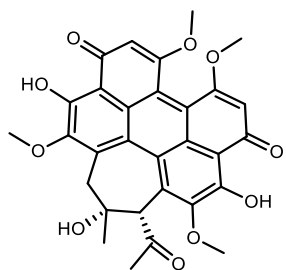
^[158]

λ_{\max} ~282nm
depending on
solvent

^[62,158]

Perylenequinone
Type I

Hypocrellin B
(C₃₀H₂₄O₉)



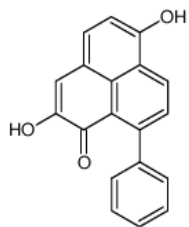
Hypocrella bambusae (Berk. &
Broome) Sacc. - (Parasitic fungi
Clavicipitaceae) [105]

China

λ_{\max} ~502-510
nm in polar
solvents like
ethanol or
DMSO [105,106,129]

Phenalenone
derivative

Lachnanthocarpon
(C₁₉H₁₂O₃)

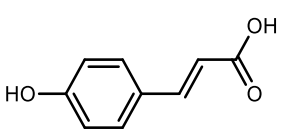
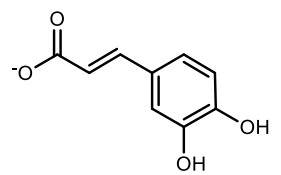


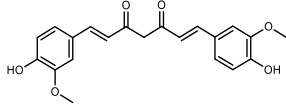
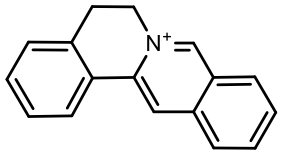
Lachnantes tinctoria –
(Haemodoraceae)

USA Atlantic coast

Phototoxic on
Staphylococcus
epidermidis [101,102,159]

Report of
lachnanthocarp
one
tetraoxygenated
derivatives
(tetraoxygenate
d
phenylphenalen
ones) in
Wachendorfia
thyrsiflora

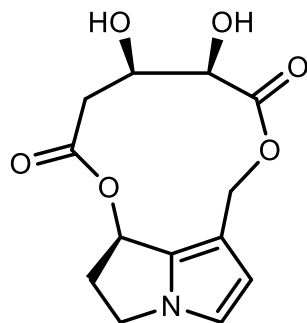
						(Haemodoraceae)	
Phenylpropanoid Type I	Hydroxycinnamic acid = (E)- <i>p</i> -coumaric acid (C ₉ H ₈ O ₃)		<i>Myrciaria cauliflora</i> (Mart.) O.Berg (Jaboticaba) - (Myrtaceae)	Americas, including Brazil	Fruits	[112]	[112]
						λ _{max} ~ 310-320 nm depending on solvent	
Polyphenol Type I	3,4-Dihydroxyphenyl polyphenolic caffeate =3,4- Dihydroxycinnamate =caffeic acid (C ₁₄ H ₁₆ O ₄)		a) <i>Froelichia floridana</i> (Nutt.) Moq. - (Amaranthaceae) [52] b) <i>Ammi majus</i> L. (Bishop's weed) - (Apiaceae) [52]	a) USA, Australia b) Southern Europe, Northern and Western Africa, Central Asia, Brazil		λ _{max} ~ 325-330 nm depending on solvent	[52]

Polyphenol Type I	Curcumin (C ₂₁ H ₂₀ O ₆)		<i>Curcuma longa</i> L. (Curcuma) - (Zingiberaceae) [41,145-147,157]	Tropical belt, including Brazil	Rhizomes	Phototoxicity [41,67,106,129,145- demonstrated in 147,150,157] several cancer cell lines and bacteria.
						λ _{max} ~ 400-500 nm depending on solvent [146,147]
Protoberberine Alkaloid Type I	Protoberberine (C ₁₇ H ₁₄ N ⁺)		<i>Chelidonium majus</i> L. (Celandine) - (Papaveraceae) [115,157]	Europe, Asia and South America, including Brazil	Leaves and stems during flowering	Phototoxic and [115,157] Pro-apoptotic in uterine cancer cells
						λ _{max} ~300-330 nm depending on solvent

Pyrrolizidine
Alkaloid

Dehydromonocrotaline

(C₁₆H₂₁NO₆)

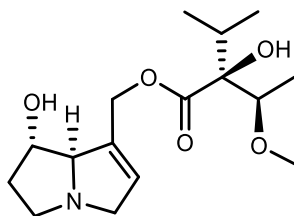


[79]

Pyrrolizidine
Alkaloid

Heliotrine

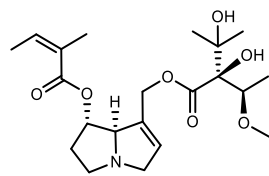
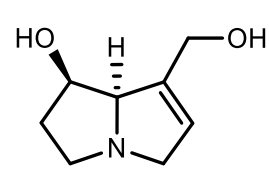
(C₁₆H₂₇NO₅)



Heliotropicum europeum (European Eurasia, Australia,
heliotrope) - (Heliotropiaceae) ^[54] USA

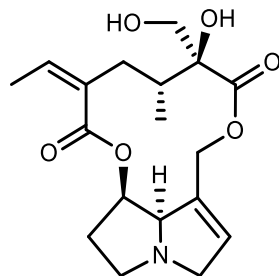
λ_{max} ~323 nm
depending on
solvent. See
Dehydromonoc
rotaline
comment

[54,79]

Pyrrolizidine Alkaloid Type I	Lasiocarpine (C ₂₁ H ₃₃ NO ₇)		<i>Heliotropium europeum</i> (European heliotrope) - (Heliotropiaceae) ^[54]	Eurasia, Australia, USA		See ^[54,79] Dehydromonoc rotaline comment
Pyrrolizidine Alkaloid Type I	Retronecine (C ₈ H ₁₃ NO ₂)		<i>Anchusa strigosa</i> Banks & Sol. - (Boraginaceae) ^[79]	Arabian peninsula, Middle East, Israel	Roots	See ^[79] Dehydromonoc rotaline comment
						λ_{max} ~265 nm depending on solvent
						λ_{max} ~330 nm depending on solvent

Pyrrolizidine
Alkaloid
Type I

Retrorsine
(C₁₈H₂₅NO₆)



- a) *Brachyglottis hectori* (Buchanan) B.Nord. - (Asteraceae)
 b) *Brachyglottis adamsii* (Cheeseman) B.Nord. - (Asteraceae)
 c) *Brachyglottis huntii* (F.Muell.) B.Nord. - (Asteraceae)
 d) *Brachyglottis perdicioides* (Hook.fil.) Hook.fil. - (Asteraceae)
 e) *Brachyglottis sciadophila* (Raoul) B.Nord. - (Asteraceae)
 f) *Brachyglottis kirkii* (Hook.fil. ex Kirk) C.J.Webb= *Urostemon kirkii* (Hook.fil. ex Kirk) B.Nord. - (Asteraceae)
 g) *Senecio jacobaea* Brot. ex Willk. & Lange, 1865 (Tansy ragwort) - (Asteraceae)
- a) New Zealand
 b) New Zealand
 c) New Zealand
 d) New Zealand
 e) New Zealand
 f) New Zealand
 g) North America, Europe, Australia
 h) Etats-Unis
 i) USA
 j) North America, Eurasia, West of South America, Australia, New Zealand

See
Dehydromonocrotaline
comment.

λ_{max}~ 250 nm
depending on
solvent

[54,79]

h) *Senecio riddellii* Torr. & A.Gray -
(Asteraceae)

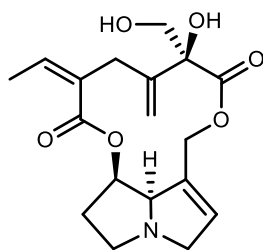
i) *Senecio douglasii* DC. -
(Asteraceae)

j) *Senecio vulgaris* L. - (Asteraceae)

Pyrrolizidine
Alkaloid
Type I

Riddelline

(C₁₈H₂₃NO₆)



Senecio riddellii Torr. & A.Gray -
(Asteraceae) ^[79]

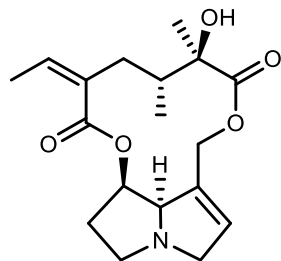
USA

See ^[79]
Dehydromonoc
rotaline
comment

λ_{max} ~ 335 nm
depending on
solvent

Pyrrolizidine
Alkaloid
Type I

Senecionine
(C₁₈H₂₅NO₅)



- Brachyglottis* spp - (Asteraceae) a) New Zealand
- a) *Brachyglottis hectori* (Buchanan) B.Nord. - (Asteraceae) b) New Zealand
- b) *Brachyglottis adamsii* (Cheeseman) B.Nord. - (Asteraceae) c) New Zealand
- c) *Brachyglottis huntii* (F.Muell.) B.Nord. - (Asteraceae) d) New Zealand
- d) *Brachyglottis perdicioides* (Hook.fil.) Hook.fil. - (Asteraceae) e) New Zealand
- e) *Brachyglottis sciadophila* (Raoul) B.Nord. - (Asteraceae) f) New Zealand
- f) *Brachyglottis kirkii* (Hook.fil. ex Kirk) C.J.Webb = *Urostemon kirkii* (Hook.fil. ex Kirk) B.Nord. - (Asteraceae) g) Mexico
- g) *Pittocaulon praecox* (Cav.) H.Rob. & Brettell - (Asteraceae) h) Mexico
- i) Mexico
- j) Mexico
- k) Mexico
- l) Europe, Mediterranean basin
- m) North hemisphere

See
Dehydromonocrotaline
comment.
 λ_{\max} ~ 245-250
nm depending
on solvent

[79]

- | | |
|---|--------------------------------|
| h) <i>Pittocaulon bombycophole</i>
(Bullock) H.Rob. & Brettell -
(Asteraceae) | n) Mediterranean
basin |
| i) <i>Pittocaulon velatum</i> (Greenm.)
H.Rob. & Brettell - (Asteraceae) | o) Italy |
| j) <i>Pittocaulon hintonii</i> H.Rob. &
Brettell - (Asteraceae) | p) Eurasia |
| k) <i>Pittocaulon filare</i> (Mc Vaugh)
H.Rob. & Brettell - (Asteraceae) | q) East Europe,
Middle East |
| <i>Senecio</i> spp. - (Asteraceae) | r) Bulgaria |
| l) <i>Senecio gibbosus</i> subsp. <i>bicolor</i> -
(Asteraceae) | s) East Europe |
| m) <i>Senecio cineraria</i> DC. -
(Asteraceae) | t) East Europe |
| n) <i>Cineraria maritima</i> L. = <i>Jacobaea</i>
<i>maritima</i> subsp. <i>maritima</i> -
(Asteraceae) | u) Europe |
| | v) East Europe |

o) *Senecio stebianus* Lacaita -
(Asteraceae)

p) *Senecio erucifolius* L. -
(Asteraceae)

q) *Senecio othonnae* M.Bieb.=
Jacobaea othonnae (M.Bieb.)
C.A.Mey. - (Asteraceae)

r) *Senecio wagneri* Degen =
Tephrosieris papposa subsp. *wagneri*
(Degen) B.Nord. - (Asteraceae)

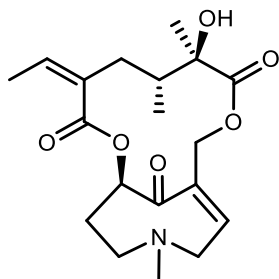
s) *Senecio subalpinus* Koch =
Jacobaea subalpina (W.D.J.Koch)
Pelser & Veldkamp - (Asteraceae)

t) *Senecio carpathicus* Herbich =
Jacobaea abrotanifolia subsp.
carpathica (Herbich) B.Nord. &
Greuter - (Asteraceae)

u) *Senecio paludosus* L. = *Jacobaea paludosa* subsp. *paludosa* -
(Asteraceae)

v) *Senecio rupestris* Waldst. & Kit.=
Senecio squalidus subsp. *rupestris*
(Waldst. & Kit.) Greuter-
(Asteraceae)

Pyrrolizidine
Alkaloid
Type I
Senkirkine = Renardine
(C₁₉H₂₇NO₆)



a) *Brachyglottis hectori* (Buchanan)
B.Nord. - (Asteraceae)

b) *Brachyglottis adamsii*
(Cheeseman) B.Nord. - (Asteraceae)

c) *Brachyglottis huntii* (F.Muell.)
B.Nord. - (Asteraceae)

d) *Brachyglottis perdicioides*
(Hook.fil.) Hook.fil. - (Asteraceae)

a) New Zealand

b) New Zealand

c) New Zealand

d) New Zealand

e) New Zealand

f) New Zealand

See
Dehydromonoc
rotaline
comment.

λ_{\max} ~ 275-280
nm depending
on solvent

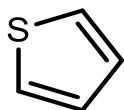
[79]

- | | |
|---|--------------------------------|
| e) <i>Brachyglottis sciadophila</i> (Raoul)
B.Nord. - (Asteraceae) | g) Mexico |
| | h) Mexico |
| f) <i>Brachyglottis kirkii</i> (Hook.fil. ex
Kirk) C.J.Webb = <i>Urostemon kirkii</i>
(Hook.fil. ex Kirk) B.Nord. -
(Asteraceae) | i) Mexico |
| | j) Mexico |
| | k) Mexico |
| g) <i>Pittocaulon praecox</i> (Cav.)
H.Rob. & Brettell - (Asteraceae) | l) East Europe,
Middle East |
| h) <i>Pittocaulon bombycophole</i>
(Bullock) H.Rob. & Brettell -
(Asteraceae) | |
| i) <i>Pittocaulon velatum</i> (Greenm.)
H.Rob. & Brettell - (Asteraceae) | |
| j) <i>Pittocaulon hintonii</i> H.Rob. &
Brettell - (Asteraceae) | |
| k) <i>Pittocaulon filare</i> (Mc Vaugh)
H.Rob. & Brettell - (Asteraceae) | |

1) *Senecio othonnae* M.Bieb.=
Jacobaea othonnae (M.Bieb.)
 C.A.Mey. - (Asteraceae)

Thiophene
 Type I

Thiophene and
 derivatives
 (C₄H₄S)



(Asteraceae) ^[47]	a) Russia, China	c) Root	ROS ^[47,106,140]
<i>Echinops</i> spp. - (Asteraceae) ^[47]			production after UV irradiation ^[157]
a) <i>Echinops latifolius</i> Tausch. - (Asteraceae) ^[47,106]	b) Worldwide, including Brazil	d) Aerial part	Phototoxic in skin and uterine cancer cell lines ^[106]
<i>Tagetes</i> spp. - (Asteraceae) ^[41,157]			λ_{max} ~ 210-225 nm depending on solvent
b) <i>Tagetes erecta</i> L. - (Asteraceae) ^[41]	c) Russia		
<i>Artemisia</i> spp. - (Asteraceae) ^[157]	d) South America, including Brazil		
<i>Balsamorhiza</i> spp. - (Asteraceae) ^[157]			
<i>Blumea</i> spp. - (Asteraceae) ^[47]			
<i>Pluchea</i> spp. - (Asteraceae) ^[47]			

Porophyllum spp. - (Asteraceae) ^[47]

Eclipta spp. - (Asteraceae) ^[47]

Heliopsis spp. - (Asteraceae) ^[41]

Rudbeckia spp. - (Asteraceae) ^[41]

c) *Leuzea carthamoides* Willd. -
(Asteraceae) ^[41]

d) *Porophyllum obscurum* (Spreng.)
DC. - (Asteraceae) ^[41]

Genus *Berkheya* - (Asteraceae) ^[41]

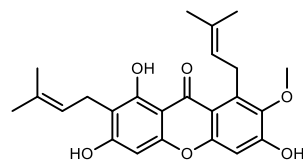
Genus *Dyssodia* - (Asteraceae) ^[41]

Genus *Echinops* - (Asteraceae) ^[41]

Genus *Bidens* - (Asteraceae) ^[41,160]

Xanthone

Mangostin



Garcinia mangostana L.
(Mangosteen) - (Clusiaceae) [88]

South hemisphere,
including Brazil

Pericarp

λ_{\max} ~ 243,
317 and 352
nm depending
on solvent

[41,89,96]

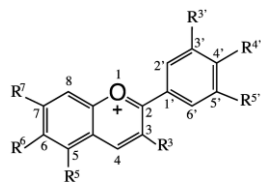
(C₂₄H₂₆O₆)

Type II

Photosensitization

Anthocyanins or
anthocyan

Anthocyanins
(flavonoids)



a) *Myrciaria cauliflora* (Mart.)
O.Berg (Jaboticaba) - (Myrtaceae)
[112]

a) Americas,
including Brazil

Fruits

Reports in
superior plants

[96,112]

[96]

Type II

(Anthocyanins are
usually considered
as photoprotective
molecules whose

(C₁₅H₁₁O⁺)

b) Red fruits, red-purple dark
vegetables, black rice [96]

[112]

biosynthesis is induced by high solar irradiation.

However, their ingestion by cattle can lead to type II photosensitization.)

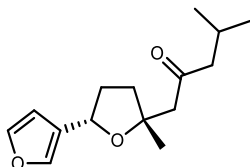
Furanosquiterpene

Type II

Ngaione

(=ipomeamarone)

(C₁₅H₂₂O₃)



Myoporum laetum G. Forst. (New Zealand manatoka) - (Scrophylariaceae)

American and European coastlines, including Brazil

Oils

Hepato-induced photosensitization

[38,54]

Lectin

Type II

Lectin *Arachis hypogaea* : PNA

Protein

Arachis hypogaea L. (Peanut) - (Fabaceae) ^[109]

Worldwide, including Brazil

Studied as PS in epidermoid carcinoma, colorectal carcinoma,

[109]

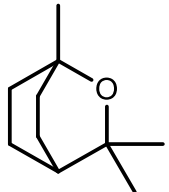
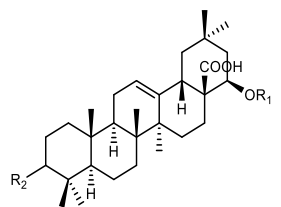
						hepato- carcinoma cell lines.	
Lectin Type II	Lectin <i>Artocarpus intregrifolia</i> : Jacalin	Protein	<i>Artocarpus integrifolia</i> L.fil. = <i>Artocarpus integer</i> (Thunb.) Merr. - (Moraceae) ^[109]	Africa, Europe, South America, including Brazil		Studied as PS in epidermoid carcinoma, colorectal carcinoma, hepato- carcinoma cell lines.	^[109]
Lectin Type II	Lectin <i>Bauhinia forficata</i> : BfL	Protein	<i>Bauhinia forficata</i> Link (Cow's foot) - (Fabaceae) ^[109]	South America, including Brazil	/	Studied as PS in the NCI-60 tumor cell lines panel. Inhibits the adhesion of	^[109]

					cancer cells on laminin, collagen I and fibronectin and induces necrosis of cancer cell and DNA fragmentation.	
Lectin Type II	Lectin <i>Glycine max</i>	Protein	<i>Glycine max</i> (L.) Merr. (Soybean) (P) - (Fabaceae) ^[109]	Americas, including Brazil, Eurasia, Africa	Studied as PS in various cancer cell lines including hepato-carcinoma, melanoma, choriocarcinoma cells. ROS-dependent induction of autophagy,	^[109]

					apoptosis and DNA damage in cells	
Lectin Type II	Lectin <i>Griffonia simplicifolia</i> : GSAIA4	Protein	<i>Griffonia simplicifolia</i> (Vahl ex DC.) Baill. - (Fabaceae) ^[109]	West Africa	Studied as PS in various cancer cell lines including Melanoma and colorectal cells.	^[109]
Lectin Type II	Lectin <i>Myrsine coriacea</i> : McL	Protein Unknown structure	<i>Myrsine coriacea</i> Merr. - (Primulaceae) ^[109]	Vietnam	Studied as PS in colon cancer cells. ROS-induced apoptosis evidenced by DNA fragmentation and Cytochrome c	^[109]

						release in the cytosol	
Lectin Type II	Lectin <i>Ricinus communis</i> : RCA	Protein Unknown structure	<i>Ricinus communis</i> L. - (Euphorbiaceae) ^[109]	Worldwide, including Brazil	/	Studied as PS in melanoma and hepatoma cell lines. ROS-induced apoptosis evidenced by chromatin condensation and nuclear fragmentation	^[109]
Lectin Type II	Lectin <i>Viscum album</i> (Mistletoe) : ML	Protein	<i>Viscum album</i> L. (Gui) - (Viscaceae) ^[109]	Eurasia, North America		Studied as PS in breast, hepatocarcinoma and colorectal cancer cells.	^[109]

					ROS-induced apoptosis in colorectal cancer cells, regulation of β -catenin expression	
Lectin Type II	Lectin <i>Ximenia americana</i> : Riproximin	Protein Unknown structure	<i>Ximenia americana</i> L. (Tallow wood) - (Ximeniaceae) ^[109]	South hemisphere, including Brazil	Studied as PS in breast carcinoma, brain, prostate, colon, leukemia cell lines. Cytotoxicity and inhibition of migration	^[109]

<p>Monoterpene Type II</p>	<p>(+)-Eucalyptol =1,8-cinéole (C₁₀H₁₈O)</p>		<p>a) <i>Eucalyptus globulus</i> Labill. (Eucalyptus / Gommier bleu) - (Myrtaceae) ^[108] b) <i>Cinnamomum camphora</i> (L.) Nees & Eberm. = <i>Cinnamomum camphora</i> (L.) J.Presl (Camphrier / Laurier de Chine) - (Lauraceae) ^[108]</p>	<p>a) Worldwide, including Brazil b) Worldwide, including Brazil</p>	<p>Widely distributed in plant essential oils. First published study evaluating the use of essential oils as PS, in addition to their well-known antibacterial activities. Eucalyptol, eugenol and thymol have been studied as potential PS.</p>	<p>[108]</p>
<p>Pentacyclic triterpenes Type II</p>	<p>Lantadenes A = (C₃₅H₅₄O₅)</p>		<p><i>Lantana camara</i> L. (Common lantana) - (Verbenaceae)</p>	<p>Worldwide</p>	<p>Reports of photosensitization after hepatic metabolism (hepato-induced)</p>	<p>[54]</p>

B = (C₃₅H₅₂O₅)

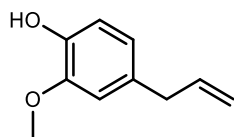
photosensitization)

C = (C₃₅H₅₄O₅)

D = (C₃₄H₅₂O₅)

Phenolic compound

Eugenol



Syzygium aromaticum (L.) Merr. & Perry = *Eugenia caryophyllata* Thunb. (Clove) - (Myrtaceae) ^[108]

Tropical rainforest, including Brazil

Clove (flower bud)

See comment for Eucalyptol

[108]

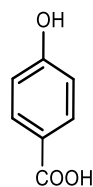
Type II

(C₁₀H₁₂O₂)

Phenolic compound *p*-hydroxy-benzoic acid

Type II

(C₇H₆O₃)



Myrciaria cauliflora (Mart.) O.Berg (Jaboticaba = Brazilian fruit) - (Myrtaceae)

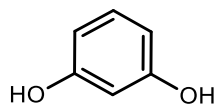
Americas, including Brazil

Fruits

[112]

Phenolic compound

Resorcinol



Myrciaria cauliflora (Mart.) O.Berg (Jaboticaba) - (Myrtaceae)

This plant is native to Brazil, and is distributed

Fruits

[56,112]

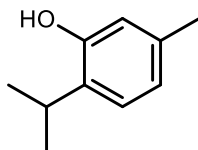
Type II

(C₆H₆O₂)

throughout the
Atlantic Forest
biome.

Phenolic compound

Thymol



a) *Thymus vulgaris* L. (Thyme)

a) Europa, Oceania, Clove, thyme, oregano,
USA, Central and cinnamon and
South Americas, peppermint oils, (as
including Brazil well as other volatile
oils)

Phototoxic in
bacteria,
viruses, fungi,
protozoans.

[108]

Type II

(C₁₀H₁₄O)

b) *Eucalyptus globulus* Labill.
(Eucalyptus / Gommier bleu) -
(Myrtaceae)

b) Worldwide,
including Brazil

Active in
sessile cells and
biofilms.

c) *Syzygium aromaticum* (L.) Merr.
& Perry = *Eugenia caryophyllata*
Thunb. (Clove) - (Myrtaceae)

c) Tropical
rainforest, including
Brazil

Widely used as
conservative in
pharmaceutical
products.

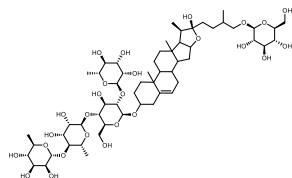
See Eucalyptol
comment.

Saponin

Type II

Dichotomin

(C₅₇H₉₄O₂₆)



a) *Brachiaria decumbens* Stapf = a) Central and South
Brachiaria eminii (Mez) Robyns - Americas, including
(Poaceae) [114] Brazil, Africa

b) *Panicum dichotomiflorum* Michx. b) Americas
(Millet) - (Poaceae) [114] (including Brazil)
Europe, Korea and
Japan, New Zealand

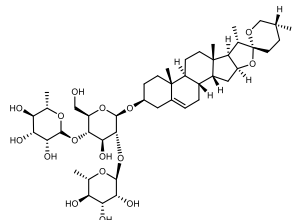
[114]

Saponin

Type II

Dioscin

(C₄₅H₇₂O₁₆)



a) *Brachiaria decumbens* Stapf = a) Central and South
Brachiaria eminii (Mez) Robyns - Americas, including
(Poaceae) [114] Brazil, Africa

b) *Costus speciosus* (J.Koenig) Sm.= b) Pacific Asia,
Hellenia speciosa (J.Koenig) Central America
S.R.Dutta (Canereed) - (Costaceae)

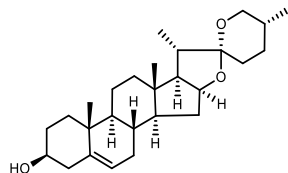
[91]

[116,161]

Saponin
Type II

Diosgenin

(C₂₇H₄₂O₃)



a) *Costus speciosus* (J.Koenig) Sm.=
Hellenia speciosa (J.Koenig)
S.R.Dutta (Canereed) - (Costaceae)

[91]

b) *Panicum dichotomiflorum* Michx.
(Smooth witchgrass) - (Poaceae)

[54,91]

c) *Brachiaria decumbens* Stapf =
Brachiaria eminii (Mez) Robyns
(Poaceae) (Meagher, Smith and
Wilkins, 2001; Muniandy *et al.*,
2020)

d) *Panicum antidotale* Retz. (Blue
panicum) - (Poaceae) [54]

e) *Panicum coloratum* L. (Coolah
grass) - (Poaceae) [54]

f) *Panicum maximum* Jacq. =
Megathyrsus maximus (Jacq.)

a) Pacific Asia,
Central America

b) Americas
(including Brazil)

Europe, Korea and
Japan, New Zealand

c) Central and South
Americas, including
Brazil, Africa

d) Australia, USA,
some occurrences in
Europe

e) Africa, U.S.A-
Mexico border, one
occurrence in Brazil

f) Americas,
including Brazil,

a) Rhizomes

Reported in
biliary crystals
associated to
hepatogenous
photosensitizati
on of sheep,
goats and cattle

[54,91,114]

B.K.Simon & S.W.L.Jacobs (Guinea Africa, East Asia,
grass) - (Poaceae) ^[54] Australia

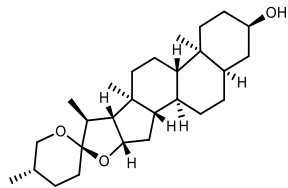
g) *Panicum miliaceum* L. (Millet) - g) North hemisphere,
(Poaceae) ^[54,114] Australia, rares cases
in Brazil

h) *Panicum virgatum* L. (Switch
grass) - (Poaceae) ^[54] h) USA, Europe, East
Asia

i) *Tribulus terrestris* L. (Tribule
terrestre) - (Zygophyllaceae) ^[91,114] i) Worldwide,
including Brazil

Saponin

Episarsasapogenin



(C₂₇H₄₄O₃)

Panicum spp. - (Poaceae)

a) Worldwide,
including Brazil

[91]

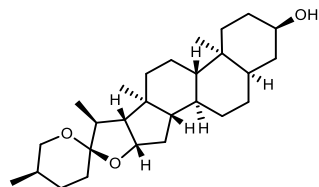
a) *Tribulus terrestris* L. (Tribule
terrestre) - (Zygophyllaceae)

b) Europe

Involved in
the
hepatogenous
photosensitizati
on of cattle.
Identified in
biliary crystals.

b) *Nartheccium ossifragum* (L.) Huds.
 (Nathrécie des marais) -
 (Narthecciaceae)

Saponin
 Type II
 Epismilagenin
 (C₂₇H₄₄O₃)
 = (3 α ,5 β ,25R)-
 Spirostan-3-ol



Panicum spp. - (Poaceae) ^[91]
 a) *Tribulus terrestris* - ^[162]
 b) *Panicum antidotale* Retz. (Blue
 panicum) - (Poaceae) ^[54]
 c) *Panicum coloratum* L. (Coolah
 grass) - (Poaceae) ^[54]
 d) *Panicum dichotomiflorum* Michx.
 (Millet) - (Poaceae) ^[54]
 e) *Panicum maximum* Jacq. =
Megathyrsus maximus (Jacq.)
 B.K.Simon & S.W.L.Jacobs (Guinea
 grass) - (Poaceae) ^[54]
 f) *Panicum miliaceum* L. (Millet) -
 (Poaceae) ^[54]

a) South Africa
 b) Australia, USA,
 some occurrences in
 Europe
 c) Africa, U.S.A-
 Mexico border, one
 occurrence in Brazil
 d) Americas
 (including Brazil)
 Europe, Korea and
 Japan, New Zealand
 e) Americas,
 including Brazil,

Involvement in
 the
 hepatogenous
 photosensitization
 of cattle. ^[54,91,162]

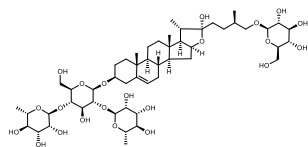
g) *Panicum virgatum* L. (Switch grass) - (Poaceae) ^[54] Africa, East Asia, Australia

f) North hemisphere, Australia, rares cases in Brazil

g) USA, Europe, East Asia

Saponin

Protodioscine



Type II

(C₅₁H₈₄O₂₂)

a) *Brachiaria decumbens* Stapf = *Brachiaria eminii* (Mez) Robyns - (Poaceae)

a) Central and South Americas, including Brazil, Africa

Grasses of the genus *Brachiaria* and leaves

Reports of Phototoxicity in cattle (buffaloes).

[116]

b) *Brachiaria brizantha* (A.Rich.) Stapf - (Poaceae)

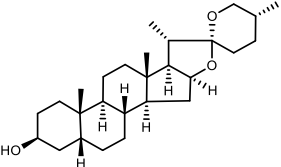
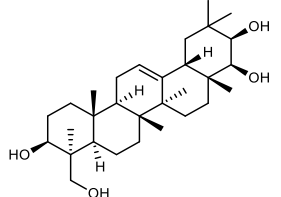
b) Central and South Americas, including Brazil, Africa, Asia

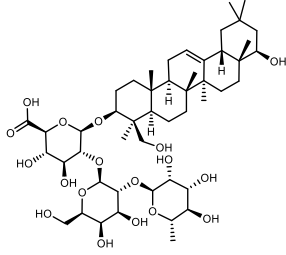
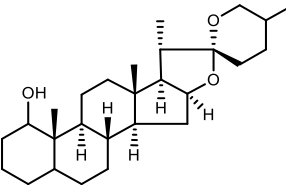
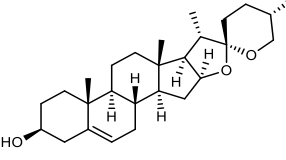
c) *Brachiaria humidicola* (Rendle) Schweick.= *Brachiaria dictyoneura*

Pacific

(Fig. & De Not.) Stapf - (Poaceae)

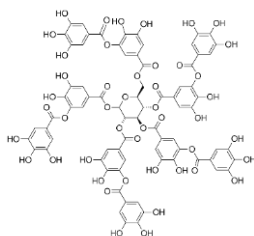
c) Central and South Americas, including Brazil, Africa

Saponin Type II	Smilagenin (C ₂₇ H ₄₄ O ₃)		<i>Narthecium ossifragum</i> (L.) Huds. (Swamp natherica) - (Nartheciaceae) [91,114]	Europe	Involved in the hepatogenous photosensitizati on of cattle. Identified in biliary crystals.	[91,114]
Saponin Type II	Soyasapogenol A: R=OH on C ₂₁ B: R=H on C ₂₁ (C ₃₀ H ₅₀ O ₄ or C ₃₀ H ₅₀ O ₃)		<i>Brachiaria decumbens</i> Stapf = <i>Brachiaria eminii</i> (Mez) Robyns - (Poaceae)	Central and South Americas, including Brazil, Africa	Saponins often found in forages include dioscin/protodi oscin, soyasapogenin, diosgenin, soyasapogenol, and yamogenin	[114]

Saponin Type II	Soyasaponin I (C ₄₈ H ₇₈ O ₁₈)		<i>Brachiaria decumbens</i> Stapf = <i>Brachiaria eminii</i> (Mez) Robyns - (Poaceae) ^[114] <i>Glycine max</i> (soybean)	Central and South Americas, including Brazil, Africa	See the soyasapogenol comment	[114]
Saponin Type II	Spirostanol C ₂₇ H ₄₄ O ₃		<i>Brachiaria decumbens</i> Stapf = <i>Brachiaria eminii</i> (Mez) Robyns - (Poaceae) ^[38]	Central and South Americas, including Brazil, Africa		[38]
Saponin Type II	Yamogenin (C ₂₇ H ₄₂ O ₃)		a) <i>Brachiaria decumbens</i> Stapf = <i>Brachiaria eminii</i> (Mez) Robyns - (Poaceae) ^[91,114] b) <i>Panicum miliaceum</i> L. (Millet) - (Poaceae) ^[114]	a) Central and South Americas, including Brazil, Africa b) North hemisphere, Australia, rares cases in Brazil c) Europe	Cattle in Brazil have exhibited symptoms of photosensitizati on after the ingestion of <i>Bracharia decumbens</i> [91,114]	[91,114]

c) *Nartheccium ossifragum* (L.) Huds.
 (Nathrécie des marais) -
 (Narthecciaceae) ^[114]

Tannin
 Type II
 Pyrogalllic and
 flobabenic tannins

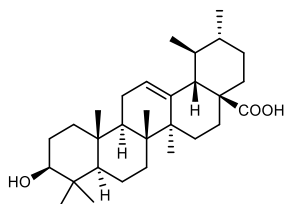


a) *Mimosa pteridifolia* Benth. -
 (Fabaceae)
 b) *Mimosa verrucosa* Benth. (Jurema-
 branca, Jurema-de-oeiras) -
 (Fabaceae)
 c) *Mimosa tenuiflora* Willd. Poir.
 (Jurema preta, calumbi) - (Fabaceae)

a) Brazil
 b) Brazil
 c) Central America
 and Brazil

[97]

Triterpene
 Type II
 Ursolic acid
 (C₃₀H₄₈O₃)



Abundant triterpene present in
 several species ^[163] including
Malus pumila (apple tree)
Ocimum basilicum (basil)

Nanovectorizati
 on strategy
 using
 indocyanine
 green and
 ursolic acid to
 treat cancers by

[144,163]

Vaccinium spp. (bilberries,
blueberries, cranberries)

laser
phototherapy

Olea europaea (olive)

Origanum vulgare (oregano)

Rosmarinus officinalis (rosemary)

Salvia officinalis (sage, salvia)

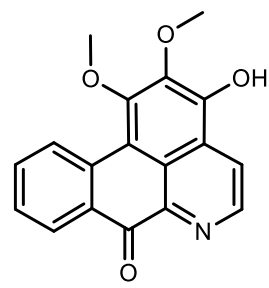
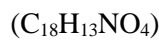
Thymus vulgaris L. (common thyme)

Type I and II Mixed
Photosensitization

Oxoaporphine
alkaloid

Type I and II

Isomoschatoline
(3-Hydroxy-1,2-
dimethoxy-7H-
dibenzo[de,g]quinoline-
7-one)



Guatteria spp. - (Annonaceae) ^[62]

a) *Guatteria blepharophylla* Mart.-
(Annonaceae) ^[61]

b) *Guatteria ferruginea* A.St.-Hil. -
(Annonaceae) ^[62]

a) South hemisphere,
including Brazil

b) North of Southern
America, including
Brazil

c) Brazil

Bark, crude extract

Antibacterial
phototoxicity in
Gram + and
Gram –
bacteria and
Candida yeasts.

Induction of
type I and II
photochemical

^[62,62]

c) *Guatteria latifolia* (Mart.) R.E.Fr.
- (Annonaceae) [62]

d) Brazil

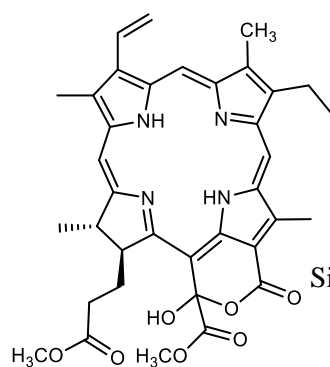
mechanisms. λ
max~600-700
nm depending
on solvent

d) *Guatteria sellowiana* Schlttdl. -
(Annonaceae) [62]

Porphyrins and
derivatives
Type I and II

20¹-Hydroxypurpurin-7
delta-lactone diesters
and derivatives
(dimethyl esters, ethyl
methyl diester, methyl
phytyl diester)

(Hydroxy purpurin 7-
lactone dimethyl ester :
C₃₆H₃₈N₄O₇)



Hydroxy purpurin 7-
lactone dimethyl ester

a) *Aglaonema simplex* (Blume)
(Malayan sword) - (Araceae)

b) *Phyllostachys bambusoides*
Siebold & Zucc (Japanese bamboo) -
(Poaceae)

a) South East Asia

b) Africa, Asia,
North and South
America, including
Brazil

a) Leaves and stems

b) Leaves

Highly
phototoxic and
pro-apoptotic
against human
promyelocytic
leukemia
(HL60) and
human
leukemia cells
(CMK-7).

[47,72,106]

$\lambda_{\text{max}} \sim 430\text{-}440$
nm depending
on solvent

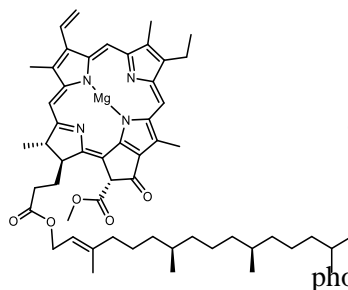
[106]

Porphyrins and
derivatives

Type I and II
(phylloerythrin
derivative, see
paragraph 4.)

Chlorophyll *a*

($\text{C}_{55}\text{H}_{72}\text{MgN}_4\text{O}_5$)



Present in all photosynthetic
organisms- Chlorophyll *a*
ecophysiological function is to
ensure photon collection for
oxygenic photosynthesis in
photosystems so its primary function
is not to act as a phototoxic
compound. However, chlorophylls
and derivatives (e.g. pheophorbides
and derivatives) show high
phototoxicity when purified.

λ_{max} chlorophyll *a*: 430, 660 nm
depending on solvent

Chlorophyll *a*
can be found at
a massive
concentration
of up to 2% in
leaves and is
therefore an
accessible,
functionalizable
pigment and
an excellent
starting
material for the
development of
new PS.

[48,76,96]

Several chlorophyll *a* derivatives have a high phototoxic activity, for example chlorin, which shows a characteristic absorption spectrum at 400 nm and 680 nm. Chlorophyll *a* is also the precursor of Pheophorbide *a*, its dephytylated and demetallized metabolite, that

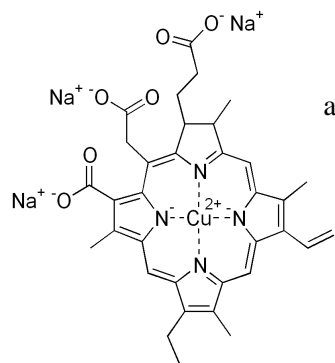
exhibits potent phototoxic activity and can be obtained through chemical or enzymatic treatment. [48]

Porphyrins and derivatives

Type I and II

Chlorophyllin *a*

(C₃₄H₃₄MgN₄O₆)



a) *Spinacia oleracea* L. (Spinach) - (Amaranthaceae) [157]

b) Many plant species

a) Eurasia, North and South Americas, including Brazil

a) Leaves

Phototoxic at [106,129,146,157]
405 nm on
Bacillus cereus,
Listeria monocytogenes,
Salmonella enterica,
Escherichia coli,
Pseudomonas aeruginosa,
Enterococcus

faecalis and
fungi. [146]

Efficient for the
photodecontam
ination of
plums (*Prunus
domestica*),
tomatoes
(*Solanum
lycopersicum*),
cauliflowers
(*Brassica
oleracea*) and
red peppers
(*Capsicum
annum*),
naturally
contaminated
with mesophilic
bacteria.

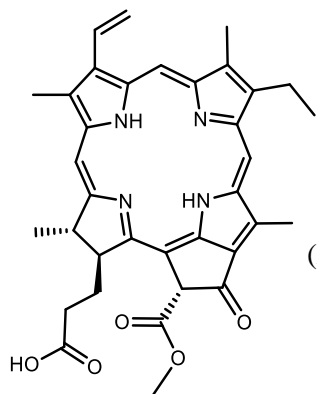
Chlorophyllin is activated in the wavelength range of 600–670 nm ^[106,157]

Porphyrins and derivatives

Type I and II

Pheophorbide *a*

(C₃₅H₃₆N₄O₅)



- a) *Leonurus sibiricus* L. - (Lamiaceae) ^[73]
- b) *Scutellaria barbata* D. Don (Barbed skullcap) - (Lamiaceae) (Mansoori *et al.*, 2019; Foresto *et al.*, 2021b)
- c) *Pentaspadon motleyi* - (Anacardiaceae) ^[73]

- a) Americas, including Brazil, Europe, Asia
- b) Southern China
- c) Asia Pacific
- d) South East Asia

λ_{\max} ^[48,50,73,76,106,129,157]
pheophorbide *a*: 410, 666 nm
depending on solvent

Pheophorbide *a* and derivatives have also been reported as the molecules responsible for the

d) *Aglaonema simplex* Blume
(Malayan sword) - (Araceae) ^[73]

e) *Euterpe oleracea* Mart. (Pinot) -
(Araceae) ^[76]

j) *Tetragonia tetragonoides* (Pall.)
Kuntze (Tetragone) - (Aizoaceae) ^[48]

e) Brazil and
Colombia

f) Coastlines,
including Brazil

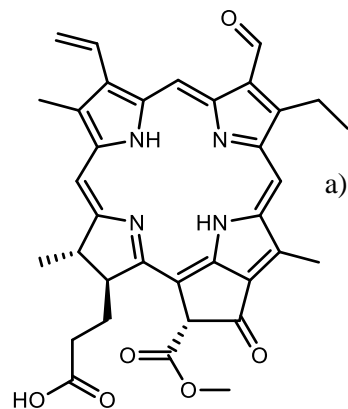
phototoxicity of
microalgae
extracts such as
Skeletonema
sp. ethanolic
extract by some
authors of this
work (French
patent
FR20/03712)

Porphyrins and
derivatives

Type I and II

Pheophorbide *b*

(C₃₅H₃₄N₄O₆)



a) *Pentaspadon motleyi* Hook.fil. -
(Anacardiaceae) ^[73]

b) *Tetragonia tetragonoides* (Pall.)
Kuntze (Tetragone) - (Aizoaceae) ^[48]

a) Asia Pacific

b) Coastlines,
including Brazil

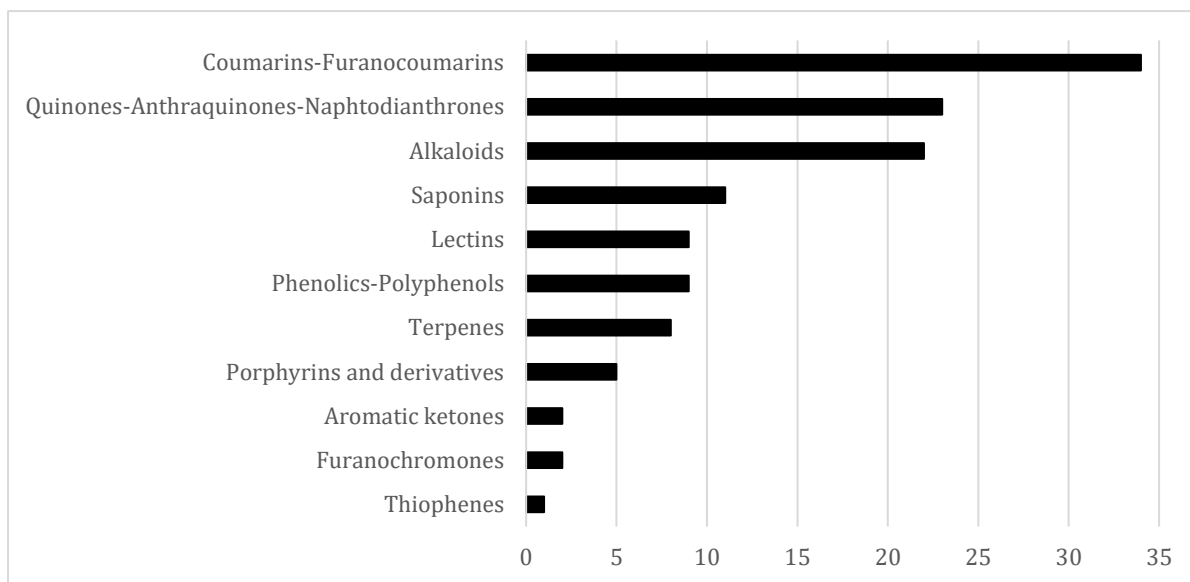
Phototoxic on
human
colorectal
carcinoma
cells. ^[106]

λ_{max}
pheophorbide
b: 435, 654 nm
depending on
solvent

[48,73]

424 Table 2. List of phototoxic plants natural products, classified in alphabetic order. For each molecule are presented the raw formula, molecular
425 structure, chemical family, producing species, geographical localization of producing species, plant tissue(s) or organ(s) containing the molecule(s)
426 and biological activity in phototoxicity models. Phototoxicity events in humans and animals are also indicated when available.

427 The distribution of plant phototoxic molecules in different chemical families is presented in
428 Figure 3. A total of 125 phototoxic molecules was listed, including 35 coumarins and
429 furanocoumarins, 23 quinones/anthraquinones/naphthodianthrones, 22 alkaloids, 11 saponins, 9
430 phenolics and polyphenols, 9 lectins, 8 terpenes, 5 porphyrins and derivatives, 2
431 furanochromones and 1 thiophene.



432
433 Figure 3. Repartition of the 125 plants phototoxic natural products in chemical families. The
434 top five chemical families including the highest number of phototoxic compounds are
435 coumarins and furanocoumarins (29), quinones, anthraquinones and naphthodianthrones (22),
436 alkaloids (20), saponins (11) and lectins (9).

437
438 Table 3. summarizes the distribution of phototoxic metabolites by botanical families. These
439 data can be useful to select a botanical family for the identification and/or purification of
440 phototoxic metabolites that belong to a targeted chemical family.

441
442
443
444
445

446

	Amaranthaceae	Anacardiaceae	Annonaceae	Apiaceae	Asteraceae	Fabaceae	Hypericaceae	Lamiaceae	Poaceae	Rubiaceae	Rutaceae
Alkaloids											
Catechols											
Coumarins and Furanocoumarins											
Lectins											
Polyphenols											
Porphyrins and derivatives											
Quinones/Anthraquinones/Naphthodianthrones											
Saponins											
Tannins											
Thiophenes											

447

448 Table 3. Distribution of phototoxic metabolites in the 11 major botanical families containing phototoxic species. A dark gray rectangle indicates
 449 the discriminant presence of these metabolites in the botanical family, a light gray rectangle indicates the non-specific biosynthesis of these
 450 metabolites (porphyrins and derivatives are photon collectors for oxygenic photosynthesis, but can be highly phototoxic once purified).

451

452

453 8. Conclusion

454 In this study, we have inventoried phototoxic plants and their phototoxic metabolites as a
455 reservoir of chemodiversity for the possible development of photosensitizers for antimicrobial
456 and antitumor phototherapy. Based on our results, we show that most biomes of the world
457 contain plant species of major interest for the isolation of natural phototoxic molecules and that
458 this high biodiversity is also related to a high chemodiversity. This implies that the biosynthesis
459 of phototoxic phytochemicals is probably a convergent evolutionary trait that has evolved in a
460 large taxonomic diversity of terrestrial plants, in reaction to a wide diversity of aggressions by
461 predators and microorganisms. However, only around 250 vascular plant species (less than
462 0.09% of all species), have been identified as phototoxic, containing a total of 125 phototoxic
463 compounds, some of which are occurring together in a given species. These data suggest that
464 this evolutionary strategy remains relatively rare for plants, although it can be observed in most
465 ecoregions of the world and in a wide variety of taxonomic families. Based on our data, we
466 could demonstrate that the botanical families Amaranthaceae, Anacardiaceae, Annonaceae,
467 Apiaceae, Asteraceae, Fabaceae, Hypericaceae, Lamiaceae, Poaceae and Rutaceae have an
468 important metabolic potential for the biosynthesis of phototoxic secondary metabolites,
469 inducing primary photosensitizers (coumarins and furanocoumarins,
470 quinones/anthraquinones/naphthodianthrones, alkaloids, porphyrins and derivatives,
471 furanochromones and thiophenes) or secondary photosensitizers (saponins, phenolics and
472 polyphenols, lectins, terpenes, chlorophylls and derivatives). Additional metabolites present in
473 terrestrial plants, such as folates and pterins derivatives can also be considered as
474 photosensitizing molecules with potential interest for the development of pharmacomodulated
475 phototoxic derivatives ^[164]. Our study also demonstrates that several phototoxic species contain
476 unidentified molecules and it would be interesting to study them to obtain new chemical
477 scaffolds with improved ROS production yields, selective photoactivation parameters,
478 interesting potential for pharmacomodulation or possible bioavailability improvements.

479 This review brought together scattered information from the literature about the world's plants
480 ability to produce natural phototoxic compounds with potential for phototherapy. Our
481 bibliographic research also revealed that a few species not belonging to the plant group also
482 synthesize phototoxic molecules. These included

483 (i) *Teloschistes flavicans* (Sw.) Norman, a golden hair lichen (*Teloschistaceae*) present in
484 Europe, South Africa, Oceania, Central and South Americas, including Brazil (Caatinga,

485 Amazônia, Mata Atlântica and Cerrado) synthesizing parietin, an anthraquinone pigment, [129].
486 There are very few scientific articles demonstrating the presence of phototoxic molecules in
487 lichens, but the finding in this species suggests that this hypothesis should be investigated
488 further (on the other hand, several publications attest to the presence of photoprotective
489 molecules in lichens [165]).

490 (ii) *Sclerotium rolfsii* Sacc. *Athelia rolfsii* (Curzi) C.C.Tu & Kimbr. (Atheliaceae), a soil fungus
491 particularly prevalent in warm tropical and subtropical regions, which causes rotting of
492 agronomic plants, present in Europe, USA, South of Africa, East of Asia and Brazil (Pampa
493 and Mata Atlântica), whose phototoxicity was related to the synthesis of furanocoumarins
494 (4,5',8-Trimethylpsoralen, 8-hydroxybergapten, bergapten, isoimperatorin, isopimpinellin,
495 xanthotoxin) [50,66].

496 (iii) *Alternaria alternata* (Fr.) Keissl. (Pleosporaceae), a worldwide plant pathogenic fungus
497 (often simply designated as "*Alternaria*"), agent of leaf spot disease, causing black spots, rot
498 and rust on a wide range of plant species, present in Brazil in Caatinga, Pampa, Mata Atlântica,
499 Cerrado and producing Altertoxin I, a phototoxic perylene dione [105].

500 (iv) *Cercospora kikuchii* (Tak.Matsumoto & Tomoy.) M.W.Gardner (Mycosphaerellaceae), a
501 worldwide phytopathogenic fungus, responsible for the *Cercospora* leaf blight and purple seed
502 stain diseases and producing the toxin cercosporin, a perylenequinone. Related
503 perylenequinone fungal toxins with potential phototoxicity include cercosporin (*Cercospora*
504 *sp.*), hypocrellin A (*Hypocrella bambusae*), Phleochrome (*Cladosporium spp*) and
505 Elsinochrome A (*Elsinoe spp*) [105].

506 (v) Basidiomycetes and sordariomycetes [166,167]: *Agaricus bisporus* (J.E.Lange) Imbach
507 (Agaricaceae), an edible basidiomycete mushroom present in Europe, USA, Australia, Asia
508 and America), contains a phototoxic lectin [109]. *Cortinarius croceus* acetone extract was
509 characterized by an $EC_{50, 9.3 J cm^{-2}}$ of $1 \mu g L^{-1}$ against cells of a lung cancer cell-line (A549) [166].
510 *Cortinarius austrovenetus* was also reported to contain austroventin, a precursor of hypericin
511 that is oxidized when insects attack the fruiting bodies of the basidiomycete [166]. *Inonotus*
512 *obliquus*, *Tapinella atrotomentosa*, *Roesleria subterranea* and *Metarhizium brunneum*
513 (sordariomycete) were also reported as containing phototoxic molecules inducing singlet
514 oxygen production [166]. Other phototoxic natural products have been reported from
515 Basidiomycetes, including questin, funalenone and 7,7'-emodinphyscion [166]. The small

516 number of articles published in the field suggests that these organisms represent an interesting
517 but under-explored source of photosensitizers.

518 (vi) Microalgae species containing phototoxic porphyrin derivatives (e.g. ethanolic extract of
519 diatoms from the genus *Skeletonema*, French patent FR20/03712 published by our group on
520 the 15th of October 2021 by the French national institute of intellectual property INPI).

521 (vii) Bacterial, archaeal or cyanobacterial species containing phototoxic pigments such as
522 prodigiosin, violacein or carotenoids.

523 The low number of phototoxic molecules identified in microorganisms suggests that these
524 taxonomic groups have not been extensively screened yet. Additionally, no phototoxic
525 molecules have been reported from bryophytes, filices and lycophytes so far, but it cannot be
526 ruled out that these species have a potential to synthesize phototoxic molecules.

527 9. Future perspectives

528 Plant phototoxic molecules have a high potential for the development of new PS that could be
529 used in topical or injectable formulations or grafted on biomaterials. Applications of these new
530 PS could include the photodecontamination of abiotic surfaces (e.g. decontamination of labs
531 and hospitals workplans), treatment of topical infections caused by bacteria, viruses and fungi
532 (e.g. chronic diabetic wounds, acne, nail mycosis), phototherapy of topical and internal tumors
533 and manufacturing of photoactive devices (e.g. tissues, fibers, clothes, bandages). The chemical
534 diversity of plant molecules inducing primary photosensitization implies that they have
535 different bioavailabilities and different maximum absorption wavelengths, which makes it
536 possible to envisage their differential use for topical or internal photoactivations using LASER.
537 They could also be used as chemical leads for pharmacomodulation to selectively target
538 microorganisms or cells to be destroyed (e.g. grafting of antibiotics or oligosaccharides to
539 target bacterial membranes, grafting of polyamines to target tumor cell membranes, coupling
540 to antibodies for vectorization against tumor antigens). Hardly any phototoxic molecules have
541 been the subject of pharmaceutical or clinical studies so far, and some of them are found in
542 common plants of agronomic, cosmetic, perfumery or medicinal interest, suggesting a possible
543 secondary valorization of these species. Indeed, the vast majority are common species that are
544 easy to cultivate, and it can be hypothesized that some valuable economic chains could be
545 developed to produce PS (some species being already cultivated for the production of fruits,
546 oils, essential oils, perfumes, spices, etc.).

547 The sustainable industrial production of natural photosensitisers from phototoxic plants will
548 undoubtedly benefit from advances in other areas of medicinal chemistry and pharmacognosy
549 research, such as the development of eco-friendly based extraction and purification processes
550 [168,169], hemisynthesis or biotechnological production of bioactive metabolites in plant
551 bioreactor cell cultures [170]. Finally, this study re-emphasises the importance of preserving
552 plants as a pharmaceutical resource for humanity, as some species at risk of extinction could
553 contain molecules allowing major innovations in the field of clinical phototherapy.

554

555 Declaration of competing interest

556 The authors declare that they have no known competing financial interests or personal
557 relationships that could have appeared to influence the work reported in this paper.

558 Authors' contributions

559 Conceptualization: LP, VT, JGDSA, RGDOJ, VS; Data collection, analysis and curation: RP,
560 JI, MG, RGDOJ, VT, LP; Writing, review and editing: All authors; Funding acquisition: LP
561 and VT; Coordination and supervision: LP.

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566

567 Keywords

568 Natural Product, Plant, Photodynamic therapy, Photosensitizer, Phototoxicity.

569

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