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Changes in carbohydrate and glucosinolate composition in white cabbage (*Brassica oleracea* var. *capitata*) during blanching and treatment with acetic acid

Mathias Wennberg [a], Jimmy Ekvall [a], Kerstin Olsson [b], Margareta Nyman [a,*]

[a] *Applied Nutrition and Food Chemistry, Center for Chemistry and Chemical Engineering, Lund Institute of Technology, Lund University, P.O. Box 124, SE-221 00 Lund, Sweden*
[b] *Svalöf Weibull AB, SW Laboratory, SE-268 81 Svalöv, Sweden*

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Abstract

The effect of blanching and treatment with white vinegar containing acetic acid on dietary fibre, low-molecular-weight carbohydrates and glucosinolates was studied in two cultivars of white cabbage (Heckla and Predikant). The total content of dietary fibre and low-molecular-weight carbohydrates was similar in both cultivars (24 and 60 g/100 g DM, respectively), while the distribution between soluble and insoluble fibre differed (19% was soluble in Heckla versus 26% in Predikant, $P < 0.01$). Further, Heckla contained higher amounts of glucose and sucrose, while the content of fructose and total glucosinolates was lower than in Predikant. The content of individual glucosinolates differed between the two cultivars. During blanching there was a loss of dry substance (30–34 g/100 g DM), where low-molecular-weight carbohydrates primarily explained the loss (82–90%), but some of the loss was also dietary fibre (about 8%), both soluble fibre containing uronic acids (mainly Predikant) and insoluble ones containing glucose (mainly Heckla). The glucosinolate levels decreased substantially in both cultivars, although the total loss was higher in Predikant (74%) than in Heckla (50%). The individual glucosinolates were affected to different degrees (15–91%). During souring with acetic acid, the content of dietary fibre (primarily insoluble ones) decreased further, while the content of low-molecular-weight carbohydrates was less affected. The total content of glucosinolates was not affected in Heckla but was further reduced in Predikant. There was, however, a substantial increase in 4-methoxyglucobrassicin in both cultivars. It is concluded that blanching and souring decrease the content of carbohydrates and glucosinolates to a great extent and both cultivars behaved similarly. However, individual components were affected differently in the two cultivars.

Keywords: White cabbage; Heat treatment; Souring; Blanching; Coleslaw; Dietary fibre; Glucose; Fructose; Cell wall polysaccharides; Glucosinolates

1. Introduction

An important vegetable crop in Sweden is white cabbage (*Brassica oleracea* var. *capitata*), and approximately 6.3 kg of *Brassica* vegetables is consumed per person annually (Jordbruksverket, 2003). The main constituents of white cabbage are carbohydrates, comprising nearly 90% of the dry weight, where approximately one third is dietary fibre and two thirds are low-molecular-weight carbohydrates (LMWC). Other characteristic components are glucosinolates. White cabbage is consumed either raw or processed in different ways, e.g., boiled or fermented. An important intake of white cabbage in Sweden is as a kind of coleslaw. For a variety

* Corresponding author. Tel.: +46 46 222 45 67; fax: +46 46 222 45 32.
E-mail address: e_margareta.nyman@inl.lth.se (M. Nyman).

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of reasons, e.g., to give the cabbage a softer texture, decrease/inactivate enzymatic activity and increase shelf life, the cabbage is usually blanched before the sour dressing, usually containing acetic acid, is added. This process may affect the different chemical components in the cabbage.

Blanching may influence the physico-chemical properties of the dietary fibre, e.g., the proportion of soluble and insoluble fibre, the viscosity and the molecular weight. During wet heat treatment, it has been shown that insoluble fibre may be solubilized or even degraded into smaller fragments and, as a consequence, lost to the processing water (Svanberg, Nyman, Andersson, & Nilsson, 1997; Wennberg, Engqvist, & Nyman, 2003). These changes may be due to cleavage of glycosidic linkages within the polysaccharides or breakage of weak bonds between dietary fibre polymers (Krall & McFeeters, 1998; Selvendran & Robertson, 1994). A similar phenomenon with hydrolysis of glycosidic linkages, may also occur in acidic environments, e.g., during fermentation and after adding of vinegar when preparing different types of salad.

During wet treatment, such as blanching, there will also be a loss of low-molecular-weight components, such as minerals, vitamins and sugars, from the plant cells into the processing water, leading to a relative increase in some components in the plant, e.g., the content of dietary fibre. Previous studies have shown that there is a loss of dry matter in peas, Brussels sprouts, carrots and swedes ranging from 11% to 31% during blanching (FAO/WHO, 1998; Nyman, Pålsson, & Asp, 1987).

When the physico-chemical properties of dietary fibre are modified, physiological effects may also be changed. Insoluble fibre is characterized by having a high faecal bulking capacity and in this way can reduce the risk of constipation and, in the long term, possibly also colonic cancer (Slavin, 2001). During heat treatment glycosidic linkages may be broken, and as a result the bulking capacity may decrease, as has been seen in several studies (Nyman et al., 1987; Wyman, Heaton, Manning, & Wicks, 1976). Furthermore, soluble and viscous fibres are usually associated with metabolic effects such as lowered postprandial glucose levels when added to a carbohydrate-rich meal. Also, decreased blood cholesterol levels (Cameron-Smith & Collier, 2001) can be abolished when the viscosity is reduced, for example, by enzymatic treatment (Wood, Beer, & Butler, 2000) or by heat-induced hydrolysis of the glycosidic linkages in the dietary fibre polysaccharides (Jenkins et al., 1978). Souring of LMWC may also have an effect, as evidenced by the augmented effects on glucose and insulin response in healthy subjects consuming carrots that had been steeped in lactic acid (Gustafsson, Asp, Hagander, & Nyman, 1994). Moreover, in a study where white wheat bread dipped in vinaigrette sauce containing acetic acid was eaten, a lowering of the postprandial glucose and insulin response was observed (Liljeberg & Björck, 1998).

Dietary fibre can also be fermented in the colon by the microflora to short-chain fatty acids (SCFA), mainly acetic, butyric and propionic acids. Two of these acids, butyric- and propionic acid, have been connected with beneficial effects on colonic health and on the metabolism, respectively (Salminen et al., 1998). The pattern of SCFA and the location of fermentation are highly dependent on the type of carbohydrates reaching the colon (Henningsson, Björck, & Nyman, 2002; Scheppach, Bartram, & Richter, 1995), and the SCFA pattern may be changed by modifying the physico-chemical properties of the carbohydrates by heat treatment or souring (Goodlad & Mathers, 1992; Henningsson, Nyman, & Björck, 2001; Muir, Birkett, Brown, Jones, & O'Dea, 1995).

Glucosinolates are sulphur-containing glycosides believed to play a general role in plant defence within *Brassicaceae* against herbivores, pests and pathogens. In white cabbage, the main components are sinigrin and glucobrassicin, while about 10 more glucosinolates might be present, although some of them only at trace amounts (Rosa, Heaney, Fenwick, & Portas, 1997). The enzyme myrosinase hydrolyses the glucosinolates when plant tissues are disrupted by slicing, chewing or when the membranes collapse during cooking. The structure of the glucosinolates and the environmental conditions, such as pH, determine whether isothiocyanates, thiocyanates, nitriles or oxazolidine-2-thiones are formed (Rosa et al., 1997). Some glucosinolates, or their breakdown products, contribute in a beneficial way to the human diet either as precursors for flavour or as potential anticarcinogens (e.g., glucoiberin and indole glucosinolates) (Fahey, Stephenson, & Talalay, 1998; van Poppel, Verhoeven, Verhagen, & Goldbohm, 1999). Others can give a bitter taste to the vegetable (progoitrin and sinigrin), impair the thyroid function (e.g., progoitrin) or lead to other undesirable physiological effects (Rosa et al., 1997).

The main hydrolysis product from glucobrassicin is non-volatile indole-3-carbinol, but indole-3-acetonitrile, and 3,3-diindolylmethane and ascorbinogen are also formed. The indoles are inducers of detoxification enzymes and have inhibitory effects on fore stomach and lung tumours in experimental rats and mice (Fahey et al., 1998; Wattenberg et al., 1986). However, in the acidic prevailing conditions in the stomach, indole-3-carbinol might be spontaneously converted to a dioxin-like structure, which could induce tumours (Fahey et al., 1998). Moreover, the thiocyanate ion from glucobrassicin is known to inhibit the accumulation of iodine in the thyroid gland and thus cause goitre if there is a shortage of iodine in the diet. Sinigrin, which has a bitter taste, usually produces volatile

2-propenyl isothiocyanate after hydrolysis. Sinigrin has been found to exert diverse effects (negative as well as positive) at different stages of carcinogenesis (Johnson, Williamson, & Musk, 1994). Progoitrin is a compound without bitterness but its breakdown product, 5-vinyl-2-oxazolidine-thione, is less volatile and has a bitter taste. Moreover, it inhibits the synthesis of thyroxin and is thus capable of inducing goitrogenic effects in mammals, probably also in humans, although clear epidemiological evidence is lacking (Mithen, Dekker, Verkerk, Rabot, & Johnson, 2000).

Generally, glucosinolates have been studied in the raw material and concentrated on the effect of chopping and pulping (Rosa et al., 1997). The glucosinolates and their breakdown products are soluble in water and are leached into the cooking water. They also show different levels of thermoresistance: sinigrin > progoitrin > glucobrassicin > glucoiberin > gluconapin > glucoiberverin (de Vos & Blijleven, 1988). Myrosinase activity is enhanced at temperatures up to 60 °C. At higher temperatures denaturation of the enzyme will occur both in the cabbage and after leaking into the cooking water (Dekker, Verkerk, & Jongen, 2000). The remaining intact glucosinolates will have low, if any, biological activity in comparison with the breakdown products.

The effects of other processing methods are less known. However, unblanched cabbage soured with a vinegar dressing containing acetic acid, was high in isothiocyanate but low in nitrile compared with the fresh cut material (West, Badenhop, & McLaughlin, 1977). This and other processing methods certainly have an effect on the final intake of bioactive compounds (Dekker et al., 2000).

The purpose of the present investigation was to study the effect of processing similar to that used when preparing coleslaw, i.e., blanching and treatment with vinegar containing acetic acid, on the dietary fibre polysaccharides, LMWC and glucosinolates in two cultivars of white cabbage.

2. Materials and methods

2.1. Materials

Two cultivars of white cabbage (*Brassica oleracea* var. *capitata*), Heckla and Predikant, grown at an experimental farm in Hammenhög (southern Sweden) were included in the study. The cultivars belonged to a late maturity type and were F1 hybrids, i.e., there was no genetic difference between the plants within each cultivar. After harvest the cabbage (about 15 kg) was stored at +4 °C for seven months (September to April) until the start of the processing experiments. Raw shredded cabbage was used as reference material and is referred to as unprocessed cabbage.

2.2. Dressing recipe

The dressing used for 1000 g blanched white cabbage was: water (30 ml), white wine vinegar (30 ml) produced by fermentation of white wine and containing 6% (v/v) acetic acid (pH 3) (Dr PersFood AB, Eslöv, Sweden), salt (13 g) and sucrose (9 g). The ingredients were mixed separately before being added to the cabbage. The recipe generally used for this salad dressing was modified to exclude canned red peppers (*Capsicum* sp.) and spices, where at least red pepper could have had an effect on the results.

2.3. Sample preparation

The outer layers of the cabbage were removed and the heads were freed from core and stalk before being shredded with a 1.5 mm knife in a food processor (Braun, Germany). Samples for analysis of dietary fibre (100 g) and LMWC (100 g) were taken out and frozen in vacuum-sealed bags (unprocessed sample). Another 5 g was taken for immediate analysis of glucosinolates (Fig. 1). A batch of 2000 g of the shredded cabbage was blanched in 2000 ml boiling tap water for 5 min. After blanching, the cabbage was drained in a colander for 15 min. The decanted liquor was saved and frozen separately for analysis of the loss of dry substance into the blanching water. Samples of the drained cabbage were taken out and frozen in vacuum-sealed bags for analysis of dietary fibre and LMWC, while the glucosinolates were analysed immediately (blanched sample). The blanched cabbage (1000 g) was mixed with the dressing and stored in a closed glass container at +4 °C in a refrigerator. After 24 h the cabbage was taken out and samples were frozen in vacuum-sealed bags for analysis of dietary fibre and LMWC (soured sample). Five gram was taken for immediate analysis of glucosinolates. Frozen cabbage samples, saved for

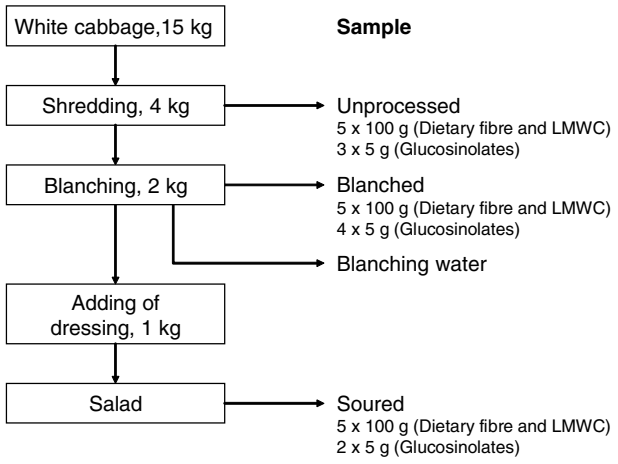

Fig. 1. Design of the experiments.

analysis of dietary fibre and LMWC, were freeze-dried and milled in a Cyclotec 1093 mill (Tecator AB, Höganäs, Sweden) to a particle size of less than 0.5 mm, and stored in an exicator.

2.4. Loss of dry substance during blanching

The loss of dry substance during blanching was determined by lyophilization of a fraction (150 ml) of the blanching water and weighing of the residue. The amount of dry substance found in the blanching water in relation to that found in the unprocessed cabbage (2000 g) was the loss of dry substance.

2.5. Dietary fibre

The dietary fibre was separated into a soluble (SDF) and an insoluble (IDF) fraction using the principle of an enzymatic gravimetric method (Asp, Johansson, Hallmer, & Siljeström, 1983) with some modifications. The initial gelatinization step with α-amylase (Termamyl) at 100 °C was excluded since no starch could be detected in cabbage and the effects of heat treatment were to be studied. This also provides conditions more like those in the human gastrointestinal tract. After isolation of the dietary fibre, the composition of the soluble and insoluble fractions was analysed by gas-liquid chromatography (GLC) with regard to neutral sugars and with a spectrophotometric method with regard to the uronic acids, according to the Uppsala method (Theander, Åman, Westerlund, Andersson, & Pettersson, 1995).

The filtrate from the SDF fraction was saved and analysed for dietary fibre monomers that could have been lost during the precipitation step in 80% (v/v) ethanol, i.e., usually polymers with a degree of polymerization less than approximately 20 (Johansson, 1987). The total amount of filtrate (500 ml) was then transferred to a dialysis tube (Spectra/Por 6® molecular weight cut-off 1000, Spectrum® Laboratories Inc., Rancho Dominguez, CA, USA). The tube was placed in 6 l deionized water which was stirred constantly for 2 1/2 days. The water was changed twice a day. The dialysed liquid was freeze-dried and the composition of fibre monomers was determined with GLC (Theander et al., 1995).

2.6. Low-molecular-weight carbohydrates

LMWC (inositol, glucose, fructose, sucrose, raffinose, stachyose and verbascose) were extracted in 50% (v/v) ethanol and quantified with high performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) (Ekvall, Stegmark, & Nyman, 2005; Nilsson et al., 2005; Nygaard Johansen, Glits, & Knudsen, 1996). Each sample was run at least in triplicate with a maximum error of less than 3%. Arabinose was used as internal standard.

2.7. Glucosinolates

Plant material (5 g) was immediately (<1 min after start of sample preparation) boiled in 10 ml 99.5% ethanol in a water bath for 10 min to inactivate endogenous myrosinase, and thus prevent degradation of the glucosinolates (Nilsson et al., 2005). Each sample was mixed with 100 μl glucotropaeolin (benzyl glucosinolate, Svalöf Weibull AB, Sweden) as an internal standard (60.4 mg in 25 ml water) and another 10 ml of 80% ethanol. After homogenization of the sample, extraction by boiling was continued for another 15 min. The extract was then cooled and centrifuged at 2500 rpm (Rotixa/RP centrifuge, Andreas Hettich), and the supernatant applied on a DEAE Sephadex A-25 column (80 mg) and washed with 6 ml water (Heaney & Fenwick, 1980). The individual glucosinolates (Table 2) were determined by high performance liquid chromatography (ISO 9167-1:1992, 1992) and the concentrations were expressed as μmol/100 g DM.

2.8. Calculations and statistical analysis

The design of the study resulted in 3 different samples (unprocessed, blanched and blanched and soured) for each cultivar (Fig. 1). To be able to study the real effects of processing and to compare different cabbage samples, results from the processed material were corrected for the loss of dry substance into the blanching water (blanched and blanched and soured material) and regarding the soured samples also for the dry substance added in the dressing (sucrose and salt).

Analysis of the content of dietary fibre and LMWC was performed at least in triplicate. Two of the samples for dietary fibre analysis were used to determine the monomeric composition. Analysis of the content of glucosinolates was performed in triplicate for unprocessed, in quadruplicate for blanched and in duplicate for soured samples. Two of the unprocessed replicates were randomly combined to give a mean value. The four blanched replicates were randomly combined into two pairs to provide a symmetrical data model. The maximum error in all analyses was <5%.

The coefficient of variation (CV, i.e., the quotient between the standard deviation and the mean value) was used to give a measure of the variation between the different cabbage samples for each cultivar. For statistical evaluation of the differences between samples, one-way ANOVA was used followed by Tukey's test for multiple comparisons between several sample groups. A two-sample *t*-test (Student's *t*-test) between paired samples was used for comparison of the differences between the two cultivars. Statistical analyses were carried out with the computer program Minitab, version 13.32 (Minitab Inc., State College, PA, USA).

3. Results

3.1. Cultivar differences in unprocessed material

Dietary fibre: The amount of total dietary fibre (TDF) was similar in the cultivars Heckla and Predikant (24.7 and 23.5 g/100 g DM, respectively) (Table 1) (Fig. 2). However, the content of soluble fibre was somewhat lower in Heckla (4.7 versus 6.2 g/100 g DM in Predikant, $P < 0.05$), while that of insoluble fibre was somewhat higher (20.0 versus 17.3 g/100 g DM, $P < 0.05$). This resulted in a higher solubility of the fibre in Predikant than Heckla (26% versus 19%, $P < 0.01$). The monomeric composition of the fibre was similar in the two cultivars. SDF polymers consisted mainly of uronic acids (61%), arabinose (19–21%) and galactose (10%), and IDF polymers of glucose (51–56%), uronic acids (16–21%), arabinose (9%), xylose (6%) and galactose (6%).

LMWC: The total content of LMWC was similar in both cultivars (61.7 g/100 g DM in Heckla and 59.8 g/100 g DM in Predikant). Glucose accounted for the main portion (about 50%) of the LMWC, followed by fructose (about 38%) and sucrose (about 11%). Small proportions of inositol (about 1%) were also detected, while the amount of raffinose, stachyose and verbascose were below the detection limit (<0.03 g/100 g DM). Heckla contained higher amounts of glucose and sucrose and lower of fructose, compared with Predikant.

Glucosinolates: The total amount of glucosinolates in unprocessed cabbage was higher in Predikant than in Heckla (1457 versus 1280 μmol/100 g DM, $P < 0.05$) (Table 2). The HPLC analysis revealed nine different glucosinolates, five aliphatic and four indolyl glucosinolates, with contents between 4 and 588 μmol/100 g DM, and trace amounts of some others (not shown). Progoitrin ($P < 0.01$), sinigrin ($P < 0.05$), gluconapin ($P < 0.001$), and 4-hydroxy glucobrassicin ($P < 0.05$), appeared at higher amounts in Predikant than in Heckla, while glucobrassicin ($P < 0.001$) appeared at lower amounts.

Sinigrin was the most abundant glucosinolate in both cultivars, constituting 36–40% of the total amount. Glucobrassicin was the second most abundant glucosinolate, representing 31% and 19% of the total glucosinolates in Heckla and Predikant, respectively. Glucoiberin was the third most common glucosinolate in Heckla (9%), while progoitrin was the third most abundant glucosinolate (13%) in Predikant.

3.2. Effect of blanching

Dry substance: The loss of dry substance into the blanching water was somewhat higher for Heckla (34 g/100 g DM) than for Predikant (30 g/100 g DM) (Table 1). Of this loss, most was LMWC (82–90%), but some was also determined to be dietary fibre (7–9%).

Dietary fibre: Both cultivars showed a similar decrease ($P < 0.001$) in TDF content during blanching, corresponding to an average loss of 11% (Fig. 2). In Heckla, most of the loss (3/4) was insoluble polymers containing glucose, while the soluble part constituted of polymers containing uronic acids. In Predikant, the insoluble fibre was more or less unaffected, while there was a considerable decrease in SDF (from 6.2 to 4.3 g/100 g DM $P < 0.01$). This led to a lower proportion of SDF in Predikant after blanching (20% versus 26% in unprocessed material, $P < 0.05$), while the distribution between soluble and insoluble fibre was barely affected in Heckla (Table 1). Most of the loss of TDF (83% and 92% for Heckla and Predikant, respectively) was found in the filtrate from the dietary fibre analysis.

LMWC: The loss of LMWC was considerable during blanching (45%), and the content decreased from in mean 60.7 g/100 g DM in unprocessed material to in mean 33.2 g/100 g DM in blanched material ($P < 0.001$). The loss was similar for glucose, fructose and sucrose.

Glucosinolates: The total amount of glucosinolates decreased by 50% and 74% in Heckla and Predikant, respectively ($P < 0.01$) during blanching (Table 2). The individual glucosinolates were affected to different degrees. In Heckla, most glucosinolates decreased by 30–63%, but 4-hydroxy glucobrassicin showed a loss of 71%. In Predikant, the losses of individual substances were generally much higher. Thus, 4-methoxy glucobrassicin was least affected with a loss of 46%, while all other glucosinolates decreased between 70 and 91%.

3.3. Effect of souring

Dietary fibre: When preparing the cabbage with dressing containing acetic acid the TDF content decreased further compared with blanched material (from e.g., 21.7 to 18.4 g/100 g DM, $P < 0.01$ in the cultivar Heckla). This was due to a considerable reduction ($P < 0.01$) of insoluble fibre polymers. As a consequence, the proportion of soluble fibre was higher after treatment with acetic acid than in material that only had been blanched (in average 25% in soured material versus 19% in blanched material, $P < 0.01$).

LMWC: The contents of glucose and fructose decreased further after souring with acetic acid in Heckla (from 17.4 to 14.7 g/100 g DM, $P < 0.001$, and 12.0 to 10.9 g/100 g DM, $P < 0.01$, respectively). Concerning sucrose, it was difficult to determine the real effects of acetic acid as sucrose was added with the dressing (about 13 g/100 g DM). In Predikant, the amount of glucose and fructose was similar after souring with acetic acid as before.

Table 1
The carbohydrate content (g/100 g DM) in unprocessed, blanched and soured white cabbage, and losses (%) of carbohydrates following blanching and souring[A]

	Heckla							Predikant						
	Unprocessed	Blanched		Soured		Total		Unprocessed	Blanched		Soured		Total	
	Mean	Mean	Losses (%)[B]	Mean	Losses (%)[B]	Mean	CV[C]	Mean[D]	Mean	Losses (%)[B]	Mean	Losses (%)[B]	Mean	CV[C]
Loss of dry substance (g/100 g DM)	–	–	(34)	–	–	–	–	–	–	(30)	–	–	–	–
TDF	24.7a	21.7b	(12)	18.4c	(25)	21.6	13	23.5a ns	21.3b	(10)	18.8c	(20)	21.2	11
SDF	4.7a	3.9b	(18)	4.6a	(2)	4.4	10	6.2a*	4.3b	(31)	4.6b	(27)	5.0	19
Monomeric composition														
Arabinose	0.9a	0.7b	(21)	0.8b	(11)	0.8	11	1.3a**	0.9b	(30)	0.9b	(28)	1.0	20
Xylose	0.1a	0.1a	(29)	0.1a	(30)	0.1	33	0.1a ns	0.1a	(46)	0.1a	(44)	0.1	36
Galactose	0.5a	0.4b	(21)	0.4b	(15)	0.4	11	0.6a*	0.4b	(30)	0.4b	(32)	0.5	20
Glucose	0.0a	0.0a	(30)	0.0a	(−4)	0.0	21	0.1a ns	0.0a	(48)	0.1a	(8)	0.1	36
Uronic acid	2.9ab	2.5a	(14)	3.0b	(−4)	2.8	9	3.7a*	2.7b	(27)	2.8b	(25)	3.0	19
Other sugars[E]	0.3a	0.2b	(33)	0.3a	(10)	0.3	18	0.4a ns	0.2b	(36)	0.3ab	(23)	0.3	21
IDF	20.0a	17.8b	(11)	13.8c	(31)	17.2	16	17.3a*	17.0a	(2)	14.2b	(18)	16.2	10
Monomeric composition														
Arabinose	1.8a	1.7a	(6)	1.3b	(31)	1.6	17	1.6a ns	1.9b	(−15)	1.5a	(9)	1.6	11
Xylose	1.2a	1.0ab	(16)	0.9b	(31)	1.0	17	1.0a ns	1.0a	(0)	0.8a	(19)	0.9	11
Galactose	1.2a	1.1a	(7)	0.8b	(29)	1.0	16	1.0a*	1.0a	(0)	0.8b	(18)	1.0	10
Glucose	10.3a	8.8b	(15)	7.6c	(26)	9.0	13	9.7a ns	8.3b	(8)	7.5b	(23)	8.6	12
Uronic acid	4.2a	4.1a	(1)	2.3b	(44)	3.5	26	2.8a*	3.7b	(−6)	2.6a	(3)	3.0	19
Other sugars[E]	1.3a	1.1b	(14)	0.9c	(31)	1.1	17	1.2a ns	1.1a	(1)	1.0a	(18)	1.1	10
Soluble fraction (%)	19a	18a		25b		20	17	26a**	20b		24a		24	11
LMWC	61.7a	33.8b	(45)	38.0c	–[G]	45.5	30	59.8a ns	32.6b	(45)	39.7c	–[G]	44.1	28
Inositol	0.8a	0.3b	(70)	0.2b	(80)	0.4	82	0.4a*	0.2b	(49)	0.3c	(36)	0.3	31
Glucose	31.5a	17.4b	(45)	14.7c	(53)	24.2	35	29.2a**	16.1b	(45)	15.5b	(47)	20.3	33
Fructose	22.0a	12.0b	(45)	10.9c	(50)	15.0	35	24.0a***	13.2b	(45)	13.1b	(45)	16.8	32
Sucrose	7.4a	4.1b	(45)	12.2[F]c	–[G]	7.9	45	6.2a**	3.1b	(50)	10.8[F]c	–[G]	6.7	51

[A] Mean value in the same row within the same cultivar followed by different letters are significantly different ($P < 0.05$).
[B] Losses in relation to unprocessed cabbage.
[C] Coefficient of variation (quotient of the standard deviation and the mean value).
[D] Significantly different from the mean value of the unprocessed cultivar Heckla: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns non-significant.
[E] Other sugars: rhamnose, fucose and mannose.
[F] Including sucrose originating from the dressing (13 g/100 g DM).
[G] Not measured, as sucrose was added to the dressing.

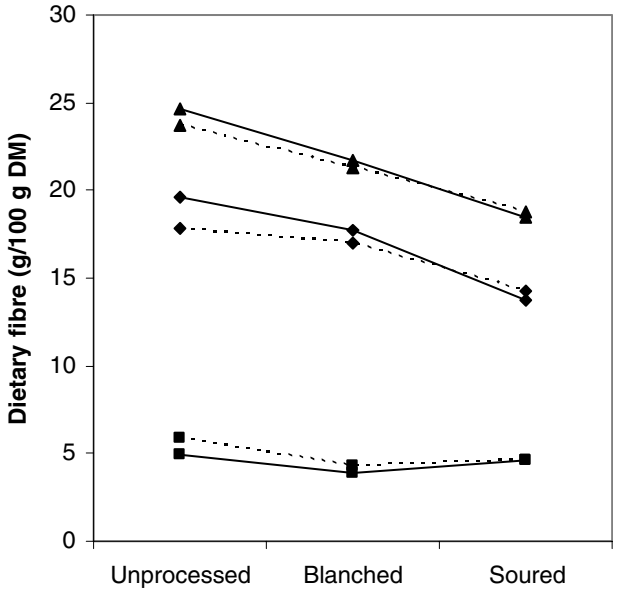

Fig. 2. Content of dietary fibre (g/100 g DM) during processing of the cultivars Heckla (—) and Predikant (– – –). TDF (▲), IDF (◆), SDF (■).

Glucosinolates: The addition of the dressing containing acetic acid to the blanched cabbage had no significant effect on the total amount of glucosinolates in Heckla, while the content in Predikant decreased ($P < 0.05$), mainly because of lower levels of sinigrin, gluconapin and glucobrassicin (Table 2). In Heckla, the level of glucoiberverin decreased ($P < 0.01$) but the other substances remained on similar levels to those before souring. There was, however, a considerable (four times) increase in 4-methoxy glucobrassicin compared with the blanched sample ($P < 0.05$) for both cultivars (Table 2 and Fig. 3).

4. Discussion

The content and composition of dietary fibre, LMWC and glucosinolates in the fresh material were in the same range as reported in earlier studies (Nilsson et al., 2005; Rosa et al., 1997; Wennberg, Engqvist, & Nyman, 2002; Wennberg et al., 2003). The two cabbage cultivars had been grown and stored under the same conditions, and the variation found in fibre, LMWC and glucosinolate level and composition in the unprocessed material is most certainly due to genetic variation.

4.1. Dietary fibre and LMWC

The considerable loss of dry matter during blanching was mainly due to leakage of LMWC into the processing water, but to some extent also to a loss of dietary fibre. This is in agreement with previous studies on other vegetables (peas, Brussels sprouts, carrots and swedes), where losses of dry matter between 11% and 31% have been reported (Nyman et al., 1987; Svanberg et al., 1997). However, the loss of dry matter from cabbage was found to be higher in this study (30–34%) than in earlier results (20–28%), although a shorter period of wet heat treatment was used (5 versus 10 min in the previous study) (Wennberg et al., 2003). One explanation of this could be that the material was shredded into smaller pieces (1.5 mm versus 4×4 cm in the previous study), resulting in a larger surface area. Furthermore, the loss of dry substance differed between the two cultivars studied, being higher from Heckla (34%) than from Predikant (30%). The loss of dry substance has also been shown to be higher in early cabbage cultivars than in late ones (Wennberg et al., 2003), and this was explained as being due to a less developed fibre network in the early cultivars. The cultivars in the present study were both late maturity types with very similar fibre contents, but it may be speculated that the degree of associations and interactions between molecules was less in Heckla than in Predikant. The water content of the samples may also be of importance in this respect as a greater diffusion of reducing sugars has been reported to be related to a higher water content, at least in carrots (Oliviera & Lamb, 1989; Svanberg et al., 1997). However, as both cultivars had very similar amounts of dry substance (8.9–9.0 g/100 g fresh cabbage, data not shown) this could not be the explanation for the differences seen in this study.

Most of the changes seen in the soluble dietary fibre fraction were related to polymers containing uronic acids, arabinose and galactose, demonstrating that the pectic structures were particularly affected by heat treatment. In the insoluble fraction most of the changes were related to the content of glucose. Similar results were obtained in a previous study on the effects of boiling on different cabbage cultivars (Wennberg et al., 2003). Dietary fibre in raw potatoes has been shown to be less sensitive to processing than those in onions, as a higher proportion of the pectic substances is associated with cellulose (Ryden & Selvendran, 1990). It may be speculated that a lower amount of pectic substances is associated with cellulose in Heckla than in Predikant, based on the higher loss of insoluble dietary fibre from Heckla during blanching.

The higher loss of SDF during blanching from Predikant may be due to a higher degree of methylation of pectin in this cultivar. Pectic structures with regions rich in methylated carboxyl groups have been shown to be degraded through β-elimination during this heat treatment, and the higher the degree of methylation the higher the rate of depolymerization (i.e., solubilization and loss of soluble fibre) (Krall & McFeeters, 1998; Sajjaanantakul, Van Buren, & Downing, 1989). Analysis of dietary fibre monomers in the filtrate further established

Table 2
The glucosinolate content (μmol/100 g DM) in unprocessed, blanched and soured white cabbage, and losses (%) of glucosinolates following blanching and souring[A]

	Heckla							Predikant						
	Unprocessed	Blanched		Soured		Total		Unprocessed	Blanched		Soured		Total	
	Mean	Mean	Losses (%)[B]	Mean	Losses (%)[B]	Mean	CV[C]	Mean[D]	Mean	Losses (%)[B]	Mean	Losses (%)[B]	Mean	CV[C]
Total glucosinolates	1280a	635b	(50)	725b	(43)	880	36	1457a*	375b	(74)	299c	(80)	710	82
Aliphatics														
Glucoiberin (3-(methylsulphinyl)propyl)	114a	80ab	(30)	56b	(51)	83	33	88a ns	25b	(71)	10b	(89)	41	91
Progoitrin (2-hydroxy-3-butenyl)	45a	24b	(47)	19b	(58)	29	43	191a**	25b	(87)	7b	(97)	74	122
Sinigrin (2-propenyl)	463a	274b	(41)	271b	(42)	336	30	588a*	175b	(70)	89c	(85)	284	84
Gluconapin (3-butenyl)	16a	14ab	(15)	11b	(33)	13	19	85a***	21b	(76)	7c	(92)	38	99
Glucoiberverin (3-(methylthio)propyl)	54a	27b	(50)	17c	(69)	33	53	45a ns	4b	(91)	0b	(100)	16	137
Indoles														
4-Hydroxy glucobrassicin (4-hydroxyindol-3-ylmethyl)	71a	20b	(71)	19b	(74)	36	74	103a*	30b	(71)	12b	(89)	48	90
Glucobrassicin (indol-3-ylmethyl)	395a	146b	(63)	160b	(60)	233	54	270a***	49b	(82)	21c	(92)	113	108
4-Methoxy glucobrassicin (4-methoxyindol-3-ylmethyl)	99ab	42a	(58)	170b	(−71)	103	58	83a ns	45b	(46)	155c	(−86)	94	53
Neoglucobrassicin (1-methoxyindol-3-ylmethyl)	22a	9a	(61)	6a	(72)	12	71	4a ns	1b	(75)	0b	(100)	2	114

[A] Mean values in the same row within the same cultivar followed by different letters are significantly different ($P < 0.05$).
[B] Losses in relation to unprocessed cabbage.
[C] Coefficient of variation (quotient between the standard deviation and mean value).
[D] Significantly different from the mean value of the unprocessed cultivar Heckla: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns non-significant.

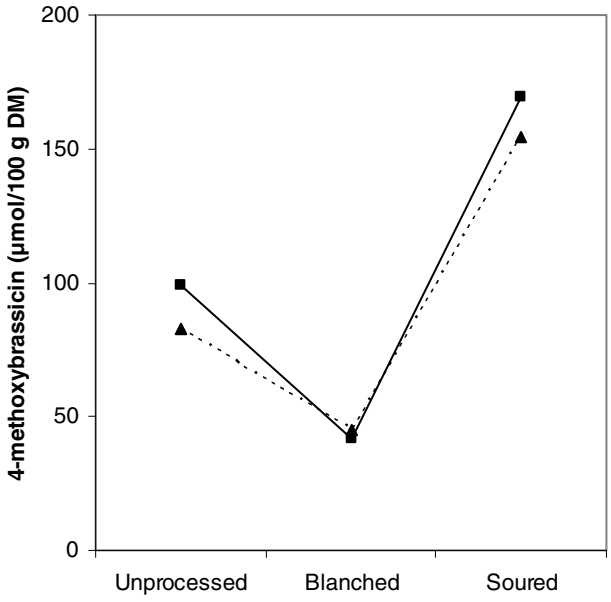

Fig. 3. Content of 4-methoxybrassicin (µmol/100 g DM) during processing of the cultivars Heckla (—) and Predikant (– – –).

the depolymerization of the polysaccharides to smaller fragments during heat treatment. Souring with dressing containing acetic acid increased this effect. This could also be expected as dilute acid hydrolyses glycosidic linkages. The effect of souring on IDF was more pronounced in Heckla than in Predikant, which further supports the suggestion that there are fewer interactions between polysaccharide chains in Heckla than in Predikant. This might also explain why the loss of glucose and fructose increased after souring compared with only blanching in Heckla but not in Predikant.

4.2. Glucosinolates

In the present study the glucosinolate levels decreased substantially in both cultivars following blanching for 5 min, although more in Predikant (74%) than in Heckla (50%). The results are in accordance with previous studies, where boiling cabbage pieces (30–40 cm^2) for 10 min reduced the glucosinolate content by 53% (Rosa & Heaney, 1993). On the other hand, when white cabbage halves were boiled for 10 min the average total loss of the glucosinolates for different cultivars was only 28% (Sones, Heaney, & Fenwick, 1984). The greater loss in Predikant and Heckla during the shorter cooking time employed in the present study (5 min) is probably due to the fact that the cabbage was shredded to smaller pieces before being immersed in the boiling water. Glucosinolates are water-soluble and most of the loss is found in the processing water. When white cabbage was cooked in water for 40 min, 90% of the intact glucosinolates, or their breakdown products, was in the cabbage tissue (40%) or the cooking water (50%) (Slominski & Campbell, 1989). However, some volatile breakdown products may also escape into the air.

The loss of individual glucosinolates after blanching varied considerably. Others have also found large variations in the loss of different glucosinolates in different cultivars (Rosa & Heaney, 1993; Sones et al., 1984). They suggested that differences between cultivars in leaching of glucosinolates into the cooking water could be due to differences in leaf thickness and waxiness, i.e., differences in fibre content and composition as well as in the fibre network. Other explanations of the difference in losses could be variation in the diffusivity of the glucosinolates. Thus, the losses of indole glucosinolates into the boiling water have been found to be higher than the losses of aliphatic glucosinolates (Ciska & Kozlowska, 2001). In the current study, this was also found for Heckla, which lost 63% of its indolyl but only 40% of its aliphatic glucosinolates. Predikant, however, showed the same loss from both glucosinolate groups (73–75%).

Treatment of the blanched cabbage with acetic acid for 24 h did not affect the total glucosinolate level in Heckla but resulted in a significant decrease in Predikant. Glucosinolates and breakdown products were probably leached out of this cultivar into the surrounding dressing. The substantial increase in 4-methoxyglucobrassicin in both cultivars is noteworthy (Fig. 3). According to our knowledge similar experiments on souring of blanched cabbage in this type of coleslaw have not been reported in the literature. Stress-induced increase in indolyl glucosinolates has, however, been demonstrated in white and red cabbage by others (Verkerk, Dekker, & Jongen, 2001). They also observed differences in the types of inducible indolyl glucosinolates between *Brassica* species but did not investigate whether such differences also exist between cultivars within species. Further, large increases in certain indolyl glucosinolates in the secondary inflorescence of broccoli (but not in the principal) have been found after storage at 4 and 20 °C for five days (Rodrigues & Rosa, 1999). The mechanisms leading to the formation of the induced glucosinolates after souring in the present investigation as well as after mechanical wounding, for example, chopping (Verkerk et al., 2001) or after storage (Rodrigues & Rosa, 1999) are unknown.

5. Conclusions

Blanching and souring with acetic acid affect the content and composition of nutrients in cabbage. Both cultivars showed similar profiles concerning the loss. However, the low-molecular-weight carbohydrates and the insoluble dietary fibre in Predikant were less affected by processing than those in Heckla, while the effect on soluble fibre was more pronounced in Predikant.

A process such as that used in the present study will drastically change the glucosinolate composition of the *Brassica* vegetable. The glucosinolate composition and levels were more affected in Predikant than in Heckla. Shredding of cabbage will result in various breakdown products due to the action of endogenous myrosinase, blanching will decrease the content of intact glucosinolates or their degradation products by leaching into the cooking water or evaporation of volatiles into the air, and souring seems to continue these processes. The large increase in 4-methoxy glucobrassicin after souring is interesting, but the importance of this finding is difficult to interpret.

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