

Natural Toxins in Food Crops and their Changes during Processing

J. HAJŠLOVÁ*, V. SCHULZOVÁ, P. BOTEK and J. LOJZA

Department of Food Chemistry and Analysis, Institute of Chemical Technology, Prague,
Czech Republic, *E-mail: jana.hajslova@vscht.cz

Abstract: Many food plant contain specific secondary metabolites which are classified as toxins or antinutrients for humans. In this short review main groups of these bioactive compounds are introduced, potential hazard posed for consumers and related regulatory aspects are mentioned. Substances which are currently of greatest concern are discussed in a greater detail. Phytoestrogens and glucosinolates are shown as compounds that may under certain conditions, exhibit health protecting effects, toxic glycoalkaloids, have been selected as an example of toxins occurring in staple crop, lectins and pyrrolizidine alkaloids represent as toxins responsible for recently documented outbreaks of food poisoning.

Keywords: natural toxins; plant secondary metabolites; food poisoning; phytoestrogens; glucosinolates; glycoalkaloids; lectins; pyrrolizidine alkaloids

NATURAL TOXINS

Occurrence of natural toxins in food and feed represents undoubtedly an important food safety issue which is of growing concern of both scientists and regulators [1].

Considering the current terminology, several approaches are applied for classification of natural toxins. The narrow definition specifies natural toxins as food constituents endogenously produced by food organisms and capable to give rise to adverse effects when the food organism or product thereof is consumed. The broader definition of natural toxins includes also toxic compounds originating from a contamination of the food. In addition to plant toxins which are discussed in a greater detail below, several other sources of natural toxins in food supply can be recognized:

(i) Microorganisms producing toxic co-metabolites may contaminate food (or raw material used for its production). Mycotoxins such as aflatoxins, ochratoxin A, trichothecenes, zearalenone, fumonisins and patulin produced by toxicogenic species of *Aspergillus*, *Penicillium*, *Fusarium* and other genera of fungi are of greatest concern both in terms of toxicity and worldwide occurrence. Once

contaminating food crop and/or animal products, their removal by common food processing practices is almost impossible (thermolabile patulin is an exception).

(ii) Also some bacteria may produce toxins (e.g. botulin, *Staphylococcus aureus* enterotoxin and *Bacillus cereus* enterotoxin). Many of them are proteins which are not, contrary to most of mycotoxins, heat-stable and can be therefore in most cases reduced/eliminated by thermal treatment of contaminated matrix.

(iii) Some unicellular microalgae that are occasionally occurring in marine and freshwater bodies throughout the world produce toxins, so called phytotoxins. Some of them like domoic acid, saxitoxin (paralytic shellfish poisoning or PSP toxin), and brevetoxin are of significant human health concern since they may bioaccumulate or are magnified in the food chain by fish and shellfish. The presence of cyanobacterial toxins (including anatoxins, microcystins, and nodularins) in drinking water represents another hazard to be considered in this context.

(iv) Non-toxic raw materials of plant origin may by accident or unlucky circumstances be contaminated or being mixed with a toxic non-nutritive

plant species, for example unripe berries of black nightshade (*Solanum nigrum*), containing several toxic glycoalkaloids may contaminate edible crops).

PLANT TOXINS

Plants contain a large number of chemical compounds which are distinct from the intermediates and products of primary metabolism. These secondary metabolites that are produced from primary metabolites and their precursor may contribute to various specific features of plants such as odours, tastes and/or colours; some of them are viewed as the key components of active and potent defence mechanisms against bacteria, fungi, insects and/or herbivores. However, the real function of these constituents for plant health and proliferation has not been fully recognized yet.

Worth to notice, most of plant species in the world are inedible for humans, many because of

the presence of toxic substances; nevertheless, over the millennia the domestication process has gradually reduced their levels in cultural species. In food plants we eat today there is fairly less compounds hazardous for consumers as compared to their wild relatives. On the other hand, the decrease/elimination of constituents that have evolved as a way to fight off predators unavoidably results in lowered resistance of modern cultivated plants to diseases.

In spite of enormous progress in breeding/growing agricultural practices and advances in food processing technologies aiming at production of high quality and safe foods, number of antinutrients (compounds with negative effects on availability of nutrients) and toxic compounds of natural origin still can occur in our diet [2–4]. In Table 1 the list of most important groups of plant toxins (some compounds constituting respective group are precursors of physiologically active metabolites) together with main plant sources are shown [5].

Table 1. Main groups of food plant toxicants

Toxicants	Plant family
Alkenyl benzenes	<i>Myristicaceae, Labiatae, Lauraceae, Piperaceae</i>
Anthraquinones	<i>Polygonaceae</i>
Capsaicinoids	<i>Solanaceae</i>
Coumarins	<i>Leguminosae, Rubiaceae, Umbelliferae</i>
Coumestans	<i>Leguminosae</i>
Cucurbitacins	<i>Cucurbitaceae</i>
Cyanogenic glycosides	<i>Leguminosae, Gramineneae, Rosaceae</i>
Furocoumarins	<i>Umbelliferae, Rutaceae,</i>
Glukosinolates	<i>Cruciferae</i>
Glykoalkaloids	<i>Solanaceae</i>
Glycyrrhizinic acid	<i>Leguminosae, Sapindaceae</i>
Hydrazons	<i>Morchellaceae</i>
Proteinase inhibitors	<i>Leguminosae</i>
Isoflavonoids	<i>Leguminosae, Rosaceae, Vitaceae</i>
Lectins	<i>Leguminosae</i>
Nitriles	<i>Leguminosae</i>
Oligosaccharides	<i>Leguminosae</i>
Oxalates	<i>Chenopodiaceae</i>
Phenylhydrazines	<i>Agaricaceae</i>
Pyrrolizidin alkaloids	<i>Asteraceae, Boraginaceae, Leguminosae, Sapindaceae</i>
Quinolizidine alkaloids	<i>Berberidaceae, Chenopodiaceae, Leguminosae, Solanaceae</i>
Saponins	<i>Leguminosae</i>
Sesquiterpen lactones	<i>Asteraceae, Convolvulaceae, Rutaceae, Umbelliferae</i>
Toxic amino acids	<i>Leguminosae</i>
Toxic fatty acid	<i>Cruciferae</i>
Toxic pyrimidines	<i>Leguminosae</i>
Xanthin alkaloids	<i>Buttneriaceae, Rubiaceae, Theacea</i>

Besides of chemical structure, the mode of action is a common criterion used for classification of plant toxins.

BIOLOGICAL ACTIVITY OF PLANT SECONDARY METABOLITES

As documented in several studies [6], bioactive plant constituents might exhibit both health protecting and adverse health effects, depending on specific conditions. In the following paragraphs selected groups of bioactive plant constituents which are currently subject of greatest concern are presented.

COMPOUNDS WITH HEALTH PROTECTING POTENTIAL

Phytoestrogens

The biological activity of phytoestrogens contained in soybean products (mainly isoflavons), whole grain cereal food, seeds, and probably berries and nuts (mainly lignans) are a good example of such controversy [7, 8]. Available epidemiologic investigations [9] strongly support hypothesis on their cancer-protective role because the highest levels of these compounds in the diet are found in countries or regions with low cancer incidence. Phytoestrogens are assumed to prevent mainly hormone-dependent cancers like breast, ovarian and/or endometrial cancer. Since recently, various food supplements containing soy estrogens daidzein, genistein, glycitein are becoming popular for reduction of menopausal syndromes in women [10]. On the other hand, concern exists about the possible ill effects of phytoestrogens during prenatal and neonatal development. For instance, loss of fertility and a number of reproductive lesions in farm animals were reported to result from grazing clover reach in coumestrol, a potent plant estrogen. In experimental rats, change of uterus weight, and decline of neuroendocrine development was observed when administered diet rich in 'plant hormones' [11].

Glucosinolates

Glucosinolates are another group of compounds that have been of great scientific interest for many years because of both health concerns and expected health benefits. They are primarily found in the

Brassicaceae family which comprises a large number of common vegetables such as different types of cabbage, cauliflower, broccoli, and Brussels sprouts. More than 100 different glucosinolates are known at present [12]. Glucosinolates themselves exhibit minimal biological activity, nevertheless, upon cell damage, they undergo hydrolysis by endogenous enzyme myrosinase to yield, amongst others, the biological active groups of isothiocyanates and indoles. Some of these breakdown products were in earlier research conducted on experimental animals found to be goitrogenic and/or mutagenic (for that reason, breeders developed and commercialised low glucosinolate rape varieties). However, the adverse effects in humans have been questioned and new research focusing on the health benefits of glucosinolates and their degradation under various processing conditions has been initiated [13–15]. Based on available data, it has been concluded that glucosinolate breakdown products modulate two distinct anticarcinogenic mechanisms that can account for at least part of the large body of epidemiological evidence showing a protective effect of *Brassicaceae* vegetables against cancers of the lung and alimentary tract. Both raw and cooked vegetables are capable of exerting potent biological activity *in vivo*.

COMPOUNDS EXHIBITING ADVERSE EFFECTS

Glycoalkaloids

One of the widely discussed groups of plant toxins is represented by glycoalkaloids that are contained in all *Solanaceous* plants including potatoes, an important staple food [16]. Various toxic effects have been shown for main potato glycoalkaloids, α -chaconine and α -solanine, and their hydrolysis products [17]. Although historical reports on acute poisoning of humans by 'solanine' (its levels are largely elevated in sprouted and/or greened potatoes) are available, it is hardly a relevant issue at present; the main concern is currently focused on chronic toxicity data. No adequate no-observed-adverse-effect level (NOAEL) is available for determination of Tolerable Daily Intake (TDI) at present. Recommendation for maximum levels of 200 mg α -chaconine and α -solanine (sum) per kg potatoes is based on estimation of 300 g daily intake [18], nevertheless, doubts exists whether this value is sufficient for consumers protection,

since the safety margin in this particular case is rather narrow. 'Solanine' content considerably varies among individual varieties and is largely affected by environmental factors such as light, irradiation, mechanical injury, and storage [19]. On the other hand glycoalkaloids appear to be largely unaffected by common food processing practices such as baking, cooking, and frying. The most efficient way of lowering dietary exposure is peeling of tubers since their outer layers are rich in these toxins. Depending on tuber size and variety, up to 60% of total content can be removed by manual peeling.

Tomatoes are another important food crop of *Solanaceous* family contributing to the glycoalkaloids intake. However, this crop seems in this respect to be much safer for humans than are potatoes, since tomatine (contains mixture of dehydro tomatine and α -tomatine) is largely degraded as the tomato fruit ripens [20]. The development of transgenic tomatoes has also stimulated interest whether their glycoalkaloids content differs significantly from that occurring in standard varieties during different stages of fruit maturity.

Cyanogenic glycosides

Several other groups of food toxins have been placed on the priority list by expert groups, some of them are present only in fresh crops and can be substantially removed by using appropriate processing [21]. Glycosides of α -hydroxynitriles (cyanogenic glycosides) releasing hydrogen cyanide via enzymic breakdown catalysed by endogenic β -glycosidases are contained in several economically important plants, the most known of them being cassava; the main cyanogen contained in this crop is linamarin. Chopping, grinding, soaking in running water as well as fermentation and cooking, are traditional processing practices used by cassava African and South American consumers for detoxification. Amygdalin is another cyanogenic glycoside that might be responsible for exposure to hydrogen cyanide when heat processed products prepared from stone fruits from which seeds were not removed are consumed [22].

Lectins

Lectins or haemagglutinins are carbohydrate binding (glyco)proteins which are ubiquitous in nature [23]. They are present in the most com-

monly edible plant foods such as leguminous species and many others hence they are ingested daily in appreciable amounts by both humans and farm animals. Due to their high stability, lectins are able to survive digestion by the gastrointestinal tract of consumers and may cause severe gastric upset. Number of outbreaks of food poisoning were reported, typically due to the consumption of uncooked or partially cooked kidney beans (*Phaseolus vulgaris*). Among many adverse effects described, interferences with digestion and absorption of nutrients have been widely discussed [24].

Pyrrolizidine alkaloids

Pyrrolizidine alkaloids are a large group of natural toxins involving almost 350 chemicals [25], many of them have been shown carcinogenic in animals and are therefore classified as potential human carcinogens. Intoxication of people can occur in several ways, often due to contamination of food supply by seeds containing these alkaloids. Another exposure route is occurrence of plants containing pyrrolizidines in traditional remedies or certain dietary supplements.

PLANT TOXINS AND SAFETY

To evaluate/regulate compounds that might be responsible for food poisoning, complex information on all the related aspects (toxicity, exposure) has to be available. However, contrary to mycotoxins and some phycotoxins, only very limited data are available. In the comprehensive review concerned with this issue [26] it was concluded that the concept applied for estimation of ADI (Acceptable Daily Intake) for pesticide residues and food additives, is not suitable for risk management and regulation of food plant toxins. Typically, narrow margin between their actual intake and potentially toxic levels would prohibit the use of particular food as far as default uncertainty factors used to establish ADI are employed. As emphasized by expert group [26], the presence of plant toxins, their bioavailability from matrix and interaction with other inherent plant constituents has to be evaluated together with potential health beneficial effects of the whole food (antioxidants and other natural protective agents can be present).

Considering severity, incidence and onset of biological symptoms induced in the context of the risk

to health of various food hazards, then following six principal categories, ranging from greatest to least, are typically ranked by scientists:

1. Microbial contaminants
2. Nutritional imbalance (excess and deficiency)
3. Environmental contaminants
4. Natural toxicants
5. Pesticide residues
6. Food additives

It should be noted that the ranking of these hazards is not linear, that of environmental contaminants and natural toxicants being about 1/1000th that of nutrient imbalance and pesticide residues and food additives being about 1/100th that of natural toxicants.

Regarding the regulatory aspects related to the inherent plant toxins, the main problem encountered in this area is, as already mentioned, is the lack of essential data on toxicological properties and information on occurrence of these substances in human diet. Generally, establishing maximum limits has to be based both on magnitude of the potential public health/safety risk and the capacity of legally enforceable standard to serve an effective risk management function [27]. In setting priorities for research and further evaluation, various criteria are considered. More than acute risk, the data (both experimental and epidemiological) on chronic toxicity are important for such purpose. Compounds assumed to be associated with high consumers' exposure in particular region are of concern. Specific risk groups should to be taken into account as well.

CONCLUSION

As outlined above, foods consumed at times often contain not only synthetic chemicals but also natural constituents that are intrinsically toxic. Also present in foods, however, may be detoxifying compounds which, together with detoxification processes in human bodies, limit the damage inflicted on our metabolism. Consumers are usually aware of the more acute responses which arise from allergens or microbial toxins, but are less aware of compounds which cause chronic diseases over time. It also should be noted that scientific perception of these facts is almost the reverse of the public's perception of risk where pesticides and food additives are seen as the greatest dangers. The popular notion equating 'natural' and 'healthy' is obviously

not realistic since natural plant toxins pose a far greater health risk than is that of many man-made chemicals occurring in our foods. To clarify all the relationships scientific effort in this field should be further intensified.

Acknowledgement: The authors wish to express their thanks to Dr. CHRISTER ANDERSSON, National Food Administration Sweden, for supporting their work in the field of natural toxins.

References

- [1] VAN EGMONT H.P. (2004): *Anal. Bioanal. Chem.*, **378**: 1152.
- [2] SINGH B.R., TU A.T. (eds) (1996): *Natural Toxins 2: Structure, Mechanism of Action and Detection*. Kluwer Academic/Plenum Publishers, Hardbound.
- [3] TU A.T., GAFFELD W. (eds.) (2000): *Natural and Selected Toxins: Biological Implications*. ACS Symposium Series, No. 745.
- [4] O'MELLO J.P.F. (ed.) (2003): *Food Safety Contaminants and Toxins*. Wallingford, Oxon.
- [5] ROSA E., ROSNER H., ANDRADE J., GEVERS E., HALLIKAINEN A., HEDLEY S., HOLM S., LAMBEIN F., LAURSEN P., STRIGL A., SØRENSEN H., VIDAL-VALVERDE C. (1998): *NETTOX List of Food Plant Toxicants Report No. 1*, Danish Veterinary and Food Administration.
- [6] ZHOU S., KOH H.-L., GAO Y., GONG Z.-Y., LEE E.J.D. (2004): *Life Sci.*, **74**: 915.
- [7] REINLI K., BLOCK G. (1996): *Environ. Health Persp.*, **26**: 123.
- [8] BARRETT J. (1996): *Health Persp.*, **104**: 478.
- [9] BINGHAM S.A., ATKINSON C., LIGGINS J., BLOCK J., COWARD A. (2000): *British J. Nutr.*, **79**: 393.
- [10] FITZPATRICK A.L. (2003): *Maturitas*, **44**, Suppl. 1: S21-S29.
- [11] WHITTEN P.L., LEWIS C., NAFTOLIN F. (1993): *Biol. Reprod.*, **49**: 1117.
- [12] TALALAY P., FAHEY J.W. (2001): *J. Nutr.*, **131**: 3027.
- [13] VERKERK R., VAN DER GAAG M.S., DEKKER M., JONGEN W.M.F. (1997): *Cancer Lett.*, **114**: 193.
- [14] MITHEN R.F., DEKKER M., VERKERK R., RABOT S., JOHNSON I.T. (2000): *J. Sci. Food Agric.*, **80**: 967.
- [15] JOHNSON I.T. (2000): *Acta Hort.*, **539**: 39.
- [16] MAGA J.A. (1994): *Food Rev. Int.*, **10**: 385.
- [17] HOPKINS J. (1995): *Food Chem. Toxicol.*, **33**: 323.
- [18] Nordic Working group on Food Toxicology and Risk Assessment (1991): *Food and New Biotechnology, Novelty, Safety, and Control Aspects of Foods Made by New Biotechnology*. Nordic Council of Ministers, Nord.

- [19] LACHMAN J., HAMOUZ K., ORSÁK M., PIVEC V. (2001): Rostl. Výr., **47**: 181.
- [20] FRIEDMAN M. (2004): J. Chromatogr., in press.
- [21] DAVÍDEK J. (1995): Natural Toxic Compounds of Foods: Formation and Change During Food Processing and Storage. CRC Press, Boca Raton.
- [22] VETTER J. (2000): Toxicol., **38**: 11.
- [23] VASCONCELOS I.M., OLIVEIRA J.T.A. (2004): Toxicol., **44**: 385.
- [24] LAJOLO F.M., GENOVESE M.I.S. (2002): J. Agric. Food Chem., **50**: 6592.
- [25] COULOMBE R.A. Jr. (2003): Adv. Food Nutr. Res., **45**: 61.
- [26] ESSERS A.J.A., ALINK G.M., SPEIJER G.J.A., ALEXANDER J., BOUWMEISTER P.-J., VAN DEN BRANDT P.A., CIERE S., GRY J., HERRMAN J., KUIPER H.A., MORTBY E., RENWICK A.G., SHRIMPTON D.H., VAINIO H., VITTOZI L., KOEMAN J.H. (1998): Environ. Toxicol. Pharmacol., **5**: 155.
- [27] ABBOTT P., BAINES J., FOX P., GRAF L., KELLY L., STANLEY G., TOMASKA L. (2003): Food Control, **14**: 383.