Mode of action and toxicology of plant toxins and poisonous plants

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Abstract

Plants have evolved the strategy to produce bioactive natural products as a means of defence against herbivores and microbes. Some plants produce toxins that can severely damage or kill a herbivore. The molecular mode of action of neurotoxins, cytotoxins, metabolic poisons, mutagens and toxins that affect skin and mucosal tissues are summarised and discussed. Important poisonous plants of Europe, their toxins and toxicology are tabulated, as this group of plants can provide lead compounds for the development of natural pesticides against insects, slugs or rodents.

1. Why do plants need toxins?

It is a trivial observation that most animals can run away when attacked by a predator. When challenged by bacteria, fungi, viruses or parasites, the immune system takes care of the problem. Some marine animals, but also most toads and frogs, are not mobile enough to escape a predator. As a common theme, sessile or slow-moving animals have evolved a battery of poisons that make them unpalatable and toxic. Chemically, the poisons are peptides but also low molecular weight compounds, such as alkaloids, terpenoids, saponins or other secondary metabolites (as these natural products are usually called) (Wink 1999a,b; Wink and van Wyk, 2008).

Considering the situation of plants, we recognise a similarity to sessile marine organisms. Plants can neither evade herbivores by flight nor do they have an immune system to fight invading microorganisms. From the early days of the evolution of land plants in the Devonian, herbivores and microbes were present and challenging plants (Wink 2003, 2008). The evolutionary solution of plants was the production of a wide variety of secondary metabolites (Fig. 1), which can interfere with the biochemistry and physiology of herbivores on one hand and some with bacteria, fungi, viruses and even competing plants on the other hand (Fig. 2) (Wink 1988, 2007b). Today, plants usually produce and accumulate not single entities but mixtures of secondary metabolites that mostly belong to several classes. For example, even plants that produce lethal alkaloids, also sequester terpenoids or polyphenols. The components in a mixture may be additive or even synergistic in their overall properties and activities (Wink 2008c).

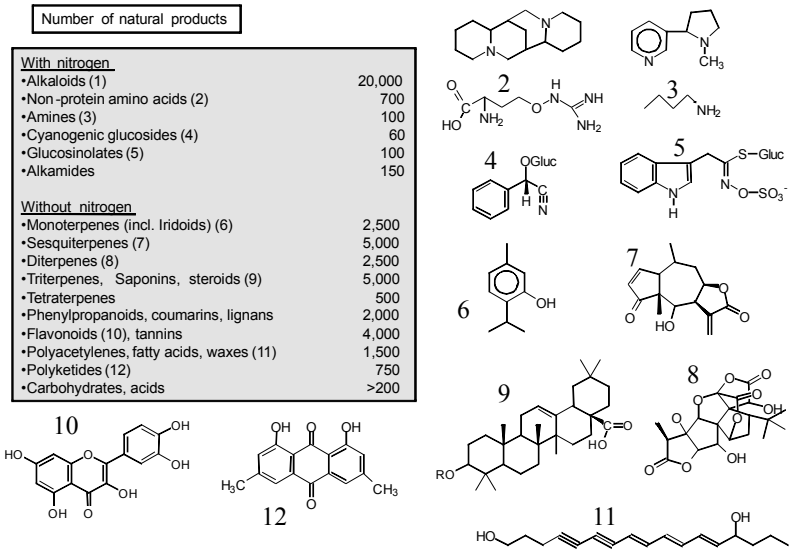

Fig. 1 Number of known secondary metabolites

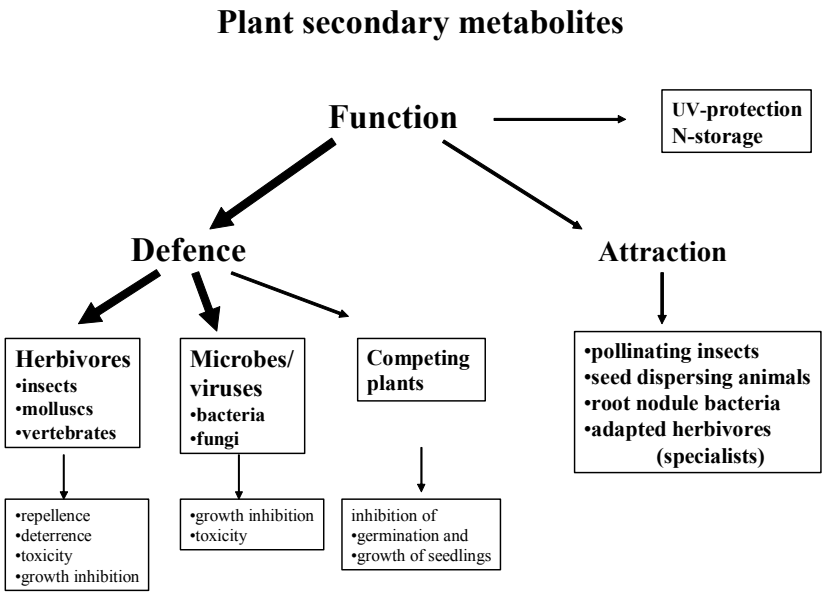

Fig. 2 Function of plant secondary metabolites

Biosynthesis, transport and storage of secondary metabolites are usually complex processes in plants, which are regulated in space and time. Some compounds, such as tropane alkaloids, which are typical for several genera of the Solanaceae (*Atropa*, *Hyoscyamus*, *Datura*, *Brugmansia*, *Duboisia*, M and*ragora*, *Scopolia* and *Schizanthus*) are produced in the roots and then translocated via the xylem to the aerial parts. In leaves, flowers and fruits the neuroactive alkaloids are stored in vacuoles. Quinolizidine alkaloids, such as lupanine or cytisine, are synthesised in chloroplasts of aerial organs, such as leaves of several legumes (especially within the genistoid legumes). These alkaloids are transported to other aerial organs (such as fruits and seeds) and roots via the phloem. These alkaloids also accumulate in vacuoles (Wink, 1997; 1999a,b).

2. What is the biochemical mode of action of poisonous secondary metabolites?

In order to be effective, the defence compounds must be able to interfere with molecular targets of cells, tissues or organs in a herbivore. For an overview over the various activities of secondary metabolites towards eukaryotic and prokaryotic cells see Wink (1993a, 2000, 2007a, 2008c). In this essay I would like to focus on plant toxins that are relevant in the context of "poisonous or hazardous plants" (Wink and van Wyk, 2008).

Toxins and poisons are classified in four categories according to their oral toxicity determined in rat experiments: class Ia: extremely hazardous (5 mg or less per kg body weight); Ib: highly hazardous (5 to 50 mg/kg body weight); class II: moderately hazardous (50 to 500 mg/kg body weight) and class III: slightly hazardous (500 mg and more per kg body weight). It is important to recall that the dose is very important; already Paracelsus (1493 – 1541) had postulated in 1537 "*sola dosis facet venenum"* (it is the dose that makes a poison) besides inherent toxic properties (Mutschler et al., 2008; Wink and van Wyk, 2008).

Toxins, which fall into the classes Ia, Ib and II interfere with central functions in an animal. The most poisonous substances are neurotoxins which affect the nervous system, followed by cytotoxins and metabolic poisons that disturb liver, heart, kidneys, respiration, muscles and reproduction.

2.1. Neurotoxins

Neurotoxins can affect important **ion channels** of neuronal cells, such as Na^+, K^+, and Ca^{2+} channels, either by activating or inactivating them permanently. Both actions will stop neuronal signal transduction and thus block the activity of the central nervous system (CNS) but also neuromuscular signaling (Alberts et al., 2008; Mutschler et al., 2008; Wink 2003a, 2000), which eventually leads to paralysis of both striated and smooth muscles of heart, lungs and skeleton. A special case is the Na^+, K^+-ATPase, which is the most important ion pump in neuronal and other cells to maintain an ion gradient important for action potentials and transport mechanisms (Alberts et al., 2008; Mutschler et al., 2008). Cardiac glycosides, which occur in several plant families and even in toad skins (genus *Bufo*) are strong inhibitors of this pump. Because this pump is extremely important, cardiac glycosides are considered to be toxins of class Ia.

Neuroreceptors are another prime target for many alkaloids, which structurally resemble the endogenous neurotransmitters, such as acetylcholine, dopamine, noradrenaline, serotonin, adrenaline, GABA or glutamate (Alberts et al., 2008; Mutschler et al., 2008; Wink 1993a, 2000; Wink et al., 1998). The neuroactive alkaloids can either function as agonists, which overstimulate a neuroreceptor or as antagonists, which would block a certain neuroreceptor. Agonists and antagonists can cause excitation, hallucinations, and general CNS disturbances, which would put a herbivore into deep sleep or coma; higher doses would lead to death by either cardiac or respiratory arrest (Mutschler et al., 2008). A herbivore that is on a "trip" has no chance in the wild; it would either fall from trees or cliffs or would be an easy prey for all sorts of enemies. The production of neuroreceptor modulators is quite safe for the plant producing them, because plants do not have neuroreceptors and thus cannot poison themselves with the defence chemicals.

Some alkaloids (Wink 2003a, 2000) inhibit the enzymes that break down neurotransmitters, such as **cholinesterase (AChE)** and **monoamine oxidase (MAO)**. These toxins have similar toxic properties as secondary metabolites that are neuroreceptor agonists, since they would lead to a higher concentration of neurotransmitters in the synaptic cleft. Higher doses would lead to death by either cardiac or respiratory arrest (Mutschler et al., 2008).

2.2 Inhibitors of cellular respiration

Cellular respiration, which takes place in mitochondria and generates ATP, is another vulnerable target in animals, since ATP is essential for all cellular and organ functions. Many plants and even some arthropods can attack this target with HCN, which binds to iron ions of the terminal cytochrome oxidase in the mitochondrial respiratory chain (Alberts et al., 2008; Mutschler et al., 2008). HCN does not occur in a free form, but is stored as cyanogenic glucosides in plant vacuoles. When plants are wounded, the cellular compartmentation brakes down and the content of the vacuoles gets into contact with cytosolic enzymes, such as β-glucosidase and nitrilase. These enzymes hydrolyse the cyanogenic glucosides and the extremely toxic HCN is released (Fig. 3).

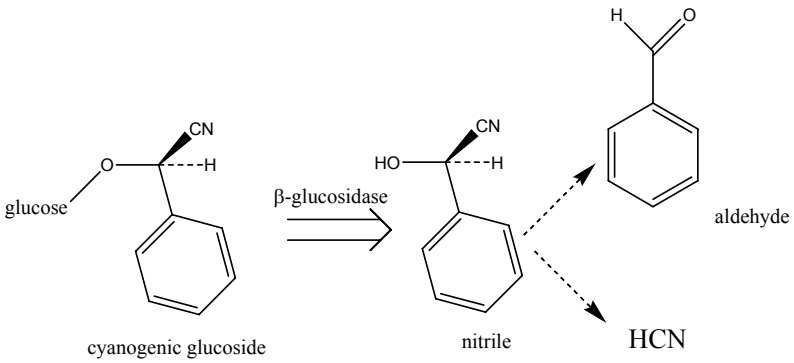

Fig. 3 Release of HCN from cyanogenic glucosides

Cyanogenic glucosides are produced by several plant families, such as Poaceae and Rosaceae, where they are stored in leaves, shoots or seeds. Also rotenoids (produced by some legumes) and some alkaloids can inhibit the mitochondrial respiratory chain. The diterpene atractyloside is a potent inhibitor of the mitochondrial ADP/ATP transporter and thus inhibits the ATP supply of a cell (Wink and van Wyk, 2008).

2.3. Cytotoxins

Several poisons can be regarded as **cytotoxins** because they interfere with important cellular functions. An important target in this context are biomembranes, which have to control the import and export of metabolites and ions in cells (Alberts et al., 2008; Mutschler et al., 2008). Membrane fluidity and integrity can be severely disturbed by both steroidal and triterpenoid saponins. Saponins are usually stored as inactive bidesmosidic saponins in plant vacuoles; upon wounding and decompartmentation, they are converted into the membrane-active monodesmosidic saponins, which are amphiphilic with detergent activities (Wink and van Wyk, 2008).

Within cells, other important targets include several enzymes and proteins but also DNA/RNA and related processes.

Protein biosynthesis in ribosomes is vital for every cell and organism. A number of strong plant toxins inhibit ribosomal protein biosynthesis, such as the alkaloid emetine from *Psychotria ipecacuanha*, amanitins from *Amanita phalloides* or a class of polypeptides, the lectins. Famous are ricin from seeds of *Ricinus communis* or abrin from *Abrus precatorius*. These toxins can attach to cells by their B-chain, the haptomer, whereas the A-chain (effectomer) is taken up by endocytosis into the cytosol, where it blocks protein biosynthesis (Alberts et al., 2008; Mutschler et al., 2008). These lectins are extremely poisonous and an oral dose of 1 mg/kg body weight is enough to kill a human; injected even 0.1 µg and less per kg body weight can be lethal (Wink and van Wyk, 2008).

The elements of the **cytoskeleton**, especially microtubules and actin filaments, are also vulnerable targets in animal cells. A number of plant toxins are known as microtubule poisons, such as colchicine, podophyllotoxin, vinblastine, chelidonine, noscapine, cucurbitacins and taxol (Wink, 2007a). These poisons will block cell division but also vesicle transport along microtubules.

Several secondary compounds can **covalently bind to proteins,** such as aldehydes, epoxides, secondary compounds with exocyclic methylene groups, with SH groups or reactive double or triple bonds (Wink, 2005, 2007b, 2008c; Wink and van Wyk, 2008). These protein modifications influence the three-dimensional structure of proteins and can inhibit their function. Therefore, many poisons with such properties have neurotoxic and cytotoxic properties or are irritants to skin and mucosal tissue.

2.4. Alkylating and intercalating DNA toxins

A number of secondary metabolites are known to attack **DNA** and **RNA**, by either intercalation or alkylation. Intercalating compounds, such as β-carboline alkaloids, emetine, berberine, sanguinarine, athraquinones or furanocoumarins, stabilise DNA and thus inhibit DNA replication (Schmeller et al., 1997; Wink 1993a, 2000). They can cause frameshift mutations, which drives a cell into apoptosis or which can cause malformations and even cancer. More common are alkylating compounds, which modify the DNA-bases in a covalent fashion. Known examples are pyrrolizidine alkaloids (occurring in Boraginaceae and several Asteraceae), aristolochic acids (from *Aristolochia*), ptaquiloside (from the bracken fern *Pteridium aquilinum*), cycasine (from cycads) and several furanocoumarins or secondary metabolites with epoxide or aldehyde groups (which are common in Apiaceae) (Wink and van Wyk 2008). If alkylated DNA bases are not repaired they can cause mutations and even cancer; in a pregnant herbivore they can induce abortion or malformation of the fetus.

2.5. Toxins of skin and mucosal tissues

Apart from internal organs, also the **skin** and **mucosal tissues** of animals can be affected by several toxins. Common in members of the Euphorbiaceae and Thymelaeaceae are diterpenes, which resemble the endogenous signal compounds diacylglycerol (DAG), an activator of the key enzyme PKC (protein kinase C) (Alberts et al., 2008; Mutschler et al., 2008). These diterpenes are classified as phorbol esters and they also stimulate PKC. When in contact to skin, mucosal tissues or the eye they cause severe and painful inflammation, with ulcers and blister formation.

Furanocoumarins, which are common in Apiaceae, can penetrate the skin and intercalate dermal cells. When the skin is exposed to sun light, the furanocoumarins alkylate DNA, which kills the cells and induces strong blister formation and necrosis.

Many species of the Ranunculaceae accumulate the glycoside ranunculin in the vacuole. Upon wounding, it is split into the active protoanemonin, which can alkylate proteins and DNA. It causes skin and mucosal irritation, followed by a severe inflammation. Similar activations have been reported for tuliposide A which is converted into the active tulipalin A (Wink and van Wyk, 2008).

In several members of the Araceae, another defence strategy is apparent. Plants, such as *Arum maculatum* produce Calcium-oxalate needles (so-called raphides) in their leaves and stems. When a herbivore tries to ingest these plants, the raphides penetrate skin and mucosa and pierce small holes into the cells (Wink and van Wyk, 2008). This already causes pain and inflammation. In addition, the plant contains proteases or other noxious proteins, which can now enter the cells or tissues and start their damaging activity. This mechanism resembles the strategy of snakes, who inject their protein cocktails (often proteinases, phosplipases, hyaluronidases, cholinesterase) with aid of their fangs.

3. Response of herbivores

Herbivores had to find solutions to avoid extremely toxic plants or to detoxify their poison cocktails. Experiments and observations show that most herbivore are selective and avoid plants of class Ia and Ib but also plants containing mutagens and mucosal toxins. Apparently, a cautious herbivores ingests only small amounts of unknown plants and if negative symptoms occur, will avoid it in the future. Plants which are less toxic are eaten at least by some herbivores (Wink 1988, 1992, 2007b, 2008b). It is well known from pharmacology, that the liver of animals, especially of herbivores or omnivores, has an active set of detoxification enzymes. Among them are cytochrome p450 oxidases (CYP), which can add hydroxyl groups to mostly lipophilic xenobiotics.

These hydroxylated metabolites are then conjugated with hydrophilic molecules, such as glucuronic acid, sulfate or amino acids and excreted via the kidneys and urine (Alberts et al., 2008; Mutschler et al., 2008). Another line of defence are ABC transporters (ATP Binding Cassette) (such as p-gp, MDR; multiple drug resistance proteins), which are membrane proteins that can pump lipophilic xenobiotics, that have entered intestinal cells by free diffusion, back to the gut lumen (Alberts et al., 2008; Mutschler et al., 2008; Wink 2007a).

Herbivores have microorganisms in their intestine or rumen, which can (but most cannot; Aguiar and Wink, 2005a,b) help to degrade nutritional toxins.

Some herbivores have a rapid digestion, which would decrease the rate of toxin absorption. A few toxin eaters (e.g. parrots) are known to ingest clay (so-called geophagy), which can bind most toxins, similar to charcoal (Aufreiter et al., 2001; Mahaney et al., 1999).

4. Toxic plants in Central Europe

In the preceding paragraphs the modes of action of the most important toxins have been discussed. In Table 1, poisonous plants of Europe are tabulated, with some details of their toxins and toxicology.

It is not only important to know these plants in order to avoid intoxication of children, pets or livestock, but these plants or their compounds might be used as natural pesticides against insects, slugs or rodents (Wink 1993b, 2007c).

Tab. 1 Overview over toxic European plants, their toxins and toxicology. Class I a: extremely hazardous; Ib: highly hazardous; II: moderately hazardous; III: slightly hazardous. IN=inflammatory; CT= cytotoxic; NT= neurotoxic; HP= heart poison, MA= mind altering; MP= medicinal plant; GI= disturbance of GI tract; AP= animal poison; MU= mutagenic,

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Neurotoxins				
Ion channel modulators				
Aconitum napellus (monkshood), *A. lycoctonum* and related species, Ranunculaceae	all parts, especially tubers	aconitine, mesaconitine, lycoctonine and other terpene alkaloids (up to 2% in tubers)	Ia NT, MA, AP, MP	aconitine activates Na^+ channels and is thus a strong nerve and muscle poison, causes numbness, causes paralysis
Consolida regalis (larkspur), *C. ajacis*, *C. orientalis* and related species, Ranunculaceae	all parts, especially seeds	delcosine, lycoctonine and other terpene alkaloids	Ia CT, NT, MA	alkaloids affect Na^+ channels and neuroreceptors, with sedating and dream inducing properties, substantial ingestion causes nausea, gastroenteritis, arrhythmia, excitations, spasms, respiratory arrest
Delphinium elatum (larkspur), *D. staphisagra*, *D. ajacis* and related species, Ranunculaceae	all parts, especially seeds	delphinine, nudicauline, staphisine, ajacine and other terpenoids alkaloids	Ib CT, NT, GI	delphinine resembles aconitine in toxicity, inhibition of neuronal transmission (Na^+ channel opener), skin irritation, nausea, disturbance of GI tract and kidneys, dyspnoea, death from cardiac arrest
Fritillaria imperialis, *F. meleagris* and related species, Liliaceae	especially bulbs	imperialine and other steroid alkaloids, tuliposide A, tulipalin A	II, NT, GI,	similar modes of action as aconitine, symptoms include vomiting, spasms, disturbances of GI tract and kidneys, hypotension, cardiac arrest
Rhododendron ponticum, *R. ferrugineum* and related species, Ericaceae	all parts, nectar (honey)	rhododendrin andromedotoxin (=grayanotoxin I), triterpens, arbutin	Ib CT, NT, GI	andromedotoxins are Na^+ channel inhibitors, symptoms include burning in mouth, salivation, vomiting, spasms, diarrhoea, CNS effects, headache, weakness, dimness of vision, convulsions, death by respiratory arrest
Veratrum album (false hellebore), *V. viride*, *V. nigrum* and related species, Melanthiaceae	all parts	protoveratrine A and B, germerine, cyclopamine	Ia NT, IN, AP, MP, MA	alkaloids activate Na^+-channels, cyclopamine causes malformation (cyclopian eye), hallucinogenic, heart and neurotoxin, death by respiratory and cardiac arrest, skin irritant
Na^+,K^+-ATPase inhibitors				
Adonis vernalis (pheasant´s eye), *A. aestivalis* and related species, Ranunculaceae	all parts	adonitoxin and other cardiac glycosides (cardenolides)	Ib CT, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase**,** symptoms of cardiac glycoside poisoning, diuresis, irritation of GI tract with strong diarrhoea, cardiac arrest
Cheiranthus cheiri (wallflower), Brassicaceae	all parts, especially seeds	cheirotoxin, cheirosid A and other cardenolides, glucosinolates (glucocheirolin)	II CT, GI, HP	cardiac glycosides inhibit Na^+,K^+-ATPase, substantial ingestion cause symptoms of cardiac glycoside intoxication with pronounced GI tract disturbance

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Convallaria majalis (Lily-of-the-valley), Convallariaceae/ Ruscaceae	all parts, flowers, fruits	convallatoxin and other cardenolides, saponins	Ib CT, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase, cardiac glycoside intoxication, nausea, gastrointestinal disturbance, diarrhoea, dizziness, hypertension, arrythmia, coma, cardiac arrest
Coronilla varia = *Securigera varia* (crown-vetch), Fabaceae	all parts, seeds	glycosides with cardiac activities (hyrcanoside, desgluco hyrcanoside), glucose esters with nitropropionic acid	Ib CT, HP, GI	glycosides appear to have similar activities as cardiac glycosides and cause similar symptoms, the nitro compounds inhibit enzymes of citric acid cycle. Substantial ingestion causes vomiting, diarrhoea and abdominal pain
Digitalis purpurea (Foxglove), *D. gr* and*iflora*, *D. lanata*, *D. lutea* and related species, Scrophulariaceae/ Plantaginaceae	all parts	several cardenolides (purpurea glycoside, lanatoside, digitoxin, digoxin)	Ia CT, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase, typical cardiac glycoside intoxication, vomiting, diarrhoea, gastroenteritis, severe headache, irregular heartbeat and pulse, convulsions, CNS disturbance, cardiac arrest, sudden death
Eranthis hyemalis (winter aconite) and related species, Ranunculaceae	all parts, especially tubers	eranthin A, B and other cardiac glycosides of the bufadienolide type	Ib CT, HP, NT, GI,	cardiac glycosides inhibit Na^+,K^+-ATPase, substantial ingestion causes symptoms of cardiac glycoside poisoning, nausea, vomiting, diarrhoea, colics, bradycardia, disturbed vision, dyspnoea, cardiac arrest
Erysimum crepidifolium, *E. diffusum*, Brassicaceae	all parts, especially seeds	erysimoside, helveticoside and other cardiac glycosides (cardenolides type), up to 3.5% in seeds)	Ib CT, HP, NT, GI, AP	cardiac glycosides inhibit Na^+,K^+-ATPase, substantial ingestion causes symptoms of cardiac glycoside poisoning with disturbance of GI tract and CNS, trembling, unrest, spasms, dyspnoea, cardiac arrest, animal poisoning, especially of geese
Euonymus europaea (spindle tree) and related species, Celastraceae	all parts, especially fruits	evobioside, evomonoside and other cardenolides, evonine and several alkaloids	Ib CT, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase, irritation of GI tract, nausea, hallucinations, extensive vomiting, shock, hyperthermia, bloody diarrhoea, liver and kidney disturbance, arrhythmia, strong spasms, coma after 12 h, cardiac arrest
Gratiola officinalis, Plantaginaceae/ Scrophulariaceae	all parts	gratiogenin, gratioside and other tetracyclic triterpenes, cucurbitacin A	Ib GI, HP, MP	nausea, vomiting, salivation, bloody diarrhoea, nephritis, respiratory and cardiac disturbances, death from respiratory arrest, abortifacient, toxicity similar to structurally similar cardiac glycosides
Helleborus viridis, *H. niger* (hellebore), *H. foetidus* and related species, Ranunculaceae	aerial parts	cardiac glycosides (bufadienolides), hellebrin, steroid saponins (helleborin), ranunculoside, alkaloids (celliamine, sprintillamine)	Ia, CP, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase, cardiac glycoside intoxication, vomiting, gastroenteritis with violent diarrhoea, delirium, convulsions, arrhythmia, death by respiratory arrest, alkaloids have similar properties as veratrine and aconitine

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Nerium oleander (oleander), (= *N. indicum*), Apocynaceae	all parts, nectar, even honey	oleandrine and several other cardenolides	Ia CT, HP, GI, MP	cardiac glycosides inhibit Na^+,K^+-ATPase, typical symptoms of cardiac glycoside poisoning, tongue and throat become numb, nausea, vomiting, bloody diarrhoea, spasms, arrhythmia, bradycardia, dilated pupils, dyspnoea, blue lips and hands, respiratory arrest, death can occur after 2-3 h
Ornithogalum umbellatum (star-of-bethlehem) and related species, Hyacinthaceae	all parts, bulbs, flowers	convallatoxin and other cardenolides in bulbs, prasinoside G and other steroid glycosides	Ib CT, NT, GI, HP	cardiac glycosides inhibit Na^+,K^+-ATPase, symptoms of cardiac glycoside poisoning, nausea, gastrointestinal disorders, abdominal pain and convulsions, heart failure and death, severe diarrhoea that may last up to three weeks
Scilla bifolia (squill), *S. hispanica* and related species, Liliaceae	all parts, especially bulbs and seeds	saponins, proscillaridin A and other bufadienolides	Ib CT, NT, HP, GI	cardiac glycosides inhibit Na^+,K^+-ATPase, saponins are haemolytic and cytotoxic, substantial cardiac glycoside toxicity (if cardenolides are present), substantial GI tract disturbance
Neuroreceptor modulators				
Amanita muscaria (fly agaric), *A. pantherina*, *A. cothurnata*, *A. gemmata*, *A. smithiana*, *A. strobiliformis*, Amanitaceae	fruiting body	ibotenic acid, muscimol, muscarine, muscazone	Ib-II NT, MA	muscimol is a strong parasympatholytic, psychoactive and hallucinogenic agent, bradycardia, rapid breathing, inebriation, manic behaviour, delirium, deep sleep
Atropa belladonna (deadly night shade) and related species, Solanaceae	all parts	hyoscyamine, scopolamine and other tropane alkaloids	Ia NT, MA, MP	mAChR antagonist with parasympatholytic properties, hallucinogenic in various forms, aphrodisiac, mydriasis, hyperthermia, inhibition of salivation, death from respiratory arrest
Claviceps purpurea (ergot), *C. paspali* and related fungi, Clavicipetaceae	fungal fruiting bodies (sclerotia)	several ergot alkaloids, grows on several grasses	Ib NT, MA, MP	ergot alkaloid affect dopamine, noradrenaline and serotonin receptors, therefore inducing psychoactive, psychedelic and hallucinogenic effects, painful muscle contractions, epileptic convulsions, vasoconstriction can cause gangrene
Conium maculatum (poison hemlock), Apiaceae	all parts, seeds	coniine, conhydrine and other piperidine alkaloids	Ia NT, MP, MA	strong neurotoxin at acetylcholine receptors, causes mental confusion, burning sensation in mouth and throat, vomiting, paralysis of muscles, low temperature, loss of sensations, convulsions, death through respiratory arrest
Conocybe cyanopus, *C. kuehneriana*, *C. siligineoides*, *C. smithii*, Bolbitiaceae	fruiting body	psilocybin, baeocystine	II NT, MA	alkaloids are serotonin receptor agonists, therefore psychoactive, psychedelic and hallucinogenic

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Corydalis cava, *C. aurea*, *C. caseana*, *C. flavula* and related species, Papaveraceae	all parts, especially tubers (6% alkaloids)	bulbocapnine and other isoquinoline, protoberberine and apomorphine alkaloids	II NT, MP, GI, AP	the alkaloids interact with several neurotransmitter receptors, inhibition of active muscle activity, hypnotic, GI tract disturbance
Cytisus scoparius (broom) and related species with sparteine/lupanine as main alkaloids, Fabaceae	all parts	sparteine and other quinolizidine alkaloids	II NT, GI, MP	sparteine is an agonist at mAChR and inhibits Na^+ channels, substantial ingestion causes diuresis, uterus contractions, vomiting, diarrhoea, abdominal pain, tachycardia, cardiac irregularity, toxicity similar to nicotine
Cytisus canariensis (= *Genista canariensis*) (Spanish broom) and related species with cytisine as main alkaloid, Fabaceae	aerial parts, seeds	cytisine and other quinolizidine alkaloids	Ib NT, GI, MA	cytisine is a strong nACHR agonist similar to nicotine, CNS active, psychedelic, euphoric, stimulant, higher doses are very toxic
Datura stramonium (thornapple), *D. metel* and related species, Solanaceae	all parts, especially seeds and roots	hyoscyamine, scopolamine, atropine	Ia NT, MA, MP	tropane alkaloids inhibit mAChR and show parasympatholytic properties causing strong hallucinations, widely used as hallucinogen and aphrodisiac
Ephedra distachya, *E. gerardiana* and related species, Ephedraceae	all parts	L-ephedrine, D-pseudoephedrine, L,D-norephedrine, D-nopseudoephedrine (0.5-3.3%)	II MA, MP, GI	sympathomimetic, amphetamine like activities (stimulant, euphoric), helps against fatigue and hunger, higher doses induce heavy perspiration, activate breathing and muscle activity, insomnia, mydriasis, constipation, hypertension, arrhythmia, death
Galanthus nivalis (snowdrop) and related species, Amaryllidaceae	mainly bulbs	galanthamine, lycrine and other alkaloids	II NT, GI, MP, AP	galanthamine inhibits acetylcholine esterase, parasympathomimetic, causes nausea, vomiting, diarrhoea, small pupils, live stock poisoning
Genista tinctoria, *G. germanica* and related species, Fabaceae	all parts	cytisine, anagyrine and other quinolizidine alkaloids (0.3%)	Ib-II NT, GI, MA	nAChR agonist, slightly psychoactive and hallucinogenic, diuretic, uterus contracting, abdominal pain, tachycardia, cardiac irregularity, vomiting, diarrhoea, dizziness, headache, toxicity similar to nicotine
Glaucium flavum and related species, Papaveraceae	all parts	glaucine, magnoflorine, protopine, sanguinarine and other isoquinoline alkaloids	II MA, NT, GI	psychoactive, narcotic, spasmolytic and pain killing, similar to opium, uterus contracting
Huperzia selago, Lycopodiaceae	all parts	lycopodine, arifoline, pseudoselagine and other alkaloids	Ib NT, MA	active at acetylcholine receptors, vomiting, dizziness, unconsciousness, psychoactive, modulates sensations
Hyoscamus niger (henbane), *H. muticus*, *H. albus*, *H. aurea*, *H. reticulatus* and related species, Solanaceae	all parts, roots, seeds	hyoscyamine, atropine, scopolamine and other tropane alkaloids	Ia NT, MA, MP	tropane alkaloids block mAChR and are parasympatholytic, strong hallucinogen and aphrodisiac, higher doses, mydriatic, cardiac stimulation, coma, death from respiratory arrest

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Laburnum anagyroides (goldenchain), *L. alpinum x wateri* (a hybrid between former species), Fabaceae	all parts, especially seeds	cytisine and other quinolizidine alkaloids, 3.5% in seeds	Ia NT, MA, GI	nAChR agonist, slightly psychoactive and hallucinogenic, diuretic, uterus contracting, abdominal pain, tachycardia, hypotension, heart irregularity, vomiting, diarrhoea, dizziness, headache, delirium, toxicity similar to nicotine
Leucojum vernum, *L. aestivum*, Amaryllidaceae	bulbs and aerial parts	lycorine, galanthamine, tazettine and other alkaloids	II MA, NT, GI	galanthamine inhibits acetylcholine esterase, with parasympathmimetic properties, nausea, vomiting, diarrhoea, small pupils
Lolium temulentum, Poaceae	all parts	temuline, loline and other pyrrolizidine alkaloids (fungal products, composition depends on the infecting fungus)	Ib-II, NT, MA, AP	alkaloids are psychoactive, symptoms include, drunkeness, dizziness (name!), staggering, tremor, headache, visual distortion, sleepiness, CNS disturbance, death via respiratory arrest, poisoning better known from horses, pigs and poultry
Lupinus polyphyllus (lupin), *L. albus*, *L. angustifolius*, *L. luteus*, *L. hirsutus* and related species, Fabaceae	all parts, especially seeds	lupanine, sparteine and related quinolizidine alkaloids (QA)	Ib-II NT, MP, AP	lupanine and other QA are modulators of nAChR and mAChR and also inhibit Na^+ channels, salivation, vomiting, problems to swallow, hyperthermia, arrhythmia, mydriasis, excitement and delirium, paralysis, death through respiratory arrest
Lycopodium clavatum, *L. annotinum* and related species, Lycopodiaceae	all parts	lycopodine, clavatine and related quinolizidine alkaloids	Ib-II MA, NT, MP	neurotoxins at acetylcholine receptors, similar to Curare, symptoms include vomiting, dizziness, unconsciousness, psychoactive, modulates sensations
Mandragora officinarum, *M. autumnalis* and related species, Solanaceae	mainly roots	hyoscyamine, atropine, scopolamine and other tropane alkaloids	Ia NT, MA, MP	mAChR antagonist with parasympatholytic properties, psychedelic, hallucination in various forms, used as hallucinogen since antiquity, higher doses: clonic spasms, strong heart beat, tachycardia (>160 beats), mydriasis, inhibition of salivation, respiratory arrest, coma
Nicotiana glauca (tree tobacco), Solanaceae	all parts	anabasine, nornicotine and other piperidine alkaloids	Ib NT, MA	anabasine is an agonist at AChR, salivation, perspiration, spasms of eye lids and lips, dyspnoea, cyanosis, mydriasis, internal bleeding in most internal organs, respiratory arrest
Nicotiana tabacum (tobacco) and related species, Solanaceae	all parts	nicotine, nornicotine and other pyridine alkaloids, 0.04 to 4%	Ib NT, MA, MP	nicotine is an agonist at nAChR, causes psychedelic and excitation, burning in mouth and throat, nausea, vomiting, disturbance of GI tract, vasoconstriction, hypertension, mydriasis, arrhythmia, seizures, collapse, respiratory arrest
Nuphar lutea, Nymphaeaceae	all parts	nupharine, desoxynupharidine and other simple quinolizidine alkaloids	II NT, MA	alkaloids probably affect acetylcholine receptors, therefore psychoactive, similar to atropine and papaverine, spasmolytic, hypotensive

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Nymphaea alba, Nymphaeaceae	all parts	nupharine, nymphaline, aporphine	II NT, MA	alkaloids probably affect acetylcholine receptors, therefore psychoactive, intoxicant, hallucinogenic, aphrodisiac, similar to atropine and papaverine, spasmolytic, hypotensive
Papaver rhoeas and other poppy species, Papaveraceae	all parts, especially latex	rhoeadine, protopin, berberine and other isoquinoline alkaloids	II CT, NT, GI, AP	alkaloids modulate neuroreceptors, vomi-ting, spasms, abdominal pain, in animals, central exitation, gastroenteritis, unrest, epileptiform spasms, unconsciousness
Phalaris arundinacea, *P. aquatica*, *P. canariensis*, *P. minor*, *P. tuberosa*, Poaceae	aerial parts	*N*,*N*-DMT, MMT, 5-MeO-DMT, gramine	III NT, MA	tryptamine derivatives are agonists at serotonin receptors, therefore psychoactive, psychedelic, hallucinogenic
Phragmites communis, Poaceae	roots	*N*,*N*-DMT, 5-MeO-DMT, gramine	III NT, MA	tryptamine derivatives are agonists at serotonin receptors, therefore psychoactive, psychedelic, hallucinogenic
Psilocybe azurescens, *P. baeocystis*, *P. bohemica*, *P. caerulescens*, *P. cyanescens*, *P. semilanceata* and many related species, Strophariaceae	fruiting body	psilocybin, psilocin, baeocystine	II NT, MA	alkaloids are serotonin receptor agonists, therefore psychoactive, psychedelic, hallucinogenic
Punica granatum, Punicaceae	bark	pseudopelletierine, pelletierine and other piperidine alkaoids (up to 0.7%), tannins, oxalate	II CT, NT, GI	alkaloids affect acetylcholine receptors, higher doses cause nausea, vomiting, disturbance of GI tract, inner bleeding, CNS disturbance, bradycardia, perspiration, convulsions, death by respiratory arrest
Scopolia carniolica and related species, Solanaceae	all parts	hyoscyamine, scopolamine and other tropane alkaloids (up to 0.8%)	Ia NT, MA, MP	mAChR antagonist, parasympatholytic properties, hallucination in various forms, clonic spasms, strong heart beat, tachycardia (>160 beats), mydriasis, inhibition of salivation, respiratory arrest, coma
Sedum acre, Crassulaceae	all parts	sedamine, sedamine, sedinine and other piperidine alkaloids	II CT, in, NT, GI	mAChR agonist, strong pungent taste (name!), severe irritation of mouth and throat, salivation, vomiting, intestinal spasms, narcotic, paralysis, respiratory arrest
Solanum dulcamara, *S. tuberosum* (potato), *S. lycopersicum* (tomato), *S. nigrum*, Solanaceae	green parts (red berries are usually not hazardous)	green fruits and leaves contain steroidal glyco-alkaloids such as soladulcidine, solanine, solasodine, chaconine etc., saponins	Ib-II CT, NT, GI, AP, MP	disturbance of GI tract, vomiting, spasms, internal bleeding, salivation, trembling, restlessness, headache, delirium, fever and coma. In severe cases death may occur through respiratory arrest
Spartium junceum, Fabaceae	all parts, especially flowers and seeds	*N*-methylcytisine, cytisine and other quinolizidine alkaloids	Ib NT, MA, GI	alkaloids affect acetylcholine receptors (agonists), psychoactive and hallucinogenic, toxicity similar to nicotine

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Cytotoxins				
Inhibitors of cellular respiration				
Aquilegia vulgaris (columbine) and other species, Ranunculaceae	all parts, seeds	cyanogenic glucoside	II CT, MP	higher doses can induce dizziness, mydriasis, unconsciousness, respiratory problems, ingestion of seeds has been fatal to children
Prunus laurocerasus (laurel cherry), *P. dulcis* (bitter almond), *P. armeniaca*, *P. avium*, *P. domestica*, *P. padus*, *P. persica*, *P. serotina*, *P. spinosa*, *P. virginiana* and related species, Rosaceae	all parts, especially seeds	amygdalin, prunasin (cyanogenic glucosides), especially high concentration in seeds (5-8%)	Ib-II CT, NT, GI	when seeds are crushed they release HCN which is a strong respiratory poison, higher doses with HCN poisoning symptoms, burning sensation in throat, sweating, abdominal pain, vomiting, red face, salivation, convulsions, respiratory and cardiac arrest
Xanthium strumarium, Asteraceae	seeds, seedlings, leaves	xanthinin, xanthine, carboxyatractylo-side (sesquiterpene lactones)	II CT, IN, AP	terpenoids inhibit ADP/ATP transporter in mitochondria, mainly animal poison (anorexy, haemorrhage, dizziness, weakness, dyspnoea, cardiac arrest), also human fatalities
Metabolic poisons				
Aethusa cynapium (fool's parsley), Apiaceae	all parts	polyacetylens (aethusin, aethusanol A & B)	Ib CT, NT, GI, IN	polyenes can bind to several proteins, symptoms include burning sensation in mouth, vomiting, diarrhoea, headache, tachycardia, mydriasis, generalized seizures and convulsions, coma, respiratory arrest
Astragalus molissimus (locoweed), *A. didymocarpus*, *A. lentiginosus*, *A. wootonii*, *A. calycosus* and related species, Fabaceae	aerial parts	hydroxyalkaloids (swainsonine)	II CT, NT	the hydroxyalkaloids inhibit glucosidases and other hydrolases in lysosomes and in the Golgi apparatus, induce structural changes in nerve cells, locoism, livestock act in an irrational and aggressive manner, clumsy gait, seizures, miscoordination, death
Buxus sempervirens (box tree), Buxaceae	aerial parts	buxine, cyclobuxine and several related steroidal alkaloids	Ib CT, GI, NT, AP, IN	contact dermatitis, initially exciting, later paralysing and hypotensive, nausea, vomiting, dizziness, diarrhoea, spasms, death by respiratory arrest
Chrysanthemum vulgare (tansy) (syn *Tanacetum vulgare*), Asteraceae	aerial parts, especially flowers	thujone and other monoterpenes	II CT, NT, MA, MP	thujone is neurotoxic and cytotoxic, at higher doses the essential oil causes strong spasms, vomiting, gastroenteritis, convulsions, arrhythmia, mydriasis, uterine bleeding, miscarriage (abortifacient), kidney and liver disturbance, death through cardiac and respiratory arrest

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Cicuta virosa (water hemlock), *C. bulbifera*, Apiaceae	aerial parts, roots	cicutoxin, cicutol (polyacetylenes)	Ib CT, NT, GI	polyenes can bind to several proteins, symptoms include burning sensation in mouth and throat, nausea, vomiting, stomach pain, large pupils, headache, tremors, epileptiform convulsions, delirium, death by respiratory arrest
Equisetum palustre (marsh horsetail), *E. fluviatile*, *E. hyemale*, *E. ramosissum*, Equisetaceae	aerial parts	palustrine, palustridine and other alkaloids (up to 0.3%), thiaminase (an enzyme), saponins	II CT, NT, GI, AP	thiaminase destroys vitamin B1, alkaloid affect cholinergic system, mainly known as animal poison for horses and cattle, animals show irritations, muscle tremor, staggering, falling down, death after complete exhaustion
Juniperus sabina, Cupressaceae	all parts, especially young twigs	3-5% essential oil with sabinen and sabinylacetate, thujone, monoterpenes	Ia CT, IN, NT, MA, AP	monoterpenes are cytoxic, strong skin irritant, symptoms with nausea, excitation, arrhythmia, spasms, respiratory arrest, nephritis, bloody urine, liver intoxication, uterus contraction, central paralysis, previously used as abortifacient (10 drops of oil are lethal)
Lactuca virosa, Asteraceae	all parts, especially latex	lactucin, lactucopicrin (sesquiterpene lactones)	Ib CT, NT, GI, MA, MP	sesquiterpenes can bind to various proteins, skin irritation, symptoms include sedative properties (similarities with opium), strong perspiration, enhanced breathing and cardiac activity, pupil dilatation, dizziness, headache, visual distortions, sleepiness
Ligustrum vulgare (privet), *L. lucidum*, *L. japonicum*, Oleaceae	aerial parts, fruits	ligustrin (=syringin), oleuropein and other secoiridoid glycosides	II CT, GI	nausea, vomiting, dizziness, headache, diarrhoea, gastroenteritis, convulsions, circulatory arrest, fatal livestock poisoning (with neurotoxicity)
Narcissus pseudonarcissus (daffodil), *N. cyclamineus*, *N. jonquilla*, *N. poeticus*, *N. tarzettus* and related species, Amaryllidaceae	all parts, especially bulbs	lycorine, haemanthamine, narciclasine, tazettine and other isoquinoline alkaloids, Ca^{++}-oxalate crystals	Ib-II CT, NT, IN, GI	Ca^{++}-oxalate and alkaloids cause skin irritation and inflammations (contact dermatitis), alkaloids, with protein biosynthesis inhibitory properties, cause nausea, vomiting, diarrhoea, abdominal spasms, heavy perspiration and death
Narthecium ossifragum, Nartheciaceae	all parts	steroidal saponins, narthecin (sarsasapogenin as aglycon), tannins (10%)	II CT, IN, GI	saponins with haemolytic and cytotoxic properties, hepatitis, edema, causes severe poisoning in sheep, toxin causes secondary photosensibilisation through narthecin
Oenanthe aquatica (water dropwort), *O. crocata*, *O. sarmentosa*, Apiaceae	all parts	oenanthotoxin (polyacetylene), essential oils	Ib CT, NT, GI, IN	polyacetylenes bind to proteins and inhibit them, symptoms include inflammation and blister formation in mouth, inflammation of GI tract, vertigo, coma, seizures with bloody foam, mydriasis, bradycardia, loss of short-term memory, poisonous to humans, cattle, horses and pigs

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Polygonatum multiflorum, *P. odoratum*, *P. verticillatum*, Liliaceae	all parts, especially fruits	acetidine 2 carboxylic acid (NPAA), steroidal saponins (diosgenin as aglycone)	II-III CT, NT, GI	NPAAs cause protein failure, only high doses toxic, nausea, vomiting, diarrhoea, cytotoxic, haemolytic, heart and CNS disturbance
Rhamnus cathartica (buckthorn), *R. frangula*, *R. purshiana*, Rhamnaceae	bark, berries	frangulin, barbaloin and related anthraquinones, saponins	II CT, GI, MP	powerful laxative, nausea, vomiting, bloody diarrhoea, abdominal pain, even nephritis and collapse, probably mutagenic, as anthraquinones can intercalate DNA
Sambucus ebulus (dwarf elder), *S. racemosa*, *S. australis*, *S. canadensis*, *S. pubens*, Adoxaceae/ Caprifoliaceae	all parts, especially fruits	ebuloside and other iridoidglycosides, lectins	III CT, GI	iridoid glucosides can bind to various proteins, symptoms include burning of throat, nausea, vomiting, bloody diarrhoea, dizziness, headache, visual problems, cardial disturbance, death, animal poisoning have been observed
Sium latifolium, *S. suave* and related species, Apiaceae	all parts, fruits	essential oil (7%) in fruits with limonen, pinen, polyacetylenes	II-III CT, IN, NT, GI	polyacetylenes inhibit proteins, cause gastroenteritis, vomiting, diarrhoea, weakness, nausea, bradycardia and muscle paralysis
Thuja occidentalis, *T. orientalis*, Cupressaceae	all parts	essential oil with thujone	Ib CT, NT, MA, MP, AP	monoterpenes are cytotoxic, symptoms include nausea, inner bleedings, convulsions, painful diarrhoea, oedema in legs, hepatitis, nephritis, paralysis of CNS, abortifacient, lung oedema, death
Vincetoxicum hirundinaria, Apocynaceae (Asclepiadaceae)	all parts, especially rhizome	vincetoxin (a mixture of steroid glycosides), tylophorine, amyrin	II CT, NT, GI	salivation, vomiting, diarrhoea, convulsions, respiratory arrest, paralysis of muscles
Viscum album (mistle toe) and related species, Santalaceae	all parts	viscotoxins, lectins, secondary metabolites depend on host plant	II CT, GI, MP	viscotoxins and lectins responsible for cytotoxic and hypotensive effects, substantial GI tract disturbance, nausea, vomiting, diarrhoea, abdominal pain, convulsions
Membrane toxins				
Cyclamen persicum (cyclamen), *C. purpurascens* and related species, Primulaceae	all parts, especially bulbs	cyclamin and other triterpene saponins	II T, GI	saponins disturb membrane fluidity and are cytotoxic, substantial ingestion causes GI tract disturbance with nausea, vomiting, abdominal pain and spasms, sweating, circulatory disturbance, respiratory arrest
Hedera helix (ivy), *H. canariensis* and related species, Araliaceae	all parts, especially leaves, fruits	alpha-hederin and other triterpene saponins, sesquiterpenes, falcarinol (a polyacetylene)	II IN, GI, MP	saponins disturb membrane fluidity and are cytotoxic, symptoms include irritation of GI tract, nausea, vomiting, palpitations, exema, dizziness, nervous depression, hypertermia, death by respiratory arrest, mydriasis, skin reactions include rashes, red, swollen skin, blisters, oedema and pain

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Ilex aquifolium (holly) and related species, Aquifoliaceae	leaves and red berries	rutin, ursolic acid, amyrin, uvaol, other saponins, some theobromine	II CT, GI	saponins disturb membrane fluidity and are cytotoxic, nausea, vomiting, diarrhoea, gastroenteritis, abdominal spasms, arrhythmia, paralysis, kidney trouble, cause of allergic reactions
Paris quadrifolia, Trilliaceae/ Melanthiaceae	all parts, especially fruits	paridin, aristyphnin and other steroidal saponins	II-III CT, NT, GI	saponins are haemolytic and cytotoxic when absorbed, sensory irritations, nausea, small pupils, nephritis, CNS disturbance, respiratory arrest
Phytolacca americana (= *P. decandra*) (pokeweed), *P. acinosa (=P. esculenta*), *P. dioica*, *P. dodecandra*, *P. octandra*, Phytolaccaceae	roots, leaves	lectins, phytolaccatoxin (triterpene saponins)	II CT, GI	saponins disturb membrane fluidity and are cytotoxic, symptoms include vomiting, diarrhoea, stomach cramps, weakened pulse, in severe cases breathing difficulty, convulsions, death, used as molluscicide
Saponaria officinalis, *S. vaccaria*, Caryophyllaceae	all parts	triterpene saponins	II-III CT, NT, GI	saponins disturb membrane fluidity and are cytotoxic, higher dose cause nephritis, disturbances of GI tract, livestock poisoning
Inhibitors of protein biosynthesis				
Agrostemma githago (corn cockle), Caryophyllaceae	all parts, seeds	agrostin (lectin), githagin, agrostemmic acid (triterpene saponins)	Ib CT, GI, IN	the lectin inhibits ribosomal protein biosynthesis, the saponins are uptake facilitators, symptoms include mucosal irritation, dizziness, vomiting, diarrhoea, respiratory distress, headache, pain in spine, tachycardia, paralysis, coma and death
Amanita phalloides, *A. verna*, *A. virosa*, *A. bisporigera*, *A. ocreata*, Amanitaceae	fruiting body	cyclopeptides, amatoxins, amantine, phalloidin, phallotoxins	Ia CT, NT, GI	amanitine inhibits protein biosynthesis, phalloidin binds to actin filaments, deadly poisonous, 6-24 h latent period before first symptoms occur, diarrhoea, severe abdominal cramps, nausea, vomiting, liver and kidney failure, death
Ricinus communis (Castor bean), Euphorbiaceae	seeds	ricin (a lectin), ricinine (pyridine alkaloid), ricinolic acid (fatty acid)	Ia CT, IN, GI, MP	oil has been used as a laxative, ricin is very toxic and inhibits protein biosynthesis, parenteral application can cause life- threatening multisystem organ failure, ingestion causes nausea, bloody vomiting, bloody diarrhoea, nephritis, liver damage, convulsions, tachycardia, circulatory arrest, also poisonous for animals (press cake)
Robinia pseudoacacia (black locust), Fabaceae	all parts, especially roots, bark, fruits	robin (a lectin), tannins	Ib CT, GI	the lectin has agglutinating properties and is cytotoxic, nausea, vomiting, diarrhoea, sleepiness, mydriasis, seizures, abdominal pain, parenteral application can cause life- threatening multisystem organ failure, toxic for cattle and horses

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Microtubule modulators				
Anagallis arvensis (scarlet pimpernel), Primulaceae	all parts, especially roots	cucurbitacin B, arvenin I and arvenin II (cucurbitacins), triterpene saponins, oxalates	II CT, GI, AP,	cucurbitacins bind to microtubules and are cytotoxic, diuretic, substantial ingestion causes gastrointestinal disturbance, trembling, slightly narcotic, kidney damage
Bryonia dioica (bryony), *B. alba* and related species, Cucurbitaceae	all parts, especially fruits (red berries), roots	bryonin, bryonidin, bryonicin and other cucurbitacins	Ib CT, IN, GI, MP	cucurbitacins bind to microtubules and are cytotoxic, skin irritant, nausea, vomiting, diarrhoea with blood, strong colic and spasms, kidney inflammation, tachycardia, respiratory arrest
Chelidonium majus (celandine) and related species, Papaveraceae	all parts, reddish latex	chelidonine, chelerythrine, sanguinarine, berberine and other isoquinoline alkaloids	II CT, NT, GI, MP	burning sensation in mouth and throat, nausea, vomiting, bloody diarrhoea, central sedative, spasmolytic and narcotic, low pulse, hypotension, cardiac arrest, chelidonine inhibits mitosis and is therefore cytotoxic
Colchicum autumnale (autumn crocus), *C. speciosum* and related species, Liliaceae	all parts, especially seeds and bulbs	colchicine and related alkaloids	Ia CT, NT, MP, GI	colchicine is a spindle poison, symptoms include nausea, dizziness, burning of throat and stomach, purging, stomach pain, spasms, internal bleeding, strong diuresis, cardiovascular collapse, respiratory arrest
Ecballium elaterium (squitting cucumber), Cucurbitaceae	fruits	cucurbitacin E, I	Ib CT, IN, GI, NT	cucurbitacins bind to microtubules and are cytotoxic, strong purgative causing salivation, vomiting, inflammation of GI tract, abdominal pain, headache, tachycardia, internal bleeding, >0.6 ml juice can be lethal
Taxus baccata (English yew) and related species, Taxaceae	all parts (except red aril of fruits)	taxin A,B,C, taxicin I, II (*T. baccata*), taxol (*T. brevifolia*), cyanogenic glucosides	Ia CT, NT, MP	taxol stabilises micotubules and is used in cancer therapy, taxins inhibit K^+ and Ca^{++} channels, symptoms include salivation, vomiting, painful diarrhoea, disturbance of circulation and heart activity, death through respiratory and circulatory arrest
DNA, Alkylants, Intercalators				
Anchusa officinalis (common bugloss), A. *caerulea* and related species, Boraginaceae	all parts	lycopsamine and other pyrrolizidine alkaloids (PAs)	II CT, NT, MU, GI	PAs alkylate DNA, they are mutagenic and carcinogenic, neurotoxic, liver (veno-occlusive disease) and lung damage
Aristolochia clematitis (birthwort) and related species, Aristolochiaceae	aerial parts	aristolochic acid and related alkaloids, magnoflorine	II CT, GI, MU, MP	aristolochic acid has mutagenic and carcinogenic properties, ingestion can induce vomiting, disturbance of GI tract, tachycardia, hypotension, respiratory arrest

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Cynoglossum officinale (hound's tongue) and related species, Boraginaceae	all parts, flowers	heliosupine, cynoglossine and other PAs	II CT, NT, MU, GI, AP	PAs alkylate DNA, they are hepatotoxic, mutagenic and carcinogenic, substantial ingestion inhibits neuronal activities, paralytic
Dictamnus albus (dittani), Rutaceae	aerial parts	dictamnine and other furoquinoline alkaloids, monoterpenes	II CT, MU, NT, IN, GI	furanocoumarins and alkaloids can inter-calate or alkylate DNA, therefore muta-genic, plant sap is a strong skin irritant, when exposed to sunlight it can cause photodermatitis and contact dermatitis
Echium vulgare (blue weed), *E. plantagineum* (Paterson´s curse) and related species, Boraginaceae	all parts, especially flowers	heliosupine and other PAs	II CT, NT, MU, AP	PAs alkylate DNA, they are mutagenic and carcinogenic, hepatotoxic (veno-occlusive disease), intoxication of sheep has been recorded in Australia
Eupatorium cannabinum, E. perfoliatum, E. rugosum, Asteraceae	all parts	eupatoriopicrin, euparin, sesquiterpene lactones and several pyrrolizidine alkaloids	II CT, NT, MU, AP	PAs alkylate DNA, they have mutagenic and carcinogenic properties, they are transferred from milk to humans, tremor, delirium, death
Pteridium aquilinum (bracken fern), Dennstaedtiaceae	all parts, young shoots	cyanogenic glucosides, ptaquiloside (sesquiterpene), thiaminase	Ib-II CT, NT, GI, MU	ptaquiloside alkylates DNA and is a strong mutagen, it causes stomach and bladder cancer (mostly cattle, also humans), thiaminase destroys vitamin B1 leading to CNS disturbances in animals
Ruta graveolens and related species, Rutaceae	all parts	bergapten, psoralen (fura-nocoumarins), kokusa-genine, skimmianine, rutamine dictamine (quinoline alkaloids)	Ib-II CT, NT, GI, MU, MP	furanocoumarins and alkaloids intercalate and alkylate DNA, strong skin irritant, blister formation, itching, internally: Sali-vation, gastroenteritis, irritation of GI tract, narcotic, abortifacient, haematuria, visual distortions,
Senecio jacobaea (tansy ragwort), *S. latifolius* (including *S. sceleratus*), *S. douglasii*, *S. vulgaris*, *S. verna*, *S. retrorsus*, *S. isatideus* and *S. burchellii* and other ragwort species, Asteraceae	all parts, especially flowers	senecionine and other pyrrolizidine alkaloids	II CT, MU, NT, MP	PAs alkylate DNA, they are hepatotoxic (veno-occlusive disease), alkylate DNA and are therefore mutagenic and carcinogenic, inhibits peripheral nerves, important animal poison
Symphytum officinale, *S. uplandicum*, *S. tuberosusm*, Boraginaceae	all parts, roots	symphytine, echimidine and other pyrrolizidine alkaloids, allantoin	II CT, NT, MU, AP	PAs alkylate DNA, they are hepatotoxic, mutagenic and carcinogenic, inhibits peripheral nerves, hepatotoxic, important animal poison
Irritants of skin and mucosal tissues				
Anemone nemorosa, *A. ranunculoides*, *A. occidentalis*, *A. patens*, *A. coronaria* and related species, Ranunculaceae	all parts	ranunculin is converted enzymatically to protoanemonin	II CT, NT, IN, GI AP	protoanemonin can bind to various proteins, symptoms include nausea and CNS disturbance, disturbance of GI tract and kidneys, mutagenic, blistering, ulceration and inflammation of skin, livestock poisoning

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Arum maculatum (cuckoopint), *A. italicum*, *A. palaestinum* and related species, Araceae	aerial parts, fruits	aroin, cyanogenic glucosides, saponins, Ca^{++} oxalate raphides	Ia CT, IN, GI	raphides penetrate mucosal cells, facilitate the entry of toxins, symptoms include skin irritant, blister formation, burning sensation in mouth and throat, cardiac arrhythmia, CNS disturbance, spasms, low body temperature, internal bleeding, disturbance of GI tract
Caltha palustris (marsh marigold), Ranunculaceae	all parts	ranunculin, produces protoanemonin upon hydrolysis, magnoflorine, triterpene saponins	II CT, IN, GI	protoanemonin can bind to various proteins, symptoms include GI tract and kidney disturbance, mutagenic properties, strong irritant to skin and mucous membranes
Clematis recta, *C. alpina*, *C. vitalba* and related species, Ranunculaceae	all parts	ranunculin is converted enzymatically to protoanemonin (2% dry weight)	II CT, IN, GI, AP	protoanemonin can bind to various proteins, symptoms include irritation of skin and mucous membranes with blistering and ulcerations, nausea, diarrhoea, intestinal bleeding, kidney disturbance, mutagenic
Daphne mezereum (mezereon), *D. cneorum*, *D. laureola*, *D striata* and related species, Thymelaeaceae	all parts, especially red berries	mezerein (phorbol ester), daphnin (coumarin glycoside)	Ia CT, IN, GI	phorbol esters stimulate protein kinase C (PKC), symptoms include skin irritant, burning of throat and stomach, nausea, vomiting, gastroenteritis, internal bleeding, spasms, paralysis, kidney disturbance, bradycardia, coma, circulatory arrest
Euphorbia cyparissias, *E. myrsinitis*, *E. marginata*, *E. helioscopa.*, *E. lathyris*, Euphorbiaceae	all parts, especially latex and seeds	phorbol esters in latex, triterpenoids, *E. pulcherrima* without phorbol esters	II CT, IN, GI	phorbol esters stimulate protein kinase C (PKC), symptoms include strong skin irritant (blister formation), burning irritation in mouth and throat, vomiting, stomach pain, purgative, bloody diarrhoea, arrhythmia, tinnitus, liver and kidney disturbances, coma, co-carcinogen
Heracleum mantegazzianum, *H. sphondylium*, Apiaceae	all parts	8-methoxypsoralen and other furanocoumarins	II CT, IN, MU, GI	furanocoumarins intercalate DNA and form crosslinks upon illumination with sun light, strongly cytotoxic, leads to serious blister formation of the skin, used in phytotherapy for psoriasis treatment
Oxalis acetosella (wood sorrel), *O. pes-caprae*, *O. corniculata* and related species, Oxalidaceae	all parts	Ca^{++}-oxalates (up to 1.3%)	II CT, IN	irritation of mucosa and GI tract, higher doses cause bradycardia, hypotension, spasms, central paralysis, circulatory arrest, death
Pulsatilla pratensis (pasque flower), *P. vulgaris* and related species, Ranunculaceae	all parts	ranunculin is converted enzymatically to protoanemonin, saponins	II IN, CT, AP, MP, MU	protoanemonin can bind to various proteins, symptoms include GI tract and kidney disturbance, mutagenic, blistering and inflammation of skin

SCIENTIFIC NAME (COMMON NAME), FAMILY	HAZARDOUS PLANT PARTS	ACTIVE PRINCIPLE	TOXICITY CLASS	MODE OF ACTION, SYMPTOMS
Ranunculus acris (buttercup), *R. bulbosus*, *R. sceleratus*, *R. multifidus* and related species, Ranunculaceae	all parts	ranunculin is enzymatically converted to the active protoanemonin	Ib-II CT, IN, MU, GI	protoanemonin can bind to various proteins, symptoms include severe skin and mucosal irritation with blisters and ulceration, internally, diarrhoea, abdominal pain, tinnitus, headache, dizziness, seizures, tachycardia, nephritis, death from respiratory and cardiac arrest
Trollius europaeus, Ranunculaceae	all parts	ranunculin is enzymatically converted to the active protoanemonin	Ib-II CT, IN, MU, GI	protoanemonin can bind to various proteins, symptoms severe skin irritation with blisters and ulceration, internally, colic, tinnitus, headache, unconsciousness, tachycardia, diarrhoea, nephritis, abdominal pain, death

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