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Upgrading the utilization of brassica wastes: physicochemical properties and sensory evaluation of fermented brassica stalks

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Abstract

The potential to utilize brassica harvest residue and processing waste to add-value and / or to eliminate environmental concerns through fermentation was investigated. Some physicochemical properties (moisture, protein, ash, acid detergent fibre, vitamin C, total phenolic and amino acids contents, acidity and shear and compression forces) for broccoli and cauliflower stalks before and after fermentation were measured. Considerable vitamin C and total phenolics concentrations were found in fresh broccoli and cauliflower stalks. Fermentation decreased ($P < 0.001$) vitamin C concentration to about 55% of that found in fresh stalks of broccoli and cauliflower and decreased ($P < 0.001$) total phenolics concentrations (by 15% and 28% for broccoli and cauliflower, respectively). The results from the sensory analysis indicated that the fermented broccoli and cauliflower stalks may be successful as condiment products for consumers familiar with fermented products.

Introduction

Over the last few years there has been a plethora of biomedical research on antioxidants and active compounds derived from plants. Epidemiological studies have linked the increased consumption of plants products with reduced incidence of diseases (Block *et al*., 1992). Edible plant parts are major sources of dietary antioxidants required for health and well-being. Thus, the majority of published studies have been of the parts of plants considered edible. These edible parts in many cases represent a small fraction of the plant and the remainder is considered harvest residue or processing waste (Bekhit *et al*., 2005; Domínguez-Perles *et al.*, 2010). The management of these materials carry economical cost and disposal may cause environmental concern due to high organic matter and their ability to support microbial growth.

As a result of global environmental changes, urbanization and increased natural disasters, arable land is decreasing and food shortages are becoming chronic in many countries. The trend to increasing vegetable processing to accommodate for the need of fast meal preparation leads to increasing amounts of wastes that are not properly utilized. Thus, there are moral and economical needs to revise the current usage of raw material available for food and utilize them to minimise waste.

Many parts of plants have significant amounts of biologically active compounds (Peschel *et al*., 2006; Domínguez-Perles *et al*., 2010). Of the many plants evaluated for their health benefits much attention has been focused on brassica vegetables. Biologically active compounds from brassica have been shown to prevent or interfere with progress of many diseases (Beecher, 1994; Podsędek, 2007). Several studies have been published optimizing the technological aspects of processing broccoli and cauliflower (Kidmose and Hansen, 1999; Murcia *et al*., 2001; Lo Scalzo *et al*., 2007) which will utilize mostly florets and generate large amounts of processing wastes. Harvest residue and processing waste of brassica can be used as a dietary source of antioxidants and other bioactive compounds (Bekhit *et al.*, 2005; Domínguez-Perles *et al.*, 2010), but this will require financial input that may not be possible in many developing nations. Simple fermentation has been shown to be economically and nutritionally advantageous for many vegetables (Motarjemi, 2002). Fermentation of brassica waste may improve financial return, as well as reduce organic waste. The present study was undertaken to investigate the possible use of broccoli (*Brassica oleracea* var. Italica) and cauliflower (*Brassica oleracea* var. botrytis) stalks as a fermented condiment that can potentially add

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value to these waste streams and improve their utilization. The impact of the fermentation step on some physicochemical characteristics of the stalks was determined.

Materials and Methods

Samples

Standing harvest residue of broccoli was collected from a mid Canterbury commercial grower in April 2005, one week after saleable broccoli florets were harvested. Plants were cut about 5 cm from the soil surface and taken to the lab for preparation. The plants were divided into edible florets, leaves, stalks, flowered buds, and woody parts and trimmings (Table 1). Broccoli stalks were divided into large and small sized stalks based on their morphology (each plant had a large stem with branched small stalks).

Ten whole cauliflowers (average weight ± SD was 1.58 ± 0.55 kg) were purchased from a local supermarket in Christchurch. Cauliflower has a large stem with no branching thus cauliflower stems were classed as large stalks. Cauliflowers were divided into different parts similar to broccoli harvest residue. Stalks from both plants were washed under warm running water (≈ 45°C), patted dry with paper towel and then fermented. Stalks from broccoli and cauliflower were placed in separate clean glass container with other ingredients (herbs, spices and whole garlic cloves). A 6% brine solution was added at a stalk to brine ratio of 4:1 (W/V). The mixture was left to ferment at room temperature (≈ 20°C) for 3 weeks. Before analysis both fresh and fermented broccoli and cauliflower samples were peeled and divided into xylem and phloem (contained epidermis, cortex and the vascular bundles tissues) reflecting the edible and non-edible parts, respectively (Table 2). This resulted in the following samples for broccoli; fresh large broccoli xylem, fresh large broccoli phloem, fresh small broccoli xylem, fresh small broccoli phloem, fermented large broccoli xylem;, fermented large broccoli phloem. Cauliflower had the following samples; fresh large cauliflower xylem, fresh large cauliflower phloem, fermented large cauliflower xylem, fermented large cauliflower phloem. Samples were frozen, freeze dried, individually pulverized, vacuum packed and stored at -20°C until analysis. All the analyses were determined in triplicates on the edible part (xylem of the stalks) unless otherwise stated. Fermented xylem from large broccoli and cauliflower were sliced and used for the sensory evaluation.

Table 1. Composition of broccoli harvest remains and cauliflower processing waste

	Broccoli harvest residue		Cauliflower	
	kg	%	kg	%
Edible Florets	1.49	9.57	11.84	62.55
Leaves	3.04	19.56	4.44	23.45
Stalks	3.38	21.75	2.25	11.89
Flowered buds	1.96	12.60	-	-
Woody parts and trimmings	5.67	36.51	0.40	2.11
Total	**15.54**	**100**	**18.93**	**100**

Moisture, protein and ash contents

Moisture content was determined using gravimetric measurement of water content by freeze drying (AOAC, 1990). Crude protein content was determined according to AOAC (1990) using a Tecator Kjeltec Auto Sampler System 1035 Analyser™ (FOSS Tecator AB, Högänas, Sweden). Ash content was determined on freeze-dried samples. The crucibles were placed in a muffle furnace which was set to run at an initial temperature of 200°C for one hour before being turned up to 550°C for four hours.

Acid detergent fibre (ADF)

The acid detergent fibre of the samples was determined according to Van Soest and Wine (1967).

Measurement of vitamin C

The vitamin C content was determined by AOAC method (AOAC, 1990) using a Metrohm 670 Titroprocessor (Metrohm Herisau, Switzerland). Vitamin C content was expressed as mg/100 g dry matter (DM).

Acidity

The titratable acidity was determined on freshly homogenized samples using the Metrohm 670 Titroprocessor. The results for titratable acidity were expressed as mg citric acid/100 g DM.

Measurement of total phenolics

Total phenolics content (TPC) was determined using Folin-Ciocalteu reagent (Singleton and Rossi, 1965). A sample (200 mg) was extracted with 2 mL of 80% methanol containing 1% hydrochloric acid for 2 h at room temperature on an orbital shaker set at 200 rpm. The mixture was centrifuged at 2000 g for 15 min and the supernatant was transferred into a 10 ml tube. The resultant pellet was extracted again as before and the combined supernatants were used for total phenolic assay. Extracts were diluted 10 fold and then oxidized with 2.5 ml of 0.2 M

Folin-Ciocalteau reagent. The reaction was neutralized by adding 2 mL of 7.5% w/v sodium carbonate, and the samples were vortexed for 20 sec. The samples were incubated at 45°C for 15 min and then the absorbance was measured at 765 nm using a spectrophotometer (UV300, Unicam Ltd, U.K.). Total phenolic concentrations were corrected for the contribution of vitamin C to this assay and were expressed as gallic acid equivalents (GAE) per 100 g DM (Toor, 2005). A standard curve for vitamin C (0-1 mg/ml) was constructed. The contribution of vitamin C content in each sample to TPC was estimated from this curve and was subtracted from the sample's TPC measured values.

Amino acid analysis

All the amino acids, except tryptophan, cysteine and methionine, were determined by HPLC analysis after acid hydrolysis as described by Carducci *et al.*, (1996). Cysteine and methionine were analysed as cysteic acid and methionine sulphone after oxidation of the sample with performic acid followed by hydrolysis with 6 M HCl, as described by McDonald *et al*. (1985).

Shear force and compression measurements

The maximum shear force was determined on 2 cm long samples with 1 cm x 1 cm cross section across the fibre axis using a modified Warner-Bratzler shearing device (the device had a rectangular hole instead of the V shaped hole) mounted on an Instron Universal Machine (series 4400). The crosshead of the Instron was fitted with a load cell (5 kN). The preset load was 1000 N and the probe displacement speed was set at 100 mm/min. Compression measurements were achieved using a two sided compression cell described by Lepetit and Buffiere, (1995) mounted on an Instron Universal Machine (series 4400). The compression area was 1 cm^2 and the samples height was 1 cm high. The operation conditions (load and probe displacement speed) were the same as in shear force analysis. Measurements obtained were: maximum load (N) and Young's modulus (MPa; also known as modulus of elasticity). The data for both analyses were processed with Instron software series IX and the mean values were obtained from 20-30 measurements.

Consumer's perception of the fermented product

The fermented products were tested in a consumer type panel to determine the acceptability of the products. The fermented broccoli and cauliflower stalks were peeled and the pith was sliced into 1 cm thick sections. The samples were presented monadically to the panellists in covered plastic containers labelled with three-digit random number after giving general instruction session. Water and plain crackers were provided to the panellists to cleanse the palate between samples. The panellists recorded their ethnicity and results were then split into two groups; New Zealander; and others (Chinese, Korean, Middle Eastern and Sri Lankan academic visitors). The panellists were asked to evaluate the physical and flavour characteristics as well as the overall acceptability of the products on 5-points category scale: like very much (5), like (4), neither like nor dislike (3), dislike (2) and dislike very much (1). They were asked to rate, again on a 1-5 scale, their likelihood of purchase each fermented product. In addition, the panellists were asked directly which product they preferred most.

Statistical analysis

Data for moisture, protein and ash contents, ADF, acidity, shear force, compression force, vitamin C and total phenolic were analysed using analysis of variance (ANOVA) using PROC GLM in MINITAB (MINITAB®Release 14.1). Differences between means were determined using Fisher's least significant difference. Data for consumer's perception of the fermented products were analysed using the restricted maximum likelihood estimation (REML) routine in GenStat (GenStat Release 7, Lawes Agricultural Trust, VSN International Ltd, Rothamsted, U.K.), and the significance of model terms were determined by Wald tests. Means presented were those estimated by the REML routine.

Results and Discussion

Raw material and processing

After the broccoli was harvested, the field residue still contained 9.5% of edible florets. About 22% of the residue was stalk that could be utilized as a raw material for further processing (e.g. fermentation). These materials are normally mulched into the soil as picking the secondary florets is not a financially viable practice and currently there is no economical use for harvest residues. Cauliflower had a lower percentage of stalks (about 12%) because of the trimming process prior to retail sale (Table 1). This percentage would increase if the harvest remains were included. While broccoli and cauliflower stalks had similar yield after fermentation (97.3% and 95.5%, respectively) the yield of edible xylem for cauliflower was at least 10% higher than that of broccoli (43.1%, 41.2% and 53.9% for large broccoli, small broccoli and cauliflower stalks, respectively).

Table 2. The effect of fermentation on moisture (%), protein (%), ash (%) and titratable acidity (mg citric acid/100 g DM) contents (mean ± SD), and maximum shear force (N), maximum compression force (N) and Young's moldulus (MPa) of broccoli (large and small) and large cauliflower stalks

	FLB	PLB	FSB	PSB	FC	PC
Moisture (%)	94.2 ± 0.46^{bc}	91.3±0.35^{a}	94.3±0.06^{c}	91.1±0.39^{a}	93.7±0.09^{b}	91.6±0.15^{a}
Protein (% DM)	16.6±0.14^{e}	6.0±0.12^{b}	12.0±0.08^{d}	4.5±0.11^{a}	19.9±0.05^{f}	8.9±0.11^{c}
Ash (% DM)	26.3±1.06^{c}	55.4±0.39^{e}	22.1±0.84^{b}	54.5±0.52^{e}	19.2±1.12^{a}	47.3±2.59^{d}
ADF (% DM)	12.2±0.35^{c}	14.0±0.21^{d}	10.2±0.39^{a}	11.4±0.27^{b}	11.1±0.30^{b}	13.64±0.47^{d}
Acidity (mg citric acid/100g DM)	54.4±13.10^{a}	519.8±3.84^{c}	101.0±30.10^{ab}	464.2±41.23^{c}	98.8±3.01^{b}	500.7±22.68^{c}
Shear force (N)	33.4±5.42^{a}	50.3±12.75^{cd}	41.6±8.54^{b}	41.5±6.55^{abc}	54.2±6.97^{d}	52.1±13.87^{d}
Compression						
Maximum force (N)	122.7±18.69^{a}	175.9±40.20^{b}	142.8±41.57^{a}	125.5±18.88^{a}	208.1±54.40^{c}	169.5±40.45^{b}
Young's Modulus (MPa)	5.32±0.89^{a}	7.54±1.93^{b}	5.66±1.43^{a}	5.16±0.99^{a}	9.07±2.71^{c}	7.95±1.59^{bc}

FLB = fresh large broccoli; PLB = processed large broccoli; FSB = fresh small broccoli; PSB = processed small broccoli; FC = fresh cauliflower; PC = processed cauliflower

$^{a-d}$ Within a row, means that do not have a common superscript letter differ at $P < 0.05$.

This higher xylem yield resulted from differences in the geometrical properties (e.g. the diameter and length of the stalk) and the ratio of phloem to xylem for the two crops.

Moisture, protein and ash contents

The moisture contents of fresh cauliflower and broccoli stalks in the present study were 93.7 and 94.3% respectively (Table 2) which is slightly higher than the range reported for broccoli stalk (90.1-93.7%) and florets (85.6-90.7%,) reported by Murcia *et al.* (1999). Size did not have an effect ($P > 0.05$) on the moisture content of broccoli stalks whereas fermentation decreased ($P < 0.05$) the moisture content in both types of stalk. This may be caused by the osmotic effect of the brine since blanching of stalks did not affect their moisture contents (Murica *et al.*, 1999).

Higher protein contents ($P < 0.05$) were found in cauliflower stalks compared with broccoli stalks and in large broccoli stalks compared with small broccoli stalks (Table 2). This trend remained consistent in the phloem with average protein contents of 13.1 ± 0.09, 9.6 ± 0.31 and 8.7 ± 0.03% DM for cauliflower, large broccoli and small broccoli, respectively. The protein level of broccoli stalks (16.6 and 12.0% DM for large and small stalks, respectively) in the present study is lower than that reported by Murica *et al*. (1999) for broccoli stalks and florets (20.1% and 32.8% DM, respectively) which may be related to differences in environmental and agricultural practices. Fermentation decreased ($P < 0.05$) the protein contents in all samples. Saxton and Jewell (1969) demonstrated significant textural and structural changes during the pickling of cauliflower stems that can lead to increased cell wall permeability. This in turn may facilitate the interaction between enzymes and microorganism, and the proteinous compounds in the stalks causing the production of free amino acids that can leach out from the stalk matrix. This contention is supported by the observed decrease in protein contents (25% after 7 h storage and 44.4% in frozen and canned) of broccoli stems as a result of post harvest treatments that activate proteolytic enzymes (Tian *et al*., 1996; Murica *et al.*, 1999).

Ash contents in fresh broccoli stalks were higher ($P < 0.05$) than that of fresh cauliflower stalks. Ash content increased with the increase of the broccoli stalk size ($P < 0.05$). Fermentation increased the ash content in both broccoli and cauliflower stalks due to the addition of salt and the decrease in moisture content (Table 2). Similarly, Murica *et al.* (1999) found that the addition of salt in canned broccoli florets increased the ash content while increased moisture content in frozen broccoli stems resulted in decreased ash content. The above results and those reported by Murica et al. (1999) and Tian *et al.* (1996) collectively demonstrate that the processing option (e.g. blanching, freezing or fermentation) and postharvest handling (e.g. storage temperature and storage time) can affect the composition of the broccoli and cauliflower stalks.

Acid detergent fibre (ADF)

ADF represents the amount of cellulose and lignins in the samples. The ADF contents of the edible xylem of large broccoli was higher than that found in cauliflower and ADF contents increased with broccoli size (Table 2). Similarly, the phloem of broccoli had higher ADF content (34.4 ± 0.01 and 28.7 ± 0.70% DM for large and small stalks respectively) compared with the phloem of cauliflower (17.8 ± 0.54% DM). Fermentation increased ($P < 0.05$) ADF contents in broccoli and cauliflower stalks by 11-23%. This was not accounted for solely by the changes in moisture contents (2.2-3.2% decrease) during fermentation. The impact of salt, microorganisms and organic acids generated during fermentation can modify

the structure of the vegetables (Saxton and Jewell, 1969; Walter *et al.*, 1985; Llorca *et al*., 2001) which probably explains the increased ADF content during fermentation. Femenia *et al*. (1997) reported that different cauliflower parts (florets, upper stem and lower stem) had variable non-starch polysaccharides (2.05, 2.85 and 6.02 g/100 g fresh weight (FW), respectively). The highest cellulose content was in the lower stem (average 34.5, 36.2 and 51.1% of non-starch polysaccharides were in florets, upper stem and lower stem parts, respectively) which corresponds to the cauliflower stalks used in the present study. The ADF contents of the phloem were 2.8 and 1.6 times, for broccoli and cauliflower respectively, higher than that found in the xylem. This can potentially affect the diffusion of salts during brining (Llorca *et al.*, 2001).

Acidity

The variation of titratable acidity (TA) of the xylem section in small broccoli was high which masked any differences with large broccoli and cauliflower (Table 2). However, cauliflower had higher TA ($P < 0.05$) compared with large broccoli. Generally, TA is lower in the broccoli stems compared with florets (Lebermann *et al*., 1968; Siomos *et al*., 2004) and TA of cauliflower is affected by season (Lo Scalzo *et al*., 2007). As with most vegetables, fermentation increased TA due to the utilization of available carbohydrates by microorganisms and the production of organic acids. There were no differences in TA among the studied fermented samples.

Shear force and compression

The shear force and the compression force reflect the force required to cut and grind the material, respectively. The shear force required to cut the samples was higher for cauliflower xylem compared with broccoli. Small broccoli samples required higher shear force to cut compared with large broccoli (Table 2). Fermentation only increased ($P > 0.05$) the shear force of large broccoli stalks. The maximum compression force that was exerted before material failure was higher for cauliflower samples than broccoli samples but there was no difference between the compression force required for small and large broccoli samples. Similar to the effects on shear force, fermentation increased the maximum compression force for large broccoli but had no effect on small broccoli. However, there was significant ($P < 0.05$) decrease in maximum compression force in cauliflower after fermentation. Young's modulus of deformability values echoed the differences in the maximum compression (Table 2). During brine fermentation of cauliflower stems, reorganization within the cell wall takes place and hydrolytic enzymes from plant or microbial origin causes swelling of the cell wall (Saxton and Jewell, 1969; Walter *et al*., 1985). This may lead to a slight softening as observed by the reduction the maximum compression force in cauliflower. Broccoli stalks on the other hand either became firmer (large stalks) or had no change (small stalks). A firming action of broccoli upon precooking at a temperature of 45-70°C for short time, have been described by Lin and Cheng (2005) which is ascribed to the action of pectin-esterase on the cell wall. The fermented material in the present study was washed with warm water and this may cause the firming of large stalks. The above results indicate that slight softening in cauliflower and slight increase in the firmness of broccoli occurred during fermentation, thus the brittleness/crispness desired in broccoli and cauliflower (Kidmose and Hansen, 1999; Lin and Cheng, 2005) was not drastically affected. Generally speaking, toughness increases and crispness decreases in broccoli florets with the increase in post harvest time and temperature (Kidmose and Hansen, 1999) which would be expected in broccoli and cauliflower stalks as well under the same conditions. However, brine fermentation seems to modify the texture favourably (increased permeability of the different cells and the cells organization) without compromising the crispness/brittleness of the stalks, the attributes desired by consumers in broccoli florets.

Table 3. The effect of fermentation on the concentration of vitamin C (mg/100 g DM) and total phenolic compounds (mg/100 g DM) of broccoli (large and small) and large cauliflower stalks.

Brassica	Size	Treatment	Part	Vitamin C (mg/100 g DM)	Total phenolics (mg/100 g DM)
Broccoli	Small	Fresh	Xylem	633.5b	188.4b
			Phloem	290.1e	116.6e
	Large	Fresh	Xylem	714.9a	187.8bc
			Phloem	269.9e	124.5e
	Large	Fermented	Xylem	366.1d	161.0d
Cauliflower	Large	Fresh	Xylem	481.0c	205.5a
			Phloem	355.8d	175.2c
		Fermented	Xylem	268.7e	158.9d
			Phloem	227.4f	111.0e
				SEM=7.1	SEM=3.3
				LSD=29.1	LSD=13.5

Means sharing the same letter are not significantly different at the 1% level.
SEM standard error of Mean
LSD least significant difference (1%)

Vitamin C

Fresh large broccoli stalks had higher ($P < 0.001$)

Table 4. Amino acid composition of fresh broccoli stems (large and small), fresh cauliflower, fermented large broccoli and fermented cauliflower stalks.

Amino acid (g/100 DM)	Fresh Broccoli (large)	Fresh Broccoli (small)	Broccoli Fermented (large)	Cauliflower Fresh	Cauliflower Fermented
Ala	0.71 ± 0.03^{b}	0.62 ± 0.03^{b}	0.23 ± 0.02^{a}	1.02 ± 0.15^{c}	0.38 ± 0.01^{a}
Arg	0.21 ± 0.01^{a}	0.22 ± 0.02^{a}	0.13 ± 0.02^{a}	0.72 ± 0.13^{b}	0.15 ± 0.00^{a}
Asp	0.91 ± 0.05^{b}	0.94 ± 0.04^{b}	0.35 ± 0.04^{a}	2.11 ± 0.30^{c}	0.51 ± 0.01^{a}
Cys	ND[a]	ND[a]	0.015 ± 0.01^{b}	0.10 ± 0.01^{c}	0.025 ± 0.00^{b}
Glu	3.08 ± 0.15^{b}	2.75 ± 0.12^{b}	0.48 ± 0.05^{a}	6.19 ± 2.20^{c}	0.80 ± 0.02^{a}
Gly	0.27 ± 0.01^{c}	0.35 ± 0.02^{d}	0.16 ± 0.02^{a}	0.61 ± 0.02^{e}	0.23 ± 0.00^{b}
His	0.12 ± 0.01^{a}	0.14 ± 0.01^{a}	0.10 ± 0.01^{a}	0.41 ± 0.05^{b}	0.11 ± 0.00^{a}
Ile	0.24 ± 0.01^{bc}	0.30 ± 0.01^{c}	0.15 ± 0.02^{a}	0.62 ± 0.06^{d}	0.21 ± 0.00^{b}
Leu	0.34 ± 0.02^{b}	0.42 ± 0.02^{c}	0.23 ± 0.02^{a}	1.02 ± 0.06^{d}	0.34 ± 0.01^{b}
Lys	0.35 ± 0.01^{c}	0.41 ± 0.02^{d}	0.22 ± 0.02^{a}	0.90 ± 0.03^{e}	0.31 ± 0.01^{b}
Met	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}	0.04 ± 0.01^{a}	0.98 ± 0.15^{c}	0.06 ± 0.00^{a}
Phe	0.19 ± 0.01^{b}	0.24 ± 0.01^{c}	0.13 ± 0.01^{a}	0.57 ± 0.04^{d}	0.19 ± 0.01^{b}
Pro	0.19 ± 0.01^{b}	0.26 ± 0.02^{c}	0.14 ± 0.02^{a}	0.46 ± 0.04^{d}	0.20 ± 0.00^{b}
Ser	0.36 ± 0.02^{b}	0.39 ± 0.02^{b}	0.20 ± 0.02^{a}	1.03 ± 0.13^{c}	0.23 ± 0.01^{a}
Tau	0.13 ± 0.01^{a}	0.23 ± 0.02^{b}	0.22 ± 0.03^{b}	0.36 ± 0.08^{c}	0.29 ± 0.01^{bc}
Thr	0.26 ± 0.01^{bc}	0.32 ± 0.01^{c}	0.16 ± 0.02^{a}	0.70 ± 0.07^{d}	0.20 ± 0.00^{ab}
Tyr	0.09 ± 0.01^{a}	0.08 ± 0.00^{a}	0.07 ± 0.01^{a}	0.32 ± 0.04^{b}	0.08 ± 0.00^{a}
Val	0.30 ± 0.02^{b}	0.34 ± 0.01^{b}	0.19 ± 0.02^{a}	0.87 ± 0.14^{c}	0.26 ± 0.01^{ab}
Total amino acids	7.81 ± 0.38^{b}	8.04 ± 0.38^{b}	3.23 ± 0.35^{a}	19.00 ± 3.10^{c}	4.57 ± 0.10^{a}

The samples were from 3 different batches of materials obtained and fermented individually in different seasons.
[a-d]Within a row, means that do not have a common superscript letter differ at $P < 0.05$.
ND = not detected

concentrations of vitamin C compared with small ones (Table 3). Vitamin C concentrations in the xylem were considerably higher ($P < 0.001$) than in phloems of fresh broccoli. It is well known that broccoli florets contain high concentrations of vitamin C (Davey *et al.*, 2000; Podsędek, 2007). The reported values for vitamin C in the edible portion of broccoli ranged from 34 – 146 (mg/ 100 g wet weight). This variation was attributed to environmental (e.g. climatic, geographical conditions) and agricultural practices (e.g. irrigation, fertilization) (Podsędek, 2007). In the present study, the freeze dried xylem of fresh broccoli stalks had 43 mg/ 100 g FW vitamin C, which is slightly lower than the average content reported for broccoli florets. There are two reasons for this; firstly, a 29% loss in vitamin C was observed due to preparation and freeze drying (fresh xylem before freeze drying was 61.17 ± 3 mg/100 g FW). This is in agreement with results of Favell (1998) who reported a 20% loss of vitamin C in broccoli florets due to freezing. Secondly, cultivation in April meant that the plants were not exposed to light and temperature conditions that enhance vitamin C accumulation. Seasonal effects on vitamin C accumulation in plants are well documented (Davey *et al*., 2000; Podsędek, 2007).

Large cauliflower stalks had significantly ($P < 0.001$) lower vitamin C concentrations in the xylem (481 mg/100 g dry matter) and higher vitamin C concentrations in the phloems (356 mg/100 g DM) than broccoli.

Fermentation decreased ($P < 0.001$) vitamin C concentration in the edible portion (xylem) to about 55% of that found in the xylem of fresh stalks of broccoli. Also, there was about 44% loss in vitamin C content in cauliflower xylem as a result of fermentation. Although almost half of the original vitamin C in stalks was lost due to fermentation, this process retains more vitamin C than storage at room temperature or partial chilling for longer periods. According to Favell (1998) broccoli florets lost 80% of its vitamin C during ambient or partial chilling/ ambient storage for 3 weeks.

Davey *et al.* (2000) listed vitamin C content in 63 fruits and vegetables. Broccoli ranked 7th on that list after acerola, rosehip, guava, blackcurrant, kale and green pepper. In New Zealand, many of the high vitamin C sources (e.g. acerola, rosehip, guava and kale) are not available fresh to the average consumers. In fact, vitamin C contents on fresh weight basis in fresh and fermented broccoli and cauliflower stalks are 2-4 times that found in several tomatoes varieties (Toor, 2005). Thus, advice on the use of broccoli and cauliflower and their stalks as rich sources for vitamin C is important. The fermented products from broccoli and cauliflower contained higher vitamin C contents than pickled garlic and cucumber, green olives, capers, sauerkraut and Jalapeño peppers (Casado *et al.*, 2004).

Total phenolic compounds

Stalk size did not affect ($P > 0.05$) the total phenolic content of fresh broccoli stalks (187.8 ± 16.4 and 188.4 ± 7 mg GAE /100 g DM, for large and small stalks, respectively, Table 3). Total phenolic content of broccoli florets was reported to be in the range of 34.5 to 337 mg of GAE/ 100 g wet weight (Podsędek, 2007). This large variation was due to

Table 5. Characteristics of panellists and average taste panel scores for fermented broccoli and cauliflower stalks. Panellists were from 2 different culture backgrounds (New Zealanders; non-New Zealanders).

Characteristic	New Zealanders	non-New Zealanders
Number	20	28
Gender		
Males	5	17
Female	15	11
Age (years)		
Average	24	33
(range)	(18-56)	(20-48)

		Sensory attributes							
		Taste	**Colour**	**Smell**	**Salt**	**Flavour**	**Hardness**	**Mouth feel**	**Acceptance**
Ethnicity									
New Zealanders		3.8a	4.8a	4.2a	4.2a	3.9a	5.0a	4.4a	4.2a
Non-New Zealanders		6.2b	6.7b	6.9b	6.8b	6.4b	7.3b	6.9b	6.6b
	P	0.001	0.003	0.001	0.001	0.001	0.003	0.001	0.001
Stalks									
Cauliflower		6.2	6.2	6.5	6.5	6.0a	6.9	7.0a	6.4a
Broccoli		5.7	6.4	6.5	5.7	5.2b	6.8	5.8b	5.7b
	P	NS	NS	NS	0.034	0.004	NS	0.001	0.002
Sex									
Female		6.1	6.8a	7.2a	6.2	6.0	7.4a	7.0	6.3
Male		5.7	5.8b	5.8b	5.5	5.3	6.3b	6.0	5.7
	P	NS	0.032	0.011	NS	NS	0.038	NS	NS

[a,b]Within a column for each factor, means that do not have a common script letter differ at stated P value. NS = not significant

the use of different extraction methods. However, it seems that soil and environmental conditions (reflected in country of origin) played a role in this variation (Podsędek, 2007). Also, in most of the reported studies, the contribution of vitamin C to total phenolic content was not taken into account. Indeed when harsh extraction conditions that would destroy vitamin C were used, total phenolic content in broccoli (florets and stem) was low (Zhang and Hamauzu, 2004). In the present study total phenolic content in the broccoli stalks was 11.3 mg GAE / 100 g wet weight compared with 4.5 mg GAE / 100 g wet weight broccoli stems reported by Zhang and Hamauzu (2004).

The xylem of fresh cauliflower had similar total phenolic content (205.5 ± 3.3 mg GAE /100 g DM) to the xylem of fresh broccoli, whereas the phloem of fresh cauliflower had higher ($P < 0.001$) total phenolic content than broccoli phloem (Table 3). Fermentation caused a reduction in total phenolic concentrations (by about 28% and 15% for cauliflower and broccoli, respectively). This was expected as polyphenols are known to degrade during fermentation (Svanberg and Lorri, 1997).

Amino acids

Glutamic acid and aspartic acid were the dominant amino acids in the fresh samples, contributing to 51% and 46% and 46% for large broccoli, small broccoli and cauliflower stalks respectively (Table 4). This in agreement with findings of Murcia *et al.* (2001) for broccoli stems. Large broccoli stems had higher alanine, glutamic acid, tyrosine and lower glycine, isoleucine, leucine, lysine, phenylalanine, proline, taurine and valine compared with small broccoli.

Fermentation decreased the content of individual amino acids in large broccoli by 16 to 84%, except for cysteine and taurine, but the dominance of glutamic acid and aspartic acid remained after fermentation. Similar amino acid profiles have been reported for pickled garlic, green olives, Jalapeño peppers and cucumbers (Casado *et al.*, 2004). Cysteine and taurine increased by 580% and 75% respectively as a result of fermentation. These changes in amino acids were probably due to proteolysis and other microbial metabolic activities (López, 1992) leading to the degradation of proteins and subsequent use of free amino acids. Higher amino acids contents were found in fermented cauliflower compared with broccoli but both had similar patterns of amino acids.

Severe losses (55-78%) in the total amino acids have been reported in broccoli, both florets and stems, as a result of blanching, freezing or bottling (Murcia *et al.*, 2001). Fermentation caused similar total amino acids losses (58-74%) and increased the level of two important amino acids (cysteine and taurine) in broccoli fermented stalks. Calculating the total amino acids content of fermented broccoli and cauliflower stalks (0.28 ± 0.03 and 0.38 ± 0.01 g/100 g fresh weight) showed that these product will resemble pickled cucumber in term of amino acids content (Casado *et al*., 2004).

Consumer's perception of the fermented product

Forty eight people participated in the consumer-type panel. The panellists expressed their ethnicity and

were then split into two groups: New Zealander and non-New Zealanders (Table 5). The majority (77%) of the non-New Zealanders group were Chinese and Middle Eastern ethnicities.

There was a significant difference in the overall acceptability of the fermented products between groups of different ethnicity (Table 5). The non-New Zealander panellists found that the fermented products were acceptable or very acceptable, while 70% of the New Zealand panellists ranked the products with 1 (dislike very much) or 2 (dislike). This may reflect a cultural background difference in that the non-New Zealander group was more familiar with fermented vegetables while in New Zealand the consumption of such products is not common.

Fermented cauliflower stalks were perceived as more preferable than broccoli stalks (Table 5). The fermented cauliflower ranked more highly in terms of saltiness, overall flavour, mouthfeel and hardness ($P < 0.05$). Although the pale green colour of the broccoli product attracted comment, there was no significant difference in the acceptability of the colour of the products. Both products attracted scores at both end of the acceptability scale from dislike very much to like very much.

The overall acceptability of fermented products was not significantly different between males and females (Table 5). Female panellists reported higher scores for all the evaluation parameters, but significant differences were found in colour, smell and hardness. When the interaction of sex and type of fermented product was considered (data not shown) females gave a higher ranking to the cauliflower fermented product than the broccoli product. The panellists were also asked about their likelihood to purchase. There was again a significant difference ($P < 0.001$) between the ethnic groups. Using a scale of 1 (very unlikely) to 5 (very likely); with 3 the neutral position indicated as "maybe", the predicted means were 1.74 and 3.67 for New Zealanders and non-New Zealanders; respectively. There was no difference in the likelihood of purchase between the broccoli and cauliflower fermented products. This data indicate that these fermented products may have potential in markets where a high proportion of consumers are familiar with fermented products. These markets could include Asian and Middle Eastern countries as well as other countries where there are large populations of these consumers. Further development of taste to suit the target market would be advised.

Conclusion

The materials used from broccoli and cauliflower represent the material that can be recovered at the grower and processor levels, respectively. With the appropriate technology it is feasible to utilize these materials. After processing, these materials can be used effectively as dietary sources of nutrients either directly as food or as an ingredient in a functional food product. In the present study, relatively high vitamin C and total phenolics contents in broccoli and cauliflower stalks and in the fermented products made from them were reported. The results from the taste panel indicated that the fermented broccoli and cauliflower stalks could be a successful product as a condiment for consumers familiar with fermented products. The potential to use harvest residue and processing by-products and target overseas markets is promising.

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