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**Series on the Safety of Novel Foods and Feeds, No. 4**

**CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF  
POTATOES: KEY FOOD AND FEED NUTRIENTS, ANTI-NUTRIENTS AND TOXICANTS**

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No. 2, Consensus Document on Compositional Considerations for New Varieties of Soybean: Key Food and Feed Nutrients and Anti-nutrients (2001)

No. 3, Consensus Document on Compositional Considerations for New Varieties of Sugar Beet: Key Food and Feed Nutrients and Anti-Nutrients (2002)

No. 4, Consensus Document on Compositional Considerations for New Varieties of Potatoes: Key Food and Feed Nutrients, Anti-Nutrients and Toxicants (2002)

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OECD Environmental Health and Safety Publications

Series on the Safety of Novel Foods and Feeds

**No. 4**

**Consensus Document on Compositional  
Considerations for New Varieties of Potatoes:  
Key Food and Feed Nutrients, Anti-nutrients  
and Toxicants**

**Environment Directorate**

**Organisation for Economic Co-operation and Development**

**Paris 2002**

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## FOREWORD

The OECD's Task Force for the Safety of Novel Foods and Feeds decided at its first session, in 1999, to focus its work on the development of science-based *consensus documents*, which are mutually acceptable among member countries. These consensus documents contain information for use during the regulatory assessment of a particular food/feed product. In the area of food and feed safety, consensus documents are being published on the nutrients, anti-nutrients or toxicants, information of its use as a food/feed and other relevant information.

This consensus document addresses compositional considerations for new varieties of potatoes by identifying the key food and feed nutrients, anti-nutrients and toxicants. A general description of these components is provided. Also included are considerations to be taken when assessing new potato varieties.

Germany served as the lead country in the preparation of this document.

The Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology has recommended that this document be made available to the public. It is published on the authority of the Secretary-General of the OECD.



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## Preamble

Food and feed products of modern biotechnology are being commercialised and marketed in OECD Member countries. The need has been identified for detailed technical work aimed at establishing appropriate approaches to the safety assessment of these products.

At a Workshop held in Aussois, France (OECD, 1997), it was recognised that a consistent approach to the establishment of substantial equivalence might be improved through consensus on the appropriate components (e.g., key nutrients, key toxicants and anti-nutritional compounds) on a crop-by-crop basis, which should be considered in the comparison. It is recognised that the components may differ from crop to crop. The Task Force therefore decided to develop consensus documents on compositional data. These data are used to identify similarities and differences following a comparative approach as part of a food and feed safety assessment. They should be useful to the development of guidelines, both national and international and to encourage information sharing among OECD Member countries.

These documents are a compilation of current information that is important in food and feed safety assessment. They provide a technical tool for regulatory officials as a general guide and reference source, and also for industry and other interested parties and will complement those of the Working Group on Harmonisation of Regulatory Oversight in Biotechnology. They are mutually acceptable to, but not legally binding on, Member countries. They are not intended to be a comprehensive description of all issues considered to be necessary for a safety assessment, but a base set for an individual product that supports the comparative approach. In assessing an individual product, additional components may be required depending on the specific case in question.

In order to ensure that scientific and technical developments are taken into account, Member countries have agreed that these consensus documents will be reviewed periodically and updated as necessary. Users of these documents are invited to provide the OECD with new scientific and technical information, and to make proposals for additional areas to be considered.

## **The Role of Comparative Approach as Part of a Safety Assessment**

In 1990, a joint consultation of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) established that the comparison of a final product with one having an acceptable standard of safety provides an important element of safety assessment (WHO, 1991).

In 1993 the Organisation for Economic Co-operation and Development (OECD) further elaborated this concept and advocated the approach to safety assessment based on substantial equivalence as being the most practical approach to addressing the safety of foods and food components derived through modern biotechnology (as well as other methods of modifying a host genome including tissue culture methods and chemical or radiation induced mutation). In 2000 the Task Force concluded in its report to the G8 that the concept of substantial equivalence will need to be kept under review.

The Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology in 2000 concluded that the safety assessment of genetically modified foods requires an integrated and stepwise, case-by-case approach, which can be aided by a structured series of questions. A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy for the safety and nutritional assessment of genetically modified foods. The concept of substantial equivalence was developed as a practical approach to the safety assessment of genetically modified foods. It should be seen as a key step in the safety assessment process although it is not a safety assessment in itself; it does not characterise hazard, rather it is used to structure the safety assessment of a genetically modified food relative to a conventional counterpart. The Consultation concluded that the application of the concept of substantial equivalence contributes to a robust safety assessment framework.

A previous Joint FAO/WHO Expert Consultation on Biotechnology and Food Safety (1996) elaborated on compositional comparison as an important element in the determination of substantial equivalence. A comparison of critical components can be carried out at the level of the food source (i.e., species) or the specific food product. Critical components are determined by identifying key nutrients and key toxicants and anti-nutrients for the food source in question. The comparison of critical components should be between the modified variety and non-modified comparators with an appropriate history of safe use. The data for the non-modified comparator can be the natural ranges published in the literature for commercial varieties or those measured levels in parental or other edible varieties of the species (FAO and WHO, 1996). The comparator used to detect unintended effects for all critical components should ideally be the near isogenic parental line grown under identical conditions. While the comparative approach is useful as part of the safety assessment of foods derived from plants developed using recombinant DNA technology, the approach could, in general, be applied to foods derived from new plant varieties that have been bred by other techniques.

## Section I - Background

This paper discusses key components (nutrients, anti-nutrients and toxicants) of potato for which data have been collected on varieties developed through conventional breeding techniques and that may contribute to an assessment of substantial equivalence (Love, 2000; Rogan et al., 2000).

### A. Production of Potatoes<sup>1</sup>

The world production of potatoes (*Solanum tuberosum* ssp. *tuberosum*) amounted to almost 308 million tonnes in 2000 (FAO, 2001), and potatoes were grown in over 120 countries (Burton, 1989).

Yield and composition of tubers may vary in wide ranges due to variety and growing conditions.

### B. Potatoes for Human Consumption

The average consumption of potatoes differs widely between countries. Relevant statistical data are given by the FAO (Table 1).

**Table 1: Average potato consumption in 1998**

	Potato consumption (kg/Cap/Year)
World	30
Africa	11
Asia	19
Europe	94
EU (15)	78
North America	63
South America	31
Developing countries	17
Developed countries	75

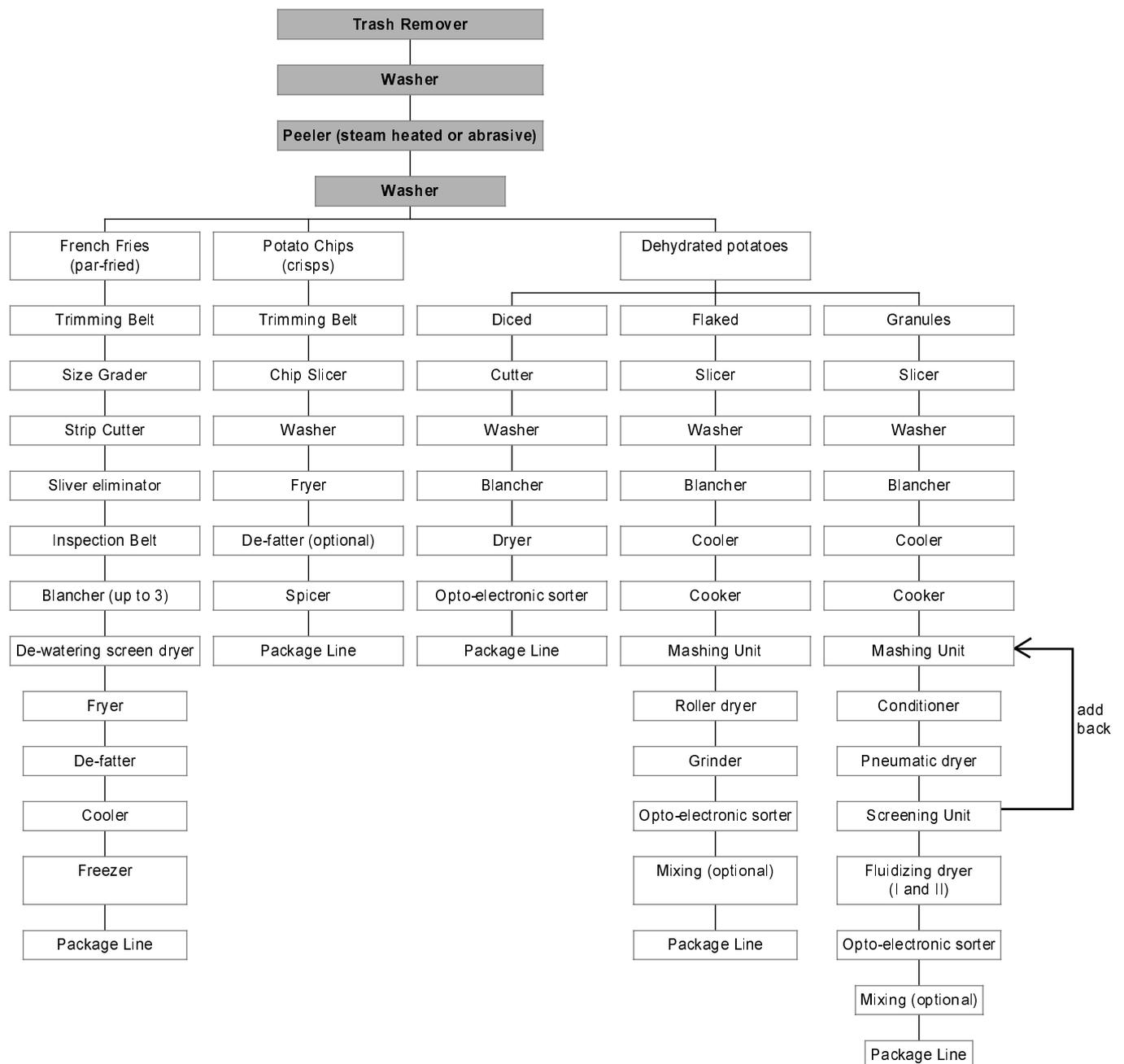
Source: FAO, 2001

Especially in industrialised countries direct consumption of potatoes has declined dramatically, whereas consumption of potato products (e.g. French fries, potato chips (crisps)) has increased (Example: In Germany consumption of fresh potatoes declined from 87 kg/Cap/Year in 1971 to 42 kg/Cap/Year in 1999, but during the same period consumption of potato products increased from 14 kg/Cap/-Year to 29 kg/Cap/Year [basis: fresh potatoes]).

<sup>1</sup> For information on the environmental considerations for safety assessment of potato, see OECD Consensus Document on the Biology of *Solanum tuberosum* subsp. *tuberosum* (Potato).

Potatoes for direct consumption should be cooked before eating because of the indigestibility of non-gelatinised starch and the presence of anti-nutritional proteins. Different kinds of preparation are in use resulting in various amounts of nutrient losses (e.g. Ascorbic acid: 13% loss during cooking of unpeeled potatoes vs. 41% loss of peeled potatoes [Weber and Putz, 1998]).

Due to consumer request, potatoes are increasingly supplied in processed form. A schematic description of different methods of potato processing are given in Figure 1.

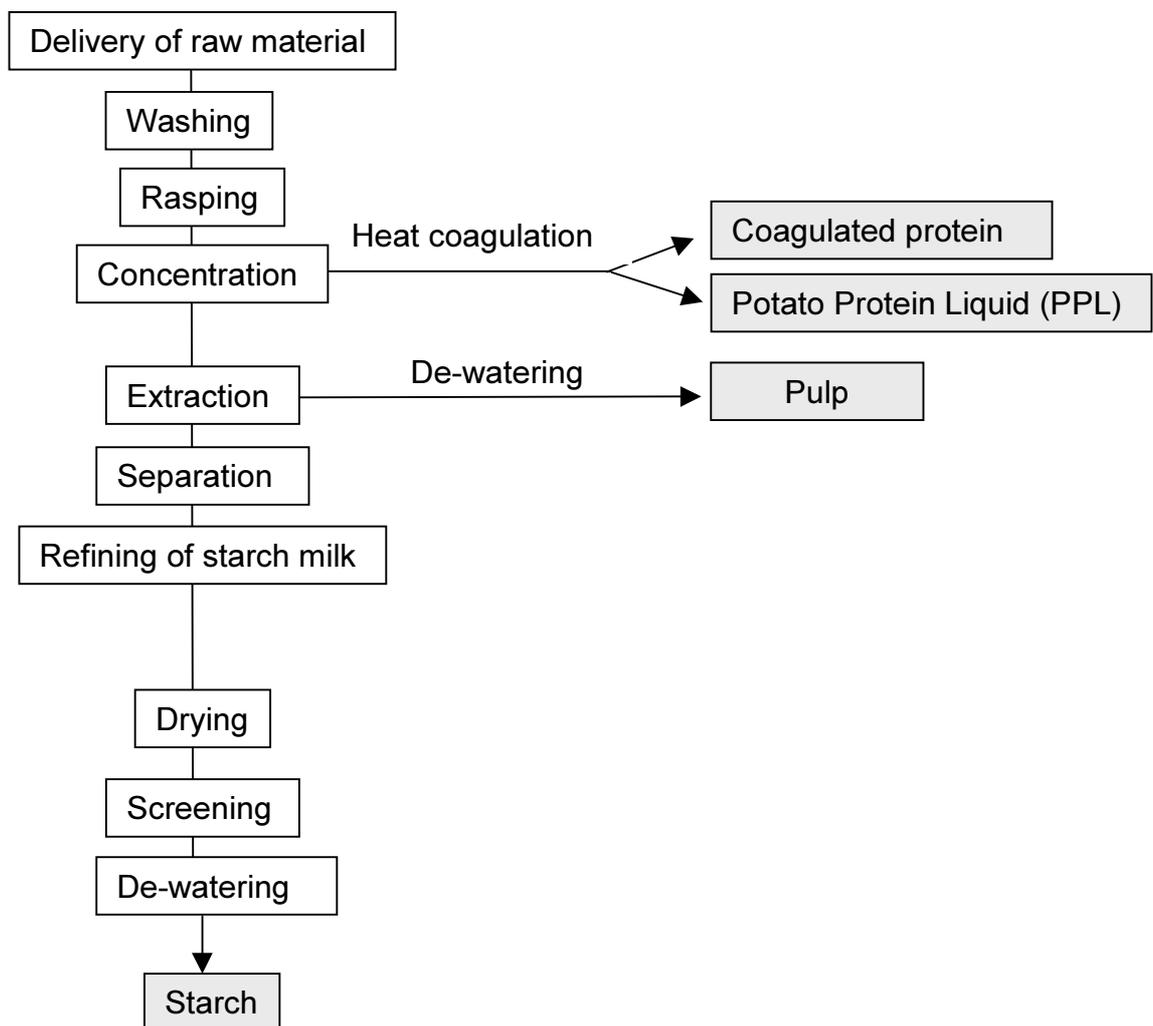


**Figure 1: Schematic Description of Potato Processing (Lisinska and Leszczynski, 1989)**

### C. Industrial Uses of Potatoes

Especially in Europe, potatoes are used as raw material for starch manufacturing. Within the European Community the annual potato starch production is about 1.9 million tons (Anonymous, 1995). Due to the high water content of the tubers and accompanying storage problems, separation of potato starch is carried out mainly in autumn and the beginning of winter because of their frost sensitivity.

Potato starch is easily separated from tubers because of its large grain size and the structure of the tubers. In addition to large factories with excellent equipment, very small and simple processing units exist (especially in developing countries). A typical potato starch processing line is described in Figure 2.



**Figure 2: Schematic description of potato starch processing**

Potato starch, which is a mixture of amylose and amylopectin (75:25), shows specific properties different from starch of other sources. Therefore several applications prefer potato starch, e.g. coating of papers, sizing of cotton, finishing in textile industry (Treadway, 1975). Potato starch is also used in the food industry, particularly, in pre-gelatinised or modified form. Additional specific applications for potato starch can be foreseen with the development of potato varieties containing mainly one or the other starch component.

By-products (pulp, coagulated protein from fruit water) are normally used in animal feeding, but trends exist for food use too.

If coagulated protein is prepared from potatoes with a high glycoalkaloid content (particularly from unpeeled potatoes) the protein cannot be used in the food industry due to its high toxin content.

Potatoes are also used for industrial alcohol production. The basic method for alcohol production is to crush and cook the potatoes in water. The resulting gelatinised starch is hydrolysed to sugars (either by acids or by technical enzymes), and pumped to vats, where it is fermented by yeast addition. The fermentation is complete after 2-3 days and the alcohol is distilled off. The potential yield of alcohol from 1 ton of potatoes varies between 60 and 140 litres.

The residues of the distillation process are used as feed stuff.

#### **D. Potatoes as Animal Feed**

The extent to which potatoes are used as animal feed varies considerably. It depends mostly on the price and availability of substitutes. Because of their low nutrient concentration, potatoes are an inefficient basic feed. On the other hand the nutrient yield per hectare is higher than in any other crops. Therefore, home-produced feeding potatoes have an advantage over other crops (Burton, 1989). Normally, potatoes are fed in combination with other feedstuffs to meet the animal's requirements and to take advantage of complementary effects (Burton, 1989; Schindler, 1996). Balanced supplementation with amino acids, minerals and vitamins has to be considered.

In countries with a significant potato processing industry (for both human food and industrial use), the residues and by-products (peel, trimmings, rejected potatoes, separated pulp and proteins) are used as feedstuff (often after dehydration). In countries without a processing industry, potatoes which do not meet food standards are traditionally fed to stock (Burton, 1989).

Potatoes are normally fed raw to ruminants, but fed steamed to pigs. Practical feeding instructions for the various species are described in papers and textbooks on feeding-stuffs and feeding (e.g. Church, 1984; Pond et al., 1995). The contribution rates to which potatoes are incorporated in diets for the various animal categories are as follows (Kling, M. and Wöhlbier, W., 1983):

- Swine: 2.4 – 7.8 kg per day according to live weight (30 – 110 kg)  
(Total consumption during the whole growing finishing period is about 700 kg potatoes);
- Beef cattle: 5 – 15 kg per day;
- Dairy cattle: 5 – 10 kg per day.

## Section II - Key Food and Feed Nutrients

Due to its vegetative origin, the potato tuber is extremely sensitive to environmental impacts. Depending on variety, climate, soil type, and farming practice, the composition of potato tubers may vary widely. The colour of potato tubers depends on the variety. Key nutrients of the potato tubers of safely consumed varieties are listed in Table 2. The cited ranges of values do not imply that values outside these ranges are necessarily unusual or harmful in any way.

**Table 2: Key nutrients of potato tubers  
(fresh weight basis)**

		Mean	Ranges
Dry matter (DM)	%	23.7	13.1 – 36.8
Starch	%	17.5	8.0 – 29.4
Protein	%	2.0	0.69 – 4.63
Fat	%	0.12	0.02 – 0.2
Dietary Fibre <sup>a)</sup>	%	1.7	1 - 2
Crude Fibre	%	0.71	0.17 – 3.48
Minerals (crude ash)	%	1.1	0.44 – 1.87
Sugars	%	0.5	0.05 – 8.0
Ascorbic acid + Dehydroascorbic acid	mg/kg	100-250	10 - 540

Sources: Lisinska and Leszczynski, 1989 and Woolfe, 1987<sup>a)</sup>

### *Dry Matter*

The dry matter (solids) content of tubers is composed of various substances, soluble or insoluble in water. The dry matter content is correlated with the specific gravity, ranging from 1.0485 to 1.151 g/cm<sup>3</sup> (Lisinska and Leszczynski, 1989). Specific gravity is a quality factor and is used for dry matter determination.

Potatoes high in dry matter content (18 - 24%) are suitable for the manufacture of dehydrated food products and animal feed. Potatoes for deep-fat frying (potato chips (crisps) and French fries), in particular, require an optimum range of dry matter content (21 – 24%).

During storage, losses of dry matter may be up to 8% FW or 2% DM caused by tuber respiration. Respiration intensity depends on storage conditions.

### ***Starch***

Potato dry matter consists of between 75 – 80 % starch.

Starch is the most important carbohydrate determining the quality of potato tubers used as food or feed. Tubers with a high starch content are more susceptible to mechanical damage (black spot susceptibility). The texture of cooked tubers tends toward mealiness if starch content is very high.

Potato starch plays an important role as both a food ingredient and as an industrial raw material (native as well as modified potato starch).

### ***Protein***

Potato protein is of high nutritional value despite protein denaturation during processing. It contains high levels of the essential amino acids lysine, methionine, threonine and tryptophan (Table 3).

**Table 3: Amino acid composition of potato tuber protein**

<b>Amino Acid</b>	<b>Ranges [%]</b>
Alanine	4.62 – 5.32
Arginine	4.74 – 5.70
Aspartic acid	11.9 – 13.9
Cysteine	0.20 – 1.25
Glutamic acid	10.2 – 11.8
Glycine	4.30 – 6.05
Histidine	2.10 – 2.50
Isoleucine	3.73 – 5.80
Leucine	9.70 – 10.3
Lysine	6.70 – 10.1
Methionine	1.20 – 2.15
Phenylalanine	4.80 – 6.53
Proline	4.70 – 4.83
Serine	4.90 – 5.92
Threonine	4.60 – 6.50
Tryptophan	0.30 – 1.85
Tyrosine	4.50 – 5.68
Valine	4.88 – 7.40

Source: Lisinska and Leszczynski, 1989

The major proteins present in potato tubers are albumin, globulin, prolamine and glutenin. Another protein fraction is made up of glycoproteins (patatin, lectin), metaloprotein, and phosphoproteins. Potato species and varieties can be discriminated by gel-electrophoresis of soluble tuber proteins.

### ***Fat***

The lipid content of potatoes is mainly composed of free fatty acids, fats and phospholipids. Linoleic acid comprises up to 40 –50% of all fatty acids, linolenic acid 20 – 30%, oleic acid 1 – 5%,

palmitic acid 20% and stearic acid 5%. Since the fat content of potato tubers is very low (0.02 – 0.2 % FW), potatoes are not regarded as an important fat source.

Among phospholipids, the most important compounds are lecithins. Free carotenoids and their esters of fatty acids are present in potato tubers in very small amounts (0.1 – 0.4% of total lipid content).

The predominance of unsaturated fatty acids in the lipids confers easy oxidation. This is a critical factor in manufacture and storage, in particular, for dehydrated potato products.

### ***Dietary Fibre and Crude Fibre***

Dietary fibre consists of insoluble and soluble polysaccharides, but also of lignin and of resistant starch. The definition of dietary fibre focuses on its "non-availability". In this view, dietary fibre is the sum of components which are not digested by enzymes of the human small intestine. Nevertheless, many of them are fermented by micro-organisms in the large intestine. Processing of food, e.g. cooking or frying, may change some fibre properties (pectin breakdown) and the amount of resistant starch.

Crude fibre consists of cellulose, hemicellulose, pentosans and pectic substances. They are particularly concentrated within the cell wall. The composition of the cell wall is responsible for the textural characteristics of potato tubers. Cell wall breakdown during cooking in combination with swollen and gelatinised starch granules leads to cell rupture, whereas breakdown of the middle lamella allows cell separation (→ soft cooking tubers). Pectin release and pectin de-esterification accompany cell wall breakdown.

### ***Sugars***

The sugar content of potato tubers varies highly depending on the variety, maturity and physiological stage of the potatoes.

Sugar content changes during storage. Specific changes in the sucrose content are used as an indicator of the age of potato tubers.

A high sugar content (especially of the reducing sugars glucose and fructose) disqualifies potato tubers from their use as raw material for processing, especially for deep-fat fried and dehydrated products. Potatoes for the chips (crisps) industry should not exceed 0.15% of reducing sugars in fresh weight, whereas potatoes for the production of French fries and dehydrated potatoes should contain less than 0.25% of reducing sugars.

Storage at +4°C inhibits sprouting, however, in most varieties the concentration of reducing sugars (resulting from starch hydrolysis) will increase at that temperature.

### ***Vitamins***

During preparation and processing of tubers, water soluble vitamins may be washed out. In addition, vitamins may be destroyed by heat and oxidation. Losses of 20 – 80% have been reported (Kolbe, 1997). The ascorbic acid content (10 – 540 mg/kg) may also be decreased during storage as it is used up as an antioxidant. Nevertheless, ascorbic acid from potatoes may contribute to the daily intake of humans, up to 40 % of the recommended amount.

***Minerals***

Potassium is the major cation in potato tubers (0.22 – 0.94% FW). Its percentage of total mineral content is about 50% (Lisinska and Leszczynski, 1989) and its contribution to the human diet is up to 30% of the recommended daily potassium intake. Therefore, in low potassium diet regimes, this mineral should be watered out prior to further preparation. The potassium content is positively correlated with the content of organic acids. Sodium content of potato tubers is very low (3% of total mineral content).

## Section III – Toxins and Allergens

### *Glycoalkaloids*

Potatoes naturally contain several types of alkaloids. The most important group of alkaloids in commercial potato varieties are the glycoalkaloids (GA), in which one or more sugar molecules (usually three) are linked to the steroidal alkaloid solanidine.

The total glycoalkaloid content (TGA) of potato tubers varies widely. Values between 2 and 410 mg/kg FW were found (Lisinska and Leszczynski, 1989), but in most cases the TGA concentration in whole tubers is between 10 and 150 mg/kg FW (van Gelder, 1990). 95% of the total glycoalkaloids in potato tubers consists of  $\alpha$ -chaconine (solanidine-glucose-rhamnose-rhamnose) and  $\alpha$ -solanine (solanidine-galactose-glucose-rhamnose).

Other combinations between the solanidine alkaloid and sugar molecules may be present in small amounts:

- $\beta$ -chaconine (solanidine-glucose-rhamnose),
- $\gamma$ -chaconine (solanidine-glucose),
- $\beta$ 1-solanine (solanidine-galactose-glucose),
- $\beta$ 2-solanine (solanidine-galactose-rhamnose),
- $\gamma$ -solanine (solanidine-galactose).

Several other glycoalkaloids might be present in certain potato varieties, especially if these have been recently crossed with wild *Solanum* species. Glycoalkaloids are not evenly distributed within the tubers, but are present in higher concentrations at the periphery (reviewed by Smith et al., 1996). Therefore, tuber size is important for the GA level. Large and often unpredictable variations in GA levels can arise from differences in variety, locality, season, cultural practice and stress factors. Today, the widely accepted safety limit for the level of total glycoalkaloids (TGA) in tubers is 200 mg/kg FW (Boemer and Mattis, 1924; Smith et al., 1996).

Glycoalkaloids are particularly concentrated in the outer region of the tuber. However, in green and sprouted tubers, the TGA concentration is also high in the internal part. In any case, peeling reduces the TGA content substantially. Glycoalkaloids are not destroyed during cooking and frying.

Glycoalkaloid poisoning causes several symptoms ranging from gastrointestinal disorders, through confusion, hallucination and partial paralysis to convulsions, coma and death (Smith et al., 1996). Available information suggests that the susceptibility of humans to glycoalkaloid poisoning is high and very variable: oral doses in the range of 1 - 5 mg/kg body weight are marginally to severely toxic to humans (Hellenäs et al, 1992) whereas 3 - 6 mg/kg body weight can be lethal (Morris and Lee, 1984).

In pig feeding with a high potato portion (steamed, but unpeeled potatoes; see paragraph 17) a TGA concentration of 150 mg/kg FW seems to be without any risks and does not result in growth depression. In cattle feeding no risk is known when maximal portions are incorporated in the ration (see

paragraph 17), as long as the sprouts, which contain TGA concentrations of 2000 – 5000 mg/kg FW, are removed (Jeroch et al., 1993).

Recently, potato tubers have been shown to also contain small quantities of calystegines, which are nortropane alkaloids with glycosidase inhibitory activity. Calystegines are concentrated predominantly in potato eyes and sprouts (Keiner et al, 2000). The biological significance of this group of alkaloids for humans is not yet known.

### *Allergens*

Until recently potatoes were not considered a source of allergens. However, potato contains multiple heat-labile proteins which can induce immediate hypersensitivity reactions when raw potatoes are consumed (Jeannot-Peter et al., 1999).

A study on patatin, the main storage protein in potatoes, reports induction of allergic reactions in sensitive children (Seppälä et al., 1999). The authors consider additional studies necessary, in order to confirm the allergenicity of patatin. In addition to patatin, concomitant IgE binding to several proteins belonging to the family of soybean trypsin inhibitors was observed (Seppälä et al., 2001)

## Section IV - Anti-nutrients

### *Protease Inhibitors*

Potato tubers contain several protease inhibitors that inhibit the activity of trypsin, chymotrypsin and other proteases, thus decreasing the digestibility and the biological value of the ingested protein. The concentration of trypsin inhibitors (TI) can be as high as 174 mg g<sup>-1</sup> protein (Baker et al., 1982). Assuming a protein content of 2% FW in potato tubers (Table 2), this may result in a TI content of up to 3.5 g/kg potato tubers.

Protease inhibitors in potatoes are largely inactivated by boiling and other thermal processes. Serious anti-nutritional reactions could occur, however, if raw or inadequately cooked potatoes are consumed or fed.

### *Lectins*

Lectins are (glyco)proteins which occur in virtually all living organisms and have the common property of binding to specific carbohydrate structures on cell surfaces, e.g. on intestinal or blood cells (Liener, 1989, Allen et al., 1996, Ciopraga et al., 2000). Some lectins found in beans are known to cause serious health effects when ingested by humans and animals. As lectins are inactivated during heating, only consumption and feeding of raw or inadequately cooked potatoes may cause adverse effects. Negative effects of lectins on animal's health and their performance are not yet known in detail (Kling and Wöhlbier, 1983; Smart et al., 1999).

## **Section V – Considerations for the Assessment of New Potato Varieties**

Agronomic characteristics of new potato varieties are important to consider since unspecific or unpredicted phenotypic traits or changes in phenotypic traits may be indicative of unintended effects of potential safety concerns that would require further investigations. In registration of new potato varieties, phenotypic traits and agronomic characteristics are tested, including yield, susceptibility and tolerance towards specific diseases. In addition, table potatoes are tested using sensory analysis, while processing potatoes are tested as French fries, chips (crisps) and dehydrated potatoes.

The comparison of the chemical composition of tubers from a modified variety with tubers from the non-modified comparator, grown at the same time under the same conditions, should include the following components (according to Love, 2000):

- Dry matter
- Sugars, especially reducing sugars
- Protein
- Vitamin C
- Glycoalkaloids.

If the analyses of these parameters indicate that a novel variety is within the ranges given in the literature, apart from the intentional modifications resulting in recombinant DNA and new proteins, it can be considered equivalent with respect to its overall composition. The safety assessment would then focus on the newly introduced (e.g. recombinant DNA and heterologous proteins) or intentionally altered constituents (e.g. starch components).

If, apart from the intentionally modified DNA and resulting new proteins, the genetic modification results in a qualitative change rather than a quantitative shift of the potato constituents outside the naturally occurring ranges, the safety assessment would focus on those differences, possibly requiring nutritional and/or toxicological studies.

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