

Solanine

Solanine is a [glycoalkaloid poison](#) found in species of the [nightshade](#) family within the genus *Solanum*, such as the [potato](#) (*Solanum tuberosum*), the [tomato](#) (*Solanum lycopersicum*), and the [eggplant](#) (*Solanum melongena*). It can occur naturally in any part of the plant, including the [leaves](#), [fruit](#), and [tubers](#). Solanine has [pesticidal](#) properties, and it is one of the plant's [natural defenses](#). Solanine was first isolated in 1820 from the [berries](#) of the European black nightshade (*Solanum nigrum*), after which it was named.^[1] It belongs to the chemical family of [saponins](#).

Solanine poisoning

Symptoms

Solanine poisoning is primarily displayed by gastrointestinal and neurological disorders. Symptoms include [nausea](#), [diarrhea](#), [vomiting](#), stomach cramps, burning of the throat, [cardiac dysrhythmia](#), [nightmares](#), [headache](#), [dizziness](#), itching, [eczema](#), thyroid problems, and inflammation and pain in the joints. In more severe cases, [hallucinations](#), loss of sensation, [paralysis](#), [fever](#), [jaundice](#), [dilated pupils](#), [hypothermia](#), and death have been reported.^{[2][3][4]}

Ingestion of solanine in moderate amounts can cause death. One study suggests that doses of 2 to 5 mg/kg of body weight can cause toxic symptoms, and doses of 3 to 6 mg/kg of body weight can be fatal.^[5]

Symptoms usually occur 8 to 12 hours after ingestion, but may occur as rapidly as 10 minutes after eating high-solanine foods.

Correlation with birth defects

Some studies show a correlation between the consumption of potatoes suffering from [late blight](#) (which increases solanine and other [glycoalkaloid](#) levels) and the incidence of [spina bifida](#) in humans. However, other studies have shown no correlation between potato consumption and the incidence of birth defects.^[6]

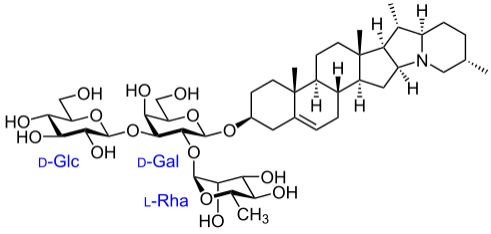
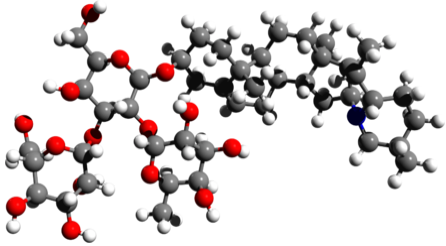
Livestock poisoning

Livestock can also be susceptible to glycoalkaloids. High concentrations of solanine are necessary to cause death to mammals. The gastrointestinal tract cannot efficiently absorb solanine, which helps decrease its strength to the mammal body.^[7] Livestock can hydrolyze solanine and excrete its contents to diminish its presence in the body.^[7]

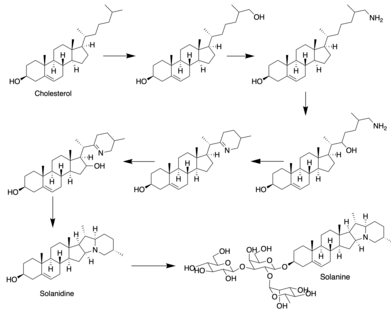
Mechanism of action

There are several proposed mechanisms of how solanine causes toxicity in humans, but the true mechanism of action is not well understood.

Solanum glycoalkaloids have been shown to inhibit **cholinesterase**, disrupt cell membranes, and **cause birth defects**.^[8] One study suggests that the toxic mechanism of solanine is caused by the chemical's interaction with **mitochondrial** membranes. Experiments show that solanine exposure opens the **potassium channels** of mitochondria, increasing their **membrane potential**. This, in turn, leads to Ca^{2+} being transported from the mitochondria into the cytoplasm, and this increased concentration of Ca^{2+} in the cytoplasm triggers cell damage and **apoptosis**.^[9] Potato, tomato, and eggplant glycoalkaloids like solanine have also been shown to affect **active transport** of sodium across cell membranes.^[10] This cell membrane disruption is likely the cause of many of the symptoms of solanine toxicity, including burning sensations in the mouth, nausea, vomiting, **abdominal** cramps, diarrhea, internal **hemorrhaging**, and stomach **lesions**.^[11]

α-Solanine	
	
	
Names	
<p>IUPAC name</p> <p>Solanid-5-en-3β-yl α-L-rhamnopyranosyl-(1\rightarrow2)-[β-D-glucopyranosyl-(1\rightarrow3)]-β-D-galactopyranoside</p>	
<p>Systematic IUPAC name</p> <p>(2<i>S</i>,3<i>R</i>,4<i>R</i>,5<i>R</i>,6<i>S</i>)-2-[[[(2<i>R</i>,3<i>R</i>,4<i>S</i>,5<i>S</i>,6<i>R</i>)-5-Hydroxy-6-(hydroxymethyl)-2-[[[(2<i>S</i>,4<i>aR</i>,4<i>bS</i>,6<i>aS</i>,6<i>bR</i>,7<i>S</i>,7<i>aR</i>,10<i>S</i>,12<i>aS</i>,13<i>bS</i>)-4<i>a</i>,6<i>a</i>,7,10-tetramethyl-2,3,4,4<i>a</i>,4<i>b</i>,5,6,6<i>a</i>,6<i>b</i>,7,7<i>a</i>,8,9,10,11,12<i>a</i>,13,13<i>b</i>,14-icosahydro-1<i>H</i>-naphtho[2',1':4,5]indeno[1,2-<i>b</i>]indolizin-2-yl]oxy}-4-[[[(2<i>S</i>,3<i>R</i>,4<i>S</i>,5<i>S</i>,6<i>R</i>)-3,4,5-trihydro-6-(hydroxymethyl)oxan-2-yl]oxy}oxan-3-yl]oxy}-6-methyloxane-3,4,5-triol</p>	
<p>Other names</p> <p>α-Solanine; Solanin; Solatunine</p>	
Identifiers	
<p>CAS Number</p>	<p>20562-02-1 (https://commonchemistry.cas.org/detail?cas_rn=20562-02-1) ✓</p>
<p>3D model (JSmol)</p>	<p>Interactive image (https://chemapps.stolaf.edu/jmol/jmol.ph)</p>

Biosynthesis



Biosynthesis of solanine From cholesterol

Solanine is a [glycoalkaloid](#) poison created by various plants in the genus *Solanum*, such as the potato plant. When the plant's stem, tubers, or leaves are exposed to sunlight, it stimulates the [biosynthesis](#) of solanine and other glycoalkaloids as a defense mechanism so it is not eaten.^[12] It is therefore considered to be a natural [pesticide](#).

Though the structures of the intermediates in this biosynthetic pathway are shown, many of the specific [enzymes](#) involved in these chemical processes are not known. However, it is known that in the biosynthesis of solanine, [cholesterol](#) is first converted into the steroidal alkaloid [solanidine](#). This is accomplished through a series of [hydroxylation](#), [transamination](#), [oxidation](#), [cyclization](#), [dehydration](#), and [reduction](#) reactions.^[13] The solanidine is then converted into solanine through a series of [glycosylation](#) reactions catalyzed by specific [glycosyltransferases](#).^[12]

Plants like the potato and tomato constantly synthesize low levels of glycoalkaloids like solanine. However, under stress, such as the presence of a [pest](#) or [herbivore](#), they increase

p?model=C%5BC%40H%5D1CC%5B
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5BC%40H%5D%2
8%5BC%40H%5D
3%5BC%40%40H%
5D%28N2C1%29
C%5BC%40%40
H%5D4%5BC%4
0%40%5D3%28C
C%5BC%40H%5D
5%5BC%40H%5D4
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0%40%5D5%28C
C%5BC%40%40
H%5D%28C6%29
O%5BC%40H%5D
7%5BC%40%40H%
5D%28%5BC%40
H%5D+%28%5BC%
40H%5D%28%5B
C%40H%5D%28O
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O%5BC%40H%5D
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5D%28%5BC%40
H%5D%28%5BC%4
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BC%40H%5D%28O
8%29CO%29O%29
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the synthesis of compounds like solanine as a natural [chemical defense](#).^[14] This rapid increase in glycoalkaloid concentration gives the potatoes a [bitter taste](#), and stressful [stimuli](#) like light also stimulate [photosynthesis](#) and the accumulation of [chlorophyll](#). As a result, the potatoes turn green, and are thus unattractive to pests.^[15] Other stressors that can stimulate increased solanine biosynthesis include mechanical damage, improper storage conditions, improper food processing, and [sprouting](#).^[16] The largest concentration of solanine in response to stress is on the surface in the peel, making it an even better defense mechanism against pests trying to consume it.^[17]

Safety

Suggested limits on consumption of solanine

Toxicity typically occurs when people ingest [potatoes](#) containing high levels of solanine. The average consumption of potatoes in the U.S. is estimated to be about 167 g of potatoes per day per person.^[11] There is variation in [glycoalkaloid](#) levels in different types of potatoes, but potato farmers aim to keep solanine levels below 0.2 mg/g.^[18] Signs of solanine poisoning have been linked to eating potatoes with solanine concentrations of between 0.1 and 0.4 mg per gram of potato.^[18] The average potato has 0.075 mg solanine/g potato, which is equal to about 0.18 mg/kg based on average daily potato consumption.^[19]

ChEBI	CHEBI:9188 (https://www.ebi.ac.uk/chebi/searchId.do?chebid=9188) ✘
ChemSpider	28033 (https://www.chemspider.com/Chemical-Structure.28033.html) ✘
ECHA InfoCard	100.039.875 (https://echa.europa.eu/substance-information/-/substanceinfo/100.039.875)
PubChem CID	6537493 (https://pubchem.ncbi.nlm.nih.gov/compound/6537493)
UNII	3FYV8328OK (https://precision.fda.gov/uniisearch/srs/unii/3FYV8328OK) ✔
CompTox Dashboard (EPA)	DTXSID9030707 (https://comptox.epa.gov/dashboard/chemical/details/DTXSID9030707)
InChI	<p>InChI=1S/C45H73NO15/c1-19-6-9-27-20(2)31-28(46(27)16-19)15-26-24-8-7-22-14-23(10-12-44(22,4)25(24)11-13-45(26,31)5)57-43-40(61-41-37(54)35(52)32(49)21(3)56-41)39(34(51)30(18-48)59-43)60-42-38(55)36(53)33(50)29(17-47)58-42/h7,19-21,23-43,47-55H,6,8-18H2,1-5H3/t19-,20+,21-,23-,24+,25-,26-,27+,28-,29+,30+,31-,32-,33+,34-,35+,36-,37+,38+,39-,40+,41+,42-,43+,44-,45-/m0/s1 ✘</p> <p>Key: ZGVSETXHNHBTRK-OTYSSXIJSA-N ✘</p>

Calculations have shown that 2 to 5 mg/kg of body weight is the likely toxic dose of glycoalkaloids like solanine in humans, with 3 to 6 mg/kg constituting the fatal dose.^[20] Other studies have shown that symptoms of toxicity were observed with consumption of even 1 mg/kg.^[11]

Proper storage of potatoes

Various storage conditions can have an impact on the level of solanine in potatoes.

Glycoalkaloid levels increase when potatoes are exposed to light because light increases **synthesis** of glycoalkaloids like solanine.^[18]

Potatoes should therefore be stored in a dark place to avoid increased solanine synthesis.

Potatoes that have turned green due to increased **chlorophyll** and **photosynthesis** are indicative of increased light exposure and are therefore associated with high levels of solanine.^[20] Synthesis of solanine is also stimulated by mechanical injury because glycoalkaloids are synthesized at cut surfaces of potatoes.^[18] Storage of potatoes for extended periods of time has also been associated with increased solanine content.^[21] A study found that the solanine levels in Kurfi Jyoti and Kurfi Giriraj potatoes increase solanine levels by 0.232 mg/g and 0.252 mg/g respectively after being poorly stored in a heap.^[22]

Effects of cooking on solanine levels

Most home processing methods like boiling, cooking, and frying potatoes have been shown to have minimal effects on solanine levels. For example, **boiling** potatoes reduces the α-chaconine

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InChI=1/C45H73NO15/c1-19-6-9-27-20(2)
31-28(46(27)16-19)15-26-24-8-7-22-1
4-23(10-12-44(22,4)25(24)11-13-45(2
6,31)5)57-43-40(61-41-37(54)35(52)3
2(49)21(3)56-41)39(34(51)30(18-48)5
9-43)60-42-38(55)36(53)33(50)29(17
-47)58-42/h7,19-21,23-43,47-55H,6,8-
18H2,1-5H3/t19-,20+,21-,23-,24+,25-,2
6-,27+,28-,29+,30+,31-,32-,33+,34-,35
+,36-,37+,38+,39-,40+,41+,42-,43+,44
-,45-/m0/s1
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Key: ZGVSETXHNHBTRK-OTYSSXIJB

SMILES

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C[C@H]1CC[C@@H]2[C@H]([C@H]3[C@
@H](N2C1)C[C@@H]4[C@@]3(CC[C@
H]5[C@H]4CC=C6[C@@]5(CC[C@@H]
(C6)O[C@H]7[C@@H]([C@H]([C@H]
([C@H](O7)CO)O)O[C@H]8[C@@H]([C
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@@H](O9)C)O)O)O)C)C
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Properties

Chemical formula	C ₄₅ H ₇₃ NO ₁₅
Molar mass	868.06
Appearance	white crystalline solid
Melting point	271 to 273 °C (520 to 523 °F; 544 to 546 K)

Except where otherwise noted, data are given for materials in their **standard state** (at 25 °C [77 °F], 100 kPa).

✗ **verify** (<https://en.wikipedia.org/w/index.php?title=Special:ComparePages&rev1=464404882&page2=Solanine>) (what is ✗?)

[Infobox references](#)

and α -solanine levels by only 3.5% and 1.2% respectively, but [microwaving](#) potatoes reduces the [alkaloid](#) content by 15%.^[23] [Deep frying](#) at 150 °C (302 °F) also does not result in any measurable change. [Alkaloids](#) like solanine have been shown to start decomposing and degrading at approximately 170 °C (338 °F), and deep-frying potatoes at 210 °C (410 °F) for 10 minutes causes a loss of ~40% of the solanine.^[10] [Freeze-drying](#) and [dehydrating](#) potatoes has a very minimal effect on solanine content.^{[24][25]}

The majority (30–80%) of the solanine in potatoes is found in the outer layer of the potato.^[25] Therefore, peeling potatoes before cooking them reduces the glycoalkaloid intake from potato consumption. Fried potato peels have been shown to have 1.4–1.5 mg solanine/g, which is seven times the recommended upper safety limit of 0.2 mg/g.^[18] Chewing a small piece of the raw potato peel before cooking can help determine the level of solanine contained in the potato; [bitterness](#) indicates high glycoalkaloid content.^[18] If the potato has more than 0.2 mg/g of solanine, an immediate burning sensation will develop in the mouth.^[18]

Recorded human poisonings

Though [fatalities](#) from solanine poisoning are rare, there have been several notable cases of human solanine poisonings. Between 1865 and 1983, there were around 2000 documented human cases of solanine poisoning, with most recovering fully and 30 deaths.^[26] Because the symptoms are similar to those of [food poisoning](#), it is possible that there are many undiagnosed cases of solanine [toxicity](#).^[27]

In 1899, 56 German soldiers fell ill due to solanine poisoning after consuming cooked potatoes containing 0.24 mg of solanine per gram of potato.^[28] There were no fatalities, but a few soldiers were left partially [paralyzed](#) and [jaundiced](#). In 1918, there were 41 cases of solanine poisoning in people who had eaten a bad crop of potatoes with 0.43 mg solanine/g potato with no recorded fatalities.^[25]

In Scotland in 1918, there were 61 cases of solanine poisoning after consumption of potatoes containing 0.41 mg of solanine per gram of potato, resulting in the death of a five-year old.^[29]

A [case report](#) from 1925 reported that 7 family members who ate green potatoes fell ill from solanine poisoning two days later, resulting in the deaths of the 45-year-old mother and 16-year-old daughter. The other family members recovered fully.^[19] In another case report from 1959, four members of a British family exhibited symptoms of solanine poisoning after eating [jacket potatoes](#) containing 0.5 mg of solanine per gram of potato.

There was a mass solanine poisoning incident in 1979 in the U.K., when 78 adolescent boys at a boarding school exhibited symptoms after eating potatoes that had been stored improperly over the summer.^[30] Seventeen of them ended up hospitalized, but they all recovered. The potatoes were determined to have between 0.25 and 0.3 mg of solanine per gram of potato.

Another mass poisoning was reported in Canada in 1984, after 61 schoolchildren and teachers showed symptoms of solanine toxicity after consuming baked potatoes with 0.5 mg of solanine per gram of potato.^[31]

In potatoes



Green potatoes usually have elevated levels of solanine and should not be eaten in large quantities.

Potatoes naturally produce solanine and [chaconine](#), a related glycoalkaloid, as a [defense mechanism](#) against [insects](#), [disease](#), and [herbivores](#). Potato [leaves](#), [stems](#), and [shoots](#) are naturally high in glycoalkaloids.

When potato [tubers](#) are exposed to light, they turn green and increase glycoalkaloid production. This is a natural defense to help prevent the uncovered tuber from being eaten. The green colour is from [chlorophyll](#), and is itself harmless. However, it is an indication that increased level of solanine and [chaconine](#) may be present. In potato tubers, 30–80% of the solanine develops in and close to the skin, and some potato varieties have high levels of solanine.

Some potato diseases, such as [late blight](#), can dramatically increase the levels of glycoalkaloids present in potatoes. Tubers damaged in harvesting and/or transport also produce increased levels of glycoalkaloids; this is believed to be a natural reaction of the plant in response to disease and damage.

Also, the tuber glycoalkaloids (such as solanine) can be affected by some chemical fertilization. For example, different studies have reported that glycoalkaloids content increases by increasing the concentration of nitrogen fertilizer.^{[32][33]}

Green colouring under the skin strongly suggests solanine build-up in potatoes, although each process can occur without the other. A [bitter taste](#) in a potato is another – potentially more reliable – indicator of toxicity. Because of the bitter taste and appearance of such potatoes, solanine poisoning is rare outside conditions of food shortage. The symptoms are mainly [vomiting](#) and [diarrhea](#), and the condition may be misdiagnosed as [gastroenteritis](#). Most potato poisoning victims recover fully, although fatalities are known, especially when victims are undernourished or do not receive suitable treatment.^[34]

The United States [National Institutes of Health](#)'s information on solanine strongly advises against eating potatoes that are green below the skin.^[3]

In other plants

Fatalities are also known from solanine poisoning from other plants in the nightshade family, such as the berries of *[Solanum dulcamara](#)* (woody nightshade).^[35]

In tomatoes

Some, such as the California [Poison Control Center](#), have claimed that [tomatoes](#) and tomato leaves contain solanine. However, Mendel Friedman of the United States Department of Agriculture contradicts this claim, stating that [tomatine](#), a relatively benign alkaloid, is the tomato alkaloid while solanine is found in potatoes. Food science writer [Harold McGee](#) has found scant evidence for tomato toxicity in the medical and veterinary literature.^[36]

In popular culture

[Dorothy L. Sayers](#)'s short story "The Leopard Lady", in the 1939 collection *[In the Teeth of the Evidence](#)*, features a child poisoned by [potato berries](#) injected with solanine to increase their toxicity.

See also

- [Lenape \(potato\)](#)
- [Solanidine](#)

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External links

- [a-Chaconine and a-Solanine, Review of Toxicological Literature](https://web.archive.org/web/20060815010907/http://ntp-server.niehs.nih.gov/index.cfm?objectid=6F5E930D-F1F6-975E-7037ACA48ABB25F4) (<https://web.archive.org/web/20060815010907/http://ntp-server.niehs.nih.gov/index.cfm?objectid=6F5E930D-F1F6-975E-7037ACA48ABB25F4>)
- *MedlinePlus Encyclopedia*: 002875 (<https://medlineplus.gov/ency/article/002875.htm>) – "Green tubers and sprouts"



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