

## A Review of Occurrence of Glycoalkaloids in Potato and Potato Products

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### ABSTRACT

There has been increasing consumption of potato products such as French fries and crisps in most countries as a result of lifestyle change in both developed and developing countries. Due to their generally pleasurable taste and texture, they are appreciated by a high number of consumers across the world, with the younger members of the population mostly those in the urban areas having a higher preference. The hard economic situations have also driven many people to their consumption as they are affordable. Moreover, these products are convenient for the younger generation who do not prepare their own food. However, there have been food safety concerns that have been linked in the past to glycoalkaloids in the raw potatoes that are used for processing. Potatoes are known to accumulate glycoalkaloids (GAs) during growth and postharvest storage. Some potato varieties have been shown to have high glycoalkaloids. These toxicants have been found to bioaccumulate in the body especially if daily consumption of foods containing the glycoalkaloids are consumed. Glycoalkaloids lead to intestinal discomfort, vomiting, fever, diarrhea and neurological problems and can lead to human or animal deaths in cases of acute toxicity. Transportation, handling, poor storage and exposure to sunlight during marketing of potatoes exposes consumers to potential risk of glycoalkaloids due to injury and greening which lead to increased levels of glycoalkaloids. Glycoalkaloids are quite stable and therefore, freeze-drying, boiling, dehydration or microwaving have got limited effect and thus persist through the processing conditions into the final products with the levels being proportional to the concentrations in the raw materials used. This current review focuses on the occurrence of glycoalkaloids in potato and potato products that are commonly consumed.

**Keywords:**  $\alpha$ -solanine,  $\alpha$ -chaconine, glycoalkaloids, Crisps, French fries, Toxicity, potato, *Solanum tuberosum*.

### INTRODUCTION

Potato products such as Crisps and French fries are important snacks that are industrially produced with a high consumption by a high proportion of urban dwellers<sup>1</sup>. As a result of high consumption, crisps for example are a major product in the snacks industry and market and therefore a large share in the supermarkets, kiosks and roadside shops. French fries are now a popular lunch time meal among the low and middle class income earners where French fries have become an almost daily food<sup>1</sup>. They are also cheap and therefore

are inexpensive alternatives especially among consumers experiencing harsh economic conditions. However, there have been food safety concerns that have been linked in the past to glycoalkaloids in the raw potatoes that are used for processing<sup>1,2</sup>.

Potatoes, *Solanum tuberosum*, contain steroidal glycoalkaloids that are toxic, derived through biosynthetic process from cholesterol<sup>3</sup>.  $\alpha$ -solanine and  $\alpha$ -chaconine are the major glycoalkaloids in potatoes. They naturally function as stress metabolites or phytoalexins and help in protecting potatoes against insect attack, fungi and phytopathogens<sup>4</sup>.

Solanine concentration increases in the potato peels and occurs concurrently with greening of the peel due to chlorophyll synthesis. They are both biochemical processes that are independent of each other but are light induced<sup>4</sup>.

Potential human toxicity as a result of glycoalkaloids has led to guideline formulation that limits the glycoalkaloids contents of new varieties of potatoes before they can be released for commercial use<sup>5</sup>. After harvesting, the glycoalkaloid content may increase during storage and transportation and this is as a result of the influence of light, heat, cutting, injury, slicing, sprouting, and exposure to phytopathogens<sup>5, 6</sup>. Potatoes are exposed to sunlight in the markets resulting to increased risk of glycoalkaloids exposure. There are high chances of buying greened tubers that are immature which correspond to glycoalkaloids accumulation<sup>6</sup>.

#### Occurrence Of Glycoalkaloids In Foods

Glycoalkaloids are usually secondary natural poisonous metabolites produced by plants of the Solanaceae family. These plants include: peppers (*Capsicum annuum*) potato (*Solanum tuberosum* L.), egg plant (*Solanum melongena*) tomato (*Lycopersicon esculentum*), nightshade, thorn apple, and capiscum. They play an important role in plants due to their toxic nature and the potential undesirable effects to exposed humans especially if consumed in high amounts. They impart flavor although at higher levels they lead to bitterness besides a burning sensation when consumed<sup>5, 6, 7</sup>.

Glycoalkaloids are distributed in all plant organs. The concentrations are highest in the unripe berries, young leaves, flowers, shoots or sprouts (metabolically active parts). They are allelochemicals that play defensive roles against pathogens and predators that include worms, fungi, insects, bacteria, and viruses<sup>8</sup>.

The steroidal glycoalkaloids from solanaceous plants vary depending on species. These variations may be as a result of presence or absence of a C-C double bond, different functional groups such as the acetyl and hydroxyl groups, sugar moieties and the functional groups stereochemistry<sup>9</sup>.

There are two major steroidal alkaloids that are found in eggplants - solasonine and solamargine and are also found in about 100 *Solanum* species<sup>10</sup>.  $\alpha$ -solanine and  $\alpha$ -chaconine are prevalent in cultivated potato. The glycoalkaloids from these plants differ in their steroidal structure<sup>9</sup>. Tomatoes have a major glycoalkaloid known as tomatine that is made up of a mixture of two glycoalkaloids,  $\alpha$ -tomatine and dehydrotomatine<sup>11</sup>. These are found in all parts of the tomato plants. Most common nightshades usually have as much as 7.6 to 8.2 mg100g<sup>-1</sup> of solanine with the peppers having about 7.7 to 9.2 mg100g<sup>-1</sup> of solanine. Eggplant solanine concentrations range from 6.1 - 11.33 mg100g<sup>-1</sup><sup>12</sup>.

#### Occurrence Of Glycoalkaloids In Potato

Production of toxic glycoalkaloids in potatoes occurs both during the farming operations and postharvest handling<sup>13</sup>. Glycoalkaloid levels vary depending with potato variety as it is genetically controlled with the regional and geographical conditions influencing the levels of glycoalkaloids as well<sup>5</sup>. Other factors include growing conditions, storage and transportation, temperature, cutting, sprouting and exposure to phytopathogens and

**Table 1: The levels of glycoalkaloids in various parts of the potato plant**

Plant part	Glycoalkaloid content (mg/kg, fresh weight)	References
Leaves	230 – 1450	18,19
Flowers	2150 – 5000	19
Berries	180 – 1350	18,20;
Stems	23 – 33	19
Sprouts	2000-9970	18,19
Bitter tasting tuber	250 – 800	19
Normal tuber	10-150	19
- Skin (2-3% of tuber)	300-640	
- Peel (10-12% of tuber)	150-1070	
- Flesh	12-100	
- Cortex	125	
- Pith	Not detectable	
Roots	180 – 850	18,19

light<sup>5,14</sup>. There is a high concentration of glycoalkaloids in the in the skin of tubers, although higher concentrations are found around the potato eyes, wounded areas and in the sprouts<sup>15, 16, 29,5,14</sup>. This is summarized in Table 1 below.

The glycoalkaloid contents of potato vary among varieties. Studies have reported various ranges in the total glycoalkaloid levels of 8.4 - 222.6 mg 100g<sup>-1</sup> in dry peels and 0.5 - 59.2 mg100g<sup>-1</sup> in dry flesh<sup>21</sup>, 17.4 - 549.7 mg 100g<sup>-1</sup> in dry peel, 64.2 mg100g<sup>-1</sup> in dry boiled flesh<sup>22</sup>, and 58.5 - 534.2 mg100g<sup>-1</sup> in dry peel and from 0.7 to 46.6 mg100g<sup>-1</sup> in dry flesh<sup>23</sup>.

Various levels of glycoalkaloid concentrations in both tubers and potato products have been reported in other countries ranging from 2 to 156 mg/100g<sup>-1</sup> in Europe<sup>2, 16, 17, 24, 28</sup> 3.5-17.5 mg/100g<sup>-1</sup> in Kenya<sup>6</sup>, 3-5449 mg/100g<sup>-1</sup> in flesh and peels of tubers from Pakistan<sup>26</sup>, 0.01-6.9 mg/100g<sup>-1</sup> in Canadian tubers<sup>27</sup>.

There are other glycoalkaloids that are present but  $\alpha$ -solanine and  $\alpha$ -chaconine account for up to 95% of the total glycoalkaloids found in potatoes<sup>2</sup>.  $\alpha$ -chaconine is usually higher in concentrations as compared to  $\alpha$ -solanine<sup>15</sup>. The other glycoalkaloids that are present although in very low concentrations include  $\beta$ - and  $\gamma$ -solanines and chaconines,  $\alpha$ - and  $\beta$ -solamarines, and 5- $\beta$ -solanidan-3- $\alpha$ -ol and demissidine<sup>2</sup>. Plant breeding involving use of wild potatoes introduces other glycoalkaloids, such as commersonine and demissine, which are derivatives of demissidine, and leptinidine derivatives that result to various leptines<sup>3</sup>. The ratio of  $\alpha$ -solanine to  $\alpha$ -chaconine quantities is dependent on cultivars, parts of the plant, as well as the agronomic practices used. This ranges from 1:2 to 1:7<sup>30</sup>.

A normal potato tuber on average contains 12–20 mg kg<sup>-1</sup> of glycoalkaloids while a green one contains average 250–280 mg kg<sup>-1</sup> and green skin 1500–2200 mg kg<sup>-1</sup><sup>34</sup>. The total glycoalkaloid content of potatoes in the U.K has been found to be about 25–150 mg kg<sup>-1</sup> fresh weight although higher levels in some varieties have been reported<sup>12</sup>. Polish potato varieties contain 12 - 159 mg kg<sup>-1</sup> while the German and American cultivars range between 20 - 220

mg kg<sup>-1</sup> and 20 - 130 mgkg<sup>-1</sup> respectively<sup>35,36</sup>. The Lenape variety was banned in Canada and USA since it had extremely high glycoalkaloids levels - 30 mg 100g<sup>-1</sup> while the Magnum Bonum variety was banned in Sweden due to high toxic glycoalkaloids levels averaging 25.4 mg 100g<sup>-1</sup> although highest reported level was 66.5 mg 100g<sup>-1</sup> fresh weight<sup>12</sup>.

Chemically, the major glycoalkaloid,  $\alpha$ -solanine and  $\alpha$ -chaconine are made up of an alkaloid that is bound to an oligosaccharide. They have aglycone solanidine attached to a trisaccharide: galactose, glucose and rhamnose in  $\alpha$ -solanine and glucose, rhamnose and rhamnose in  $\alpha$ -chaconine. The glycoalkaloid,  $\alpha$ -chaconine is more toxic than  $\alpha$ -solanine, although the two have got synergistic effects when present in the same tissue and the severity of their toxicity is dependent on their levels of as we well as their ratio<sup>14</sup>.

#### Glycoalkaloids Toxicity

Glycoalkaloids have been shown to be less toxic to other animals as compared to man. The toxicity may be due to anticholinesterase activity of the glycoalkaloids on the central nervous system and due to disruptions of cell membranes affecting the digestive system and other organs<sup>13</sup>. Low levels of glycoalkaloids intake can cause gastrointestinal discomfort mainly abdominal pain diarrhea and vomiting<sup>31</sup>. Higher doses of GAs lead to acute intoxication while the severe symptoms, including neurological disorders, rapid pulse, low blood pressure, and in extreme cases coma or death may be experienced<sup>32</sup>.

The toxic dose is approximated at 2-5 mg kg<sup>-1</sup> body weight while the lethal dose is estimated at 3-6 mgkg<sup>-1</sup> of body weight<sup>33</sup>. Glycoalkaloids levels above 14mg100<sup>-1</sup>g result to bitterness while varieties having more than 20 mg 100<sup>-1</sup>g lead to a burning sensation in the throat and mouth<sup>35</sup>. A study by valcarel *et al.*<sup>28</sup> estimated a total daily intake of between 0.4 - 1.7 mg per person per day of glycoalkaloids based on consumption of an estimated 158 g of potatoes per capita. Consumption of these potatoes with peels would result to a daily intake of 3.6 - 8 mg per person<sup>28</sup>.

Glycoalkaloids are studied because of their impact on health through exposure via food

consumption<sup>37</sup>. The mechanism of glycoalkaloids toxicity is by exerting their toxic effects on the nervous system in which they interfere with the ability to regulate acetylcholine, which is involved in transmission of nerve impulses. Glycoalkaloids disrupt membranes with solanine toxicity leading to headaches, fatigue, vomiting, abdominal pains, nausea and diarrhea<sup>38</sup>. These toxicants have been found to bioaccumulate in the body especially if daily consumption of foods containing the glycoalkaloid are used. It has been shown that glycoalkaloids remain within the body after 24 hours of ingestion<sup>39</sup>.

In a single dose study to evaluate toxicity, the involved volunteers were administered with various oral doses of total glycoalkaloids through consumption of mashed potatoes having glycoalkaloid doses of 0.95, 1.10 and 1.25 mgkg<sup>-1</sup> body weight (BW). An individual who had the highest dose of 1.25 mgkg<sup>-1</sup> body weight started nauseating and vomited after 4 hours as a result of glycoalkaloid toxicity<sup>39</sup>.

An oral everyday intake of about 1 - 5 mgkg<sup>-1</sup> body weight can have marginal to severe toxic effects to humans which would later cause harmful effects to consumers<sup>31</sup>. Therefore cumulative safety risk may be possible among daily or frequent consumers of potato and potato products in the long term. Diagnosing of poisoning is compounded by the fact that symptoms of toxicity are similar to other gastrointestinal disorders<sup>41</sup>. It is important to consider the extent of glycoalkaloid accumulation from the diet as influenced by metabolism in the body. A study by Harvey *et al.*<sup>42</sup>, showed a correlation between glycoalkaloid concentration in the serum and potato dietary intake of the subjects under study. When two individuals withdrew from consumption of potato and potato products, glycoalkaloid concentration in the serum declined significantly becoming negligible in the second week onwards. The rate of excretion once in the bloodstream appears to be low, which is an indication that these compounds may bioaccumulate in different organs of the body, including the liver<sup>41, 42</sup>.

#### **Effect of Processing on Glycolkaloids**

Glycolkaloids in the potato tubers can be reduced when various unit operations are carried out during processing including peeling, chipping, cutting and dicing when producing

products such as fries<sup>42</sup>. Peeling of tuber reduces the glycoalkaloid levels by 20% to 58% of the total glycoalkaloids<sup>43, 44</sup>, although cooking has variable effects since glycoalkaloids are very heat stable, with  $\alpha$ -solanine decomposing at temperatures of between 260 and 270°C<sup>45</sup>. Boiling and microwaving have got insignificant effect on the glycoalkaloid contents<sup>46</sup>. Boiling of peeled potatoes leads to a reduction of about 39%<sup>44</sup>. Frying is the most effective method of lowering the levels of glycoalkaloids, with reported differences between raw, peeled and fried potatoes being 77 to 94%<sup>42,44</sup>.

A study by Liu *et al.*<sup>47</sup> on crisps showed that all the sampled products contained  $\alpha$ -chaconine and  $\alpha$ -solanine in widely varying concentrations. The amount of  $\alpha$ -chaconine was higher than that of  $\alpha$ -solanine in all samples. This shows that the glycoalkaloids tend to persist through the processing conditions and therefore consumers are at risk of exposure through consumption of such products.

According to Tajner-Czopek *et al.*<sup>48</sup>, it was found out that the ratio of  $\alpha$ -solanine to  $\alpha$ -chaconine concentration of raw and processed French fries of coloured-fleshed potato varieties decreased in studied samples during French fries processing compared with raw material although Peksa *et al.*<sup>42</sup> observed that after peeling, slicing and washing out in water,  $\alpha$ -solanine content decreased more than  $\alpha$ -chaconine.

The industrial practice involves blanching of peeled potatoes which is mostly in water at 75°C for 15 min although other temperature - time combinations can be used depending on the final product desired and quality of the processed potato products. Blanching results to a significant loss of glycoalkaloids by up to 28 % compared to peeled potatoes. Cieslik<sup>49</sup> observed that blanching decreases the total glycoalkaloids by about 40–50 %. This is because they dissolve in water although  $\alpha$ -solanine is poorly dissolved as compared to  $\alpha$ -chocanine<sup>50</sup>.

#### **Exposure to Glycoalkaloids**

The epidemiological and experimental studies from human and laboratory animal studies have resulted to data that is not adequate to estimate the real safety level of glycoalkaloid intake<sup>39</sup>. In

an ascending dose study one of the two human volunteers receiving the highest dose of 1.25 mg/kg body weight had nausea and vomited about four hours after administration<sup>39</sup>.

Toxicological studies of glycoalkaloids have mostly been carried out on rabbits, mice, rats, and hamster. These studies have shown that the LD<sub>50</sub> for  $\alpha$ -solanine and  $\alpha$ -chaconine and tomatine in mice were 27, 30, and 34 mg/kg body weight, respectively. For most animals the LD<sub>50</sub> for various other glycoalkaloids have been found to be within 30 - 60 mg/kg body weight. It has been shown that solanidanes may be toxic as compared to spirostanes - solamargine, solasonine and solasodine<sup>51</sup>.

Poisoning due to exposure to glycoalkaloids has resulted to about 2000 human cases, in which 30 deaths occurred<sup>52</sup>. These cases have been reported from 1865 to 1983<sup>52,53</sup>. Many more cases of glycoalkaloid poisoning may be undiagnosed since symptoms of toxicity are similar to bacterial food poisoning<sup>19</sup>.

McMillan and Thompson<sup>54</sup> reported an incident in which 78 adolescent boys attending a school in United Kingdom were taken ill after consuming potatoes that had been stored during summer term. Seventeen (22%) boys who consumed

the potatoes had symptoms of abdominal pains, nervous system effects, vomiting, hallucinations, fever and severe diarrhea. The peeled and boiled potatoes had 0.25 to 0.3 mg/g of glycoalkaloid contents. In 1983, 61 out of 109 schoolchildren and teachers in Canada fell sick as a result of consuming baked potatoes that had 0.5 mg of solanine/g potato<sup>55</sup>.

## CONCLUSION

Glycoalkaloid contents of both raw and processed potato products are of interest to the potato industry, policymakers and potato breeders. The occurrence of the glycoalkaloids in potato and potato products cannot be wished away. Glycoalkaloid intake through consumption should also consider the effects that various processing and postharvest handling practices may have on the levels of glycoalkaloids. There is need for assessment of glycoalkaloid occurrence in potato and potato products in growing and consuming countries. Intake levels need to be established to guide policy makers.

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