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Anti-nutritional Compounds in Potatoes, Depending on the Type of Raw Material and Conditions of Processing Potatoes into Food Products

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ABSTRACT

The nutritional quality of potato, which is directed towards consumption or intended for food processing, is determined by the presence of nutritional components such as starch, protein or vitamins and also by the low content of anti-nutritional ingredients in potato tubers. Anti-nutritional components in potato exist naturally in tubers, are created as effects of destabilization of the plant's metabolism, or they can be absorbed from a polluted environment. The most common natural anti-nutritional ingredients in potato include nitrates V, toxic glycoalkaloids and nitrates III, although heavy metals and pesticides used during potato cultivation can penetrate potato tubers. Usually, potatoes used in the food industry originate from conventional cultivation, which is characterized by heavy fertilization and plant protection. This could be a reason for the increase in toxic components as well as anti-nutritional ingredients – mainly glycoalkaloids (solanine and alpha-chaconine) and nitrates – in potato tubers. The technology used in the production of French fries, chips or dried potato products depends on the parameters used at particular stages of the production line, affecting the content of those components in processed potatoes to a different degree. The differences in the content of glycoalkaloids and nitrates can appear not only because of the differences in the methods used to' peel or cut potato tubers, but also because of the different parameters (time and temperature) used during three key processes: blanching, frying and drying. High temperatures used in the processing of potato products also need to take into consideration the development of acrylamide.

Keywords: anti-nutritional compounds, food processing, potato, storage

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INTRODUCTION

Potato is one of the main crops in the world, grown in different climatic and soil conditions (Lisińska and Leszczyński 1989; Lisińska *et al*. 2009; Burlingame *et al*. 2009). The high popularity of potato is associated not only with its taste but also with its high nutritional value which depends primarily on its chemical composition: carbohydrate compounds, protein, vitamin C and minerals. The nutritional value of potato has been extensively discussed before (Leszczyński 2000; Lisińska 2006; Lisińska *et al*. 2009; Burlingame *et al*. 2009). Apart from its nutrients, potato tubers also contain some undesirable substances. They can be of natural origin but can also result from disturbances in metabolism or from environmental contamination (Leri *et al*. 2011) (**Fig. 1**).

Some of the undesirable natural potato ingredients are, for example, the inhibitors of proteolytic enzymes present in all tuber tissues (Lisińska and Leszczyński 1989; Leszczyński 2000). They represent about 15% of the water-soluble proteins of potato tubers, and through inhibition of the enzymatic breakdown of proteins they limit the use of protein in the process of digestion. Some inhibitors are resistant to high temperatures, therefore their inactivation requires a specific heat treatment (Zhao and Camire 1995).

Two glycoalkaloids, chaconine and solanine, collectively known as solanine, are important natural toxic components of potato tubers. They share the same terpenoid aglycone – solanidine – bound with three molecules of simple sugars; glycalkaloids differ only in one molecule of

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Invited Review

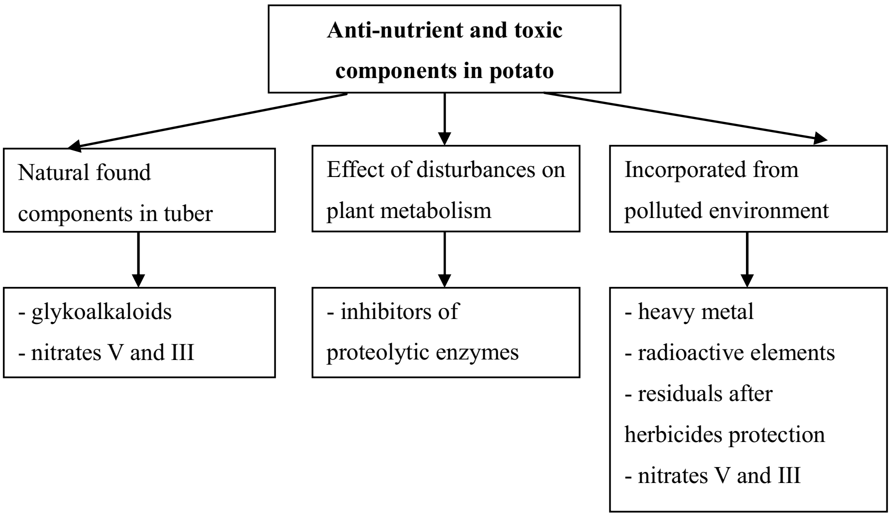

Fig. 1 Classification of anti-nutrient and toxic components in potato.

these sugars and in their configuration (Maga 1980; Friedman and Dao 1992; Leszczyński 1994; Friedman and McDonalds 1997; Ostry *et al.* 2010). Glycoalkaloids found in potatoes occur as α-chaconine (*ca.* 40%) and α-solanine (*ca.* 60%) (Friedman *et al.* 1991; Blankemeyer *et al.* 1992; Friedman and McDonald 1997; Haase 2010). Due to the fact that α-chaconine is more toxic than α-solanine, attention is paid to their mutual ratio. The ratio of chaconine concentration to α-solanine varies depending on the anatomy of the potato or its variety, and ranges from 40: 60, through 25: 75, up to 60: 40 (Friedman and McDonald 1997; Speijers 1998; Bejarano *et al.* 2000). Glycalkaloids are potent poisons (Friedman *et al.* 1991; Blankemeyer *et al.* 1992; Friedman 2006; Donald 2008; Haase 2010; Leri *et al.* 2011) with a lethal dose of 3-5 mg/kg of body weight, which is similar to strychnine and arsenic (Morris and Lee 1984; JECFA 1992; Haase 2010). However, potatoes, specifically *Solanum tuberosum*, usually contain small amounts of glycoalkaloids, ranging from 3-10 mg/100 g on average in mature tubers (Wünsch and Munzert 1994; Friedman and McDonald 1997; Speijers 1998; Pęksa *et al* 2002; Knuthsen *et al.* 2009). It is noteworthy that potatoes produced for consumption or processing into food products cannot contain more than 20 mg glycoalkaloids/100 g potatoes (FAO/WHO 1999; Ginzberg *et al.* 2009), recently reduced to 10 mg/100 g potatoes (Speijers 1998; Leszczyński 2000; Knuthsen *et al.* 2009). Above 11 mg/100 g, glycoalkaloids start to give unprocessed tubers a bitter taste (Maga 1980; Osman 1983; Leszczyński 2000). Levels are reviewed in **Table 1**.

Glycoalkaloids occur in all anatomical parts of the potato (Valkonen *et al.* 1996; Friedman and McDonald 1997; Donald 2008; Haase 2010). Their concentration is highest in flowers, fruits, young leaves and sprouts. Flowers may contain about 500 mg/kg of glycoalkaloids, and sprouts as much as 17,000 mg/kg (Wünsch and Munzert 1994). In potato tubers, the greatest concentration of total glycoalkaloids (TGA) is in the skin and just beneath the surface (up to 1.5 mm thick), and within the eyes and damaged areas (Wünsch and Munzert 1994; Friedman and McDonald 1997; Friedman 2006; Ostry *et al.* 2010). Glycoalkaloids increase the resistance of the potato to infectious diseases and pests, hence their concentration in mechanically damaged or disease-affected potatoes is higher. There are great differences in TGA content between individual tubers of the same variety of potato (Valkonen *et al.* 1996; Friedman and McDonald 1997; Leszczyński 2000; Friedman 2006; Leri *et al.* 2011).

Potatoes, like most plants, contain nitrates (V). The permissible amount of these compounds in potatoes produced for consumption should not exceed 200 mg NO_3^-/kg (Hill 1999) and of toxic nitrates III - 5 mg $NaNO_3$/kg (Cieślik and

Table 1 Glycoalkaloid content of various potato products (mg/kg) (built on Friedman and McDonalds 1997).

Product	Total glycoalkaloids	Reference
Commercial French fries,	0.8-8.4	Friedmann and Dao 1992
fresh	19-58	Davies and Blincow 1984
	10	Rytel *et al.* 2005
Partially cooked fries,	23-55	Jones and Fenwick 1981
frozen	4	Tajner-Czopek *et al.* 2008
	< 100	Knuthsen *et al.* 2009
Precooked fries, frozen	19-35	Jones and Fenwick 1981
Commercial wedges, fresh	44	Friedmann and Dao 1992
Commercial skins, baked	31	Friedmann and Dao 1992
	52-63	Bushway *et al.* 1983
	5	Ostry *et al.* 2010
Commercial skins, fried	55-203	Friedmann and Dao 1992
	120-242	Bushway *et al.* 1983
	5	Ostry *et al.* 2010
Commercial potato chips	24-109	Friedmann and Dao 1992
	95-720*	Sizer *et al.* 1980
	23	Pęksa *et al.* 2006
Potato pancake powder	45	Friedmann and Dao 1992
	6	Mäder *et al.* 2009
Peel wedges, frozen	76-120	Bushway *et al.* 1983
Pell slices, frozen	66-71	Bushway *et al.* 1983

* High value attributed to sample with large amount of peel

Praznik 1996). The European Scientific Committee for Food (SCF) has set the Acceptable Daily Intake (ADI) for NO_3^- at 3.65 mg/kg body weight/day (Commission of the European Communities Scientific Committee for Food 1997).

Although potatoes (*S. tuberosum*) are classified as vegetables with a low nitrate content (Corre and Breimer 1979; Schuddeboom 1993; Ierna 2009), their high consumption around the world considerably contributes to the consumption of these compounds by humans Santamaria *et al.* 1999; Santamaria 2006; Ierna 2009). In general, vegetables are the source of 85% of nitrates and from 16 to 43% of nitrites in the human diet (Gangolii *et al.* 1994; Cassens 1995; Walters 1991; Amr and Hadidi 2001). Nitrates (V) themselves are not toxic to humans, but the intestinal microflora may reduce them to nitrates III, which participate in the formation of carcinogenic nitrosamines. On the other hand, nitrates in the digestive tract inhibit the growth of some human pathogens (McKnight *et al.* 1999; Leszczyński 2000). In Central Europe, potato tubers contain from 10 to 74 mg $NaNO_3$/100 g, and on average 15-30 mg/100 g (Cieślik 1995a; Murawa 2008), which is several times less than in other vegetables: green lettuce (150-300 mg/100 g), cabbage (from 100 to 650 mg/100 g), parsley root (40-110 mg/100 g), and beetroots (140-320 mg/100 g) (Murawa 2008). The amount of these compounds is highly variable, depending on the variety, growing season, environmental factors, or storage conditions (Amr and Hadidi 2001; Ierna 2009). The largest concentration of nitrates is in the skin or just beneath the surface, therefore peeling the tubers and boiling significantly reduces their content (Rytel *et al*. 2005; Pęksa *et al*. 2006).

In addition to these components, potatoes may also contain various pollutants, the result of deliberate or accidental human activities. Air pollution is responsible for heavy metal content, for example lead and radioactive elements, generally present in trace amounts, not exceeding one hundredth of a milligram per 100 g (Leszczyński 2000).

Lead occurs between 0.2-1.6 μg/100 g (Bibak *et al.* 1999), and from 10-11 μg/100 g (Rembiałowska 1999) to 100 mg/100 g in areas contaminated with heavy metals (Leszczyński 1994). Cadmium is present in amounts ranging from 0.2 to 23 mg/100 g (McLaughlin *et al.* 1997), albeit rarely exceeding 1 μg/100 g (McLaughlin *et al.* 1999).

While cadmium is evenly distributed throughout the tuber, lead is mainly located in the skin and can be removed during culinary preparation. Mercury occurs in quantities at the detection limit, i.e. 2.5 μg/100 g dry weight. The content of arsenic is similar to mercury (Prośba 1999).

Radioactive strontium enters the potato tubers in minimal amounts, even at relatively high contamination levels of the soil and vine. Most of the trace amounts of radionuclides are removed during peeling and processing of potatoes (Leszczyński 1994).

For many years potatoes have also been contaminated by plant protection products. Despite the use of pesticides at appropriate times and dosages, and compliance with waiting periods depending on the rate of decay of the active substance in the product, some quantities of these compounds are still present in food products. Each plant protection product has its residue limits within which there is no stated risk to health. Almost all currently used plant protection products are only partly soluble in water, but highly soluble in fats. As potatoes have a very low fat content, mainly in the cytoplasmic membranes, they accumulate pesticides to a very small extent. The potato contains trace amounts of these compounds, usually a few hundredths of milligram per 100 g of tubers (Leszczyński 2000).

As is apparent from the aforementioned data, potatoes can be considered healthy food, with a low level of toxic or anti-nutritional compounds. However, the chemical composition of potato tubers is not constant. The contents of the individual components of their dry weight, including anti-nutritional compounds, can vary widely depending on many factors. The variability of the chemical composition of potatoes is mainly genetically conditioned, but may be modified by different environmental conditions during the growth of the potato (Lisińska and Leszczyński 1989; Valkonen *et al.* 1996; Lisińska *et al*. 2009).

THE CONTENT OF ANTI-NUTRITIONAL COMPOUNDS IN POTATOES IN RELATION TO ENVIRONMENTAL FACTORS

Environmental conditions that may affect the chemical composition and quality of potato tubers are objective factors that result from deliberate human activity. The former include climatic conditions, weather, crop area, soil type and diseases. The latter are the regulation of soil moisture, seed handling, planting date, crop type and harvest time. This group also includes chemicalization of agriculture, primarily the use of mineral fertilizers and plant protection products (Lisińska and Leszczyński 1989).

The contemporary global economy is oriented to the maximization of profits. This also applies to agriculture with its intensive farming methods used to obtain the highest yields. These methods involve, for example, the use of high doses of mineral fertilizers and large quantities of pesticides, in order to avoid losses caused by diseases, pests and weeds (Leszczyński 2002). Mineral fertilizers may be contaminated with heavy metals which pollute the environment and crops via the soil. The use of some nitrogen fertilizers in high doses may increase nickel, vanadium and chromium concentrations in tubers. However, among various crops, the potato contains the lowest amounts of these metals (Lisińska and Leszczyński 1989).

The potato in its growth period takes from the soil a certain amount of different components necessary for its development. Fertilizers, especially mineral ones, in which components are easily assimilable by plants, are also intensively taken up by tubers (Leszczyński 2002). The greatest impact on the chemical composition of tubers is induced by nitrogen, which may increase the content of glycoalkaloids (solanine and chaconine) (Mondy and Munshi 1990b; Rogozińska 1995). The accumulation of glycoalkaloids in potatoes is also affected by the prevailing weather during the growing season, albeit the response of potatoes to changing weather conditions is very different, depending on the variety (Cieslik and Praznik 1998; Haase 2010). Potato varieties that synthesize higher amounts of TGA maintain this elevated level of synthesis regardless of the environmental conditions and accumulate more of these compounds than potato varieties with a lower susceptibility to the formation of TGA (Friedman and McDonald 1997).

Both heavy rainfall and low temperatures during the growth of the tubers, or on the other hand a small amount of rainfall and high temperatures, may intensify the accumulation of glycalkaloids in potato tubers (Hellenas *et al*. 1995; Friedman and McDonald 1997; Haase 2010). During potato vegetative growth, the content of toxic compounds varies with the growth of tuber size; during growth and maturation of potato, TGA decreases from a level that is already significant after 52 days of growth (Sinden *et al.* 1984). In 100 g of immature tubers, 2.8-3.8 mg solanine and 6.6-8.4 mg chaconine were observed, and in mature tubers 0.4-1.0 mg of solanine and 1.1-3.0 mg of chaconine (Lisińska and Leszczyński 1989; Love *et al*. 1994). Potato tubers are smaller when harvested before maturity, and the outer layers are proportionally richer in both solanine and chaconine (Sinden *et al.* 1984; Pęksa *et al* 2002; Rytel *et al.* 2005). The potato vegetative period, lasting 118 days, is sufficient for most varieties to reach maturity, and the content of glycoalkaloids in tubers changes during subsequent vegetative growth, which might be caused by factors other than maturation (Sinden *et al.* 1984; Pęksa *et al.* 2002).

Similarly to glycoalkaloids, the concentrations of nitrites and nitrates in potato tubers also depend on environmental factors and weather conditions (Lisińska and Leszczyński 1989; Międzobrodzka *et al*. 1992; Leszczyński 1994; Cieślik 1995b; Van Velzen *et al*. 2008). According to Cieslik (1996), Międzobrodzka *et al*. (1992) and Van Velzen *et al*. (2008), the content of nitrates and nitrites in potatoes of the same variety may differ over a few years of cultivation. These authors (Międzobrodzka *et al*. 1992; Cieślik 1995b; Van Velzen *et al*. 2008) observed a close relationship between the content of these compounds and the mean air temperature during the potato growing season.

According to Cieślik (1995b), higher daily air temperature during the growing season and lower rainfall increased the amount of nitrates in potatoes. In addition, it is believed that larger quantities of nitrates are accumulated by early varieties of potatoes, compared to mid-late or late varieties. Potatoes harvested at a later stage are characterized by a 40% decrease, compared with nitrates in potatoes harvested earlier.

Another important factor affecting the level of nitrates in potato tubers is the dosage and form of the fertilizer (Leszczyński 1994). Increasing doses of nitrate fertilizers significantly increase the nitrate content in potatoes. Very high doses of nitrogen fertilization not only cause a weaker development of the plants but also substantially reduce the content of nitrogen compounds in the dry weight of tubers, and increase the accumulation of nitrates (Lisińska and

Leszczyński 1989; Leszczyński 1994). The content of nitrate and ammonium nitrogen increases with increasing doses of nitrogen fertilization. The amount of nitrates in potatoes also depends on the soil moisture (Lisińska and Leszczyński 1989) and pH. As NO_3^- ion uptake increases with a decrease in soil pH, a low pH favors the accumulation of nitrates in plants (Rożek 2000).

THE CONTENT OF ANTI-NUTRITIONAL COMPOUNDS IN POTATOES IN RELATION TO STORAGE FACTORS

Usually, potatoes produced for food purposes must be stored for a period ranging from several weeks to the time of next harvest (i.e., 9 months). During storage, excessive losses resulting from natural loss, germination of tubers and diseases should be avoided. Changes in the chemical composition and organoleptic characteristics of tubers may also occur, lowering the quality of potatoes. These losses and changes depend mainly on the quality of potatoes destined for storage (Leszczyński 1994).

Only mature potatoes should be stored. Long-term storage is suitable for varieties with a long period of dormancy, with possibly late germination. Tubers must not be damaged or infected by pathogens.

The quality of stored potatoes is mainly affected by the storage temperature. Potatoes for French fries and snack production are stored at 6-7°C, and for fries at 7-10°C, because of the accumulation of reducing sugars (Czerko and Zgórska 2008). Tubers stored at 2-4°C contain significantly more sucrose and reducing sugars than before storage or at 7-13°C (Leszczyński 1994). The accumulation of sugars in stored tubers at a low temperature is caused by a relatively small decrease in the rate of starch conversion into sugars (Lisińska and Leszczyński 1989). On the other hand, storage of potatoes at lower temperatures in the range of 1-7°C contributes to a lower TGA synthesis compared to storage at higher temperatures from 20 to 28°C (Hwank and Lee 1984). Storing potatoes at around 3°C contributes to a greater synthesis of TGA than at 8°C (Jadhvav and Salunkhe 1975; Bushway and Ponnampalam 1981).

This effect is probably associated with the same response of potatoes to stress (temperature), as in the synthesis of reducing sugars. According to Friedman (1997), the factor which significantly affects the amount of TGA in potatoes is their susceptibility to stressors. The author recommends that for low accumulation of TGA in tubers, potatoes should be stored at temperatures no higher than 15°C and not lower than 5°C, while for potatoes immediately after harvest the optimum temperature is 7-10°C.

Apart from temperature, the accumulation of glycoalkaloids in potato tubers depends on the length of the storage period. The longer the storage period, the greater the amount of synthesized glycoalkaloids (Love *et al.* 1994; Friedman and McDonald 1997). Potatoes are usually stored in the dark. The exposure of potatoes to light, regardless of its nature, will result in the formation of chlorophyll and synthesis of toxic glycoalkaloids, α-solanine as well as α-chaconine, depending on the variety and tuber size, in 2-6 times higher levels than that found in potatoes stored in darkness (Jain *et al.* 1995; Machado *et al.* 2007; Haase 2010). Only 48-h exposure at 24°C increased glycoalkaloid content from 2 to 74 mg/kg (Percival *et al.* 1993; Friedman and McDonald 1997).

The period and temperature of storage also affect the amount of nitrates V and III. According to Cieślik (1994), during storage at a mean temperature of 5-6°C and 85-90% relative air humidity, the amount of nitrates V can decrease by 40-69% compared with their initial content, while the amount of nitrates III is reduced only slightly. The drop in nitrates V and III depends primarily on the storage temperature. Storing potatoes for 6 months at 10°C helped reduce the level of nitrates V and III in potatoes, while at 4˚C the amount of nitrates V increased and the level of nitrates III decreased (Cieślik and Praznik 1996).

CHANGES IN THE CONTENT OF ANTI-NUTRITIONAL COMPOUNDS IN POTATOES IN VARIOUS STAGES OF PROCESSING

Appropriately selected material with good quality values and properly conducted technological processes ensures the greatest level of nutrients. The content of potato components and the ratios between them changes during the production process of dried or fried potato products (Lisińska 2006; Lisińska *et al.* 2009). Many of the soluble substances are released in peeling, cutting, washing, blanching and frying, which results in an increase in the proportion of insoluble substances in dry potatoes. The removal of soluble substances belonging to anti-nutritional constituents (e.g. nitrates) is desirable, and the loss of pro-nutritional components, such as vitamin C, is an example of an irreversible reduction in the nutritional value of tubers in their treatment processing.

Regardless of the type of product, processing potatoes in the food industry involves the use of a series of similar technological measures. These are processes involving prewashing, peeling, slicing and washing tubers. This prepared material is then subjected to blanching and processes characteristic for a given product group, i.e. drying during the production of dried potatoes, or frying during the production of French fries and potato snacks.

Effect of washing, peeling and slicing tubers on the content of anti-nutritional compounds

Preliminary processes, including peeling, may be conducted using a variety of factors: high pressure steam, lye, or mechanical peeling. Depending on the type of a product produced, different methods of peeling are used. Mechanically peeled potatoes are used for chips, while steam peeling is used for dried potatoes and fries (Pęksa and Rytel 2008; Rytel 2010).

In mechanical peeling, potatoes are compressed against the abrasive material with different grains (silicon carbide) covering the inside of a peeler. Abrasive material made from silicon carbide can be substituted by knives or graters (Pęksa and Rytel 2008).

Steam peeling is carried out in pressure vessels with a periodic or continuous operation. A peeler is fed with vapour under pressure, 0.6-0.9 MPa, and the time of evaporation depends on the type and quality of raw material; it ranges from 5 to 70 secs (Pęksa and Rytel 2008; Rytel 2010).

Lye-steam peeling – this type of peeling combines two factors for softening the top layers of tubers; first, the hot lye (temperature of 75-95°C) at a concentration of 5-20%, then steam (Pęksa and Rytel 2008; Rytel 2010).

Peeling methods affect not only the volume of waste generated during this process (greatest during mechanical peeling, the smallest for lye and steam peeling), but also the loss of dry weight components of the potatoes. The size of the loss of ingredients during production depends on their distribution in potato tubers. Most of the anti-nutritional (nitrates V) and toxic (glycoalkaloids) compounds in potatoes are in the skin or just beneath it, and in the vicinity of eyes, so that pre-processing (peeling and additional washing) removes the bulk of these compounds (Rytel *et al.* 2005; Pęksa *et al.* 2006). Depending on the size and variety of tubers and the peeling techniques, a decrease in potato TGA can reach 80%-96%, and in an incomplete removal of the skin, from 20 to 35% (Rytel *et al.* 2005; Pęksa *et al.* 2006). The peeled tubers still have about 1-10 mg TGA/100 g (Leszczyński 2000); however, the process of peeling may not be sufficient for varieties with a pungent taste of flesh, i.e. with large quantities of glycoalkaloids (Lisińska and Leszczyński 1989; Leszczyński 2000).

Also, the nitrate V content is significantly reduced (~ 30%) in the process of peeling (Rytel *et al.* 2005; Pęksa *et al.* 2006). Further stages of the production process have a lesser impact on the reduction in these compounds.

Cutting tubers

Cutting potatoes in the food industry is performed using equipment for mechanical cutting or by a hydro-cutting machine. Mechanical cutting machines have various constructions, depending on the product to be achieved: slices, cubes, pillars, etc. Water cutting is performed with a constant jet of distilled water (Pęksa end Rytel 2008; Rytel 2010).

Cutting only slightly reduces the amount of glycoalkaloids and nitrates in potatoes. According to some authors (Rytel *et al.* 2005; Friedman 2006; Pęksa *et al.* 2006) changes in the TGA content of edible potatoes during processing are associated mainly with the peeling of tubers, while the degree of fragmentation and most cooking methods do not affect or have little impact on the level of TGA in semi-finished and finished products. Slicing and rinsing with water do not have the influence on the chaconine/solanine ratio (Rytel *et al.* 2005; Pęksa *et al.* 2006).

Effect of blanching on the content of anti-nutritional compounds

Cut potatoes are blanched in water at 60-90°C; the time varies (2-20 min) and depends on the quality of raw material and type of product to be obtained, while steam blanching takes much less time, from 4 to 8 min at normal steam pressure (Lisińska and Leszczyński 1989; Pęksa *et al.* 2006; Rytel 2010).

Blanching potatoes is carried out in order to improve the color of the finished product (through the inactivation of enzymes that cause darkening and leaching of sugars), to improve the consistency of the obtained products (French fries, dies) and reduce the absorption of fat (fries) (Lisińska and Leszczyński 1989). Only in the production of chips is blanching regarded as a "necessary evil" and used only at increased content of reducing sugars in potato tubers (above 0.1%) in order to improve the color of the finished products. Other indicators of chip quality (texture, oiliness) deteriorate after this treatment (Lisińska and Leszczyński 1989; Lisińska *et al.* 2009).

The process of blanching causes leaching of soluble substances from fragmented tubers (irreversible loss of these components), with a simultaneous increase in insoluble compounds in potato dry matter.

During thermal processes, a further drop in the content of anti-nutritional compounds is observed, the level of total glycoalkaloids decreases slightly compared to the process of peeling, which can be explained by the thermostable nature of these compounds (Friedman and McDonald 1997; Friedman 2006). Nitrates are easily soluble in water and as a result of blanching, especially of well-ground material (such as sliced chips), the amount of nitrates in the processed raw material could be reduce by an average of 20% (Rytel *et al.* 2005; Pęksa *et al.* 2006).

Effect of boiling on the content of anti-nutritional compounds

The consumption of potatoes must be preceded by heat treatment, which gelatinizes the starch in potatoes and thus makes it easily digestible. Boiling is a heat treatment that is often used in households; usually potatoes are boiled in water, and less frequently using steam or microwaves. The method of boiling potatoes affects not only their sensory properties but also the size of the loss in pro- and anti-nutritional components, depending on the temperature and time of operation.

Boiling independently on the method used does not cause a significant reduction in glycoalkaloids. Many authors (Friedman 2003; Rytel *et al.* 2005; Friedman 2006; Pęksa *et al.* 2006) argue that most thermal treatments used in industry and households have little effect on decreasing the amount of glycoalkaloids due to the compounds' high thermal stability and low solubility at temperatures below 170°C (Friedman 2006). According to Tajner-Czopek *et al.* (2008) the level of TGA in boiled whole potatoes drops on average by about 22%, with a greater decrease in chaconine (by about 23%) than solanine (by about 18%). However, according to Takagi *et al.* (1990) the content of chaconine and solanine in potatoes is reduced by only a few percent (traditional boiling), and in microwave cooking in water by 15%.

Nitrate compounds dissolve well in water, so after boiling their concentration in brine or broth is greater than in the potatoes. The decrease in nitrate V and III concentrations is similar to blanching, and is on average 20% (Becka *et al.* 1992; Cieślik 1995a).

Effect of frying on the content of anti-nutritional compounds

Fries are produced industrially as semi-finished or finished products and hence different frying times ranging from 45 seconds to about 5 min in oil at 170-185°C. The time of frying chips (dehydrated to a moisture level of less than 2%) is several minutes in oil at 170-185°C (Lisińska and Leszczyński 1989; Pęksa and Rytel 2008).

In the process of frying slices of potatoes (in different shapes), enhanced oil penetration and a high temperature (above 170°C) results in the removal of up to 40% of toxic glycoalkaloids from the material, partly by leaching and partly by decomposition (Friedman and McDonald 1997). Comparing the changes in the TGA in potatoes influenced by frying, baking and cooking, it is only frying that reduces the amount of these compounds (Friedman and McDonald 1997; Rytel *et al.* 2005; Pęksa *et al.* 2006). Also, the amount of nitrates after frying is reduced to about 10% of their initial content in raw material (Rytel *et al*. 2005).

Effect of drying on the content of anti-nutritional compounds

Drying potato dies involves hot air at 130°C and a final temperature of 50°C for 6-8 h (Lisińska and Leszczyński 1989; Pęksa and Rytel 2008; Rytel 2010).

Potato granules are dried in two stages; first in a pneumatic drier, in hot air stream (inlet 177°C and outlet 80°C), and then in a fluidized bed drier with alternately hot and cold air (Lisińska and Leszczyński 1989; Pęksa and Rytel 2008). Drying is a thermal process using temperatures exceeding 100°C. Based on the data in the literature, it can be concluded that the higher the temperature of the process and the longer the duration of its action, the greater should be the reduction in glycoalkaloids and nitrates. According to Friedman (2003) frying at 150°C resulted in no significant changes in the content of glycoalkaloids, but after 10 min of frying at 210°C, the level of these compounds dropped by 40%. In the process of frying potato crisps as slices or bars, the high loss of toxic substances was due to the facilitated penetration of oil and high temperature (above 170°C). According to Friedmann and McDonald (1997) during this process glycoalkaloids are removed from the material partly by leaching and partly through their degradation. **Table 1** indicates the TGA content in various potato products. The highest content of these compounds is found in potato products obtained from potatoes with the skin. It can be concluded that irrespective of the potato product, it is peeling that

Table 1 The changes of anti-nutrient components in potato after particular stages of the process, regarding their content in tubers before peeling.

Stage of the process	Glykoalkaloids (%)	Nitrate (%)
peeling	90% decrease	decrease
cutting	no effect	no effect
blanching	decrease	20% decrease
cooking	22% decrease	20% decrease
frying	40% decrease	10% decrease
drying	decrease	decrease

mostly reduces the levels of these toxic compounds.

Processing potatoes for food at high temperatures (frying, drying), may contribute to the formation of acrylamide, a toxic compound present in semi-finished and finished products, not occurring in the raw material.

ACRYLAMIDE

This compound is present in fried and baked high-starch foods exposed to temperatures above 120°C (Friedman 2003), especially fried potato products, such as crisps and chips (or: chips and fries) (Kita *et al.* 2009). In chips and fries, its content varies from 30 to 2300 mg/kg (Kita *et al.* 2009). Acrylamide has not been found in unheated or boiled foods (Grob *et al.* 2003). The formation of acrylamide in the final product depends on the amount of reducing sugars and asparagine (amino acid) in the raw material, the temperature and the duration of drying or frying (Friedman 2003). A potential mechanism for the formation of acrylamide in food is related to the reaction between asparagine and reducing sugars during heating at high temperatures in high-starch products (Friedman 2003). This mechanism accompanies the Maillard reaction occurring between the free amino groups and carbonyl groups of reducing sugars (glucose and fructose) during baking, frying or drying (Friedman 2003).

An important factor influencing the amount of acrylamide in the final products is the chemical composition of raw materials, including in particular the content of reducing sugars in tubers. Currently, potatoes for French fries and chips are characterized by a low content of reducing sugars (Amrein *et al.* 2003; Becalski *et al.* 2003, 2004). Such a selection of varieties has been conducted for years by producers of potato chips and fries, who, primarily because of the desired color of the products, have identified acceptable levels of the reducing sugars in potato tubers (less than 0.5%). The selection also involves potato varieties and their storage conditions (mainly temperature) in order to minimize the accumulation of reducing sugars in potato tubers (Blekinshop *et al*. 2002; Noti *et al* 2003; Olsson *et al*. 2004).

Another effective treatment, used in industrial conditions and resulting in a lower content of acrylamide in potato products, is blanching of potato chips. In the case of increased sugar levels in raw material (Pedreschi *et al.* 2004; Wicklund *et al*. 2006), blanching itself is not sufficient, and therefore research is being carried out on the addition of organic acids (citric acid, acetic acid) to blanching, and on keeping slices in solutions with added amino acids, including glycine (Jung *et al.* 2003; Kita *et al*. 2008; Tajner-Czopek *et al*. 2008a). These procedures allow for the effective reduction of acrylamide in the finished product, even by 50%. Currently, manufacturers of French fries and chips use much lower frying temperatures (below 175°C), which is one of the easiest ways to reduce acrylamide in foods. No less important is the frying time. Grob *et al.* (2003) showed that frying time longer by even a few seconds may increase the amount of acrylamide in the product. The content of acrylamide in potato products is also influenced by the type of frying medium. In the experiment conducted by Gertz and Klosterman (2002) a higher content of acrylamide was found in fries fried in palm oil.

CONCLUSIONS

Research on the content of toxic or anti-nutritional compounds in potatoes is being systematically carried out by scientists from many countries, due to the high rank of the problem. The test results are being tracked by consumers and food producers. Consumers are looking for healthy food with the lowest content of anti-nutritional compounds and the absence of toxic substances. The ongoing research, in close cooperation with industry, can meet these demands. Potatoes are a special material which produces an ever growing range of finished products and intermediates based on which a variety of food products are produced: fresh, chilled, frozen, dried and fried. An excessive quantity of anti-nutritional (and toxic) compounds in the raw material can remain in the manufactured semi-finished products and this contributes to the excess accumulation of toxic compounds in further processed products.

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