Research Article

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Vitamin C, total phenolics and antioxidative activity in tip-cut green beans (*Phaseolus vulgaris*) and swede rods (*Brassica napus* var. *napobrassica*) processed by methods used in catering

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Abstract

BACKGROUND: Retention of nutrients in vegetables during blanching/freezing, cooking and warm-holding is crucial in the preparation of both standard and therapeutic diets. In the present study, conventional cooking in water, and cooking by pouch technology (boil-in-bag, *sous vide*) were compared in their ability to retain vitamin C, total phenolics and antioxidative activity (DPPH and FRAP) in industrially blanched/frozen tip-cut green beans and swede rods.

RESULTS: After conventional cooking, 50.4% total ascorbic acid, 76.7% total phenolics, 55.7% DPPH and 59.0% FRAP were recovered in the drained beans. After boil-in-bag cooking, significantly ($P < 0.05$) higher recoveries were obtained, i.e. 80.5% total ascorbic acid, 89.2% total phenolics, 94.8% DPPH and 92.9% FRAP. Recoveries after *sous vide* cooking were comparable to those of boil-in-bag cooking. By conventional cooking, 13.5–42.8% of the nutrients leaked into the cooking water; by *sous vide* about 10% leaked to the exuded liquid, while no leakage occurred by boil-in-bag cooking. Warm-holding beans after cooking reduced recoveries in all components. Recoveries in swede rods were comparable but overall slightly lower.

CONCLUSION: Industrially blanched/frozen vegetables should preferably be cooked by pouch technology, rather than conventional cooking in water. Including cooking water or exuded liquid into the final dish will increase the level of nutrients in a meal. Warm-holding of vegetables after cooking should be avoided.

Keywords: green beans; swede; cooking; boil-in-bag; *sous vide*; warm-holding; vitamin C; total phenolics; DPPH; FRAP

INTRODUCTION

Consumption of vegetables rich in nutrients and phytochemicals is today recommended as a means to ensure a health-beneficial diet.[1–3] Many vegetables are consumed fresh, but others are processed to various extents in the catering and foodservice industries or in the private home prior to consumption. Processing may influence nutrients or phytochemicals positively by release of compounds and increase in bioavailability[4] or negatively by physical losses and chemical degradation.[5,6] Thus, to ensure the nutritional quality of diets for healthy persons as well as for therapeutic use, it is crucial to know how the various processing steps contribute to the levels of nutrients at the time of consumption.[7–9] This is emphasised by the fact that many hospitalised patients today have inadequate intakes of nutrients, such as water-soluble vitamins.[8]

Common processing steps for vegetables include blanching, freezing, cooking and, occasionally, warm-holding. Blanching and subsequent freezing facilitate distribution and further processing of vegetables year-round, independent of season and place of growing.[5] Various technologies are available for cooking in catering and foodservice kitchens as well as in-home, i.e. conventional cooking in water,[6,10–17] baking in oven,[10] heating by microwave,[6,10,11,13–15,17,18] steam,[7,11,13,15] stir-frying,[6,10,12,14,16,17] cook–chill,[8,19] or the more recent technologies of *sous vide*[20] and boil-in-bag[21] cooking. Both intentional[19,22] and unintentional warm-holding after cooking are also practised in many cases. The pouch technologies, boil-in-bag and *sous vide*, will most likely play an important role in culinary treatment of blanched/frozen vegetables in catering, professional kitchens and in the retail market in the future. Boil-in-bag involves one heating step but requires available freezing and heating capacities close to where the food is to be served. *Sous vide* requires two heating steps as well as cooling and heating facilities. The initial heating can, however, be performed efficiently at locations separate from where the food

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is reheated and consumed. Still, the boil-in-bag technology should be less expensive than *sous vide*, and in costs be comparable to conventional cooking in water. A comparison of how the three cooking methods influence the retention of nutrients and phytochemicals will help the catering and foodservice industry, as well as the individual consumer, to select optimal cooking technology for blanched/frozen vegetables.

Vitamin C, comprising L-ascorbic acid and dehydro-ascorbic acid, is water soluble and sensitive to heat and oxygen. The vitamin is the least stable among nutrients in vegetables and is thus often used as an indicator of the strain nutrients are exposed to during processing.[5–7,23] The many studies performed over the years on the retention of vitamin C in vegetables during processing, have recently been reviewed[2,5,24] and reveal that substantial amounts of the vitamin may be lost, either due to leakage to the cooking medium or by chemical deterioration.

Polyphenolics are abundant in vegetables.[3,5,24,25] These compounds are still not fully acknowledged as essential nutrients but their potency is often ascribed to their antioxidative potential. During processing, polyphenolics are affected in various ways.[13] Sultana *et al*.[14] reported deleterious effects from cooking on total phenolics but not on reducing power, and Turkmen *et al*.[15] reported that total antioxidant activity remained constant or increased upon cooking, depending upon type of vegetable. Other studies also reported varying effects of processing on the level of individual phenolics[16,26,27] and antioxidative properties.[10,11,28,29] Most compounds are water soluble and polyphenolics are recovered in the water after cooking.[27,30] Further studies on how polyphenolics respond to culinary processing as performed in catering, foodservice and home-cooking, are needed.

The present study was conducted to examine the effects of conventional cooking in water as well as cooking by boil-in-bag and *sous vide* technologies, on vitamin C, polyphenolics and antioxidative properties of two model vegetables: green beans and swede. The vegetables were analysed throughout the entire processing process from harvest through industrial blanching and freezing, cooking and final warm-holding. The main focus was directed towards the effects of processing on industrially blanched/frozen vegetables which often serve as starting materials in the catering and foodservice industry. Parameters studied were dry matter, L-ascorbic acid, total ascorbic acid, total phenolics and antioxidative activity measured by two different assays as has been recommended until antioxidant activity in foods are fully understood. The effects were evaluated by concentrations in processed vegetables, but also by mass balances in the vegetable, and in cooking water and liquid exuded from the vegetables during processing. A systematic study of sources of error at each stage of the experiment was used as a guide for the experimental design.

MATERIALS AND METHODS

Vegetable material

Green beans (*Phaseolus vulgaris*, var. Aras) were industrially tip-cut and blanched at 80–85 °C for 5 min, cooled in water, frozen (−35 °C) in a flow-freezer and filled into 15 kg paper bags at Findus Norge AS, Grimstad, Norway. Swede (*Brassica napus* var. *napobrassica,* var. Vige) were cut into rods (10 × 10 × 50 mm^3), blanched at 75–80 °C for 5 min, cooled, frozen and packed. Eight 15 kg paper bags from each vegetable were randomly selected during a 2-day production period. The frozen vegetables were transported frozen to Nofima Mat and stored at −20 °C until processing.

A fresh sample (5 kg) of each vegetable was randomly collected at the production site and immediately transported to Nofima Mat. The next day vitamin C was measured in the fresh samples, while the rest (tip-cut green beans; swede cut in rods) were frozen in liquid nitrogen and stored in 100 mL screw-capped cups at −80 °C until analyses.

Cooking procedures

During all cooking procedures, vegetables, water and liquid exuded from the vegetables were weighed before and after treatment and mass balances of each analysed compound were performed.

Conventional cooking in water

Industrially blanched/frozen vegetables were conventionally cooked in a cooking vessel (18/10 Stainless Hackman, Iittala Group Oy Ab, Helsinki, Finland) in boiling water using a hot-plate (2000 W; Kervel, Skien, Norway). Frozen vegetables (1200 g) were added to the boiling water (2400 g), which took 9 min to regain 100 °C (2000 W), and were boiled for another 5 min at reduced intensity (450 W).

Boil-in-bag

Boil-in-bags (LINvac® 80N (75-8) PA/PE; Linpac Plastics Pontivy, S-gruppen ASA, Norway) with 600 g frozen vegetables in each, were heated at 100 °C (100% steam) in a steam oven (Air-O-Steam™; Electrolux Professional, Pordenone, Italy) for 60 min.

Sous vide

Vacuum pouches (LINvac® 80N (75-8) PA/PE; Linpac Plastics) with 600 g frozen vegetables in each, were vacuumed (Intevac Verpackungsmaskinen GmbH, Wallenhorst, Germany) and preheated at 100 °C (100% steam) for 15 min in the steam oven. The internal temperature of the vegetables was 84 °C. The pouches were removed from the heater, cooled and stored at 4 °C for 5 days. Stored *sous vide* pouches were reheated either one by one in a microwave oven (Electronic Whirlpool Talent Compact MT 222; Whirlpool Sweden AB, Norrkoeping, Sweden) at reheat (750 W) for 4 min, or two at a time in the steam oven at 100 °C (100% steam) for 5 min.

Warm-holding

Conventionally cooked vegetables were immediately drained in a strainer, and about 600 g was transferred to a tray that was kept in the steam oven at 70 °C (50% steam) for 60 min. The tray was covered with a glass plate during the heating period. Boil-in-bags and *sous vide* pouches, reheated by microwaves or steam, were warm-held unopened in the steam oven under the same conditions.

Chemical analysis

Samples and extracts

After heating, all vegetables were cooled to room temperature in ice water. Pouches were cooled without opening. Vegetable samples (about 600 g or one pouch) were homogenised (Braun 4262; Braun, Kronberg, Germany) and weighed. Aliquots extracted with metaphosphoric acid were applied for immediate vitamin C analysis. The homogenised material was frozen in smaller portions in liquid nitrogen and stored at −80 °C for later analysis.

For extracts intended for the analysis of total phenolics and antioxidant activity (2,2-diphenyl-1-picrylhydrazyl radical (DPPH•) and ferric reducing antioxidant power (FRAP) assays), 10 g of thawed, homogenised vegetables (Braun CombiMax 700) or exudate was mixed with 10 mL methanol. The mixture was homogenised (Polytron PT3100; Kinematica AG, Littau, Switzerland) and centrifuged at 27 200 × *g* and 4 °C (Beckman J2-21M/E; Beckman Instruments Inc., Fullerton, CA, USA) for 10 min. The supernatant was decanted into a 25 mL measuring flask. The pellet was resuspended in 10 mL 70% methanol in water (v/v), followed by centrifugation. The combined supernatants were diluted to 25 mL with 70% methanol. The extracts were frozen in small tubes at −80 °C until further analysis. Water was used for any further dilutions of the methanol extracts.

Dry matter

Dry matter was determined by vacuum drying at 70 °C for 18 h.[31]

L-Ascorbic acid and total ascorbic acid

L-Ascorbic acid and total ascorbic acid (L-ascorbic acid + dehydro-ascorbic acid) were determined by HPLC according to a slightly modified method described by Aaby *et al*.[32] To 10 g homogenised sample, 20 mL of 4.5% metaphosphoric acid was added. The samples were homogenized with a Polytron PT3100 homogeniser before being diluted to 50 mL with metaphosphoric acid and filtered through a folding filter (Schleicher & Schuell GmbH, Dassel, Germany). Samples were kept on ice during preparation. For the determination of total ascorbic acid, dehydro-ascorbic acid was reduced to L-ascorbic acid in 800 mmol L^{-1} Trizma base, pH 10.5, containing 5 mmol L^{-1} tris(2-carboxyethyl)phosphine (TCEP). Filtrate (100 µL) was mixed with TCEP (50 µL) and allowed to stand for 20 min in the dark at room temperature before 0.2 mol L^{-1} sodium phosphate buffer, pH 6.5 (350 µL), was added. Quantification of L-ascorbic acid was performed using an Agilent 1100 series HPLC system (Agilent Technologies, Waldbronn, Germany) equipped with a Chromolith Performance RP-18e column (100 mm × 4.6 mm i.d.; Merck KGaA, Darmstadt, Germany). The mobile phase was 2% acetonitrile and 98% of an aqueous solution of 2.5 mmol L^{-1} NaH_2PO_4, 2.5 mmol L^{-1} dodecyltrimethyl ammonium chloride and 1.25 mmol L^{-1} Na_2EDTA. The flow was 1 mL min^{-1} and the injection volume 15 µL. Samples were filtered through Millex HA 0.45 µm filters (Millipore Corp., Billerica, MA, USA) prior to injection on the column. Peaks were detected at 264 nm and quantified using L-ascorbic acid as the standard. Results were expressed as mg kg^{-1} fresh weight.

Total phenolics

Total phenolics were determined according to the Folin–Ciocalteu procedure.[33] To the diluted methanol extract (200 µL) in a cuvette, 1 mL of Folin–Ciocalteu solution (diluted 1 : 10 in water) was added. After 2 min, 800 µL Na_2CO_3 (7.5%) was added, mixed for 5 s on a whirl mixer and incubated in the dark at room temperature for 60 min. Absorbance was measured at 765 nm in an Agilent 8453 spectrophotometer (Agilent Technologies). Gallic acid (GA) was used as standard and total phenolics were expressed as mg gallic acid equivalent (GAE) kg^{-1} fresh weight.

2,2-Diphenyl-1-picrylhydrazyl

The scavenging capacity towards the stable 2,2-diphenyl-1-picrylhydrazyl radical (DPPH•) was assessed as described by Brand-Williams *et al*.[34] Methanolic extract (0.1 mL) was added to 2.4 mL DPPH• solution in a cuvette, mixed and stored in the dark for 120 min. The absorbance was measured at 515 nm (Agilent 8453 spectrophotometer). The amount of sample needed to decrease the initial DPPH• concentration by 50% (EC_{50}) was calculated by linear regression of remaining DPPH• versus sample concentration. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) was used as a reference and DPPH level was calculated as EC_{50}^{-1}, i.e. µmol Trolox equivalents (TE) g^{-1} fresh weight.

Ferric reducing antioxidant power

Ferric reducing antioxidant power (FRAP) was determined as described by Benzie and Strain[35] and modified by Aaby *et al*.[36] Trolox was used as a control sample and $FeSO_4$ as a standard. Sample, standard or control (80 µL) was pipetted into the wells, and freshly prepared FRAP reagent (2.4 mL) consisting of 10 mmol L^{-1} TPTZ (2,3,5-triphenyltetrazolium chloride) in 40 mmol L^{-1} HCl, 20 mmol L^{-1} $FeCl_3 \cdot 6H_2O$, and 300 mmol L^{-1} acetate buffer, pH 3.6, in the ratio 1 : 1 : 10 (v/v/v) was added. The absorbance at 593 nm was read in an Agilent 8453 spectrophotometer after 60 min at room temperature. Aqueous Fe(II) solutions ($FeSO_4 \cdot 6H_2O$) were used for calibration. FRAP values were calculated as mmol Fe kg^{-1} fresh weight.

Calculation of total recovery

The percent recovery obtained by each cooking method relative to levels in blanched/frozen vegetables was calculated for cooked vegetables, in cooking water and in exudate based on concentrations and weight of products before and after cooking of blanched/frozen vegetables.[12,19,37] Recovery (%) was calculated according to the formula:

$$\text{recovery} = \left(\frac{C_{\text{cooked}} \times W_{\text{cooked}}}{C_{\text{blanched/frozen}} \times W_{\text{blanched/frozen}}} \right) \times 100$$

where C is concentration and W is weight of sample for the cooking method at each step considered. Total recovery (%) was calculated as the sum of recoveries in vegetable and in cooking water/exudates. With boil-in-bag cooking no liquid leaked from the vegetables causing total recovery to be identical with recovery in cooked vegetables only. In this context, the equation [100 – total recovery (%)] represents the % deterioration of a compound or assayed parameter.

Experimental layout

The experiment was designed as outlined in Fig. 1. On day 1, blanched/frozen vegetables were treated by one of the cooking methods including warm-holding, and samples for analysis were withdrawn at each processing stage. The entire procedure was repeated on day 2, giving two independent treatments for each cooking method.

At each processing stage (blanched/frozen, cooking, warm-holding) two samples were withdrawn. Each sample was extracted twice, and each extract was analysed once. This layout was decided after a pilot study where conventionally cooked and warm-held green beans were studied according to an expanded experimental layout with duplicate total phenolics analysis also of extracts.

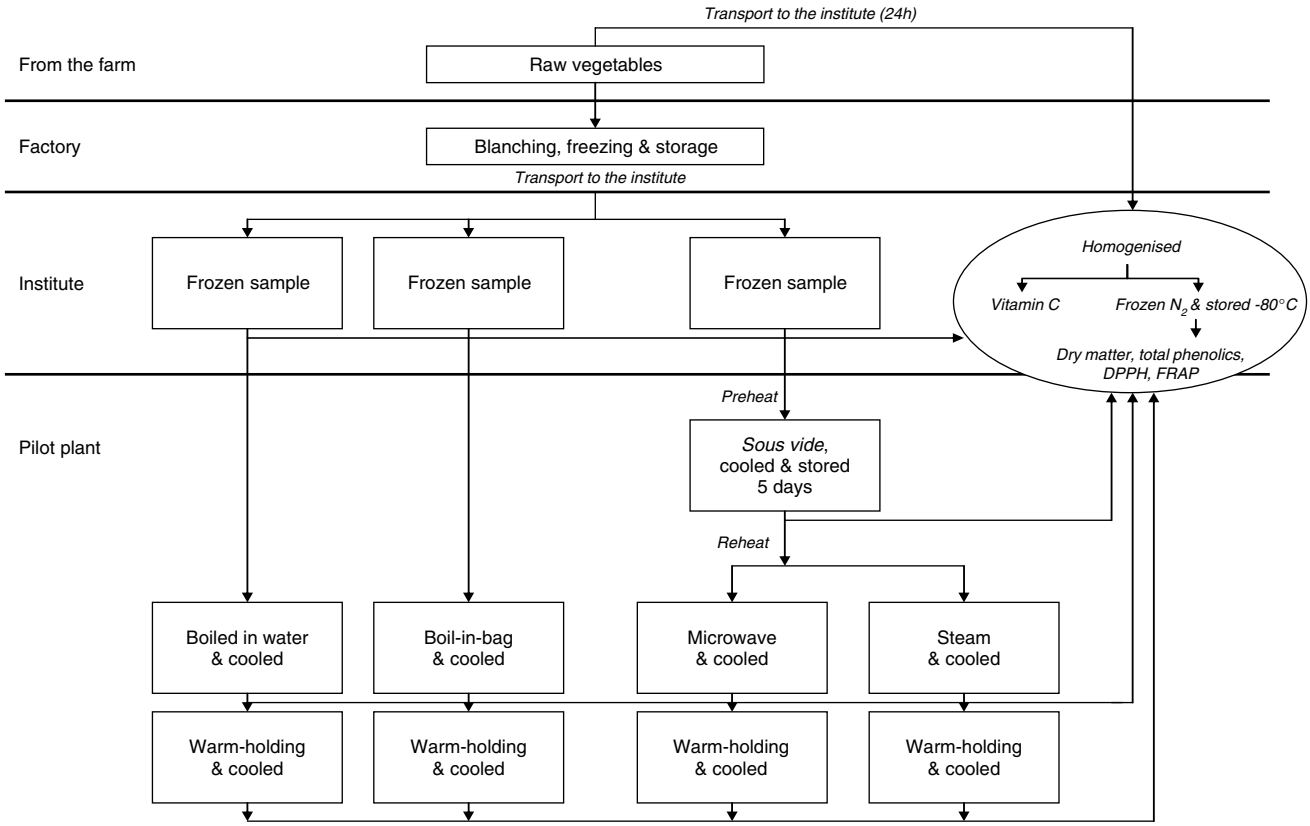

Figure 1. Experimental procedure of analysis carried out in green beans and swede. For each vegetable the entire processing was repeated twice (day 1, day 2).

Statistical analysis

All statistical analyses were performed using the Minitab v15 statistical software (Minitab Inc., State College, PA, USA). A variance component analysis using adjusted sum of squares (SS), was used to reveal sources of error in the total phenolics analysis of blanched/frozen, conventionally cooked and warm-held green beans. One-way ANOVA was used to test effects of processing steps on each compound and parameter for green beans and swede, separately. One-way ANOVA was also used to test effects of warm-holding on each vegetable for each cooking method. Further, effects of cooking methods on % recovery in each parameter were tested by one-way ANOVA. Significant differences ($P \leq 0.05$) were evaluated by using Tukey's multiple-comparison test. Two-way ANOVA was used to test effects of reheating method (microwave, steam) and treatment (reheating, warm-holding) on total recovery in *sous vide* treated green beans and swede. Errors (SE) were calculated as the square root of the mean square error from each ANOVA. The significance level was 5% ($P \leq 0.05$) unless otherwise stated.

RESULTS AND DISCUSSION

Introductory study: sources of error

Mean total phenolics in blanched/frozen green beans, conventionally cooked and followed by warm-holding, analysed according to the expanded experimental design with duplicate samples at all stages are shown in Table 1. Conventional cooking and further warm-holding reduced levels of total phenolics compared with blanched/frozen beans. Total standard error was 8.66 mg GAE kg^{-1} or 3% of the initial level of the blanched/frozen beans. The variance component analysis revealed the contribution of each experimental stage to total variance (Table 1). The variation due to replication of the experiment on two different days contributed 16.2% of total variance, whereas duplicate sampling from each of blanched/frozen, cooked and from cooked/warm-held material made up 29.6%, and duplicate extraction of each sample was 37.2% of total variance. The contribution from duplicate analysis, including random error was 17.1%. The analysis revealed no interaction between processing stage (blanched/frozen, cooked, warm-held) and replication of total experiment on two different days. Based on these findings, duplicate sampling and extractions were maintained throughout the entire experiment, while duplicate analyses of extracts were omitted.

Effects of processing green beans

Industrial blanching and freezing of raw green beans

Levels of constituents and antioxidative activities in the raw green beans are presented in Table 2. The content of 108.7 g kg^{-1} dry matter in raw beans is similar to the figure of 100 g kg^{-1} reported by Masrizal *et al.*[17] The total ascorbic acid level of 146 mg kg^{-1} was within the range of 100–200 mg kg^{-1} reported previously.[17,18,23,38,39] The levels of L-ascorbic acid and total ascorbic acids in the present study correspond to 50 mg dehydroascorbic acid kg^{-1} in the raw beans. The concentration of total phenolics was very low compared to the 800 mg kg^{-1} reported by Jiratanan and Liu.[28] Turkmen *et al.*[15] and Zhou and Yu[40] reported total phenolics on the basis of dry matter. When converted

Table 1. Mean total phenolics, total standard error (SE and %), and contribution from processing stages to total variance in cooking experiment with blanched/frozen, conventionally cooked, and cooked/warm-held green beans

Processing stage	Total phenolics (mg GAE kg^{-1})
Blanched/frozen	289.1
Conventional cooking	218.2
Conventional cooking and warm-holding	238.8
Total SE (% of level in blanched/frozen)	8.66 (3.0)
Contribution of processing stage to total variance	%
Replicate processing experiment	16.2
Replicate × Processing stage	0.0
Duplicate sampling	29.6
Duplicate extraction	37.2
Error (duplicate analysis and random error)	17.1

into wet weight, their concentrations were also two to three times higher than the concentration obtained in the present study.

The industrial blanching and freezing caused a significant reduction in dry matter content (Table 2). Increased moisture content during blanching and freezing has been reported previously and are postulated to be due to absorption of water into damaged cells and water sticking to the bean surface.[18] Leakage of dry matter into the blanching water will also increase moisture content in the vegetable. Total ascorbic acid concentration was fully retained during blanching and freezing. The level of L-ascorbic acid was 34% higher than in the raw beans; however, ascorbic acid is prone to rapid degradation in raw green beans, even when chilled.[18,23,24] Favell[23] reported that fresh green beans lose up to 30% of the ascorbic acid upon 1 day storage at ambient temperature. In the present study, the raw green beans were transported to the laboratory and analysed 24 h after harvesting, whereas the industrial blanching was implemented within a few hours from harvesting. Thus, oxidation of the ascorbic acid in the raw green beans prior to analysis may have occurred, causing higher levels of dehydro-ascorbic acid in the raw green beans than in the blanched/frozen.[5] Blanching and freezing have also previously been reported to cause slight or no decrease in ascorbic acid content.[18,23] Tosun and Yücecan,[38] however, reported a 38.3%

Table 2. Effects (a) of processing by conventional, boil-in-bag or sous vide cooking on compositional data in green beans

Cooking method	Dry matter (g kg^{-1})	L-Ascorbic acid (mg kg^{-1})	Total ascorbic acid (mg kg^{-1})	Total phenolics (mg GAE kg^{-1})	DPPH (μmol TE g^{-1})	FRAP (mmol Fe kg^{-1})
Raw	108.7^{a}	96^{b}	$146^{a\ (ab)\dagger}$	$221^{a\ (ab)\ddagger}$	$0.729^{b\ (c)\S}$	2.60^{a}
Blanched/frozen	$90.2^{b\ (c)\S}$	129^{a}	147^{a}	244^{a}	0.992^{a}	2.53^{a}
Conventional cooking						
Cooked	85.9^{c}	72^{c}	84^{b}	213^{a}	0.630^{bc}	1.70^{b}
Cooking water	6.7^{d}	5^{e}	11^{c}	57^{b}	0.191^{d}	0.23^{c}
Warm-holding after cooking	96.4^{b}	28^{d}	38^{c}	236^{a}	0.585^{c}	1.92^{b}
Standard error	1.88	8.02	15.20	24.12	0.0462	0.172
Boil-in-bag cooking						
Cooked	92.5^{b}	101^{b}	118^{a}	218^{ab}	0.940^{a}	2.35^{ab}
Warm-holding after cooking	93.0^{b}	45^{c}	50^{b}	179^{b}	0.675^{b}	1.91^{b}
Standard error	1.90	8.31	15.97	25.30	0.0467	0.189
***Sous vide* cooking**						
Preheated	91.9^{c}	92^{b}	$119^{ab\ (a)\P}$	$240^{a\ (ab)\P}$	0.893^{b}	1.93^{b}
Reheating by microwaves						
Reheated	98.9^{b}	83^{b}	107^{b}	226^{a}	0.785^{c}	2.05^{b}
Exudate	43.2^{d}	98^{b}	109^{b}	199^{a}	0.655^{c}	1.70^{b}
Warm-holding after reheating	98.8^{b}	78^{b}	96^{b}	192^{a}	0.765^{c}	1.90^{b}
Warm-holding exudate after reheating	45.2^{d}	80^{b}	90^{b}	217^{a}	0.765^{c}	1.95^{b}
Standard error	1.93	8.51	14.97	22.09	0.0405	0.188
Reheating by steam						
Reheated	97.0^{b}	84^{bc}	100^{a}	212^{a}	0.720^{c}	1.75^{b}
Exudate	43.9^{d}	93^{bc}	106^{ab}	202^{ab}	0.695^{c}	1.65^{b}
Warm-holding after reheating	96.9^{b}	67^{c}	81^{b}	183^{b}	0.670^{c}	1.65^{b}
Warm-holding exudate after reheating	44.9^{d}	76^{bc}	84^{b}	207^{ab}	0.680^{c}	1.75^{b}
Standard error	1.70	8.02	14.87	2.36	0.399	0.197

[a] Separate ANOVAs are performed for each cooking method including raw/frozen and blanched/frozen green beans.
Values in each column followed by different letters are significantly different ($P < 0.05$) with the Tukey test. Letters in parenthesis apply where there are discrepancies between ANOVAs:
† *Sous vide*, reheating by microwaves.
‡ Boil-in-bag.
§ *Sous vide*, reheating by microwaves or by steam.
¶ *Sous vide*, reheating by steam.
Standard error is the square root of the mean square error from each ANOVA.

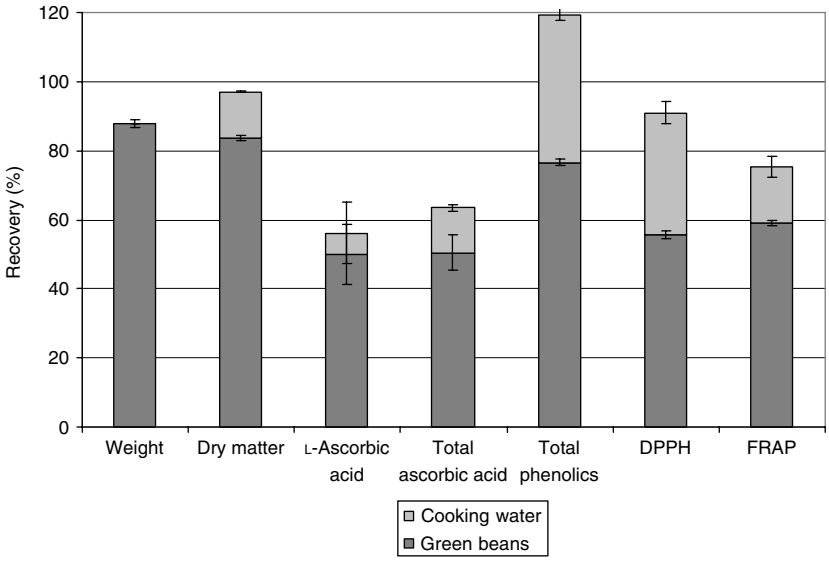

Figure 2. Recoveries (%) in drained green beans and cooking water after conventional cooking of blanched/frozen green beans. Vertical bars represent ± standard deviation ($n = 2$).

loss in vitamin C during blanching and freezing of tip-cut green beans in a commercial freezer. The losses during blanching have been postulated to be due to leaching into the blanching medium and to thermal degradation of ascorbic acid to dehydro-ascorbic acid and further oxidation.[6,18,30]

Blanching and freezing had no significant effect on concentration of total phenolics or FRAP values, while there was a 36% increase in the level of DPPH (Table 2). As there was no control of weight of beans or processing water during the industrial blanching, no calculations of recovery could be made at this stage of the processing process.

Conventional cooking

There was a significant decrease in the level of dry matter during conventional cooking of blanched/frozen green beans, and substantial amounts of dry matter was detected in the cooking water (Table 2). Total recovery in dry matter after cooking as determined relative to the blanched/frozen beans, amounted to 97.1% (Fig. 2), of which 13.6% were recovered in the cooking water and 83.5% in the green beans (Table 3). Conventional cooking significantly reduced L-ascorbic acid and total ascorbic acid concentrations of the blanched/frozen beans (Table 2). Total recoveries in L-ascorbic acid and total ascorbic acid were 56.2% and 63.5%, respectively (Fig. 2), of which about 50% were recovered in the beans (Table 3) and the remaining in the cooking water. This is in accordance with the findings of Masrizal *et al.*[17] of 56% vitamin C retained in green beans after conventional cooking. In the present study, concentration of dehydro-ascorbic acid was 12 mg kg^{-1} or 140 mg kg^{-1} DM after cooking. This is somewhat lower than the approximately 200 mg dehydro-ascorbic acid kg^{-1} DM previously reported in blanched green beans after cooking in water.[24]

Concentrations of total phenolics were not significantly altered during conventional cooking, although a significant amount of total phenolics was recovered in the boiling water (Table 2). Turkmen *et al.*[15] reported the concentration of total phenolics to increase to 114% (w/w DM) after boiling of raw green beans. When calculated similarly, the concentration of total phenolics in

Table 3. Recoveries (a) (%) after conventional, boil-in-bag or *sous vide* cooking of blanched/frozen green beans, followed by 1 h warm-holding at 70 °C

Constituent recovered	Conventional	Boil-in-bag	*Sous vide*	Standard error
Dry matter				
Cooking	83.5^{Bb}	102.6^{Aa}	102.9^{Aa}	0.585
Warm-holding	92.2^{Ba}	103.1^{Aa}	101.9^{Aa}	1.775
Standard error	1.565	1.597	0.480	–
L-Ascorbic acid				
Cooking	49.9^{Aa}	79.8^{Aa}	66.8^{Aa}	7.416
Warm-holding	18.7^{Cb}	35.6^{Bb}	57.4^{Aa}	3.795
Standard error	6.277	7.176	3.647	–
Total ascorbic acid				
Cooking	50.4^{Ba}	80.5^{Aa}	70.7^{ABa}	5.263
Warm-holding	22.3^{Bb}	33.8^{Bb}	60.6^{Aa}	4.517
Standard error	4.439	5.010	5.235	–
Total phenolics				
Cooking	76.6^{Bb}	89.2^{Aa}	89.2^{Aa}	2.713
Warm-holding	83.4^{Aa}	73.3^{Bb}	77.9^{Aa}	2.098
Standard error	1.473	2.484	3.048	–
DPPH				
Cooking	55.7^{Ca}	94.8^{Aa}	75.1^{Ba}	2.358
Warm-holding	50.9^{Ba}	68.1^{ABb}	72.4^{Aa}	4.290
Standard error	2.189	1.127	5.468	–
FRAP				
Cooking	59.0^{Ba}	92.9^{Aa}	74.2^{ABa}	5.394
Warm-holding	65.4^{Aa}	75.5^{Aa}	70.5^{Aa}	5.908
Standard error	2.694	6.008	7.259	–

[a] Standard error is the square root of the mean square error from the one-way ANOVAs.
Values in each row followed by different capital letters are significantly different ($P < 0.05$) with the Tukey test. Values in each column for each parameter followed by different lowercase letters are significantly different ($P < 0.05$) with the Tukey test.

the present study was 122% of that in raw green beans, indicating that components responding in the Folin–Ciocalteu assay may actually be formed and/or made assessable to the reagents during the heating process. The recovery in total phenolics was distributed with 76.6% in the green beans (Table 3) and 42.8% in the cooking water when compared with blanched/frozen beans (Fig. 2). Price *et al*.[27] reported full recovery in flavonols in canned green beans, when the 21.5% recovery in flavonols in the cooking water was included. Ewald *et al*.[16] reported that cooking had no effect on flavonoid content determined as quercetin and kaempferol in green beans.

Levels of DPPH and FRAP in blanched/frozen green beans decreased significantly during conventional cooking (Table 2). Antioxidative capacity given as FRAP, has previously been reported as 1300 mg ascorbic acid equivalents (AAE) kg^{-1} DM in cooked blanched/frozen green bean extracts.[24] By using a conversion factor of 0.011 mmol Fe mg^{-1} ascorbic acid,[32] the present FRAP value converts into comparable 1420 mg AAE kg^{-1} DM. Jiménez-Monreal *et al*.[10] detected no loss in ABTS radical anion scavenging after boiling of green beans. Turkmen *et al*.[15] reported 162% recovery in DPPH in green beans after boiling in water. In the present study, the recovery in DPPH relative to the raw green beans was considerably lower (86%). Analyses of both DPPH and FRAP showed that about 60% of the level in the blanched/frozen beans were recovered in the drained material, whereas 35.3% of the DPPH and 16.3% of the FRAP recovery were ascribed to the cooking water (Fig. 2). This demonstrated slightly different responses to various compounds between the two antioxidant activity assays applied.

Warm-holding of drained green beans for 1 h at 70 °C significantly increased dry matter content while concentrations of L-ascorbic acid and total ascorbic acid decreased to less than half (Table 2). After warm-holding, the recovery in vitamin C was about 22.3% of the level in the blanched/frozen green beans (Table 3). Warm-holding slightly increased recovery in total phenolics while there were no significant effects on DPPH and FRAP values. It has previously been reported that levels of the two flavonoids quercetin and kaempferol remained constant during 2 h of warm-holding.[16]

Boil-in-bag

No liquid exuded during steam cooking of the blanched/frozen green beans packed in boil-in-bag pouches and dry matter content remained unchanged (Table 2). Vitamin C concentration, however, was significantly decreased (Table 2), the recovery in both L-ascorbic acid and total ascorbic acid of the cooked beans being close to 80% (Table 3). Recovery in total phenolics was 89.2% after cooking, while the antioxidant parameters DPPH and FRAP were recovered with more than 90% after cooking in the boil-in-bags.

Also, during warm-holding, no liquid was observed in the pouches. Concentration of vitamin C decreased further and was recovered by about one-third after warm-holding. There were also decreased recoveries in total phenolics and DPPH after warm-holding of the boil-in-bag pouches, and the beans turned brownish during the warm-holding.

Sous vide

Preheating of the blanched/frozen green beans in the *sous vide* bags had no significant effect on level of dry matter and concentration of total phenolics, whereas L-ascorbic acid, total ascorbic acid and the antioxidant parameters DPPH and FRAP decreased slightly (Table 2). While no liquid was observed in the pouches after preheating, an average of 10.2% (w/w) leaked out during reheating and the following warm-holding. During reheating, all parameters in the plant material except dry matter were in near equilibrium with those in the exuded liquid. This applied both when reheating was performed by microwaves and by steam and implies that the recoveries for each parameter tested in the exudate were comparable to the weight proportion of exudate (Fig. 3). Total recoveries were calculated for beans and exudates after reheating by microwaves or by steam. Two-way ANOVA with effects of treatment (reheating, warm-holding) and reheating method (microwave, steam) as the factors, revealed that the two processing methods differed in recoveries in DPPH and FRAP only. The total recovery after reheating with microwave was 11% higher for DPPH and 15% higher for FRAP than the corresponding recovery obtained after reheating with steam. This

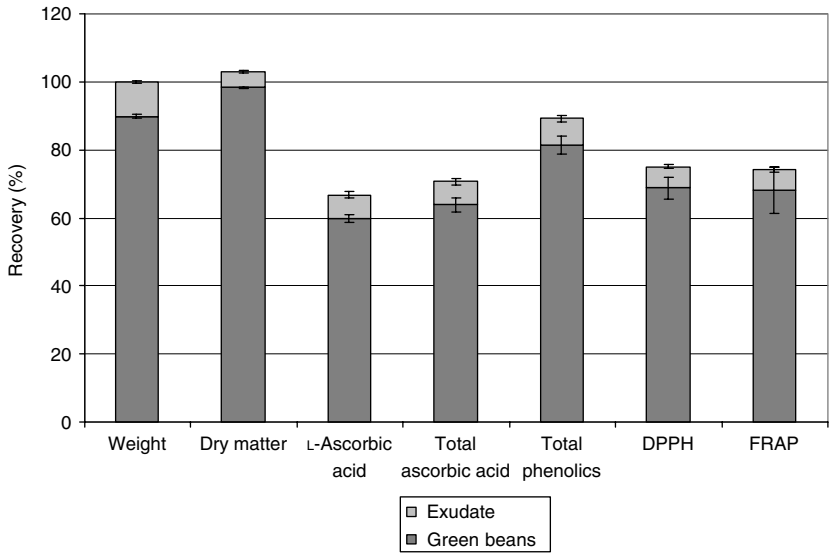

Figure 3. Recoveries (%) in drained green beans and exudate after *sous vide* reheating with microwaves or steam. Vertical bars represent ± standard deviation ($n = 2$).

indicates that under our processing conditions, reheating by microwave was slightly more gentle than reheating by steam. This is most likely due to a difference in the amount of energy supplied during reheating by the two methods, as could easily happen when the extent of heating was based on suggested doneness of the beans, rather than on assessment of exact energy supply. In the catering industry, the two methods may be interchanged as long as the exact conditions are monitored. Recoveries after reheating, calculated as an average of the two reheating methods, are presented in Fig. 3. Although recoveries appeared lower after warm-holding, the statistical analysis revealed no significant effects of warm-holding on recovery in any of the investigated parameters (Table 3).

Comparison of cooking technologies

When cooking blanched/frozen green beans, the boil-in-bag technology revealed significantly higher recoveries than conventional cooking for all nutrients analysed, except L-ascorbic acid where the difference in recovery was close to significant ($P = 0.061$) (Table 3). Cooking by boil-in-bags was comparable to *sous vide* cooking except for antioxidant activity measured as DPPH, where boil-in-bags were superior. Cooking by *sous vide* demonstrated significantly higher recoveries than conventional cooking in dry matter, total phenolics and DPPH.

Effects of processing swede

Industrial blanching and freezing of raw swede rods

The raw swede dry matter of 100.0 g kg^{-1} (Table 4) is comparable to the tabular value of 110 g kg^{-1} reported for raw swede.[39] Also, levels of L-ascorbic acid and total ascorbic acid,[29,39] total phenolics[29] and FRAP[41] were in agreement with previous reports.

The industrial blanching and freezing of the swede rods resulted in significantly lower concentration of all parameters analysed (Table 4). The reductions in concentrations ranged from 27% in FRAP to 44.5% in L-ascorbic acid. Also, Puupponen-Pimiä *et al.*[29] reported 20–25% reductions in initial concentrations of vitamin C and total phenolics and in DPPH index during blanching and freezing of raw swede rods under industrial processing conditions. Except for the study by Puupponen-Pimiä *et al.*,[29] the authors are not aware of any published reports on processing of swede.

Conventional cooking

Conventional cooking of blanched/frozen swede rods significantly lowered levels of all parameters analysed (Table 4). Recovery calculations revealed that 58.8% of the initial dry matter was retained in the rods after conventional cooking, while 32.9% was recovered in the cooking water (Fig. 4). Eight per cent of the initial dry matter was not accounted for in the analysis, possibly due to sampling from inhomogeneous cooking water. Total recoveries

Table 4. Effects (a) of processing by conventional, boil-in-bag and *sous vide* cooking on compositional data in swede rods

Cooking method	Dry matter (g kg^{-1})	L-Ascorbic acid (mg kg^{-1})	Total ascorbic acid (mg kg^{-1})	Total phenolics (mg GAE kg^{-1})	DPPH (μmol TE g^{-1})	FRAP (mmol Fe kg^{-1})
Raw	100.0^{a}	308^{a}	335^{a}	418^{a}	1.865^{a}	4.55^{a}
Blanched/frozen	76.8$^{b\ (c)\dagger}$	171^{b}	225^{b}	252^{b}	1.158^{b}	3.30^{b}
Conventional cooking						
Cooked	49.1^{d}	67^{c}	83^{c}	115^{c}	0.460^{c}	1.31^{c}
Cooking water	13.6^{e}	42^{c}	47^{c}	71^{c}	0.268^{d}	0.40^{d}
Warm-holding after cooking	60.2^{c}	55^{c}	59^{c}	118^{c}	0.403^{cd}	1.26^{c}
Standard error	0.98	8.60	15.03	15.59	0.0432	0.085
Boil-in-bag cooking						
Cooked	76.7^{b}	147^{b}	180^{b}	218^{bc}	0.915^{c}	2.76^{c}
Warm-holding after cooking	75.5^{b}	63^{c}	75^{c}	176^{c}	0.550^{d}	1.81^{d}
Standard error	1.02	9.39	16.06	16.58	0.0412	0.083
***Sous vide* cooking**						
Preheated	79.7^{bc}	109^{c}	140^{c}	208$^{bc\ (c)\ddagger}$	0.770^{c}	2.24$^{cd\ (c)\ddagger}$
Reheating by microwaves						
Reheated	80.7^{bc}	106^{cd}	117^{cd}	199^{c}	0.738^{cd}	2.24^{cd}
Exudate	53.8^{d}	117^{cd}	132^{c}	247^{bc}	0.870^{c}	2.55^{c}
Warm-holding after reheating	81.8^{b}	77^{cd}	77^{d}	182^{c}	0.633^{d}	2.02^{d}
Warm-holding exudate after reheating	56.2^{d}	77^{d}	82^{d}	227^{bc}	0.548^{d}	2.21^{cd}
Standard error	1.03	10.91	14.66	14.76	0.0346	0.112
Reheating by steam						
Reheated	83.4^{b}	89^{cd}	9.5^{cd}	201^{c}	0.685^{cd}	2.09^{c}
Exudate	55.4^{d}	84^{cd}	10.5^{cd}	235^{bc}	0.635^{cd}	2.16^{c}
Warm-holding after reheating	83.6^{b}	61^{d}	6.3^{d}	187^{c}	0.593^{d}	1.99^{c}
Warm-holding exudate after reheating	55.9^{d}	55^{d}	6.2^{d}	218^{bc}	0.540^{d}	1.92^{c}
Standard error	0.84	9.94	1.404	14.32	0.0366	0.114

[a] Separate ANOVAs are performed for each cooking method including raw/frozen and blanched/frozen swede rods.
Values in each column followed by different letters are significantly different ($P < 0.05$) with the Tukey test. Letters in parenthesis apply where there are discrepancies between ANOVAs:
† *Sous vide*, reheating by microwaves or by steam.
‡ *Sous vide*, reheating by steam.
Standard error is the square root of the mean square error from each ANOVA.

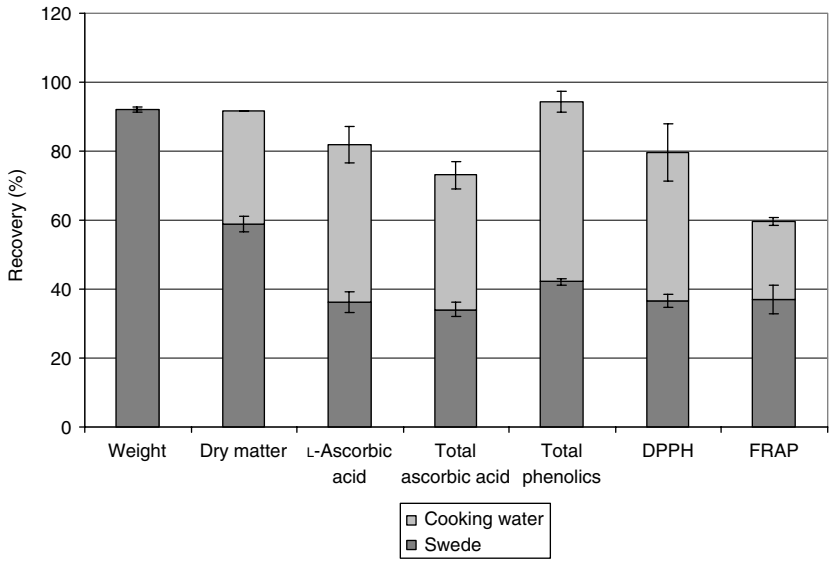

Figure 4. Recoveries (%) in drained swede rods and cooking water after conventional cooking of blanched/frozen swede rods. Vertical bars represent ± standard deviation ($n = 2$).

in L-ascorbic acid and total ascorbic acid were 81.8% and 73.1%, respectively (Fig. 4), with less than half in the rods (Table 5). Similarly, Nagra and Jamil[9] reported 80% loss of vitamin C after cooking turnip (*B. napus*) for 45 min. Podsędek *et al*.[42] reported 64% and 84% recovery in vitamin C in two varieties of red cabbage after 10 min of conventional cooking of chopped material. With both varieties, about 19% of the initial vitamin C levels were recovered in the cooking water.

Among the antioxidative parameters, total phenolics were best retained, followed by DPPH and FRAP (Fig. 4). With both total phenolics and DPPH, less than half of the total recoveries, 42.2% and 36.6%, respectively, were found in the rods (Table 5). With FRAP, the recovery was slightly higher in the rods than in the cooking water.

The level of dry matter increased during warm-holding of the drained, cooked rods for 1 h at 70 °C (Table 4), most likely due to evaporation of water from the rods. Warm-holding caused a significant decrease from 34.0% to 22.9% in the recovery in total ascorbic acid, whereas no significant decreases in the recoveries in the antioxidant parameters were seen (Table 5). Williams *et al*.,[19] studying broccoli, reported 70.4% retention in vitamin C level relative to the level immediately after cooking and 36.6% retention after 2 h of warm-holding cooked broccoli.

Boil-in-bag

Cooking of blanched/frozen swede rods by boil-in-bag had only minor effects on compositional data (Table 4). Among the parameters tested, only DPPH and FRAP revealed significantly lower levels after cooking. The recoveries were in the range of 79.1% to 99.8% (Table 5). Warm-holding within the bags caused substantial reductions in the recovery in all parameters except dry matter.

Sous vide

Preheating of the *sous vide* bags containing blanched/frozen swede rods caused no exudation of liquid from the vegetable material. Compared with the blanched/frozen rods, the preheating caused no significant changes in concentration of dry matter while

Table 5. Recoveries (a) (%) after conventional, boil-in-bag or *sous vide* cooking of blanched/frozen swede rods, followed by 1 h warm-holding at 70 °C

Constituent recovered	Conventional	Boil-in-bag	*Sous vide* microwave	Standard error
Dry matter				
Cooking	58.8^{Bb}	99.8^{Aa}	100.8^{Aa}	1.549
Warm-holding	69.4^{Ba}	98.3^{Aa}	102.2^{Aa}	1.105
Standard error	1.603	1.300	1.082	–
L-Ascorbic acid				
Cooking	36.2^{Ca}	85.6^{Aa}	62.6^{Ba}	3.795
Warm-holding	28.6^{Ba}	36.6^{ABb}	45.0^{Ab}	2.674
Standard error	2.544	3.661	3.536	–
Total ascorbic acid				
Cooking	34.0^{Ca}	80.1^{Aa}	53.0^{Ba}	1.646
Warm-holding	22.9^{Bb}	33.1^{Ab}	34.4^{Ab}	1.772
Standard error	1.766	1.510	2.022	–
Total phenolics				
Cooking	42.2^{Ba}	86.5^{Aa}	81.3^{Aa}	1.789
Warm-holding	41.4^{Ba}	70.0^{Ab}	74.5^{Aa}	1.559
Standard error	1.889	1.425	1.688	–
DPPH				
Cooking	36.6^{Ca}	79.1^{Aa}	65.1^{Ba}	1.764
Warm-holding	30.8^{Ba}	47.5^{Ab}	53.7^{Ab}	2.538
Standard error	1.967	2.202	2.366	–
FRAP				
Cooking	36.9^{Ca}	84.4^{Aa}	69.7^{Ba}	2.802
Warm-holding	34.2^{Ba}	55.4^{Ab}	62.5^{Aa}	2.948
Standard error	3.521	3.090	1.700	–

[a] The standard error is the square root of the mean square error from the one-way ANOVAs.
Values in each row followed by different capital letters are significantly different ($P < 0.05$) with the Tukey test. Values in each column for each parameter followed by different lowercase letters are significantly different ($P < 0.05$) with the Tukey test.

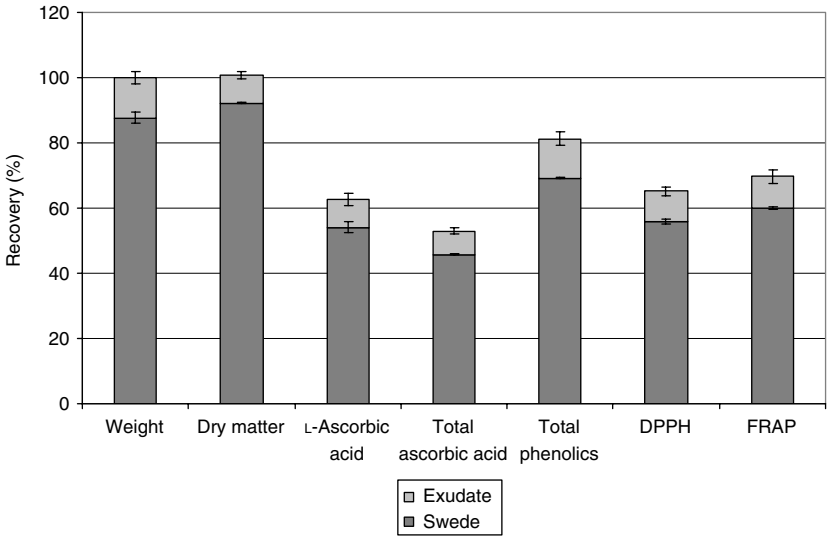

Figure 5. Recoveries (%) in drained swede rods and exudate after *sous vide* reheating by microwaves. Vertical bars represent ± standard deviation ($n = 2$).

concentration of L-ascorbic acid and total ascorbic acid and levels of the antioxidant parameters decreased significantly (Table 4). During reheating by either microwaves or steam, 12–13% (w/w) liquid leaked from the rods into the bags (Fig. 5). No further leakage was observed after 1 h warm-holding of the rods within the sealed *sous vide* bags. The limited amount of exudate during *sous vide* cooking may be consumed along with the rods, thus increasing the nutritional quality of the swede.

Reheating by microwaves or steam caused no significant decreases in L-ascorbic and total ascorbic acid or in any of the antioxidant parameters compared with the concentrations after preheating (Table 4). When compared with the blanched/frozen rods, reheating by microwave or steam significantly reduced concentrations of L-ascorbic acid, total ascorbic acid and the antioxidant parameters.

In general, reheating and warm-holding the swede rods in the *sous vide* bags caused no significant differences among component concentrations in rods and exudates, indicating a near equilibrium between the two phases (Table 4). Dry matter was the exception with significantly lower levels in the exudate than in the rods. The distribution of recoveries between rods and exudate reflects this equilibrium (Fig. 5).

A two-way ANOVA of effects of treatment (preheating, reheating, warm-holding) and reheating method (microwave, steam) revealed that total recovery was significantly affected by the method used for reheating for all parameters except total phenolics and FRAP (data not shown). Reheating by microwaves caused higher total recoveries in L-ascorbic acid, total ascorbic acid and DPPH than heating by steam. Thus, under the applied conditions microwaves appeared to be a more gentle method for reheating *sous vide*-treated swede rods than steam. Under practical conditions, the energy supply during reheating may easily be adjusted so that the two methods become equalised. Only recovery data from reheating by microwave are presented (Fig. 5, Table 5).

The highest recovery after reheating of swede rods was obtained for total phenolics, followed by FRAP and DPPH, while lowest recovery was obtained for total ascorbic acid (Table 5). Warm-holding significantly reduced recoveries, but only the recoveries in L-ascorbic acid, total ascorbic acid and DPPH values were significantly lower than those after reheating.

Comparison of cooking methods

When comparing the three methods used for cooking blanched/frozen swede rods, boil-in bag appeared to be the most gentle method (Table 5). Immediately after cooking, recoveries in boil-in-bag cooking were significantly highest, followed by *sous vide* and by conventional cooking for all parameters except dry matter and total phenolics. With these parameters recoveries were highest for the two methods applying heating in pouches. After warm-holding, the benefits from the boil-in-bag cooking versus *sous vide* cooking diminished, and there were no differences between boil-in-bag and *sous vide* cooking. However, the superiority of pouch technologies over conventional cooking was maintained also after 1 h warm-holding of the cooked swede.

Comparison of tip-cut green beans and swede rods

Vitamin C, total phenolics and antioxidative properties (DPPH, FRAP) in raw swede (Table 4) were nearly twice as high as in the raw green beans (Table 2), but after blanching and freezing the levels were almost equal for all parameters in the two vegetables. This is most likely due to the less-injured surfaces of the tip-cut green beans compared to the swede rods where leakage may easily occur. A further reduction occurred when the vegetables were exposed to the different cooking regimes, especially conventional cooking. The loss in nutrients during cooking was higher in swede rods than in tip-cut green beans.

CONCLUSIONS AND APPLICATIONS

With vitamin C as a marker of nutritional quality, the results demonstrated that to minimise nutritional and phytochemical losses, catering, foodservice, and in-home cooking of industrially blanched/frozen vegetables preferably should be performed by pouch technology like boil-in-bag or *sous vide*, rather than by conventional cooking in water. The inclusion of any liquid exuded during pouch cooking or of cooking water into the final dishes will increase the level of nutrients in a meal. Warm-holding of vegetables after cooking should be avoided.

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