Nutritional value of cruciferous oilseed crops in relation to profile of accumulated biomolecules with especial regard to glucosinolate transformation products

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Abstract

Cruciferous oilseed crops accumulate relatively high concentrations of nutritional high quality oil and proteins in their seeds. In addition to these major seed components, their co-occurrence with high concentrations of dietary fibre (DF) and various bioactive components as glucosinolates/glucosinolate products is decisive for the nutritional value of the seed meal or products obtained from it. Depending on structural types and concentration of glucosinolates and glucosinolate derived products, these compounds can be either health beneficial or act as antinutrients. The effects of these components depend, however, strongly on the type of animal and development of the animals fed with the diets based on these compounds. Results from studies based on differently treated and processed seeds and from use of individual isolated seed components included in standard diets are evaluated and treated in relation to literature data as a basis for recommendations of acceptable concentrations of glucosinolates/glucosinolate products in animal diets. The relation between these recommendations of acceptable concentrations in feed to different animals and those reported as necessary for plant pathogen control (biofumigation) and health beneficial effects (chemoprotection) is discussed.

Introduction

The nutritional value of cruciferous oilseed crops has been a hot subject for a long time, with research being intensified some decades ago as a result of the success plant breeders had in connection with the production of double low oilseed rape (Bunting, 1981; Sørensen, 1985). Advantages of double low oilseed rape cultivars are related to the opportunities for an optimal utilization of relatively high yielding oil- and protein rich agricultural crops with ca. 45 % oil and 20 % protein in seed dry matter (DM), and less than 0.5% erucic acid in the oil and less than 20 μmole of glucosinolates per g. of seed DM (GCIRC, conf., 2003). Both of these major seed components have a high nutritional value and quality if problems caused by dietary fibres (DF) and especially glucosinolates can be solved (Bille et al. 1983a; 1983b; Bjergegaard et al. 1991). This gives the need for consideration of effects caused by processing and biorefining (Bagger et al. 2007) as well as the need for taking into account the variation in effects caused by structurally different glucosinolates and glucosinolate derived products (Bille et al. 1983; Bjerg et al. 1987a; Loft et al. 1992; Bonnesen et al. 1999; Bjergegaard et al. 2000; Vang et al. 2001). The great variation in structurally different glucosinolate derived products reflects primarily the glucosinolate structures (Bellostas et al. 2007) and the reaction conditions during non-enzymatic and enzyme/myrosinase (EC 3.2.1.147) catalysed reactions (Bjergegaard et al. 1994; Agerbirk et al. 1998; Bjergegaard et al. 1999; Buskov et al. 2000a; 2000b; 2000c; Barba et al. 2005; Bellostas et al. 2006). Thereby, it is also expected and found that effects on:

- feed and food quality,
- animal or human health and diseases and
- the value of final products,

are a function of structure and concentrations for both the glucosinolates and products thereof (Bille et al., 1983b; Bjerg et al., 1989; Jensen et al., 1991; Michaelsen et al., 1994; Bonnesen et al., 1999; Bjergegaard et al., 2001; Vang et al., 2001; Bellostas et al., 2007).

Materials and Methods

Details and comprehensive descriptions of the applied analytical methods are presented elsewhere (Sørensen et al., 1999; Sørensen 2001; Bellostas et al., 2003; Bellostas et al., 2006) as are applied procedures for evaluations of nutritional values and effects of allelochemicals/xenobiotics, N-balance trials with rats (Bille et al., 1983b; Bjerg et al., 1989), mink trials (Danielsen et al., 1987), young bull trials (Andersen and Sørensen, 1985) and evaluations of health and anticarcinogenic effects (Loft et al. 1992; Bonnesen et al., 1999; Vang et al., 2001).

Results and Discussion

Cruciferous oilseed crops are important sources for both vegetable oil (40-45% of seed DM) and protein (20-25 % of seed DM). Oil from these crops has been used as energy sources from ancient times, and in the recent years, additional focus has been directed at this oil for its use as fuels of biodiesel (Knothe, 2006; GCIRC conf., 2003). With introduction of double low oilseed rape, an increased interest in the oil has been focused on the nutritional applications, as it has been found to be high quality oil (Bunting, 1981; Sørensen, 1985; GCIRC conf. 2003). The result of a large and increasing production of oils from cruciferous seeds is thus a great amount of deoiled meal for applications as feed, food and non-food, where the main limitations in its uses are caused by dietary fibres (DF, Bjergegaard et al. 1991) and especially glucosinolates and glucosinolate derived products. The lipophilic and volatile glucosinolate derived products may also create environmental (smell, taste, toxicity) and oil-quality problems, depending on structures of the glucosinolate products (Sørensen, 2001), which again is linked to the plant source and glucosinolate type. Cruciferous plant sources most often used belong to genera of the family Brassicaceae, and these sources are quantitatively dominated by Brassica cultivars; *B. napus* and *B. rapa* (Table 1).

Table 1. Quantitatively dominating seed glucosinolates in different Brassicaceae species.

Species	Glucosinolate dominating
Brassica napus L. *B. rapa* L. *B. oleracea* L.	10-16 different gluosinolates (Bjerg et al., 1987b)
B. nigra (L.) Koch *B. carinata* Braun *B. juncea* (L) Czern & Coss	Sinigrin (Bellostas et al., 2006)
Crambe abyssinica Hoechst. ex R.E. Fries	(2S)-2-Hydroxybut-3-enylglucosinolate
Barbarea vulgaris R. Br.*	(2S) and (2R)-2-hydroxy-2-phenylethylglucosinolate
B. verna (Miller) Ascherson*	Phenethylglucosinolate
Lepidium campestre (L.) R. Br.*	Sinalbin
Camelina sativa (L.) Crantz	(R)-Methylsulphinyl-$(CH_2)_n$-glucosinolates#
Sinapis alba L.	Sinalbin

Ref. (* Andersen et al., 1999; Sørensen, 2001) # Dominating glucosinolates with n=9 and 10.

The cruciferous meal available for feed, food and non-food applications after deoiling contains thus various types and concentrations of glucosinolates defined by the applied type of seeds, and depending on storage and processing conditions a great number of glucosinolate derived products can be present in the meal. When applied at few percent in diets to monogastric animals, this will give reduced nutritional value for the cultivars with more than 20 µmol/g seed DM. A great number of oilseed rape cultivars – even double low oilseed rape – also have a level and composition of glucosinolates that give nutritional problems (Bille et al., 1983; Bjerg et al., 1987; Jensen et al., 1991).

The acceptable level of glucosinolates in diets to monogastric animals needs to be below 2nd level (Table 2) or 1-2 µmol/g DM to avoid nutritional problems. However, as described elsewhere (Bjerg et al., 1987), the acceptable level depend on the type of animal, its age/development and especially the structure of the glucosinolate/glucosinolate products.

Table 2. Glucosinolate level in seed, seed meal and diets (DM) to monogastric animal without the presence of glucosinolate transformation products

	level 1**	level 2	level 3''	level 4
Diets (µmol/g DM)	0.5	2.5	12.5	as level 2 but with active myrosinase added
Feed with 20 % rapeseed meal: (µmol/g rapeseed meal)	2.5	12.5	62.5	
Seed before deoling: (µmol/g seed; depend on oil and water content)	1-2	6-8	30-40	

** Generally safe. '' Create nutritional problems.

The quantitatively dominating glucosinolates in double low oilseed rape are (2R)-2-hydroxybut-3-enylglucosinolate (progoitrin) and 4-hydroxyglucobrassicin, which as result of hydrolysis give (5S)-5-vinyloxazolidine-2-thione (goitrin) and thiocyanate ion, respectively. Both hydrolysis products have strong effect on the thyroid gland and thereby on the metabolism, growth and development of the animals. The indolyl group of 4-hydroxyglucobrassicin gives, as result of transformations, appreciable negative effects on rapeseed products caused by a complex group of structurally different compounds (Jensen et al. 1991; Bellostas et al., 2007). Appreciable variations are also found for other types of glucosinolate transformation products as isothiocyanates (ITC's; R-N=C=S) and nitriles (RCN):

Table 3. LD_{50} of glucosinolate hydrolysis products on rats and mice.

Glucosinolate precursor	Compound	Animal	LD_{50} mmol/kg	References
Sinigrin	allyl-ITC	rats	1	Langer& Geer 1968
Glucoiberin	CH_3-SO-$(CH_2)_3$-ITC	rats	0.5	Langer& Geer 1968
Phenethyl-glucosinolate	Phenethyl-ITC	rats	0.3-0.5	Langer& Geer 1968
Epiprogotrin	(5R)-5-vinyloxazaolidine-2-thione	mice	11-13	Van Etten et al., 1969
Epiprogotrin	1-cyano-2-hydroxy-3,4-epithiobutane	rats	1.5-2.0	Van Etten et al., 1969
Epiprogotrin	1-cyano-3,4-epithiobutane	rats	0.8	Van Etten et al., 1969
Epiprogotrin	(2S)-1-cyano-2-hydroxybut-3-ene	rats	2.2-2.4	Van Etten et al., 1969
Glucobrassicin	Indol-3-ylacetonitrile	rats	1.1	Fenwick et al., 1983

Comparing the concentration levels and structures of glucosinolates and glucosinolate derived products acceptable for nutritional purposes and those needed for food, feed and plant protection (Bellostas et al., this conference; 2007) gives the basis for progress in these fields.

Conclusion

Glucosinolates and transformation products of glucosinolates are key factors for the nutritional value of cruciferous oilseed crops and for the value of products produced from them. Considering the physiological effects of glucosinolates and glucosinolate products it seems to be possible to use appropriate structural types in concentrations of the compounds where they can function as food, feed and plant protection agents and/or as chemoprotection or health beneficial compounds without reaching the toxic levels of the compounds.

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