Phytochem Rev (2008) 7:345–384
DOI 10.1007/s11101-007-9073-1

Effect of domestic processing on bioactive compounds

Alejandro Ruiz-Rodriguez · Francisco R. Marín · Aurelio Ocaña · Cristina Soler-Rivas

Received: 4 June 2007 / Accepted: 27 September 2007 / Published online: 20 October 2007

Abstract Nowadays, most of the consumed foods are rarely ready for direct consumption. Food can be purchased at the local supermarket as fresh raw product such as meat, fruit, fish etc. or as manufactured product after an industrial processing (canned meat, dried fish, packed fruit etc.). But later on, both food types are usually submitted to culinary treatments which will transform the selected food into a cooked dish ready to eat. Domestic methods of food processing have been developed over the centuries to make the final product more attractive in flavour, appearance, taste and consistency. But, until the last centuries, none of the *gourmets* realize that at the same time, the cooking process was making their foods more digestible, microbiologically safer and more or less nutritive depending on the selected cooking technology. Besides consumer preferences, the selected cooking method is an important factor affecting not only the food chemical composition, but also the intake of bioactive compounds under normal dietary conditions. Therefore, in this work, the different culinary treatments and domestic cooking methods will be compared to define the optimal process to reduce the degradation of biologically active metabolites present in foods commonly consumed as an elaborated dish. Compounds such as carotenoids, glucosinolates, flavonoids and other phenolic compounds, ω-3 fatty acids, tocopherols, phytosterols, etc. have been pointed as bioactive compounds beneficial for human health. Apparently, they are able to prevent cardiovascular diseases (CVD), tumour formation, hiper-cholesterolemia in blood and other deleterious disorders. An adequate domestic practice might help to increase in taking of those functional molecules enhancing their functionality and reducing the risk of chronic diseases.

Keywords Culinary methods · Domestic practices · Nutraceuticals · Functional food

Abbreviations

AA	Arachidonic acid
ALA	Linolenic acid
ACSO	S-alk(en)yl-L-cysteine sulfoxide
CVD	Cardiovascular diseases
DF	Dietary fibres
DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
GSNs	Glucosinolates
HHT	High heat transfer
HNE	4-Hydroxy-2-trans-nonenal

A. Ruiz-Rodriguez
REQUIMTE, Departamento de Química, FCT (Faculdade de Ciencias e Tecnología), Universidade Nova de Lisboa, Quinta da Torre, 2829-516 Caparica, Portugal

F. R. Marín · A. Ocaña · C. Soler-Rivas (✉)
Edificio de Ciencias, Sección Departamental Ciencias de la Alimentación, Universidad Autónoma de Madrid (UAM), Modulo C-XVI (502.1), Ctra de Colmenar, km 15, 28049 Madrid, Spain
e-mail: Cristina.soler@uam.es

LA	Linoleic acid
LOX	Lipoxygenase activity peroxidase
LHT	Low heat transfer
MA	Malonaldehyde
PO	Peroxide value
POD	Peroxidase activity
PUFAs	Polyunsaturated fatty acids
SDA	Stearidonic acid
SFAs	Saturated fatty acids
TBA	2-Thiobarbituric assay
TS	Thiosulfinates
TG	Triglyceride

Carotenoids and retinol

Carotenoids are yellow, orange or red pigments with a symmetrical tetraterpene skeleton as basic structure that might suffer hydrogenation, cyclisation, oxidation etc yielding other carotenoid derivatives (Fig. 1a). They are widely found in edible vegetables and fruits with those colours (carrot, tomato, orange, banana etc), but also, in those leafy vegetables with green colour where chlorophylls cover the colour of these compounds (lettuce, pepper, spinach etc.). Animal tissues (trout, salmon and seafood) have certain types like astaxanthin but most of them transform these carotenoids into retinol or vitamin A (found in eggs, milk and liver). Vegetarian ready-to-eat foods also contain carotenoids but in significantly lower levels than traditionally cooked meals (Agte et al. 2002).

They were first included in the list of functional ingredients because of their provitamin A activity (β-carotene, α-carotene and β-cryptoxanthin) but epidemiological studies demonstrated that they exert beneficial activities for human health acting as radical scavengers in lipidic matrix, protecting against tumour formation, macular degeneration, cardiovascular diseases (CVD) etc.

Domestic processing

Domestic processing and cooking methods are probable one of the most important factors affecting the daily intake of carotenoids (van den Berg et al. 2000).

Before cooking selected vegetables, meats, fishes etc. are submitted to different treatments in order to modify or adapt their size and characteristics facilitating the later heat application. These domestic pretreatments such as washing, removing of skin or non-edible parts, cutting, drying and also their maintenance stored at room temperature in a refrigerator or a freezer might influence negatively the final carotenoid content of the prepared dish. For instance, boiling of an entire piece of chicken liver resulted in 5% retinol loss and if the liver was previously cut in small pieces 8% retinol was lost (Sungpuag et al. 1999).

Cutting of vegetables allows exposure of inner tissues to oxygen and light. This, together with the disintegration of tissues due to acids additions (lemon, vinegar etc.) result in the destruction of the provitamin A carotenoids and rest of carotenoids. Acid and light have been reported to cause

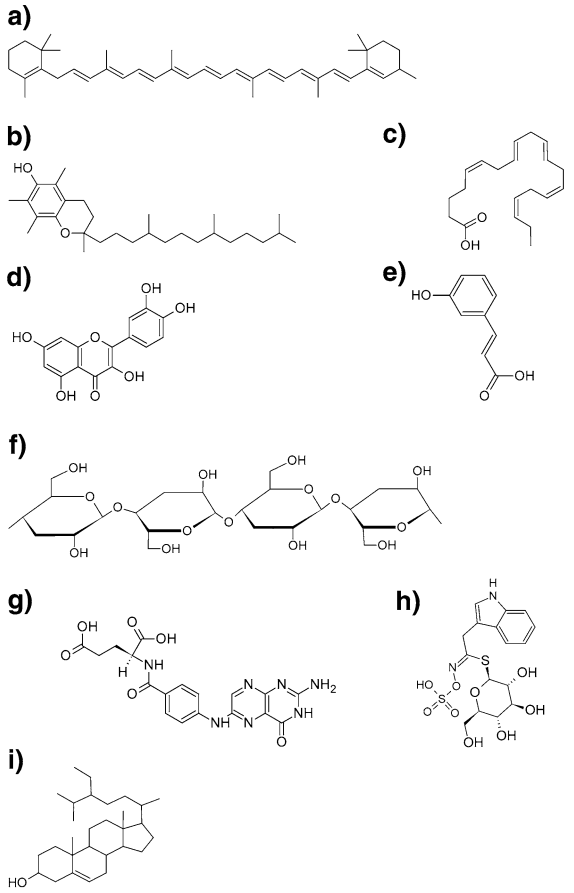

Fig. 1 Chemical structures of a few molecules examples of the bioactive compounds (**a**) β-caroteno, (**b**) α-tocopherol, (**c**) EPA, (**d**) quercetine, (**e**) 3-hidroxy-cis cinnamic acid, (**f**) cellulose, (**g**) folic acid, (**h**) glucobrassicin, and (**i**) β-sitosterol

isomerization of carotenoids from the all-*trans* form to the *cis* form which is biologically less active (Gayathri et al. 2004).

Peeling and juicing result in substantial losses of provitamin A, often surpassing those associated with heat treatment, although lycopene in tomatoes seems to be more stable (both retention and isomer distribution) with these treatments (van den Berg et al. 2000).

Automatic peeling followed by shredded and maintained at room temperature (27–28°C) for approximately 3 h and placed on workbenches under transparent plastic sheets simulating the awaiting time between preparation and distribution in a catering service showed more carotenoid losses than boiling, pressure-cooking or steaming. Carrots after such a treatment retained only 59% of total carotenoids (62.2% of α-carotene and 74.5% of β-carotene) while still after the most heavy heat treatment 64% of the total pigments were still intact inside the carrot matrix (Pinheiro Sant'Ana et al. 1998). Obviously, domestic chopping or mashing is less aggressive since chopped food is almost immediately consumed (Singh and Kulshrestha 2006) but other short processing such as making an omelette can be very aggressive because breaking of the shell leaves the egg yolk directly exposed to air (Sungpuag et al. 1999).

In some countries, solar drying is a common practice for preserving different plants (amaranth, cowpea, peanut, pumpkin sweet potato leaves) leading to significant reductions in carotenoid and vitamin A content (50–60%) (Mosha et al. 1997).

Smoke-curing of rainbow trout, another typical home processing in certain countries only produced carotenoids concentration (astaxanthin and cantha-xanthin) (Choubert et al. 1992).

The enzyme lipoxygenase occurs widely in vegetables and the loss of carotenoids in peas has been linked to its activity during storage. However, if the heat treatment is rapidly applied the enzyme is inactivated. Storage of spinach in polyethylene bags at 5°C and 30°C (24–48 h) lead to β-carotene lost between 0–1.3% and 1.5–2.1% respectively (Kala Yadav and Sehgal 1995).

Freezing (on a domestic freezer) produced a slightly reduction of trans-β-carotene (Howard et al. 1999) depending on the freezing temperature. Blanching before freezing improved carotenoid retention (Gebczynski and Lisiewska 2006) but long thawing was detrimental. The lag time after thawing decreased the carotene concentrations of carrots, broccoli and spinach, severe degradation was observed 6 h after thawing (Park 1987).

Cooking methodologies

The carotenoid content in elaborated dishes depends on the ingredients chemical nature, even when they are submitted to similar cooking conditions their values might change depending on the matrix in which they are involved (high/low fat content, antioxidants, metals, ripening status, etc). This is one of the reasons which explain the differences and even opposite results found among different authors concerning the carotenoid stability during cooking processes in diverse foods (Table 1).

Some authors have reported losses of total carotenoids with cooking, some others observed insignificant changes and on the contrary, some concluded that thermal processing increase carotenoids concentration.

Baloch et al. already in 1977 pointed the enzymatic destruction of carotenoids in unblanched vegetable tissues, the incomplete extraction of pigments from raw vegetables and/or leaching of soluble solids during processing of the vegetables as the possible explanations for the apparent increase in carotenoid content during processing, since values increased only if results were expressed on a percentage dry weight basis of the processed material. When carotenoid content was expressed on a water-insoluble solids basis, no increases were observed, indicating that leaching of soluble solids was the cause of the apparent increases.

Other reports pointed enzyme activities as the reason for increasing values since they might catalyze degradation of specific protein-carotenoid aggregates (Johnson 2000) similarly as those responsible for the colour change observed during cooking of seafood. Blue crabs change from blue-green to red-orange because their xanthophylls are complexed with certain protein, with heating, dissociation takes place and allow the pink-reddish colour to appear. The best known example is α-crustacyanin, the carotenoprotein responsible for the blue coloration of the lobster carapace. It contains the carotenoid astaxanthin,

Table 1 Effect of different cooking procedures on the carotenoids content of several vegetables according to various authors

Food	Pigment (mg/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stir-fried	Baked	Microwaved	Reference
Eggplant	α-Catonete		nd						Kim et al. (2007)
	β-Carotene		0.0349						Kim et al. (2007)
	β-cryptoxanthin		nd						Kim et al. (2007)
	Lutein		0.1218						Kim et al. (2007)
	Zeaxanthin		nd						Kim et al. (2007)
	Lycopene		nd						Kim et al. (2007)
Cucumber	α-Catonete		nd						Kim et al. (2007)
	β-Carotene		0.8832						Kim et al. (2007)
	β-Cryptoxanthin		nd						Kim et al. (2007)
	Lutein		1.4082						Kim et al. (2007)
	Zeaxanthin		nd						Kim et al. (2007)
	Lycopene		nd						Kim et al. (2007)
Broccoli	Neoxanthin	8.56	7			8.26			de Sá and Rodriguez-Amaya (2004)
			7.46			6.95			de Sá and Rodriguez-Amaya (2003)
	Violaxanthin	14.86	7.3			9.93			de Sá and Rodriguez-Amaya (2004)
			5.3			4.55			de Sá and Rodriguez-Amaya (2003)
		0.37	0.31					0.33	Zhang and Hamauzu (2004)
	Lutein	28.6	25.5			29.7			de Sá and Rodriguez-Amaya (2004)
			35.1			32.75			de Sá and Rodriguez-Amaya (2003)
		1.05	1.08					1.07	Zhang and Hamauzu (2004)
	β-Carotene	15.6	12.86			16.36			de Sá and Rodriguez-Amaya (2004)
			18.9			15.75			de Sá and Rodriguez-Amaya (2003)
		0.63	0.35					0.38	Zhang and Hamauzu (2004)
		0.07	0.37	0.35	0.28				Bernhardt and Schlich (2006)
Endive	Neoxanthin	6.8				7.6			de Sá and Rodriguez-Amaya (2004)
						7			de Sá and Rodriguez-Amaya (2003)
	Violaxanthin	8.9				6.65			de Sá and Rodriguez-Amaya (2004)
						6.8			de Sá and Rodriguez-Amaya (2003)
	Lutein	22				26.4			de Sá and Rodriguez-Amaya (2004)
						23.4			de Sá and Rodriguez-Amaya (2003)
	β-Carotene	13.6				15.25			de Sá and Rodriguez-Amaya (2004)
						12.4			de Sá and Rodriguez-Amaya (2003)

Table 1 continued

Food	Pigment (mg/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stir-fried	Baked	Microwaved	Reference
			9.6						Sweeney and Marsh (1971)
Green bean	Neoxanthin	nd	nd			nd			de Sá and Rodriguez-Amaya (2004)
			nd			nd			de Sá and Rodriguez-Amaya (2003)
	Violaxanthin	nd	nd			nd			de Sá and Rodriguez-Amaya (2004)
			nd			nd			de Sá and Rodriguez-Amaya (2003)
	Lutein	2.3	2.6			2.9			de Sá and Rodriguez-Amaya (2004)
			2.5			2.73			de Sá and Rodriguez-Amaya (2003)
		0.73	2.055	1.62	1.71			1.27	Cruz-García et al. (1997)
	β-Carotene	1.1	1.8			1.9			de Sá and Rodriguez-Amaya (2004)
			1.63			1.76			de Sá and Rodriguez-Amaya (2003)
		1.165	5.7	4.82	5.86			3.78	Cruz-García et al. (1997)
			1			0.8			Godoy and Rodriguez-Amaya (1998)
Kale	Neoxanthin	13.2				17.2			de Sá and Rodriguez-Amaya (2004)
						6.36			de Sá and Rodriguez-Amaya (2003)
			27.6						Khachik et al.1992
	Violaxanthin	22.4				13.66			de Sá and Rodriguez-Amaya (2004)
						5.63			de Sá and Rodriguez-Amaya (2003)
			7.7						Khachik et al. (1992)
	Lutein	43.66				60.66			de Sá and Rodriguez-Amaya (2004)
						31.53			de Sá and Rodriguez-Amaya (2003)
			235						Khachik et al. (1992)
	β-Carotene	37.26				50.2			de Sá and Rodriguez-Amaya (2004)
						23.06			de Sá and Rodriguez-Amaya (2003)
			126						Khachik et al.1992
Carrot	α-Carotene	1057.1	1326.3	1037	1139.7		951.9		Pinheiro Sant'Ana et al. (1998)
	β-Carotene	1960	2345	2110	2220		1810		Pinheiro Sant'Ana et al. (1998)
Tomato	Licopene	46.75	40.15			24.2	43.35		Sahlin et al. (2004)
Red pepper	β-Carotene	0.74	0.57	0.5	0.52				Bernhardt and Schlich (2006)
Soybean sprout	α-Catonete		0.0007						Kim et al. (2007)
	β-Carotene		0.0088						Kim et al. (2007)
	β-Cryptoxanthin		nd						Kim et al. (2007)
	Lutein		0.0898						Kim et al. (2007)

Table 1 continued

Food	Pigment (mg/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stir-fried	Baked	Microwaved	Reference
	Zeaxanthin		0.0018						Kim et al. (2007)
	Lycopene		nd						Kim et al. (2007)
Spinach	α-Catonete		nd						Kim et al. (2007)
	β-Xarotene		1.3775						Kim et al. (2007)
	β-Cryptoxanthin		nd						Kim et al. (2007)
	Lutein		3.2704						Kim et al. (2007)
	Zeaxanthin		nd						Kim et al. (2007)
	Lycopene		nd						Kim et al. (2007)

nd: not detected

which is bound in a stoichiometric but non-covalent way to the apoprotein (Weesie et al. 1995).

According to Hart and Scott (1995) boiled green vegetables showed an increase of 31% of total carotenoids. Furthermore, in case of cooked broccoli, a higher increase of β-carotene (38%) than lutein (24%) was observed, however for green cabbage the opposite trend was noted. The cooking of frozen Brussels sprouts in water for 15 min resulted in 28% and 2% increases in *cis*-β-carotene and lutein contents respectively and 7% decrease of β-carotene level (Podsedek 2007). Gliszczynska-Swiglo et al. (2006) found an increase on both β-carotene and lutein content in steam-cooking and boiling of broccoli as compared with fresh broccoli but Lim (2007) observed in spinach that cooking did not alter the carotenoid profiles of the samples, only the level of all carotenoids that was greater in cooked samples than in fresh samples. Steaming increased the total carotenoids contents, especially that of *trans*-β-carotene. Lutein was little affected by cooking method while 9-*cis* and 13-*cis*-β-carotene isomers were the major types formed during cooking.

As previously mentioned, thermal processing swings to greater chemical extractability, it provokes the breakdown of food structures, leading (probably also in vivo) to increased bioavailability. In deed, Liu et al. (2004) demonstrated using in vitro test (using Caco-2 cell lines) that cooking corn grain significantly enhanced carotenoid bioavailability. Cooking in boiling water within 4 min increased the extractable lutein content in chekup manis (*Sauropus androgynus*) Indian leaves by almost 20% (Liu et al. 2007).

However, carotenoids are highly unsaturated structures which make them sensitive o light oxygen and heat therefore; they are extremely susceptible to degradation. The degradation level was dependent on the cooking methodology utilised including temperature and time conditions. Higher carotenoids degradation was observed with longer processing time, higher temperatures and cutting in smaller pieces or maceration of the food (van den Berg et al. 2000). Nevertheless, their decomposition rate was lower than that of chlorophylls (Kim et al. 2003).

Effect of various cooking methods on levels of carotenoids in raw and cooked (microwaved, boiled, steamed, stewed) green vegetables and tomatoes was

studied and it was shown that while the epoxycarotenoids were somewhat sensitive to heat treatment, lutein and hydrocarbon carotenoids such as neurosporene, α- and β-carotene, lycopene zeta-carotene, phytofluene and phytoene survived the heat treatments (Khachik et al. 1992). Heat also induced *cis/trans* isomerisation (eg formation of 5-*cis*-lycopene and 13-*cis* β-carotene), and different carotenoid by-products are formed. In freshly harvested broccoli, Brussels sprouts, collards, kale, spinach carrots, squash, sweet potatoes, pumpkin and red peppers the cooking treatment converted all-*trans* carotene to isomers with lower vitamin A activity (Sweeney and Marsh 1971).

Blanching

Blanching is a culinary method applied to food before freezing. It is a short incomplete cooking aimed to enzyme inactivation. Blanching of carrots by hot water, steam or microwaves resulted in yellowing. These colour changes are usually small, a little bleaching occur in carrots, which have carotene inside the chromoplast. Some high-carotenoid vegetables, such as squash, show a distinct colour change when heated in water. This has been partly attributed to isomerization of the *trans*-carotenoids to the less highly coloured *cis*-forms and also to degradation of chromoplast and solution of carotenes in other cellular lipids (van den Berg et al. 2000).

Blanched broccoli before freezing may provoke some losses but inactivation of oxidative enzymes prevents further losses. Therefore, it seemed an adequate method to improve the carotenoid content more that just freeze them raw (Gebczynski and Lisiewska, 2006). β-Carotene was found to be about 1.9 times more susceptible to heat damage than α-carotene during normal blanching and cooking processes (Baloch et al. 1977).

Steam-blanching seems to be better than blanched in water at 98°C not only for carotene content but also for sensory quality and nutrient retention (Onayemi and Badifu 1987) and blanching by boiling (100°C 5 min) better than stir-frying (180°C 2 min) since boiling did not cause heavy β-carotene losses in swamp cabbage (11%) respect to stir-frying (18%) (Sungpuag et al. 1999).

Boiling in water

One of the most labile vitamins during culinary processes are retinol (vegetable boiling, 33% retention), vitamin C, folate and thiamine (Leskova et al. 2006) but carotenoids, retinol precursors, are less affected than the vitamin A.

A large study where 33 types of leafy vegetable (including herbs and *Brassica* spp.) 16 other vegetables and 6 types of fruit, were compared for their carotenoid content using fresh and processed vegetables, pointed out that leafy vegetables generally had a higher carotenoid content than the other vegetables and fruit and that losses, expressed as vitamin A activity, were lower during boiling (14%) than in other domestic treatments (Speek et al. 1988). Boiling after soaking of several varieties of beans, chick peas and lentils did not generally results in a significant decline in β-carotene (Atienza et al. 1998). Tomato lycopene content was neither affected by cooking treatment for 4, 8 and 16 min at 100°C (Thompson et al. 2000).

A comparison between various cooking methods frequently used at catering services obtained similar conclusions, water-cooking (boiling 21 min) without pressure was the best heat treatment where retention was 72.4% of total carotenoids (78% of α-carotene and 89% of β-carotene) compared to pressure cooking (with water 17 min) or steam cooking (15 min) with respectively 64% and 76% retention of total carotenoids (α-carotene 61% with pressure-cooked and 67% steam-cooked and β-carotene respect. 80% and 84%) (Pinheiro Sant'Ana et al. 1998).

Effects of boiling water using induction or conventional fire places and microwave steaming of broccoli, carrots, green beans and sweet potatoes were also compared. No differences in the retentions of α-carotene, β-carotene and lutein/zeaxanthin were observed in the vegetables by any of the selected cooking methods with the exception of β-carotene retention in broccoli and sweet potatoes where retentions were higher in those induction boiled (90.3 and 86.1% respect.) than those microwave steamed (62.2 and 66.4% respect.) (Nunn et al. 2006).

The water volume used for cooking was pointed as another influencing parameter affecting the carotenoid retention. The highest retention was obtained when vegetables were cooked almost without water and the lowest retention was associated with the use of a large amount of water during cooking (Leskova et al. 2006).

Addition of spices with antioxidant properties such as tumeric or onion powder to the boiling water influenced positively the retention of β-carotene in boiled carrots. Onion powder improved from 84% up to 97.5% retention on carrots. Retention of β-carotene was higher in boiled pumpkin in the presence of turmeric or combinations of tamarind and onion/citric acid and turmeric (Gayathri et al. 2004).

Steaming and pressure cooking

Boiling green beans in a covered pot, pressure-cooking or microwaving them caused lower losses of pigments than steam-cooking (Cruz-García et al. 1997). Steaming (100°C 40 min) of pumpkin resulted in 15% of β-carotene loss (Sungpuag et al. 1999). But the effect of pressure-cooking compared with boiling on an open pan differed from author to author. Kala Yadav and Sehgal (1995) reported pressure cooking (10 min) as more adequate method than boiling (30 min)). On the contrary, Gayathri et al (2004) and other reports previously described, indicated that carrots and pumpkin cooked in a pressure-pan (10 min) retained 73% and 29% respect. of β-carotene while 84% and 51% respect. were retained with normal boiling.

The addition of acidulants (tamarind and citric acid), able to decrease pH of the cooking medium, appeared to influence carotenoid retention. Tamarind addition improved β-carotene retention in carrot during pressure cooking (10% lower losses). Additions of tamarind and citric acid on pumpkin pressure cooking considerably improved β-carotene retention (37 and 43% respectively) (Gayathri et al. 2004).

Pressure cooking resulted in increases in β-carotene bioavailability of 19, 48 and 100% for carrots, amaranth and fenugreek leaves, respectively, but had no significant influence on pumpkin according to in vitro digestion assays (Veda et al. 2006).

Frying

Conditions during stir-frying might be more drastic than those of boiling, thus reducing the carotenoid levels in a higher percentage than boiling. Boiled broccoli (5 min) retained approx. 7% more carotenoids (neoxanthin, lutein) than stir-fried broccoli (4 min) except for β-carotene which did not change much and violaxanthin which is more susceptible to boiling. Violaxanthin is a very labile carotenoid and it may be completely destroyed during prolonged heat treatments, whatever is the cooking method (stir-frying or boiling) (Sá and Rodriguez-Amaya 2003).

But, results changed if other foods are considered since no significant differences were found in boiled (5 min) or stir-fried (10 min) green beans (Sá and Rodriguez-Amaya 2004). Frying chicken eggs to make omelette (200°C 2 min) provoked a 43% of retinol losses compared to the initial retinol content found in a raw egg, while if the egg is boiled (100°C, 10 min) only 11% of retinol is destroyed (Sungpuag et al. 1999). If tomatoes are fried at 145°C and 165°C for 1 min only 36.6% and 35.5% lycopene respectively is retained (Mayeaux et al. 2006).

Surprising results were those of Padmavati et al. 1992 which indicate that deep-frying resulted in twice the amount of loss that occurred during shallow-frying (tested in 12 vegetables). Because of the easier oxygen accessibility in a shallow-frying opposite results would have been expect.

In particular preparations (spinach dough), the frying process might help carotenoids leaching out of the dough to the oily medium as they are lipid soluble compounds besides dough protection which might act as physical barrier (Kim et al. 2003).

Stir frying might also facilitate carotenoid intake as the process improves their bioavailability in a 53, 63, 192 and 263% for pumpkins, carrots, amaranth leaves and fenugreek leaves respectively according to an in vitro digestion test (Veda et al. 2006).

Baking

Baking as well as deep-frying resulted in substantial losses of provitamin A carotenoids. However, not many reports include the baking effect on their cooking methods for comparisons.

Old reports mentioned that carotenoid degradation in sweet potato (*Ipomoea batatas*) was higher in an electric oven at 200°C (20 to 45 min) than boiling in 3 times their weight in water (10–30 min) (Sarhan et al. 1975; El Wakeil and Morsi 1976). Baking of tomato slurry at 177° and 218°C for 15 min respectively lead to only 37.3% and 25% lycopene retention, higher baking times increased losses (Mayeaux et al. 2006). Roasting of meats also

decreased retinol content by 10–15% and at higher temperatures even 30% retinol losses can be reached (Leskova et al. 2006).

Ground-oven baking, a traditional Pacific cooking style characterized by digging a hole in the ground and making inside a particular stone oven, was not a recommendable cooking method to maintain retinol and carotenoid content as compared, for instance, to microwaving (20–91% retinol retention) (Kumar and Aalbersberg 2006b).

Microwaving

Reports on the effects of microwaves on carotenoids are contradictories. Some authors reported losses of total carotenoids in broccoli during conventional and microwave cooking (Zhan and Hamauzu, 2004). The florets and stems cooked for 5 min by these both methods lost approx. 23% of total carotenoids. Among analysed carotenoids, the levels of β-carotene and violaxanthin declined during the conventional and microwave cooking, but the level of lutein increased gradually in both cooking methods. This could be due to transformation of the *cis* isomer of lutein to the *trans* form, which has been noted during microwave cooking of broccoli (Uplike and Schwartz 2003).

Other authors pointed microwave heating as less destructive cooking method than steaming and boiling. Howard et al. (1999) reported minimal effects on *trans*-β-carotene in broccoli, carrots or green beans while Mayeaux et al. (2006) indicated that lycopen in tomato was highly affected since only 64.4% of lycopene remained after 1 min of microwave heating at high power. Muradian et al. (2000) also observed significant reduction (11% to 26%) on pro-vitamin A carotenoids of celery and serrlha (*Sonchus oleraceus*). The same author described no carotenoid reduction for mint remarking the important role of the food matrix on the carotenoid stability submitted to the different cooking methodologies.

Tocopherols and derivatives

The term 'vitamin E' is used to describe all tocol and tocotrienol derivatives that qualitatively exhibit the biological activity of α-tocopherol. Tocopherols are derivatives of 2-methyl-6-chromanol onto which is attached a saturated 16 carbon isoprenoid chain at C-2. α-tocopherol is methylated at C-5, C-7 and C-8 on the aromatic ring (Fig. 1b). The other homologues (β- γ- δ-) differ in the number and positions of the methyl groups on the ring. Tocotrienols differ from the corresponding tocopherols in that the isoprenoid side chain is unsaturated at C-3′, C-7′ and C-11′ (Bramley et al. 2000).

Vegetables in addition to fats, oils and cereal grains constitute the major source of tocopherols and tocotrienols in our diet. They are present in different concentration depending on oil origin and they are considered very important bioactive compounds mainly because of their ability to react with and quench free radicals in cell membranes and other lipid environments, thereby preventing PUFA from being damaged by lipid oxidation. Tocopherols also influence cellular responses to oxidative stress by modulating signal-transduction pathways, prevent cardiovascular diseases (CVD), tumour formation, neurological disorders etc.

Domestic processing

Tocopherols are rather stable at freezing, cooling (Murcia et al. 1992) and room temperatures if they are keep out of oxygen and light. Therefore, their levels are maintained during in most of the domestic storage operations and some of processes that take place before the cooking treatments. Only prolonged oils storage might influence their levels since they are the first molecules to be oxidized (20% α-tocopherol after 2 months, 92% after 12 months storage) protecting others such as squalene and *o*-diphenols characteristic compounds of extra virgin olive oils (Rastrelli et al. 2002). Tocopherols and tocotrienols are the most important natural antioxidants in fats and oils, acting as primary or chain-breaking antioxidants by converting lipid radicals to more stable products (Bamley et al. 2000). As a result of their antioxidant activity they are themselves subject to destruction by oxygen, giving rise to a number of products including quinones, dimers, trimers an epoxides.

Domestic hot-smoking of trout, a common practice in Nordic kitchens, did not affect α-tocopherol content (Jittinandana et al. 2006). But, other more usual process such as dough-making to prepare French bread might produce more than one-third of

α-tocopherol reduction because of the oxygen which is incorporated into the dough (Wennermark et al. 1994). Preparation of other dough-containing products such as Mexican tortillas destroyed almost completely the high tocopherols content of raw corn (8.1 mg/100 g) (Wyatt et al. 1998).

One of the most drastic domestic processing for tocopherols is the preparation of an omelette (Murcia et al. 1999). Egg beating prior to cooking, breaks the micellar phase of the yolk, thus increase susceptibility to oxidation. This may bead to the formation of peroxides, intermediate products in the auto-oxidation of the fatty acids, destroying the tocopherols since these would react with the peroxides.

Cooking methodologies

Tocopherols and tocotrienols are fat-soluble molecules so it was not expected to be highly influenced by water-involve cooking methods (Table 2). According to Bernhardt and Schlich (2006) and Gliszczynska-Swiglo et al. (2006), cooking methods such as boiling, stewing, steaming, pressure steaming and microwaving did not modify the tocopherol content in broccoli or red pepper, on contrary, they provoked a significant release of α- and γ-tocopherol when fresh broccoli were cooked (from 0.32 mg/100 g in raw broccoli to 1.54 after boiling or to 1.70 mg/100 g after pressure steaming). This effect was not observed if frozen broccoli were cooked. However, a few authors reported significant losses on aqueous media bringing again to discussion the controversies pointed before for the previously described lipidic compounds: the increase of the chemical extractivily of lipidic molecules with the heat treatment.

Boiling, steaming pressure cooking and mixed cooking

Tocopherol losses in carrots, cabbages, Brussels sprouts and leeks during cooking in water were reported to be between 10 and 20% (Elmadfa and Bosse 1985) depending on the type of food and cooking time. In several cereals and legumes, conventional cooking caused higher losses ranging from 22 to 55% in cereals and 9% to 59% in legumes (Wyatt et al. 1998). The latter results were in disagreemet with others where no significant α- and γ-tocopherol reduction was found after a soaking and boiling process of several legume varieties (beans, chick peas and lentils) (Atienza et al. 1998) or, they were never lower than 88% (Leskova et al. 2006). Differences in legume varieties and cooking procedures from two different countries might explain the variation in their results because, for instance, the amount of water utilized for cooking influenced significantly the tocopherol and tocotrienol degradation when rice bran is boiled. Rice bran is a good source of tocopherols and tocotrienols (103 mg/100 g). When 6 and 12 g of water per 100 g bran were utilized for cooking almost all tocopherols and tocotrienols were destroyed (97–99%) while if 50 and 400 g water were used, tocopherol and tocotrienol destruction ranged from 51 to 72% (Anil-Kumar et al. 2006).

Boiling meat products showed a detrimental effect on tocopherol content as boiling rabbit meat lead to 39% tocopherol reduction while other processes such as frying (12%) or roasting (14%) were less aggressive (dal Bosco et al. 2001).

In the so called 'mixed cooking' methods, a water or steam cooking is conducted after or together with a short frying (brasing, stewing etc.). In this special combination, if a mixture of virgin olive oil and water is selected as cooking media in a pressure cooker (30 min) no significant reduction of the α-tocopherol fraction takes place (Brenes et al. 2002).

The use of other fats to stew such as margarine could be detrimental to the tocophenol content. If peas are stewed (3 min 70°C), some loss of tocopherol occurred in those brought by the margarines. The total tocopherol losses are much higher when stewing is carried out in a stainless steel pot (57%) than in a glass pot (0.7%) (Steinhart and Rathjen 2003).

The final tocopherol concentration of beef fillets (*Psoas major*) submitted to brasing (pan-fried with oil for 5 min followed by 90 min steam cooking) was also dependent on the utilized oil. Beef increased its α- and γ-tocopherol concentration because of the incorporation of these compounds from the cooking medium. But, the final α-tocopherol content was higher if olive oil was utilized compared with corn oil or partially hydrogenated plant oil. Only if corn oil was used higher γ-tocopherol content was found in the beef fillets (Saghir et al. 2005).

Table 2 Effect of different cooking procedures on the tocopherols levels of fish, vegetables and meat according to various authors

Food	Compound (mg/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stewing	Stir-fried (in olive oil)	Braised	Reference
Sand smelt	α-Tocopherol	0.06					1.93		Kalogeropoulos et al. (2007a)
Anchovy	α-Tocopherol	0.08					2.78		Kalogeropoulos et al. (2007a)
Picarel	α-Tocopherol	0.03					2.79		Kalogeropoulos et al. (2007a)
Striped mullet	α-Tocopherol	nd					2.97		Kalogeropoulos et al. (2007a)
Bogue	α-Tocopherol	0.1					2.92		Kalogeropoulos et al. (2007a)
Scad	α-Tocopherol	0.03					2.29		Kalogeropoulos et al. (2007a)
Hake	α-Tocopherol	0.01					2.36		Kalogeropoulos et al. (2007a)
Sardine	α-Tocopherol	0.03					2.61		Kalogeropoulos et al. (2007a)
Potato	α-Tocopherol	0.28					1.72		Kalogeropoulos et al. (2007b)
Green pepper	α-Tocopherol	0.16					1.21		Kalogeropoulos et al. (2007b)
	α-Tocopherol	0.31	1.89						Kim et al. (2007)
	γ-Tocopherol	0.22	nd						Kim et al. (2007)
	δ-Tocopherol	0.01	nd						Kim et al. (2007)
Red pepper	α-Tocopherol	3.93	3.59	3.7	3.39	3.45			Bernhardt and Schlich (2006)
Zucchini	α-Tocopherol	0.09					1.5		Kalogeropoulos et al. (2007b)
Eggplant	α-Tocopherol	0.18					5.61		Kalogeropoulos et al. (2007b)
	α-Tocopherol		0.19						Kim et al. (2007)
	γ-Tocopherol		0.6						Kim et al. (2007)
	δ-Tocopherol		0.1						Kim et al. (2007)
Soybean sprout	α-Tocopherol		0.17						Kim et al. (2007)
	γ-Tocopherol		1.77						Kim et al. (2007)
	δ-Tocopherol		0.2						Kim et al. (2007)
Spinach	α-Tocopherol		3.41						Kim et al. (2007)
	γ-Tocopherol		3.46						Kim et al. (2007)
	δ-Tocopherol		nd						Kim et al. (2007)
Broccoli	α-Tocopherol	0.32	1.54	1.7	1.58	1.61			Bernhardt and Schlich (2006)
Beef	α-Tocopherol	5.2					6.3	6	Saghir et al. (2005)
	γ-Tocopherol	0.18					0.27	0.21	Saghir et al. (2005)

nd: not detected

Frying

The α-tocopherol content of raw fishes such as sand smelt, picarel, anchovy, striped mullet, bogue, scad, hake and sardine was less than 0.1 mg/100 g fw. When they were pan-fried in virgin olive oil, the oil was absorbed by fish during the frying process (as occurred in brasing) resulting in a significant enrichment of α-tocopherol in the fried samples ranging from 1.93 mg/100 g fw to 2.97 mg/100 g fw representing an increase of 1–2 orders of magnitude (Kalogeropoulos et al. (2007a)) when similar frying processes were performed with different vegetables, the α-tocopherol increase was 6–30 times more depending on the vegetable considered (Kalogeropoulos et al. 2007b). The tocopherols in this type of oil are stable during any of the usual domestic heating conditions (160–190°C for 30–120 min) because of the effective protective effect of its polyphenols, both molecules work synergically as lipidic antioxidants (Pellegrini et al. 2001). The use of other oils (corn oil, partially hydrogenated vegetable oil, etc.) is not negative for the tocopherol content if the frying process are not very long such as, i.e. during a pan-frying of salmon fillets (Al Saguir et al. 2004). In this case, the tocopherol levels remained almost stable and were not affected by oxidation.

Reutilization of the oil in successive frying cycles (cooking–cooling–storage–cooking-) decreased the tocopherol levels. α-Tocopherol was more susceptible of oxidation than other isomers in deep-frying on potatoes on rapeseed oil since after 4 or 5 cycles a 50% reduction was noticed. β- and γ-Tocopherols reached similar reductions after 7 or 8 cycles (Gordon and Kourimska 1995). This effect was more destructive if a pan was used for frying compared with deep-frying (Andrikopoulos et al. 2002a, b) because in the pan, the oil is more exposed to oxygen.

Tocopherol retention in deep-fat oils is affected by the presence or absence of a food coating. Miyagawa et al. (1991) demonstrated that when potato slices were tempura-fried (flour coated) higher tocopherol reduction was observed than when they were fried without coating.

Roasting or baking

The use of margarine as fat to help roasting of steaks and potatoes (6 min 180°C and 15 min 120°C) resulted in some loss of tocopherols from the margarines. The highest total tocopherol losses occurred during roasting of steaks (17.2–49.9 mg/100 g fat) more than of potatoes (Steinhart and Rathjen 2003). Margarine is also not recommended for doughs because baking of cakes and cookies (60 min 175°C and 12 min 200°C) provoke loss on the margarine tocopherols depending on its PUFA content. Oxidation was also higher in cakes than in cookies (Steinhart and Rathjen 2003).

As previously described, the α-tocopherol of a French break mix is reduced during dough making. Afterwards, further losses will occur during the baking of the baguette with an overall reduction of about 56–65% (Wennermark et al. 1994).

Microwaving

Foods containing high levels of fat readily absorb microwaves, yet relatively little is known about how microwave heating affects the lipidic components of foods. Microwave heating is another method (like frying) used to prepare omelettes. A substantial tocopherol reduction was observed in egg yolks (up to 50%) when both treatments were applied while boiling was a less drastic treatment (Murcia et al. 1999). Yoshida and Kajimoto (1989) reported that microwave processing of soybean seeds led to an approx. 40% loss of tocopherol. However, microwaving seemed a better method than frying at 180°C to maintain unchanged the α-tocopherol content of olive oils (Brenes et al. 2002). The order of stability during microwave heating was $\delta > \beta > \gamma >$ α-tocopherol (Yoshida et al. 1991).

Polyunsaturated fatty acids

Polyunsaturated fatty acids (PUFAs) ω-6 and ω-3 are essential lipids for human health. Actually, people from developed countries include large amounts of saturated and ω-6 PUFAs in their diets which are detrimental to their health increasing the risk of CVD and other chronic diseases. Nowadays, inclusion of fish in the diet is encouraged and food industry is designing new functional foods supplemented with ω-3 fatty acids to balance the ω-6/ω-3 ratio.

Linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are essential PUFAs because mammals cannot synthesize them *de novo* (Whelan and Rust 2006). They are indispensable components of the cell membrane, important in brain and retina, cell growth and division, platelet aggregation, inflammatory responses, haemorrhage, vasoconstriction and vasodilatation and immune functions. Recent studies have shown their role in prevention and treatment of CVD, diabetes, arthritis, cancer and other disorders (Simopoulos 1999).

Important ω-6 fatty acids in nutrition are: linoleic acid (LA, 18:2) and the arachidonic acid (AA, 20:4), a physiologically significant ω-6 fatty acid and precursor of prostaglandins and other physiologically active molecules.

Dietary sources of ω-6 fatty acids include cereals, whole-grain breads, most vegetable oils, eggs and poultry and baked goods. Most seed oils contain LA while fish oil, soybean oil, canola oil, flaxseed oil, and green leafy vegetables are the major sources of ω-3 fatty acids. ALA is found in a wide range of plant products while the best sources of EPA and DHA are cold water oily fish such as wild salmon, herring, mackerel, anchovies and sardines. Although fish do not synthesize them, they obtain them from the algae in their diet, thus new alternative natural sources such as many species of marine microalgae are appearing in the market.

Domestic processing

Lipids containing polyunsaturated fatty acids and their esters are easily oxidised by molecular oxygen by a free radical chain mechanism called autoxidation. In general terms, and depending on the storage conditions, storage of fatty products leads to a decrease in the content of the PUFAs fraction (Table 3). Refrigeration and freezing are domestic procedures commonly used for fish storage. Cold storage in a fridge for 7 days was detrimental for lipids of the dark meat of sardine (*Sardinops melanosticta*), which were unstable and susceptible to oxidation (Yamamoto and Imose 1989). At freezing temperatures, most of fatty acids of catfish fillets (especially PUFAs) gradually decreased in fish fillets stored at –10°C. This decreasing tendency was also noticed even when fillets were kept at lower temperatures (Eun et al. 1994).

Cooking methodologies

Heating treatments of fatty products always involve oxidative processes that lead to the production of toxic volatile and non-volatile compounds. Polyunsaturated fats are more susceptible to oxidation during heating than monounsaturated fats. Heating at different cooking temperatures leads to an increase in volatile compounds such as acetaldehyde, propenal, and propanal resulting from ω-3 fatty acids oxidation, whereas the formation of compounds such as hexanal corresponds to losses of linoleic acid (Boyd et al. 1992). Dienaldehydes are also by-products of PUFA peroxidation and they are commonly found in many foods or food-products, like heated oils. When marine species are processed at high temperatures, damage to PUFAs lead to primary and secondary lipid oxidation products, which might result in browning (Pokorny 1981), formation of fluorescent compounds (Lubis and Buckle 1990), flavour changes (Kunert-Kirchhoff and Baltes 1990), and loss of essential nutrients (Nielsen et al. 1985).

Enriching foods with long-chain ω-3 PUFAs is an interesting approach to increase the dietary intake of these beneficial nutrients. Supplementation of meat and eggs can be achieved by adding flaxseed, fish oil, or fishmeal to pig, beef or poultry feeds. But, when these enriched meats are submitted to a usual domestic cooking, higher levels of lipid oxidation products are found. Volatiles such as n-alkanals, 2-alkenals, 1-alkanols, and alkylfurans increased up to four-fold in aroma extracts of cooked steaks (with increased PUFAs content). Most of these compounds were derived from the autoxidation of the more abundant mono- and di-unsaturated fatty acids during cooking and such autoxidation appeared to be promoted by increased levels of PUFAs (Elmore et al. 1999). Similar effects were observed when lambs were fed with fish oil: unsaturated aldehydes, unsaturated hydrocarbons and alkylfurans increased up to four-fold due to PUFAs autoxidation during cooking (Elmore et al. 2000). Nevertheless, other authors reported that when using a specific stabilized tuna fishmeal formulation as a source of DHA for enrichment of park and poultry products the increases were retained after cooking (Howe et al. 2002). These PUFAs stabilization might be carried out by supplementing ω-3-enriched-product with antioxidants such as α-tocopheryl acetate or natural antioxidants such

Table 3 Effect of different domestic treatments on the PUFAs content of different foods according to various authors

Food	Compound	Storage (freezing)	Blanching	Boiling	Steaming	Frying	Grilling	Microwaving	Reference
Sardine	PUFAs	(–)							Yamamoto and Imose (1989)
								0	Hearn et al. (1987)
	ω-6/ω-3 ratio					(+)			Sánchez-Muniz et al. (1992)
						(+)			Candela et al. (1998)
						(–)			Castrillón et al. (1997)
Catfish	PUFAs	(–)							Eun et al. (1994)
Sweet corn	PUFAs		0						Rodriguez-Saona et al. (1995)
									Dornenburg and Davies (1999)
Meat	PUFAs		(–)						Fox et al. (1994)
Hake	PUFAs			0					Mendez et al. (1992)
Silver carp	ω-3 PUFAs			0					Tothmarkus and Sasskis (1993)
Albacore	PUFAs				(+)				Gallardo et al. (1989)
Culinary oils	PUFAs					(–)			Claxson et al. (1994)
									Silwood and Grootveld (1999)
									Seppanen and Csallany (2006)
								(–)	Hassanein et al. (2003)
Sole	ω-6/ω-3 ratio					(+)			Yanar et al. (2007)
Bake	ω-6/ω-3 ratio					(+)			Yanar et al. (2007)
Codfish	ω-6/ω-3 ratio					(+)			Yanar et al. (2007)
Sea bass	ω-6/ω-3 ratio					(+)			Yanar et al. (2007)
	PUFAs						(+)		Yanar et al. (2007)
								0	Yanar et al. (2007)
Herring	ω-6/ω-3 ratio					(+)			Aro et al. (2000)
	PUFAs						(+)		Regulska-Ilow and Ilow (2002)
								0	Regulska-Ilow and Ilow (2002)
Salmon	ω-6/ω-3 ratio					(+)			Candela et al. (1998)
						0			Al-Saghir et al. (2004)
							0		Al-Saghir et al. (2004)
	PUFAs					(–)			Gladyshev et al. (2006)
Mackerel	ω-6/ω-3 ratio					(+)			Candela et al. (1998)
	PUFAs						(+)		Shozen et al. (1995)
								0	Hearn et al. (1987)

Table 3 continued

Food	Compound	Storage (freezing)	Blanching	Boiling	Steaming	Frying	Grilling	Microwaving	Reference
Butterfish	PUFAs							0	Hearn et al. (1987)
Mullet	PUFAs							0	Hearn et al. (1987)
Soybeans	PUFAs							0	Yoshida et al. (1999)
								(–)	Takagi et al. (1999)
Sunflower seeds	PUFAs							0	Yoshida et al. (2002)
Pumpkin seeds	PUFAs							0	Yoshida et al. (2006)
Egg yolk	PUFAs							(–)	Murcia et al. (1999)

(0): no significant losses; (+) Increase in the content; (–): decrease in the content

as the diterpene phenolic fraction from *Rosmarinus officinalis* (Vareltzis et al. 1997). Domestic processing of eggs enriched with ω-3 PUFAs reduced significantly the α-tocopherol content (16%) and increased lipid oxidation two- to nine-fold. PUFAs oxidation levels were higher in hard-boiled eggs (30.4%) than in scrambled eggs (Cortinas et al. 2003).

Blanching

Lipid oxidation is the quality-limiting attribute in many vegetables that generates off-flavours. Lipoxygenases, which catalyze the oxygenation of polyunsaturated fatty acids, are key enzymes in this pathway and their presence is believed to be the chief reason for the need for blanching prior to frozen storage. Some authors stated that a complete inactivation of lipoxygenase (LOX) and peroxidase (POD) from sweet corn can be achieved within 9 and 15 min of steam blanching, protecting the PUFAs from degradation (Rodriguez-Saona et al. 1995; Dornenburg and Davies 1999). On the contrary, blanching of raw meat led to a decrease in PUFAs content, higher free fatty acid levels and significantly higher peroxide values (Fox et al. 1994).

Boiling, steaming and pressure cooking

Boiling or water cooking processes seemed adequate methods to maintain the lipidic profile in fishes. For instance, not significant change in the total PUFAs amount was observed in boiled hake (*Merluccius hubbsi*) when compared to raw hake (Mendez et al. 1992). Morover, only a slightly modification on the relative proportions of saturated and polyunsaturated fatty acids was found on trout fillets due to cooking process (Bouzidielmehdaoui et al. 1993). Boiling of silver carp was also recommended for keeping the ω-3 PUFAs level better than deep-fat frying since the latter method, either in the form of fillets or of minced patties, provoked a loss of fish oil of about 30–40%. According to Tothmarkus and Sasskiss (1993), the PUFAs EPA and DHA were surprisingly stable.

Steam cooking seemed a more drastic method than boiling since steaming of albacore (*Thunnus*

alalunga) provoked a general decrease in total lipid content. Nevertheless the decrease was on saturated and monounsaturated fatty acids while an increase in polyunsaturated fatty acids were observed in diglycerides of different fish muscles. (Gallardo et al. 1989).

Frying

Frying temperatures and methods affects the lipidic composition of the oil or fat used as cooking medium and of the food fried on it because important lipid exchange occurs between both components. In general terms, the oxidation of one component induces the oxidation of the other.

Thermal stressing of PUFAs-rich culinary oils (30–90 min at 180°C) generated high levels of n-alkans, *trans*-2-alkenals, alka-2,4-dienals and 4-hydroxy-*trans*-2-alkenals via decomposition of their conjugated hydroperoxydiene precursors, whereas in oils with a low PUFAs content only low concentrations of selected aldehydes were produced indicating that the higher the level of unsaturations the lower the oil stability to frying procedures (Claxson et al. 1994). If oils are subjected to repeated frying episodes, an increase of saturated and α-, β-unsaturated aldehydes is observed as lipid oxidation products from culinary oils (Silwood and Grootveld 1999). Moreover, continuous oil exposure to frying temperatures (185°C) increases the formation of HNE (4-Hydroxy-2-*trans*-nonenal), a cytotoxic secondary lipid peroxidation product of linoleic acid, and other polar lipophilic aldehydes. The formation of HNE and other hydroxyaldehydes at frying temperatures was a cumulative result of PUFAs oxidation over time (Seppanen and Csallany 2006).

PUFAs ω-6 content of sardines rose 4, 6.3 and 19.9 times when they were deep-fried on olive oil, lard, and sunflower oil, respectively. The PUFAs ω-3 fell 3.3 times in the case of sunflower oil and 2.2 times with olive oil, with no changes with lard. Therefore, results confirmed that frying produced an exchange between the sardine fat and the frying medium, which caused significant changes in the fatty acid composition and in the ω-6/ω-3 ratio of the oily fish (Sánchez-Muniz et al. 1992). Similar results were obtained with other fishes: frying of sole (*Solea solea*), bake (*Merluccius merluccius*), codfish (*Gadus morrhua*) (Candela et al. 1997), sea bass (*Dicentrarchus labrax*) (Yanar et al. 2007) and Baltic herring (*Clupea harengus membras*) (Aro et al. 2000) provoked similar increase in the ratio *cis*-polyunsaturated/ saturated fatty acids (PUFAs/SFAs) due to the absorption of the cooking medium, leading to an increase in the ω-6/ω-3 ratio.

Nevertheless, the precise effect of deep-fat frying on the fish ω-3 content is specie-dependent. For instance, raw sardines and mackerel are important sources of ω-3 polyunsaturated fatty acids, but this ω-3 PUFAs content decreased significantly during frying from 24.0 and 16.6 g/100 g fat, to 6.6 and 5.4 g/100 g fat, respectively. On the other hand, salmon, despite having the lower amount of eicosapentaenoic acid and docosahexaenoic acid in raw samples, was the best source of these fatty acids after frying (1.7 g/100 g of food). Therefore, the ratios of total ω-6/ω-3 fatty acids increased with cooking from 0.12 to 1.07 in salmon, from 0.12 to 6.19 in mackerel, and from 0.07 to 5.98 in sardines (Candela et al. 1998).

Pan-frying or shallow-frying (in olive oil) also produced losses in saturated and polyunsaturated fatty acids from sardine fillets (Castrillón et al. 1997). But, no significant change was detected in the ω-3 fatty acids content and in the polyunsaturated/ saturated-ratio of cooked salmon fillets submitted to different cooking processes such as grilling on a pan without oil, and pan-frying with olive oil, corn oil, or with partially hydrogenated plant oil (Al-Saghir et al. 2004). Only a modest reduction of PUFAs contents was reported by Gladyshev et al. (2006) when fillets of humpback salmon were subjected to frying. It was hypothesized that the absence of significant reduction of PUFAs contents in *Salmonidae* family during heat treatment may be due to a high level of natural antioxidants.

Grilling and baking

Grilling of marine fish products (rich in EPA) such as dried products made from Japanese whiting, squid buccal mass and northern cod, produced a fairly large decrease in the levels of PUFAs. On the contrary, grilling of fishes with lower levels of EPA, such as salted-dried Pacific round herring (Regulska-Liow and Liow 2002), sea bass fillets (Yanar et al. 2007)

and fermented-dried horse mackerel, caused a relatively low PUFAs degradation (Shozen et al. 1995).

Moreover, baking did not significantly modify the fatty acid composition of sea bass fillets (Yanar et al. 2007) but led to losses in the content of tocopherol during the preparation of hot meals, which may have an effect in the lipid, and hence in the PUFAs oxidation (Steinhart and Rathjen 2003).

Microwaving

It has been suggested, that the high levels of energy involved in the microwaving process promotes the oxidative processes in PUFAs and the formation of conjugates and polymers within minutes since microwaves force the molecules to vibrate strongly, affecting especially the hydrogen atoms of the active methylene groups which are adjacent to the unsaturated centres (Radwan et al. 1991). But, when the stability in microwave ovens of PUFAs from different food products such as butterfish, mullet, mackerel and sardines (Hearn et al. 1987), herring (Regulska-Iiow and Iiow 2002), cultured sea bass (Yanar et al. 2007), soybeans (Yoshida et al. 1999), sunflower seeds (Yoshida et al. 2002), kernels of pumpkin seeds (Yoshida et al. 2006), was investigated, microwave heating did not lead to significant losses of polyunsaturated fatty acids. Only Murcia et al. (1999) reported a decrease in 18:2, 18:3, 20:4 and 22:6 PUFAs in samples of egg yolk subjected to microwaving, and Takagi et al. (1999) in the percentages of PUFAs from soy beans (Takagi et al. 1999).

Furthermore, when corn and palm oils, ghee and camel fat were submitted to different heating times (5, 10 and 15 min) some TG were hydrolyzed to free fatty acids. An increase in the lipid oxidation was observed leading to a decrease in PUFAs percentage and an increase in the saturated ones (Matalgyto and Al-Khalifa 1998). Moreover, heating of sunflower, soybean and peanut oils resulted in a generally decrease of PUFAs with the increasing of the heating period (Hassanein et al. 2003). These results may suggests that, in the case of high lipid-containing food such as fats and oils, the microwaving process cause more adverse effects than in food products such as above cited, where lipids are involved in a matrix together with other compounds such as proteins or carbohydrates.

Phenolic compounds and flavonoids

Phenolic compounds are usually classified in two main groups: Those consistent with a skeleton C_6–C_1, and those corresponding to a skeleton C_6–C_3. To first group belong chemicals as hidroxybenzoic acid while to the second group others such as cafeic, ferulic and isoferulic acid (Fig. 1e). Flavonoids are characterized by a skeleton of three units, C_6–C_3–C_6, that forms a cyclic structure in most cases (Geissman 1962). In this skeleton two aromatic rings, referred to as A and B (in chalcones), can be distinguished, and an additional third ring (C), in the rest of the flavonoids (Fig. 1d). Different flavonoids can be classified according to the oxidation degree of the three carbon central segment. From a lower to higher oxidation degree the flavonoids are usually named as catechins, chalcones, flavanones, isoflavones, flavan-3, 4-diols, flavones, aurones, flavonols and anthocyanins. The different basic structures can show different substitution patterns. These may include, as more often, hydroxylations, methoxylations, glycosilations and more rarely substituted methylendioxiflavonoids, such as pirano and furano flavonoids, with isoprenes, and even more unusually alkaloids, such as ficin, filospadin and litalin (Wollenber 1993).

Phenolics and flavonoids are widespread throughout the plant kingdom. They are present, as traces, in practically all the edible plants that express the metabolism of the shikimate pathway. Within the different kinds of these products, flavanones occur as major flavonoids in citrus and their derivatives (Benavente-García et al. 1997). Isoflavones, such as genistein and daizdein, are found in legumes (most kind of beans) and particularly in soy and soy containing product, such as infant foods, vegetarian formulations, among others (Peterson and Dweyer 1998). Flavones are often found in grains and herbs (i.e. parsley, lamiaceae plants and cereal grains) and vegetables such as celery (Peterson and Dweyer 1998), lemons, olives, peppers and red grapes, and in fruit skins. Some polymethoxylated flavones are found in citrus peel and herb exudates. Flavonols are found throughout plant foods, some of the most extensively present in the plant kingdom are quercetin, rutin (the glycoside form of quercetin), kaempferol, isorhamnetin and myricetin. They are present in onions, apple peel, in berries, black grapes, tea, broccoli, endives, leeks, grapefruit, pears

and corn) (Marín et al. 2002). Anthocyanins occur widely in the red to blue coloured parts of plants. They can be found in several berry fruits, such as cherries and strawberries, in plums, eggplants, red cabbages, radishes and coloured wines (Strack and Wray 1993). Catechins, also known as flavan-3-ols, are present as epicatechins, gallocatechins, and epigallocatechins in fruits but they mainly occur in considerable amounts in green tea and in smaller amounts in black grapes and red wine (Rice-Evans and Miller 1996; Robards and Antolovich 1997). Regarding to phenolics they are even more ubiquitous than flavonoids being present in practically all plants as are formed directly from the shikimate pathway.

Within the last years, flavonoids have been highlighted as possible chemopreventive dietary agents against cancer. They have shown ability to absorb ultraviolet (UV) radiation protecting DNA. They have also shown protective effect on bleeding and capillary fragility, and other properties including antimicrobicide and antioxidant activities (Marin et al. 2002).

Domestic processing

Domestic processing may affect to the final content of flavonoids and phenols in two ways. Firstly, with the skinning, peeling and in some cases seeds separation of fruits and vegetables. This can be considered as anatomical separation and no much opportunity is offered to enzymes, but interesting sources of bioactive compounds may be discharges. Secondly, foodstuff may undergo mechanical conditioning such as chopping. In this case, the noticed losses may be explained by enzymatic activities.

As an example of the first situation Toor and Savage (2005) found that skin and seed fraction of tomatoes are a very rich source of phenolic and flavovonoids accounting for approximately half of the total amount. Therefore, removal of these fractions during home cooking or processing results in a loss of their potential health benefits. A similar situation happens with strawberries. Thus, achenes contribute until 66, 38 and 44% of the total phenolics, flavonoids and anthocyanins respectively of the whole fruit while less than 10% of the weight. It is hard to imagine somebody taking out the achenes from the berry, but if anybody does it is wasting the main source of phenolics (Cheel et al. 2007).

As example of the second case, Makris and Rossiter (2001) reported that chopping of onion bulbs, followed by 60 min maceration, resulted in a decrease in quercetin 3,4′-diglucoside, reported in less than 2.3%, with concomitant increase in quercetin 4′-glucoside (0.8%) and quercetin (3.7%), which it may be explained by a glycosidase activity elicited during the chopping process. Overall, a negligible loss of 1% was also found (Makris and Rossiter 2001). Chopping of asparagus spears, as reported by Makris and Rosisiter, resulted in a considerable decrease in rutin (18.5%) with no detected transformation into quercetin.

Other kind of pre-treatment is overnight soaking used for beans. In this case it has been reported losses of less of 2% of total phenolics, and the detection of *p*-coumaric, ferulic and sinapic acid in the soaked water (Luthria and Pastor-Corrales 2006). Although soaking is not home-used for soy, at industrial manufacture has been reported losses up to 12% of isoflavones (Wang and Murphy 1996).

Storage lead, in onions, to a slight decrease in the total quercetin content. The losses are reported since the first week and during the whole period of the study (24 weeks). These losses vary depending on the onion variety from 16% to a 36% in brown and red skinned respectively (Price et al. 1997).

Cooking methodologies

Boiling

During boiling flavonoids seem to undergo a double process. On one hand they lower their amount in food due to leaching and on the other hand, appear new products due to breakdown of the naive flavonoids (Table 4). Thus, boiling of onion bulbs considerably affect the content of quercetin 3,4′-diglucoside, quercetin 4′-glucoside and quercetin, yielding losses of 8.4, 37.6 and 43.2% respectively, with an overall loss being 20.6%. From these losses approximately 36.4% of quercetin 3,4′-diglucoside and 22.7% of quercetin 4′-glucoside leached into the cooking water, being favoured the leaching of quercetin 3,4′-diglucoside as a more polar compound (Makris

Table 4 Losses of phenolic compounds, as percentage, under different culinary methods

Food	Compound	Boiled (%)	Stir-fried (%)	Baked (%)	Microwaved (%)	Steaming (%)	Reference
Onion	Quercetin 3,4′-diglucoside	8.4					Makris and Rossiter (2001)
	Quercetin 4′-glucoside	37.6	35		64		Crozier et al. (1997)
	Quercetin	43.2	21				Crozier et al. (1997)
Asparagus	Rutin	70					Makris and Rossiter (2001)
Beans	Phenolic acids	15					Makris and Rossiter (2001)
Strawberries	Quercetin	18					Häkkinen et al. (2000)
	Ellagic acid	20					
Brocoli	Total flavonoids	82	11		43	11	Gliszczyuska-Swigo et al. (2006)
	Caffeoyl-quinic derivatives	60	8		87	8	Zhang and Hamazu (2004)
	Sinapic and feruoyl derivatives	51			76	1	Podsedek (2007)
Tomatoes	Quercetin 4′-glucoside				65		Crozier et al. (1997)
	Total phenolics		30	12			Sahlin et al. (2004)
Pear	Flavan-3-ols	80					Renard (2005)
	Caffeoylquinic acid	40					
Potatoes	Total polyphenols		62				Kalogeropoulos et al. (2007a, b)
Green pepper	Total polyphenols		62				Kalogeropoulos et al. (2007a, b)
Egg plant	Total polyphenols		71				Kalogeropoulos et al. (2007a, b)
Zucchini	Total polyphenols		75				Kalogeropoulos et al. (2007a, b)

and Rossiter 2001). They also reported that during boiling of chopped onion new products are also formed. Boiling of asparagus tissues yielded a rutin losses of approximately 70%, being a 30% leached and a 43.9% decomposed in bunch of compounds with shorter retention times (Makris and Rossiter 2001). Boiling also affects the final content of phenolics in beans, where 15% of total phenolic acids may either be oxidized during the cooking process or else converted into other phenolic compounds (Luthria and Pastor-Corrales 2006). Recently, Buchner et al. (2006) have studied the effect of thermal processing on rutin and quercetin. They found that a strong degradation of the former substances take place under weak basic and oxidative conditions. They also found that rutin and quercetin split through different breakdown patterns, which can be explained by the 3-C glycosilation of rutin. To this respect, quercetin shows the most intense degradation, being protocatechuic acid one of the cleavage reaction product. Other, such as 2,5,7,3′,4′-penthahydroxy-3,4-flavandione, among others, are suggested as second cleavage products.

Although most studies have been done with onions and tomatoes, many authors have used fruits as food model. Thus, Renard published in 2005 a paper where the effect of boiling on flavan-3-ols (epicathequin and its procyanidin olygomers) and phenolics is reported. To this respect, these compounds undergo a pattern consistent with that observed for other matrix. Thus, after 20 min and 1 h boiling pear sections the flavan-3-ol content is reduced to a 80% and 65% respectively while the content in caffeoylquinic acid drops down to 40% of the initial as soon as 20 min after boiling. The amount of flavan-3-ols detected in the cooking water was 2% (of the initial food content) at maximum, while phenolics acid can reach up to 20% (of the initial food content). Notwithstanding is interesting to notice that for both classes of compounds, and after 1 h boiling, their amount decrease progressively, which is consistent with the observations above discussed (Renard 2005). A similar pattern has been observed for other fruits. Thus, in strawberries losses of quercetin (18%) and ellagic acid (20%) are described when home made jam was prepared (Häkkinen et al. 2000).

When comparing boiling with other thermal processes such as microwaving and frying, the first seems to be the less friendly for flavonoid conservation Thus, Crozier et al. (1997) reported contents in conjugated quercetin, respect to the uncooked food, of 18%, 35% and 65% respectively in tomatoes and 25, 36 and 79% respectively in onions. These results point that frying may not reduce significantly the amounts of the original flavonoid content while boiling might reduce them drastically.

Steaming and pressure cooking

Opposite of boiling, steam-cooking, in broccoli, has been reported to increase the content in polyphenols (Gliszczynska-Swiglo et al. 2006). However, other studies, although report a good rate of phenolic, show very slight losses of total flavonoids and caffeoylquinic derivatives in broccoli (11% and 8% respectively), while no loss of total sinapic and feruloyl derivatives occurred. According to the authors, during steaming, phenolic compounds remained in the edible part of broccoli, probably owing to the inactivation of oxidative enzymes (Vallejo et al. 2003).

Frying

Temperature affects both flavonoid and phenolic content of the foodstuff and also the polyphenol compounds present in the oil used for frying. In the first case, Crozier et al. (1997) reported losses of conjugated quercetin of 21% and 35% in fried onions and tomatoes, respectively. Similar results for total phenolic content (30% of losses) in fried tomatoes is reported by Sahlin et al. (2004). On the contrary, Price et al. 1997 reported slight, but significant, increases in quercetin 3,4′-diglucoside after frying 5 min red skinned onions. Regarding to the flavonoids and the phenolics of the oil, Andrikopoulus et al. (2002), reported losses in these compounds that increase with frying sessions. Thus, the losses can be of 20% in the first cycle and arise up to 80% in the cycle eight. They also found that deep frying, in electric fryer, causes less losses than when is done in a pan, and that there is a different behaviour depending on the compound. Thus, tannins and hydroxyl-tyrosol-elenolic acid dialdeydic form exhibited remarkable resistance to oxidation when the used frying medium was olive oil.

On the other hand, other authors (Kalogeropoulos et al. 2007a, b) have studied the interchange of flavonoids and phenolics between the vegetable and virgin olive oil during frying. They reported a study with potatoes, green pepper, zucchini and egg plant. They found an increase on the total polyphenol concentration in the fried vegetables, with the exception of fried eggplants, in which the decrease of the major compound, chlorogenic acid, resulted in a respective decrease of total polyphenol concentration. It is noteworthy to highlight that eggplant is the vegetable with the highest content in phenolics of all the studied. Therefore, in the other plants, the increase could be explained by a net enrichment in phenolics from those originally present in the virgin olive oil. On the contrary, when the initial phenol concentration is higher in the food, the input from oil could not make up for the deterioration by frying.

Baking

Not too much attention has been focused on the effect of baking on flavonoid and phenolics content. To this respect Sahlin et al. (2004) reported slight losses in the total content of phenolics in baked tomatoes respect to the raw ones, being these of about of 12% of the initial content. These authors found a pattern similar to a boiling process, with variation in the total phenolic contents no higher than 3% between them.

Microwaving

Crozier et al. (1997) reported losses of conjugated quercetin of 64% and 65% in microwaved onions and tomatoes, respectively. Also, Zhang and Hamazu (2004) reported looses in total phenolics of 62% in broccoli florets and of 43% in broccoli stems. However, they did not found differences with traditional boiling, which suggest that, as no soaking effect is produced, losses may be attributed to degradation. To this respect, Vallejo et al. (2003) reported a study where the losses in phenolics compounds were compared when broccoli was submited to high-pressure boiling, low-pressure boiling, steaming and microwaving. The authors found clear disadvantages when microwaving was used noticing losses of 97, 74, and 87% in flavonoids, sinapic acid derivatives and caffeoylquinic acid derivatives.

Dietary fibres

Dietary fibre (DF) includes a wide range of compounds. Historically, according to Trowell et al. (1976) definition, dietary fibre is composed of the remnants of plant cells resistant to hydrolysis by human alimentary enzymes and that includes all indigestible polysaccharides (celluloses, hemicelluloses, oligosaccharides, pectins, gums) waxes and lignins (Fig. 1f). However, from time to time there have arisen questions about compounds that may be dietary fibre and which do not precipitate as dietary fibre called for in the AOAC method for dietary fibre analysis. One of the last definitions was adopted at the International Food Technologist society meeting, in July 1999, as follows: "Dietary fibre is the remnants of the edible part of the plant and analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the human large intestine. It includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibre exhibits one or more of either laxation (fecal bulking and softening; increased frequency, and/or regularity), blood cholesterol attenuation, and/or blood glucose attenuation (Prosky 1999).

Dietary fibre is naturally present in cereals, vegetables, fruits, and nuts. The amount and composition of fibres differ from food to food. Cereals are one of the main sources of DF, contributing for about 50% of the fibre intake in western countries; 30–40% of dietary fibre may come from vegetables, about 16% from fruits and the remained 3% from other minor sources (Rodriguez et al. 2006).

The biological effect of dietary fibre varies from those affecting to bioavailability of nutrients until those affecting to physiological functions, such as intestinal transit, and the development of pathologies.

Fibre polysaccharides affect the lipids absorption (Dunaif and Schneeman 1981), interfere in the cholesterol absorption (Thebaudin et al. 1997; Lairon et al. 2007) and influence negatively on the digestion and assimilation of proteins (Rodriguez et al. 2006). Insoluble DF seems to have little or no effect on

carbohydrate metabolism. However, water-soluble fibres and foods rich in viscous fibres have been found to reduce postprandial blood glucose levels (Rodriguez et al. 2006).

Domestic processing

As mentioned above, the main sources of fibres are cereals, vegetables—including legumes—and fruits. The different morphology and histology of each of them lead to a variety of pre-treatments. Thus, cereals usually are not pre-processed at home; legumes undergo an overnight soaking to soften them while fruits and other vegetables are peeled before eating or cooking, also chopping is used to conditioning these foodstuffs.

Peeling fruits is the simplest process and it leads to a substantial loss of the total fibre content. For example, citrus peel may content approximately until 70% of the total fibre of the whole fruit, and the peel (albedo and flavedo) is never consumed using only the remaining 30% (Fernandez-Lopez et al. 2004; Marin et al. 2007). On the other hand, legumes (chick-pea, bean, lentil, etc) are soaked overnight, which has been reported—in lentils—to reduce the quantity of fibre, due to a great decrease in hemicelluloses (Rodriguez et al. 2006). Other authors reported previously similar results for kidney-beans with decreases of 66, 23 and 14% in resistant starch, insoluble and total dietary fibre respectively (Kutos et al. 2003), being these results consistent with those reported by other authors (Zia-ur-Rehman and Shah 2004). On the contrary, the aforementioned authors also found increases of approximately 40% in the content of soluble dietary fibre. The same authors also studied the effect of the water quality during soaking, i.e. $CaCO_3$ in hard waters reduce the fibre content slightly more than soft waters. On the opposite, hard waters increase the content in soluble dietary fibre (Kutos et al. 2003).

A new trend in the consumption of legumes is to germinate them before eating or cooking. To this respect it has been reported increases of soluble fibre of 89, 74, 37 and 3% in lentil, chickpea, green gram and cowpea respectively after germination and no significant changes in insoluble fibre (Ghavidel and Prakash 2007).

During storage changes in fibre quantity and quality depend to a great extent on storage conditions. For example, in apples stored in bags with controlled atmosphere to assure their stability, no changes in the content of the total fibre were observed. However, in onions, stored in less restrictive conditions, a pronounced increase of polymers derived from uronic acid—i.e. pectins has been reported (Marlett 2000). Other vegetables, such as cauliflower, broccoli and asparagus suffer a hardening process. In asparagus, for instance, deposition of lignin, cellulose and hemicelluloses in the basal portion has been reported which explain the increase in the fibrousnesses (Rodriguez et al. 1999).

Cooking methodologies

Boiling usually results in the inactivation of practically all the enzymes that could negatively affect the sensorial properties of the foodstuff. Some of the undesirable effects that could happen are excessive softening of the plant tissues, loss of colour and flavour and/or development of odd colours and flavours. Although a large amount of foods undergo a thermal process there are not many references to the modifications that DF suffers during thermal processing (Table 5).

Boiling

There has been a number of investigations on the changes of dietary fibres and cell walls in plant tissue during cooking, mainly concerned potatoes, carrots and green beans, and the influence of preheating on texture change and pectinmethylesterase activation. Thermal treatments affect pectins in the first instance, owing to their susceptibility to β-elimination and the almost ubiquitous presence of pectinmethylesterases in plants. In the case of pears, the pectin fraction is degraded during cooking while xylanes and cellulose are not affected. To this respect, short periods do not affect the content in dietary fibre while long periods, over 1 h, lead to losses in the pectin content. Thus, it has been reported that the pectin content in the cooking water can increase upon 400% after 1 h boiling, when compared with the pectin content after 20 min boiling (Renard 2005). Other authors reported

Table 5 Changes in Fibre content under different culinary methods

Food	Compound	Peeling	Soaking	Germination	Boiling	Stir-fried	Steaming	Reference
Citrus	Soluble fibre	(–) (70%)						Marin et al. (2007)
Kidneybeans	Resistant starch		(–) (66%)		(+)			Kutos et al. (2003)
	Insoluble fibre		(–) (23%)		(–)			Kumar and Aalbersberg (2006a)
	Total dietary fibre		(–) (14%)					Tatjana et al. (2002)
	Soluble fibre		(+) (40%)					Zia-ur-Rehman and Shah (2004)
Lentil	Soluble fibre			(+) (89%)			(+)	Zia-ur-Rehman and Shah (2004)
	Cellulose							Clavidel and Prakash (2007)
Chickpea	Soluble fibre			(+) (74%)			(+)	Zia-ur-Rehman and Shah (2004)
	Cellulose							Clavidel and Prakash (2007)
Green gram	Soluble fibre			(+) (37%)			(+)	Zia-ur-Rehman and Shah (2004)
	Cellulose							Clavidel and Prakash (2007)
	Soluble fibre			(+) (3%)			(+)	Zia-ur-Rehman and Shah (2004)
	Cellulose							Clavidel and Prakash (2007)
Pears	Pectin				(–)			Reward (2005)
	Xylanes				0			
	Cellulose				0			
Flour	Resistant starch					(+) (5%)		Sanz et al. (2007)

(0): no significant losses; (+) Increase in the content; (–): decrease in the content

that during cooking kidney-beans a solubilisation of the aforementioned polysaccharides is produced, which results in a decrease of the total fibre content, mainly soluble (Tatjana et al. 2002). Similar results have been reported for cabbage (Wennberg et al. 2003). Nevertheless, other authors have reported increases in the fibre content, during boiling, which are explained by formation of complexes between polysaccharides and other compound of the food, such as protein (Rodriguez et al. 2006). A similar increase in soluble dietary fibre and insoluble dietary fibre has also been reported by Almeida-Costa et al. (2006) when legumes were cooked and lately freeze-dried. This increase in DF, after boiling, has been explained (Kumar and Aalbersberg 2006a) by the formation of resistant starch in the samples; this resistant starch formed upon cooking becomes analytically associated with non-starch polysaccharides, which is one component of dietary fibre. Other authors also reported increases in total dietary fibre even after the correction of the analytical results by removing the results of resistant starch and when resistant starch is considered as dietary fibre (Kutos et al. 2003).

Steaming and pressure cooking

As above-mentioned, boiling lead to an increase in total DF, which might be explained by formation of resistant starch. On the contrary, steam cooking lead to slight losses, less than 8%, of the total dietary fibre upon cooking. This loss could be attributed, according to Kumar and Aalbersberg (2006a), to the water loss into the drippings. In that way, it has been reported that pressure cooking has a pronounced effect on reduction of chemical components of insoluble dietary fibre. As a result of pressure cooking these authors reported reduction ranges of 17.0–35.8% and 37.6–42.3% in cellulose and hemicellulose for black grams, chickpeas, lentils, red kidney beans and white kidney beans, while no effect was observed for boiling and microwaving (Zia-ur-Rehman and Shah 2004). Similar results were reported, by the same authors, when the fibre sources were vegetables (cabbage, carrot, cauliflower, egg plant, onion, potatoes, radish, spinach, turnips), in which maximum losses corresponded to pressure cooking (Zia-ur-Rehman et al. 2003).

Frying

Foodstuffs with high fibre content (vegetables, fruits, legumes, etc) are not usually cooked by frying. However, flours are normally used to prepare coatings for products prior to frying. In this case it has been reported slight increases of total fibre content (5%) in the batter crust, which has been explained by a retrogradation of the wheat flour after frying (185°C) and cooling the battered food (Sanz et al. 2007).

Regarding to the total fibre content of the consumed foods it is also interesting the use of flours specially formulated for battering. These flours are supplemented with resistant starches to improve sensorial properties, such as crispness, that can arise till 20% of DF. However, as a side effect, an increase in the total fibre content of the meal is produced (Sanz et al. 2007).

Folic acid and folates

The generic term "folate" refers to the class of compounds having a chemical structure and nutritional activity similar to that of folic acid or pteroyl-L-glutamic acid (Fig. 1g). In nature, the vitamin exists primarily as reduced, one-carbon-substituted forms of pteroylglutamates, differing in substituent and number of glutamyl residues attached to the pteroyl group. Five different one-carbon units (methyl, formyl, formimino, methylene and methenyl) are known. Most of the naturally occurring dietary folates have a side chain of five to seven glutamate residues connected by γ-peptide linkages.

Naturally occurring folate is present in a wide range of foods, especially leafy green vegetables, legumes, yeast and liver (Stea et al. 2006). Vegetables-containing ready-to-eat foods contained less folate than fresh vegetables, ranging from 26 to 111 μg/100 g folates, because during their industrial processing (industrial cooking) they loss on average 32.2% of folates (Agte et al. 2002).

Folates are considered bioactive compounds, not only because of their role as B vitamin, participating in one-carbon transfer reactions required in many metabolic pathways, recent studies pointed folates as protective compounds against neural tube defects occurring during early pregnancy. In addition, other

studies suggests that they might reduced risk of occlusive vascular disease, risk of cancer, particularly colon cancer, etc. (Morrison et al. 1995).

Domestic processing

Folates are water soluble compounds therefore processes involving food immersion in water at room or boiling temperatures produce large folates losses. For instance, soaking and later boiling of legumes (26 different types) caused a significant loss of folate due to leaching of the compounds to the medium as soaking and cooking waters were found to contain a large amount of folates (Arcot et al. 2002a, b). Apparently, the longer the soaking time the higher the folate content leached to the soaking water (Hoppner and Lampi 1993) although these parameters do not always correlated. The degree of loss can be influenced by some factors, including pH, oxygen content, metal ion concentration, antioxidant levels etc. The presence of reducing agents in the food can increase folate retention during thermal processing and the presence of metals (Fe^{2+}) can increase folate loss (Gregory 1985; Leskova et al. 2006).

Vegetables have a higher folate levels compared to animal foods (meat, poultry and fish) but as leaching losses are not typically encountered, folate losses in the processing of meat may not be as high as for vegetables (Hawkes and Villota 1989).

Stability of folates during frozen storage of beef fiver, strawberries (up to 7 months) and other vegetables was very high (Vahteristo et al. 1998; Puuponen-Pimia et al. 2003). At room temperature and in dry conditions, folic acid seemed also reasonably stable as stored flours and cereal grains (Ranhotra and Keagy 1995).

Cooking methodologies

Boiling, steaming and pressure cooking

Folate intake is strongly influenced by the selected cooking method (Table 6). Boiling resulted in only 49% folate retention in spinach (191.8 and 94.4 μg/100 g for raw and boiled spinach respectively), and only 44% in broccoli (177.1 and 77.0 μg/100 g for raw and boiled broccoli respectively). Steaming of spinach or broccoli, in contrast, resulted in no significant decrease in folate content, even for the maximum steaming periods of 4.5 min (spinach) and 15.0 min (broccoli) (McKillop et al. 2002). Similarly, pressure-cooking allowed significantly higher folates retention compared to boiling in chickpeas (*Cicer arietinum*) (62.2 and 53% respect.) and field peas (*Pisum sativum*) (51 and 45% respect.). Retention of folates in chickpeas was greater and produced lower leaching than peas irrespective of the processing procedure used (Dang et al. 2000). Also boiling of potatoes (with and without skin) for 60 min did not result in a significant change in folate content (125.1 and 102.8 μg/100 g for raw and boiled potato respect.) (McKillop et al. 2002), therefore, the final folate retention is, apart from the cooking method, also depended on the food nature.

Moreover, as for the processing, boiling of animal foods resulted in lower folate reduction than vegetables. Leskova et al. (2006) estimated a retention range for total folate in meat and poultry to be 55–70% for boiling, braising and stewing and 60–90% for roasting and baking. In fish and shellfish, the retention range was 70–100% for poaching and steaming, and 0–90% for oven cooking.

Another important parameter to take into consideration is the boiling time, since during the first minute of boiling, spinach retains still 80.7% of folates but after 20 min only 5.5% remained. Most of the folates can be found in the cooking water, but after the second minute only the 68% can be recovered from the medium and after the third minute only 51.3%, rest of folates were probably degraded since they are termolabile compounds (Min 1998).

Blanching of Brussels sprouts caused relatively small folate losses (Malin 1977) apparently, their stability was partially attributed to the presence in relatively high concentrations of endogenous reducing agents that, as previously mentioned, enhance folate retention.

Frying

Stir-frying, in particular using a wok as Asian countries, is a better method to retain folates in vegetables than boiling since no water is involved. Folate content of 12 commonly consumed vegetables

Table 6 Effect of different cooking procedures on the folate content of several food products according to various authors

Food	Compound (ug/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stir-fried	Baked	Grilled	Microwaved	Reference
Spinach	Total folate	191.8	94.4		190					McKillop et al. (2002)
	Folacin (folic acid)	161	157						183	Klein et al. (1981)
	Total folate	150	90							Scott et al. (2000)
	Total folate	342	212							Han et al. (2005)
Broccoli	Total folate	177.1	77		170					McKillop et al. (2002)
	Tetrahydrofolate	147	111		123					Stea et al. (2006)
	5-Methyltetrahydrofolate	748	934		1139					Stea et al. (2006)
	Total folate	866	1009		1219					Stea et al. (2006)
Cabbages	Total folate	43	26							Han et al. (2005)
Potatoes	Total folate	125.1	102.8							McKillop et al. (2002)
	Ttetrahydrofolate	nd	nd				nd			Stea et al. (2006)
	5-Methyltetrahydrofolate	65.4	47.5				41.4			Stea et al. (2006)
	Total folate	63.2	45.7				39.8			Stea et al. (2006)
	Total folate	27	21							Han et al. (2005)
Peas	Total folate	101.5	45.7	51.1						Dang et al. (2000)
	Undeconjugated folates	87.5	38.9	43.4						Dang et al. (2000)
	Tetrahydrofolate	12.8	8.5		11				8.5	Stea et al. (2006)
	5-Methyltetrahydrofolate	226	175		165				170	Stea et al. (2006)
	Total folate	230	177		169				172	Stea et al. (2006)
	Total folate	62	47							Scott et al. (2000)
Carrots	Total folate	12	17							Scott et al. (2000)
	Total folate	31	24							Han et al. (2005)
Pumpkin	Total folate	55	42							Han et al. (2005)
Onions	Total folate	8	7							Han et al. (2005)
Chickpeas	Total folate	149.7	78.8	93						Dang et al. (2000)
	Undeconjugated folates	121.5	63.3	73.8						Dang et al. (2000)
Kidney beans	Total folate	182	141							Han et al. (2005)
Rice	Total folate	25	9							Han et al. (2005)
Barley	Total folate	37	10							Han et al. (2005)
Corn	Total folate	205	129							Han et al. (2005)
Soy bean sprouts	Total folate	152	85							Han et al. (2005)
Oyster mushrooms	Total folate	132	18							Han et al. (2005)

Table 6 continued

Food	Compound (ug/100 g)	Raw	Boiled	Preassure cooked	Steamed	Stir-fried	Baked	Grilled	Microwaved	Reference
Trout	Tetrahydrofolate	10.7					5.8			Vahteristo et al. (1998)
	5-Methyltetrahydrofolate	2.2					5.2			Vahteristo et al. (1998)
Mackerel	Total folate	43				16				Han et al. (2005)
Common squid	Total folate	6	5							Han et al. (2005)
Pollack	Tetrahydrofolate	3.5					0.4			Vahteristo et al. (1998)
	5-Methyltetrahydrofolate	14.2					12.8			Vahteristo et al. (1998)
Eggs	Total folate	139	127							Han et al. (2005)
Chicken	Tetrahydrofolate	2.9					2.3			Vahteristo et al. (1998)
	5-Methyltetrahydrofolate	1.6					1.9			Vahteristo et al. (1998)
	Total folate	15	8							Han et al. (2005)
Beef	Total folate	54.3						51.5		McKillop et al. (2002)
	Total folate	4	4							Han et al. (2005)
Pork	Total folate	2	1							Han et al. (2005)

was measured before and after boiling and a high folate reduction were noticed, leafy vegetables retained only 50% of folate while non-leafy vegetables between 50 and 90%. When the same vegetables were stir-fried, the leafy vegetables retained 43–70% of folate and non-leafy vegetables retained nearly all folate (Lin and Lin 1999).

Deep-frying caused folates losses of similar magnitude than stir-frying, the folate content of raw soybeans was estimated approx. 4.04 mg total folate/kg and after tempeh preparation and deep-fried 2.35 mg/kg was observed indicating a 41% folate reduction (Arcot et al. 2002a, b).

Grilling or baking

Most of the folate losses are due to their leaching into the water, they are not soluble in oils therefore less reduction was observed during frying. In this case, the losses were due to the heat since they are also thermolabile. Grilling and baking are dry cooking methods but they might reach very high temperatures nevertheless prolonged grilling of beef (16 min) did not result in a significant decrease in folate content (54.3 and 51.5 μg/100 g for raw and grilled beef respectively) (McKillop et al. 2002). Levels of tetrahydrofolate (THF), 5-formyl-THF, 10-formylfolate, and 5-methyl-THF were also found stable throughout the complete bread processing and with relatively good stability during the baking process (Osseyi et al. 2001). But, this was not the case in other food products, tetrahydrofolate retention in rainbow trout and pollack after oven-baking was poor (9–60%) while 5-methyltetrahydrofolate retention was above 65% for both fish species and chicken meat (Vahteristo et al. 1998). The folate reduction in baked potatoes was also high, approx 63% compared to raw potatoes (Stea et al. 2006).

When the bread processing was studied more in detail, variances in the folate levels were changing depending on the considered step. In dough before proofing, proofed dough, and bread from this flour, total folate levels were 81, 136, 90 and undeconjugated folate levels 33, 43, 40 μg/100 g resp. Increased levels in the dough are attributed to contributions from yeast (baker's yeast contributed markedly to the final folate content of bread by synthesizing folates during fermentation) and malt

flour while decreased levels during baking are attributed to thermal lability of folate (Arcot et al. 2002a, b). Folate losses in baking might reach approximate 12% or 21, up to 25% depending on the type of breads and flours (rye and wheat breads) and the wider variety of sourdoughs and baking processes (Kariluoto et al. 2004; Gujska and Majewska 2005).

Microwaving

Results on the effect of microwave cooking in the folate retention are in discordance. Microwave heating of spinach (for 40 s) reduced only 45% of the folate content, values lower than boiling due to the minimal loss of folate into cooking water (Min 1998). On the contrary, Stea et al. (2006) reported a 75% of folate loss during peas microwaving, the highest reduction observed if compared with steam boiling (73%) and blanching (71%).

Glucosinolates and their degradation products

Glucosinolates (GSNs) are a type of β-thioglucoside N-hydrosulfates (Fig. 1h). From a dietary point of view they are restricted to a few vegetables such as *Brassica* species—i.e. broccoli, cauliflower, cabbage, Brussels sprouts-, mustard, papaya, caper, and some ethnic foods such as *añú*, an edible tuber consumed in South America (Fahey et al. 2001).

Glucosinolates share a central skeleton formed by a thioglucoside bound to a suphonate oxime carbon and an R functional group derivate from an amino acid (Bones and Rossiter 2006). According to the amino acidic moiety glucosinolates, and their degradation products, may be classified into aromatics (alkil, alkenil, hidroxialkenil and w-metilthioalkenil) and aliphatics (bencil and bencil derivatives), which also determine their biological activity (Mithen 2001; Bones and Rossiter 2006).

The GSNs degradation is produced enzymatically by myrosinase. This enzime transform them, through an unstable aglycone intermediate, thiohydroxamate-*o*-sulfonate, into a wide range of bioactive metabolites: isothiocianates, thiocyanates, nitriles and cyanoepithioalkanes, among others (Bones and Rossiter 2006; Rungapamestry et al. 2007a). Most of these compounds are volatiles provoking a strong smell and flavour not only when cooking. Particularly, the allyl isthiocyanate is largely responsible for the characteristic hot flavours of condiments made from mustard and horseradish, and the glucosinolates sinigrin and progoitrin confer the bitterness on Brussels sprouts and other *Brassica* vegetables.

GSNs were always considered as natural pesticides since they provoked metabolic stress on invertebrate herbivores and impaired growth. They were firstly studied because their degradation products provoked adverse effect on the thyroid metabolism of higher animals. In principle, they could also induce goitrogenic effects in humans, but there was no epidemiological evidence that GSNs in taking had any effect on thyroid hormones levels, presumably because cooking had inactivated myrosinase and hence reduced the biological availability of the goitrogenic breakdown products to sub-clinical levels. On the contrary, the epidemiological evidence strongly suggest that consumption of *Brassica* vegetables is associated with reduced risk of cancer at alimentary tract and other sites and GSNs breakdown products exerted anticarcinogenic activity in experimental animal models (Mithen et al. 2000; Brown et al. 2002).

Domestic processing

Vegetables containing GSNs usually undergo domestic processing before cooking. Normally, they—broccoli or cauliflower type—are cut; others such as cabbage are prepared in julienne, which may have similar effects to chopping; while others such as papaya are peeled, cut and immediately eaten.

At the cell level, GSNs are physically separated of the myrosinase. Therefore, the breakdown of the tissular integrity is essential for the formation of vast range of products such as isothiocianates, thiocyanates, among others (Purrington 2000; Rungapamestry 2007b). The enzymatic activity depends of several environmental factors such as pH, temperature, Fe^{2+}, ascorbic acid content, among others (Ludikhuyze et al. 2000; Lambrix et al. 2001; Bones and Rossiter 2006) some of these elements could be the reason for the elevated levels of all indolyl GSNs and some aliphatic found by Verkerk et al. (1997a, b) after chopping a

prolonged exposure to air of different kinds of Brassica. Therefore, the GSN-myrosinase system may be affected 5–10 folds in each step of the complete home-processing and cooking chain (Devos and Blijleven 1988; Dekker et al. 2000, 2003; Farnham et al. 2004, Vallejo et al. 2004).

Domestic cold storage at 4°C for 3 weeks of broccoli sprouts, kohl rabi, white radish and rocket caused no significant changes in individual GSNs concentrations except for rocket, which showed a significant decline in glucoerucin and glucoraphanin after 1 and 2 weeks, respectively. Results indicate that these products may be stored under domestic refrigeration conditions without significant loss of potential anti-cancer compounds. Rocket sprouts, on the other hand, should be consumed soon after purchase (Force et al. 2007).

Cooking methodologies

Thermal processing, i.e. boiling, blanching, steaming, baking, results in myrosinase denaturalization which lead to a lower conversion of GSNs into isothiocyanates during chewing (Song et al. 2007). Furthermore, the cooking process involves partial or total inactivation of the GSN-myrosinase system, breakdown of glucosinolates and finally leaching of them and their products into the cooking water if they have been boiled (Table 7). Intensive or excessive heat exposure increases the volatilization and thermal destruction of the GSNs degradation products, reducing drastically their levels (Dekker et al. 2000; Oerlemans et al. 2006; Rungapamestry et al. 2007a). However, the most efficient reduction of GSN content (by approx. 35%) occurred during the first 5 min of cooking white cabbage. Later, GSNs levels decreased by 10–15% each 5 min cooking (Ciska and Kozlowska 2001).

Short heat treatments such as blanching before freezing inhibited the myrosinase activity and did not induce significant reduction of glucosinolates in Brussels sprouts (Wathelet et al. 1996) whereas in broccoli similar blanching caused large GSNs losses. Therefore, GSNs reduction is highly dependent on the food nature and their texture (Goodrich et al. 1989).

The effect of culinary factors—i.e. cooking method, time- time has been investigated by several authors with contradictory results (Verkerk et al. 1997a, b; Dekker et al. 2000; Smith et al. 2003; Verkerk and Dekker 2004; Rungapamestry et al. 2007a). For instance, it has been reported that boiling red cabbage for 1 h lead to losses lower than 10% in glucobrassicins and formation of new products such as 2-(30-indolylmethyl) glucobrassicin (Chevolleau 2002, Verkerk and Dekker 2004). Other authors observed 30–60% GSNs reduction depending on cooking method (conventional, microwave, pressure cooking), time, temperature and type of compound (Mithen et al. 2000; McNaughton and Marks 2003). On the contrary, other glucosinolates such as allyl cyanide and 1-cyano-2,3-epyithiopropane, have been reported to be stable at shorter boiling times and internal temperatures below 100°C (Verkerk and Decker 2004; Rungapamestry et al. 2006, 2007b).

Recently, Oerlemans et al. (2006) inactivated myrosinase in red cabbage prior to cooking to study the direct effect of temperature on glucosinolate degradation. They found that all the identified GSNs showed degradation at temperatures over 100°C, being 4-hydroxy-glucobrassicin and 4-methoxyglucobrassicin the most sensitive to degradation, even at temperatures below 100°C. They also observed that cooking caused more indole GSNs degradation (38%) than aliphatic GSNs degradation (8%) while blanching did not have a severe effect on them. Moreover, GSN leaching into the cooking water was the first mechanism for loosing them but not the only one since their level in the boiling water remained constant irrespective of the cooking time and reduction of certain GSNs, particularly the aliphatic glucoiberin were observed. Some GSNs were more thermolabile than other (Ciska and Kozlowska 2001). Concluding, the size of cut pieces and cooking time (Rosa and Heaney 1993; Ciska and Kozlowska 2001) are two of the most important factors for glucosinolates losses, with values that range from 10% until 60% according to conditions.

No all the GSNs breakdown products increased their levels during cooking, in cabbage, broccoli and cauliflower, sulphides and isothiocyanates levels increased but nitriles and thionitriles decreased during cooking (Cesare et al. 1998). After prolonged cooking, they were all hardly detectable, with the exception of the thiocyanate ion and ascorbigen (Mithen et al. 2000).

Microwave cooking results in high losses (approx. 74% total) of both aliphatic and indole/aromatic

Table 7 Effect of different domestic treatments on the glucosinolates content of different foods according to various authors

Food	Compound	washing	chopping	Storage (freezing ≤ 1 week)	Blanching	Canning	Boiling	Steaming	Frying	Microwaving	Reference
Several brassicae family members	Total glucosinolates	(–)									Benner et al. (2003)
	Indolyl glucosinolates		(+)								Verkerk et al. (2001)
Cauliflower	Total glucosinolates, Glucoraphanun, glucoiberin, sinigrin, gluconapin, gluconasturtiin, glucoalysisin, progoitrin			0			(–)	0	0	0	Song and Thornalley (2007)
Cabbage	Indole (as glucobrassicin and 4-methoxy glucobrassicin) and aliphatic glucosinolates (as glucoiberin)						(–)				Ciska and Kozlowska (2001)
											Vallejo et al. (2002)
											Rosa and Heaney (1993)
	Total glucosinolates						(–)				Sones et al. (1984), Rosa and Heaney (1993)
Red cabbage	Total glucosinolates									(+)	Verkerk and Dekker (2004)
Green cabbage	Total glucosinolates, Glucoraphanun, glucoiberin, sinigrin, gluconapin, gluconasturtiin, glucoalysisin, progoitrin			0			(–)	0	0	0	Song and Thornalley (2007)
Broccoli	Total glucosinolates						(–)				Dekker et al. (2000)
	Total glucosinolates									(–)	Vallejo et al. (2002)
	Glucoiberin						0	0		0	Vallejo et al. (2002)
	Glucoraphanin						0	0		(–)	Vallejo et al. (2002)
	Neoglucobrassicin							0			Vallejo et al. (2002)
	Glucobrassicin							(–)			Vallejo et al. (2002)
				0							Rangkadilok et al. (2002)

Table 7 continued

Food	Compound	washing	chopping	Storage (freezing ≤ 1 week)	Blanching	Canning	Boiling	Steaming	Frying	Microwaving	Reference
				(–)							Rodrigues and Rosa (1999)
	Glucoiberin, glucoraphanin and glucobrassicin				(–)						Vallejo et al. (2002)
	Total glucosinolates, Glucoraphanun, glucoiberin, sinigrin, gluconapin, gluconasturtiin, glucoalysisin, progoitrin			0			(–)	0	0	0	Song and Thornalley (2007)
							(–)	(+)			Gliszczynska-Swiglo (2006)
						(–)					Oerlemans et al. (2006)
Brussels sprouts	Progoitrin (2%), sinigrin				0						Goodrich (1989)
	Glucobrassicin				(–)						Goodich (1989)
	Total glucosinolates, Glucoraphanun, glucoiberin, sinigrin, gluconapin, gluconasturtiin, glucoalysisin, progoitrin			0			(–)	0	0	0	Song and Thornalley (2007)
Synthetic	Glucobrassicin										Chevolleau (1997, 2002)

(0): no significant losses; (+) Increase in the content; (–): decrease in the content

glucosinolates. It was the more destructive cooking method if compared with conventional (55%) and pressure (33%) cooking. The most recommended method to maintain high the GSNs levels was steaming with a minimum effect because no leaching is produced (Vallejo et al. 2002). Microwaving was also detrimental for GSNs hydrolysis products such as sulforaphane, sulforaphane nitrile, cyanohydroxybutene, iberin or iberin nitrile (Howard et al. 1997). On the contrary, Verkerk and Dekker in 2004 reported an increase (about 78%) in total GSN content after microwave cooking. The latter results were explained by the authors as an artefact due to an increase on the chemical extractability. In other thermal processing such as steam-cooking, increasing of the content of the major glucosinolates was reported when compared with fresh broccoli (Gliszczynska-Swiglo et al. 2006) which may be explained by a similar effect that the above mentioned for microwaving.

Other sulfur-containing bioactive molecules

Many plants belonging to the *Allium* group such as garlic, onion, shallot etc. are characterized for the presence of many sulphur-containing compounds which appeared to have interesting functionalities.

Oganosulfur are compounds produced after the lysis of S-alk(en)yl-L-cysteine sulfoxide (ACSO) by a degradative enzyme (alliinase) and further condensation reactions (Block 1992). The ACSO is located in the vacuole of several plants and the enzyme stored in the cytoplasm. Therefore, the reaction only takes place when alliinase is brought in contact with the ACSOs due to cell descompartimentalization. This occurs in different process such as chewing or in common domestic processes involving crushing, chopping or cutting of tissues (Lancaster and Collin 1981).

Thiosulfinates (TSs) are the major sulfur compounds produced by the alliinase reaction (Block et al. 1992). TS are a very unstable wide variety of organsulfur compounds deriving from a common precursor, allicin (allyl 2-propenethiosulfinate) (Block et al. 1992; Nishimura et al. 2000). The TSs are responsible for the strong flavours and characteristic aromas of the *Allium* plants and also for several biological effects. TSs are considered as beneficial for the human health because of their potential implication as antitumoral agents, as protective molecules against different diseases, including cancer, cardiovascular diseases, hypercholesterolemia, diabetes, hypertension and others (Lanzotti 2006; Ariga and Seki 2006). The most studied property of these compounds is the effect as potent antithrombotic agents (Goldman et al. 1996; Cavagnaro 2007).

Only a few reports have evaluated the effect of domestic cooking on TSs levels via their antithrombotic activity. Boiling completely inhibited the antithrombotic activity in uncrushed garlic and Welsh onion (Ali et al. 1995; Chen et al. 2000) probably due to the heat inactivation of the alliinase before it could produce the antithrombotic agents.

Cagnavaro et al. (2007) pointed a high dependence of the TSs content on the domestic process considered. In this respect, oven-heating at 200 °C or boiling water for 3 min or less did not affect the ability of garlic to inhibit platelet aggregation (as compared to raw garlic), whereas heating for 6 min completely suppressed antiagregatory activity in uncrushed garlic but not in garlic crushed before heat treatments.

Phytosterols

Plant sterols or phytosterols are a large group of molecules but nowadays investigations are mainly focused mostly upon five types: campesterol, β-sitosterol, stigmasterol, campestanol and β-sitoestanol called dietary phytosterols by nutritionists. They are 4-desmethylsterols which have the same structural base as cholesterol, but with one or two extra carbon atoms in the side chain (Fig. 1i). In cereals and oils, the riches natural sources of these compounds, phytosterols exist in four different forms: free or esterified to fatty acids, sugar moieties and phenolic acids (Normen et al. 2002).

Phytosterols play an important role on the plant membranes as cholesterol does on animal membranes but actually, the studies on these molecules are focused on other recently discover biological functions which might have implications for human health. Phytosterols are known to lower the serum cholesterol levels reducing the CVD morbidity and mortality. They might also have a preventive effect on the development of colon cancer, on the reduction

of tumour formation and other beneficial bioactivities (Piironen et al. 2000).

Very little information can be found on the stability of plant sterols after domestic processing. Cooking of 13 different vegetables and fruits did not show significantly loss of phytosterols respect to uncooked controls. Concentrations ranged from 0.55 to 6.95 g kg^{-1} for raw foods while cooked food ranged from 0.64 to 8.39 g kg^{-1} (Nomen et al. 1999). However, if the data are compared as mg/100 g e.p. results indicated that boiling decreased the average phytosterols concentration in cereals being higher decreases in campesterol and sitosterol (Nomen et al. 2002). But apparently, the most drastic reduction seems to occur at deep-frying temperatures where the most important factor determining the stability of sterols was the ring structure of the steryl moiety, when free sterols and steryl esters were compared (Lampi et al. 1999). Frying in a rapeseed oil/palm oil blend resulted in the highest amount of sterol oxidation products (Dutta 1997).

Albi et al. (1997) studied the effects of microwave (120 min, 170°C and specific intervals) and electric oven (120 min, 180°C) on five oils. There were no significant differences in the sterol contents of untreated and treated oils.

Conclusions

Carotenoids, tocopherols and PUFAs are not water-soluble compounds. They are part of lipidic membranes and oily fractions of foods therefore cooking methods involving water are less aggressive than those using oils as cooking medium besides stir-frying might reach higher temperatures than water-cooking. Baking or grilling request even higher temperatures but losses seemed to be not extremely high; these cooking methods provoke dehydratation and a Maillard coating which might protect inside compounds. Moreover, compounds such as PUFAs are protected from oxidation by tocopherols. The latter might also be protected if the cooking medium is, i.e., olive oil since this fat contains phenolic compounds which might act synergically with tocopherols as antioxidants. Worthwhile to remember is that, if ω-3-rich foods are fried on ω-6-rich oils exchange of fatty acids will occur between them changing the ω-6/ω-3 ratio and the lipidic profile of the food. Studies on the effect of microwaves on these lipidic molecules are still incomplete and somehow contradictories. Nevertheless, carotenoids seemed to be the most thermostable compounds being more affected by light and oxygen exposure (chopping, storing etc). Tocopherols and carotenoids become more available with blanching or steaming since the water treatments hydrolyze the structures in which they are located. Phytosterols are also lipidic compounds and probably they behave as the previously mentioned compounds but nowadays, reports are insufficient to draw conclusions.

Opposite to non-polar compounds, those more polar such as phenolics, folates, glucosinolates and sulphur compounds lower their content by water cooking processes, which is explained firstly by leaching and later by their thermal lability. Therefore, high amounts of water such as those used for boiling usually represent higher loss of these compounds, in particular folates. Other methods such as steaming, with almost no osmotic processes, are more recommended to maintain a high level of these compounds inside the food. This is also applicable to microwave cooking (low water and short cooking time) except for glucosinolates and their degradation products where microwaves seemed to be detrimental. Glucosinolates are transformed into sulphides, isothiocyanates thiocyanatesions etc mainly during the chopping of the *Brassicas* before cooking. Cutting provokes cell descompartimentalization allowing enzymes to catalyze their transformation. Similarly, the alliinase of *Allium* produce many sulphur containing compounds.

However, the cooking times, the food nature, the additions of acidulants, spices, or other condiments to the water or other media used for cooking, the presence of certain compounds or conditions inside the food (iron, ascorbic acid, low pH etc.), even the fire place utilized might influence positive or negatively the losses not only of water-soluble compounds but also of those fixed to lipidic matrix.

Dietary fibres are part of the plant cellular walls, they are large and complex molecules affected by hot water but difficult to extract them completely and therefore they are difficult to analyse. They seemed to be rather stable to cooking procedures including baking of dough but reports are until now contradictories.

References

Agte V, Tarwadi K, Mengale S, Hinge A, Chiplonkar S (2002) Vitamin profile of cooked foods: how healthy is the practice of ready-to-eat foods? Int J Food Sci Nutr 53:197–208

Albi T, Lanzon A, Guinda A, Perez-Camino MC, Leon M (1997) Microwave and conventional heating effects on some chemical and physical parameters of edible fats. J Agric Food Chem 45:3000–3003

Ali M (1995) Mechanism by which garlic (*Allium sativum*) inhibits cyclooxygenase activity. Effect of raw versus boiled garlic extract on the synthesis of prostanoids. Prostaglandins Leukotrienes Essent. Fatty Acids 53:397–400

Almeida-Costa GE, Queiroz-Monici KS, Machado-Reis SMP, Costa de Oliveira A (2006) Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea, common bean, chickpea and lentil legumes. Food Chem 94:327–330

Almeida-Muradian LB, Vanderlinde DW, Sasaki R (2000) Provitamin A activity of raw and cooked Brazilian leaves. Food Sci Technol Int 151–153

Al-Saghir S, Thurner K, Wagner K, Frisch G, Luf W, Razzazi-Fazeli E, Elmadfa I (2004) Effects of different cooking procedures on lipid quality and cholesterol oxidation of farmed salmon fish (*Salmo salar*). J Agric Food Chem 52(16):5290–5296

Andrikopoulos NK, Dedoussis GVZ, Falirea A, Kalogeropoulus N, Hatzinkola HS (2002a) Deterioration of natural antioxidant species of vegetable edible oils during the domestic deep-frying and pan-frying of potatoes. Int J Food Sci Nutr 53:351–363

Andrikopoulos NK, Kalogeropoulos N, Falirea A, Barbagianni MN (2002b) Performance of virgin olive oil and vegetable shortening during domestic deep-frying and pan-frying of potatoes. Int J Food Sci Technol 37:177–190

Anil-Kumar HG, Khatoon S, Prabhakar DS, Gopala Krishna AG (2006) Effect of cooking of rice bran on the quality of extracted oil. J Food Lipids 13:341–353

Arcot J, Wong S, Shrestha AK (2002a) Comparison of folate losses in soybean during the preparation of tempeh and soymilk. J Sci food Agric 82:1365–1368

Arcot J, Wootton M, Alury S, Chan HY, Shrestha AK (2002b) Folate levels in twelve Australian wheats and changes during processing into bread. Food Aust 54:18–20

Ariga T, Seki T (2006) Antithrombotic and anticancer effects of garlic-derived sulfur compounds: a review. Biofactors 26(2):93–103

Aro T, Tahvonen R, Mattila T, Nurmo J, Sivonen T, Kallio H (2000) Effects of season and processing on oil content and fatty acids of Baltic herring (*Clupea harengus membras*). J Agric Food Chem 48:6085–6093

Atienza J, Sanz M, Herguedas A, Alejos JA, Jimenez JJ (1998) Beta-carotene, alpha-tocopherol and gamma-tocopherol contents in dry legumes. Influence of cooking. Food Sci Technol Int 4:437–441

Baloch AK, Buckle KA, Edwards RA (1977) Effect of processing variables on the quality of dehydrated carrot I. Leaching losses and carotenoid content. J Food Technol 12:285–293

Benavente-García O, Castillo J, Marín FR, Ortuño O, Del Río JA (1997) Uses and properties of Citrus flavonoids. J Agric Food Chem 45(12):4505–4515

Benner M, Geerts RFR, Linnemann AR, Jongen WMF, Folstar P, Cnossen HJ (2003) A chain information model for structured knowledge management: towards effective and efficient food product improvement. Trends Food Sci Tech 14:469–477

Bernhardt S, Schlich E (2006) Impact of different cooking methods on food quality: retention of lipophilic vitamins in fresh and frozen vegetables. J Food Eng 77:327–333

Block E (1992) The organosulphur chemistry of the genus Allium. Implications for organic sulphur chemistry. Agnew Chem Int Ed Engl 31:1135–1178

Block E, Naganathan S, Putman D, Zhao SH (1992) Allium chemistry: HPLC analysis of thiosulfinates from onion, garlic, wild garlic (ramsoms), leek, scallion, shallot, elephant (greatheaded) garlic, chive, Chinese chive. Uniquely high allyl to methyl ratios in some garlic samples. J Agric Food Chem 40:2418–2430

Bones AM, Rossiter JT 2006 The enzymic and chemically induced decomposition of glucosinolates. Phytochem 67(11):1053–1067

Bouzidielmehdaoui S, Gandemer G, Laroche M (1993) Influence of heating on the composition of sea bred brown trout (salmo-trutta) fillets. Sci Aliment 13(2):221–228

Boyd L, King M, Sheldon B (1992) A rapid method for determining the oxidation of n-3 fatty acids. J Am Oil Chem Soc 69(4):325–330

Bramley PM, Elmadfa I, Kafatos A, Kelly FJ, Manios Y, Roxborough HE, Schuch W, Sheehy PJA, Wagner KH (2000) Vitamin E. J Sci Food Agric 80:913–938

Brenes M, Garcia A, Dobarganes MC, Velasco J, Romero C (2002) Influence of thermal treatments simulating cooking processes on the polyphenol content in virgin olive oil. J Afric Food Chem 50:5962–5967

Brown AF, Yousef GG, Jeffrey EH et al (2002) Glucosinolate profiles in broccoli: variation in levels and implications in breeding for cancer chemoprotection. J Am Soc Hortic Sci 127:807–813

Buchner N, Krumbein A, Rohn S, Kroh LW (2006) Effect of thermal processing on the flavonols rutin and quercetin. Rapid Commun Mass Sp 20:3229–3235

Candela M, Astiasarán I, Bello J (1998) Deep frying modifies high-fat fish lipid fraction. J Agric Food Chem 46: 2793–2796

Castrillón A, Navarro P, Alvárez-Pontes E (1997) Changes in chemical composition and nutritional quality of fried sardine (*Clupea pilchardus*) produced by frozen storage and microwave reheating. J Sci Food Agric 75:125–132

Cavagnaro PF, Camargo A, Galmarini CR, Simon PW (2007) Effect of cooking on garlic (*Allium sativum* L) antiplatelet activity and thiosulfinates content. J Agric Food Chem 55(4):1280–1288

Cesare LF, Proietti M, Riva M, Schiraldi A (1998) Influence of cooking on the volatile fraction of Brassica grown in Italy. Ind Aliment 37:182–186

Cheel J, Theoduloz C, Rodríguez JA, Caligari PDS, Schmeda-Hirschmann G (2007) Free radical scavenging activity and phenolic content in achenes and thalamus from *Fragaria*

chiloensis spp. *chiloensis*, *F. vesca* and *F. x ananassa* cv Chandler. Food Chem 102:36–44

Chen JH, Chen HI, Tsa SJ, Jen CJ (2000) Chronic consumption of raw but not boiled Welsh onion juice inhibits rat platelet function. J Nutr 130:34–37

Chevolleau S, Gasc N, Rollin P, Tulliez J (1997) Enzymatic, chemical and thermal breakdown of H3-labeled glucobrassicin, the parent indole glucosinolate. J Agric Food Chem 45:4290–4296

Chevolleau S, Debrauwer L, Boyer G, Tulliez J (2002) Isolation and structure elucidation of a new thermal breakdown product of glucobrassicin, the parent indole glucosinolate. J Agric Food Chem 50(18):5185–5190

Choubert G, Blanc JM, Courvalin C (1992) Muscle carotenoid content and colour of farmed rainbow trout fed astaxanthin or canthaxanthin as affected by cooking and smoke-curing procedures. Int J Food Sci Technol 27(3):277–284

Ciska E, Kozlowska H (2001) The effect of cooking on the glucosinolates content in white cabbage. Eur Food Res Technol 212(5):582–587

Claxson A, Hawkes G, Richardson D, Naughton D, Haywood R, Chander C, Atherton M, Lynch E, Grootveld M (1994) Generation of lipid-peroxidation products in culinary oils and fats during episodes of thermal stressing – a high-field H-1 NMR study. FEBS Lett 355(1):81–90

Cortinas L, Galobart J, Barroeta A, Baucells M, Grashorn A (2003) Change in alpha-tocopherol contents, lipid oxidation and fatty acid profile in eggs enriched with linolenic acid or very long-chain omega 3 polyunsaturated fatty acids after different processing methods. J Sci Food Agric 83:820–829

Crozier A, Lean MEJ, McDonald MS, Black C (1997) Quantitative analysis of the flavonoid content of commercial tomatoes, onions, lettuce and celery. J Agric Food Chem 45:590–595

Cruz-García CDL, González-Castro MJ, Oruña-Concha MJ, López-Hernández J, Simal-Lozano JA, Simal-Gándara J (1997) The effects of various culinary treatments on the pigment content of green beans (*Phaseolus vulgaris*, L.) Food Res Int 30:787–791

Dal Bosco A, Castelline C, Bernardini M (2001) Nutritional quality of rabbit meat as affected by cooing procedure and dietary vitamin E. J Food Sci 66:1047–1050

Dang J, Arcot J, Shrestha A (2000) Folate retention in selected processed legumes. Food Chem 68:295–298

Dekker M, Verkerk R (2003) Dealing with variability in food production chains: a tool to enhance the sensitivity of epidemiological studies on phytochemicals. Eur J Nutr 42(1):67–72

Dekker M, Verkerk R, Jongen WMF (2000) Predictive modelling of health aspects in the food production chain: a case study on glucosinolates in cabbage. Trends Food Sci Technol 11:174–181

Devos RH, Blijleven WGH (1988) The effect of processing conditions on glucosinolates in cruciferous vegetables. Z Lebensm Unter Forsch 187:525–529

De Sa MC, Rodriguez-Amaya DB (2003) Carotenoid composition of cooked green vegetables from restaurants. Food Chem 83:595–600

De Sa MC, Rodriguez-Amaya DB (2004) Optimization of HPLC quantification of carotenoids in cooked green vegetables – comparison of analytical and calculated data. J Food Compost Anal 17:37–51

Dornenburg H, Davies C (1999) The relationship between lipid oxidation and antioxidant content in post harvest vegetables. Food Rev Int 15(4):435–453

Dunaif G, Schneeman BO (1981) The effect of dietary fibre on human pancreatic enzyme activity in vitro. Am J Clin Nutr 34:1034–1035

Dutta PC (1997) Studies on phytosterol oxides. II: content in some vegetable oils and in French fries prepared in these oils. J Am Oil Chem Soc 74:659–666

Elmadfa I, Bosse W (1985) Vitamin E. Stuttgart Wiss Verlagsgesellschaft 44–45

Elmore J, Mottram D, Enser M, Wood J (1999) Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. J Agric Food Chem 47:1619–1625

Elmore S, Mottram D, Enser M, Wood J (2000) The effects of diet and breed on the volatile compounds of cooked lamb. Meat Sci 55:149–159

El-Wakeil FA, Morsi MKS (1976) Chemical changes in sweet potatoes during cooking. Agr Res Rev 54(3):99–109

Eun J, Boyle J, Hearnsberger J (1994) Lipid-peroxidation and chemical-changes in catfish (Ictalurus-Punctatus) muscle microsomes during frozen storage. J Food Sci 59(2): 251–255

Fahey JW, Zalcmann AT, Talalay P (2001) The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. Phytochem 56(1):5–51

Farnham MW, Wilson PE, Stephenson KK, Fahey JW (2004) Genetic and environmental effects on glucosinolate content and chemoprotective potency of broccoli. Plant Breeding 123:60–65

Fernández-López J, Fernández-Ginés JM, Aleson-Carbonell L, Sendra E, Sayas-Barberá E, Perez-Alvarez JA (2004) Aplication of functional citrus by-products to meta products. Trends Food Sci Technol 15:176–185

Force LE, O'Hare TJ, Wong LS, Irving DE (2007) Impact of cold storage on glucosinolate levels in seed-sprouts of broccoli, rocket, white radish and kohl-rabi. Postharvest Biol Technol 44:175–178

Fox C, Blow P, Brown J, Watson I (1994) The effect of various processing methods on the physical and biochemical properties of shrimp head meals and their utilization by juvenile *Penaeus-monodon* fab. Aquaculture 122(2–3): 209–226

Gallardo J, Aubourg S, Perez-Martin R (1989) Lipid classes and their fatty acids at different Loci of Albacore (*Thunnus alalunga*): effects of precooking. J Agric Food Chem 37:1060–1064

Gayathri GN, Platel K, Prakash J, Srinivasan K (2004) Influence of antioxidant spices on the retention of -carotene in vegetables during domestic cooking processes. Food Chem 84:35–43

Gebczynski P, Lisiewska Z (2006) Comparison of the level of selected antioxidative compounds in frozen broccoli produced using traditional and modified methods. Innovat Food Sci Emerg Tech 7:239–245

Geissman TA (1962) The occurrence of flavonoids in nature. McMillan Co, New York

Ghavidel RA, Prakash J (2007) The impact of germination and dehulling on nutrients, antinutrients, in vitro iron and calcium bioavailability and in vitro starch and protein digestibility of some legume seeds. LWT 40:1292–1299

Gladyshev M, Sushchik N, Gubanenko G, Demirchieva S, Kalachova G (2006) Effect of way of cooking on content of essential polyunsaturated fatty acids in muscle tissue of humpback salmon (*Oncorhynchus gorbuscha*). Food Chem 96:446–451

Gliszczynska-Swiglo A, Ciska E, Pawlak-Lemanska K, Chmielewski J, Borkowski T, Tyrakowska B (2006) Changes in the content of health-promoting compounds and antioxidant activity of broccoli after domestic processing. Food Addit Contam 23(11):1088–1098

Godoy HT, Rodriguez-Amaya DB (1998) Occurrence of cis-isomers of provitamin A in Brazilian vegetables. J Agric Food Chem 46:3081–3086

Goldman IL, Kopelberg M, Debaene JP, Schwartz BS (1996) Antiplatelet activity in onion (*Allium cepa* L) is sulfur dependent. Thromb Haemostasis 76:450–452

Goodrich RM, Anderson JL, Stoewsand GS (1989) Glucosinolate changes in blanched broccoli and Brussels-sprouts. J Food Process Preserv 13:275–280

Gordon MH, Kourimska L (1995) Effect of antioxidants on losses of tocopherols during deep-fat frying. Food Chem 52:175–177

Gregory JF (1985) Chemical changes of vitamin during food processing. In: Richardson T, Finley JW (eds) Chemical changes in food during processing. AVI Publishing Company, Westport

Gujska E, Majewska K (2005) Effect of baking process on added folic acid and endogenous folates stability in wheat and rye breads. Plant Food Hum Nutr 60:37–42

Häkkinen SH, Kärenlampi SO, Mykkänen HM, Heinonen IM, Törrönen AR (2000) Ellagic acid content in berries: influence of domestic processing and storage. Eur Food Res Technol 212:75–80

Han YH, Yon M, Hyun TH (2005) Folate intake estimated with an updated database and its association to blood folate and homocysteine in Korean college students. Eur J Clin Nutr 59:246–254

Hart DJ, Scott KJ (1995) Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. Food Chem 54:101–111

Hassanein M, El-Shami S, El-Mallah M (2003) Changes occurring in vegetable oils composition due to microwave heating. Grasas Aceites 54(4):343–349

Hawkes JG, Villota R (1989) Folates in food: reactivity, stability during processing and nutritional implications. Crit Rev Food Sci 28:439–538

Hearn T, Sgoutas S, Sgoutas D, Hearn J (1987) Stability of polyunsaturated fatty acids after microwave cooking of fish. J Food Sci 52(5):1430–1431

Hoppner K, Lampi B (1993) Folate retention in dried legumes after different methods of meal preparation. Food Res Int 26:45–48

Howard LA, Jeffery EH, Walling MA, Kein BP (1997) Retention of phytochemicals in fresh and processed broccoli. J Food Sci 62(6):1098–1100

Howard LA, Wong AD, Perry AK, Klein BP (1999) Beta-Carotene and ascorbic acid retention in fresh and processed vegetables. J Food Sci 64(5):929–936

Howe P, Downing J, Grenyer B, Grigonis-Deane E, Bryden W (2002) Tuna fishmeal as a source of DHA for n-3 PUFA enrichment of pork, chicken, and eggs. Lipids 37(11):1067–1076

Jittinandana S, Kenney PB, Slider SD, Jamloms JA (2006) Effect of high dietary vitamin E on lipid stability of o-vencooked and hot-smoked trout fillets. J Food Sci 71(3):C130–C136

Jonhson EJ (2000) The role of lycopene in health and disease. Nutr Clin Care 3:35–43

Kala-Yadav S, Sehgal S (1995) Effect of home processing on ascorbic acid and beta-carotene content of spinach (*Spinacia oleracea*) and amaranth (*Amaranthus tricolor*) leaves. Plant Food Hum Nutr 47(2):125–131

Kalogeropoulos N, Chiou A, Mylona A, Ioannou MS, Andrikopoulos NK (2007a) Recovery and distribution of natural antioxidants (α-tocopherol, polyphenols and terpenic acids) after pan-frying of Mediterranean finfish in virgin olive oil. Food Chem 100:509–517

Kalogeropoulos K, Mylona A, Chiou A, Ioannou MS, Andrikopoulos NK (2007b) Retention and distribution of natural antioxidants (α-tocopherol, polyphenols and terpenic acids) after shallow frying of vegetables in virgin olive oil. LWT Food Sci Technol 40:1008–1017

Kariluoto S, Vahteristo L, Salovaara H, Katina K, Liukkonen KH, Piironen V (2004) Effect of baking method and fermentation on folate content of rye and wheat breads. Cereal Chem 81:134–139

Khachik F, Goli MB, Beecher GR, Holden J, Lusby WR, Tenorio MD, Barrera MR (1992) Effect of food preparation on qualitative and quantitative distribution of major carotenoid constituents of tomatoes and several green vegetables. J Agric Food Chem 40(3):390–398

Kim M, Lee J, Choe E (2003) Effects of the number of fryings on pigment stability in frying oil and fried dough containing spinach powder. J Food Sci 68(3):866–869

Kim YN, Giraud DW, Driskell JA (2007) Tocopherol and carotenoid contents of selected Korean fruits and vegetables. J Food Compost Anal 20(6):458–465

Klein BP, Kuo CHY, Boyd G (1981) Folacin and ascorbic acid retention in fresh raw, microwave and conventionally cooked spinach. J Food Sci 46(2):640–641

Kumar S, Aalbersberg B (2006a) Nutrient retention in foods after earth-oven cooking compared to other forms of domestic cooking. Proximates, carbohydrates and dietary fibre. J Food Compost Anal 19:302–310

Kumar S, Aalbersberg B (2006b) Nutrient retention in foods after earth-oven cooking compared to other forms of domestic cooking: 2. Vitamins. J Food Compost Anal 19:311–320

Kunert-Kirchhoff J, Baltes W (1990) Model reactions on roast aroma formation. VIII. Volatile reaction products from the reaction of phenylalanine with 2,5-dimethyl-4-hydroxy-3-(2H)-furanone (Furaneol) by cooking in a laboratory autoclave. Z Lebensm Unter Forsch 190:14–16

Kutos T, Golob T, Kac M, Plestenjak A (2003) Dietary fibre content of dry and processed beans. Food Chem 80: 231–235

Lairon D, Play B, Jourdheuil-Rahmani D (2007) Digestible and indigestible carbohydrates: interactions with postprandial lipid metabolism. J Nutr Biochem 18:217–227

Lambrix V, Reichelt M, Mitchell-Olds T et al (2001) The Arabidopsis epithiospecifier protein promotes the hydrolysis of glucosinolates to nitriles and influences Trichoplusia in herbivory. Plant Cell 13(12): 2793–2807

Lampi AM, Hovi RL, Toivo J, Piironen V (1999) Stability of plant sterols and their effects on oils at 180°C. In: Lasztity R, Pfannhauser W, Simon-Salardi L, Tömösközi S (eds) Functional foods. A new challenge for the food chemist. Pubishing company of TUB, Buapest, pp 513–516

Lancaster J, Collin H (1981) Presence of allinase in isolated vacuoles and of alkyl cysteine sulphoxides in the cytoplasm of bulbs of onion (*Allium cepa*). Plant Sci Lett 22:169–176

Lanzotti V (2006) The analysis of onion and garlic. J Chromatogr A 1112(1–2):3–22

Ludikhuyze L, Rodrigo L, Hendrickx M (2000) The activity of myrosinase from broccoli (*Brassica oleracea* L cv Italica): influence of intrinsic and extrinsic factors. J Food Prot 63(3):400–403

Leskova E, Kubikova J, Kovacikova E, Kosicka M, Porubska J, Holcikova K (2006) Vitamin losses: retention during heat treatment and continual changes expressed by mathematical models. J Food Compost Anal 19:252–276

Lim YL (2007) Changes in the contents of carotenoids and cis/trans beta-carotenes of fresh and cooked spinach in foodservice operations. J Korean Soc Food Sci Nutr 36:117–123

Lin BF, Lin RF (1999) Effect of Chinese stir-fry cooking on folate contents of vegetables. J Chin Agr Chem Soc 37:443–454

Liu CS, Glahn RP, Liu RH (2004) Assessment of carotenoid bioavailability of whole foods using a Caco-2 cell culture model coupled with an in vitro digestion. J Agric Food Chem 52:4330–4337

Liu Y, Perera CO, Valiyaveettil S (2007) Comparison of three chose vegetables with others from South East Asia for their lutein and zeaxanthin content. Food Chem 101:1550–1556

Lubis Z, Buckle K (1990) Rancidity and lipid oxidation of dried-salted sardines. Int J Food Sci Technol 25:295–303

Luthria DL, Pastor-Corrales MA (2006) Phenolic acids contents of fifteen dry edible bean (*Phaseolus vulgaris* L) varieties. J Food Compost Anal 19:205–211

Makris DP, Rossiter JT (2001) Domestic processing of onion bulbs (*Allium cepa*) and Asparagus spears (*Asparagus officinalis*): effect on flavonol content and antioxidant status. J Agric Food Chem 49:3216–3222

Marín FR, Frutos MJ, Pérez-Álvarez JA, Martínez-Sánchez F, Del Río JA (2002) Flavonoids as nutraceuticals: structural related antioxidant properties and their role on ascorbic acid preservation. In: Atta-ur-Rahman (ed) Studies in natural products chemistry, vol 26. Elsevier Science Publishers, Amsterdam, pp 741–748

Marín FR, Soler-Rivas C, Benavente-García O, Castillo J, Pérez-Álvarez JA (2007) By-products from different citrus processes as a source of customized functional fibres. Food Chem 100:736–741

Malin JD (1977) Total folate activity in Brussels sprouts: the effects of storage, processing, cooking and ascorbic acid content. J Food Technol 12:623

Marlett JA (2000) Changes in content and composition of dietary fiber in yellow onions and red Dellicious apples during commercial storage. Anal Chem Int 83:992–996

Matalgyto F, Al-Khalifa A (1998) Effect of microwave oven heating on stability of some oils and fats. Arab Gulf J Sci Res 16(2):431–450

Mayeaux M, Xu Z, King JM, Prinyawiwatkul W (2006) Effects of cooking conditions on the lycopene content in tomatoes. J Food Sci 71:C461–C464

McKillop DJ, Pentieva K, Daly D, McPartlin JM, Hughes J, Strain JJ, Scott JM, McNulty H (2002) The effect of different cooking methods on folate retention in various foods that are amongst the major contributors to folate intake in the UK diet. Br J Nutr 88:681–688

McNaughton SA, Marks GC (2003) Development of a food composition database for the estimation of dietary intake of glucosinolates, the biologically active constituents of cruciferous vegetables. Br J Nutr 90:687–697

Mendez E, Fernandez M, Pazo G, Grompone M (1992) Hake roe lipids – composition and changes following cooking. Food Chem 45(3):179–181

Min HS (1998) Changes of folate content in spinach by cooking and storage. The comparisons of thermal destruction and loss of folate into cooking water by blanching time of spinach. J Korean Soc Food Sci Nutr 27:286–290

Mithen RF (2001) Glucosinolates and their degradation products. Adv Bot Res 35:213–262

Mithen RF, Dekker M, Verkerk R, Rabot S, Johnson IT (2000) The nutritional significance, biosynthesis and bioavailability of glucosinolates in human foods. J Sci Food Agric 80:967–984

Miyagawa K, Hirai K, Takezoe R (1991) Tocopherol and fluorescence levels in deep-frying oil and their measurement for oil assessment. J Am Oil Chem Soc 68:163–166

Morrison HI, Schaubel D, Desmeules M, Wigle DT (1995) Serum folate and risk of fatal coronary heart disease. J Am Med Assoc 275:1893–1896

Mosha TC, Pace RD, Adeyeye S, Laswai HS, Mtebe K (1997) Effect of traditional processing practices on the content of total carotenoid, beta-carotene, alpha-carotene and vitamin A activity of selected Tanzanian vegetables. Plant Food Hum Nutr 50(3):189–201

Murcia MA, Vera A, Garcia-Carmona F (1992) Determination by HPLC of changes in tocopherol leves in spinach after industrial processing. J Sci Food Agric 60:81–84

Murcia MA, Martinez-Tome M, Cerro ID, Sotillo F, Ramirez A (1999) Proximate composition and vitamin E levels in egg yolk: losses by cooking in a microwave oven. J Sci Food Agric 79(12):1550–1556

Nielsen H, Finot P, Hurrell R (1985) Reactions of proteins with oxidizing lipids. I. Analytical measurements of lipid oxidation and amino acid losses in a whey protein-methyl linoleate model system. Br J Nutr 53:75–83

Nishimura H, Takahashi T, Wijaya CH et al (2000) Thermochemical transformation of sulfur compounds in Japanese domestic Allium, *Allium victorialis* L. Biofactors 13(1–4):257–263

Nomen L, Johnsson M, Andersson H, van Gameren Y, Dutta P (1999) Plant sterols in vegetables and fruits commonly consumed in Sweden. Eur J Nutr 38:84–89

Normén L, Bryngelsson S, Johnsson M, Evheden P, Ellegård L, Brants H, Andersson H, Dutta P (2002) The phytosterol content of some cereal foods commonly consumed in Sweden and in the Netherlands. J Food Compost Anal 15:693–704

Nunn MD, Giraud DW, Parkhurst AM, Hamouz FL, Driskell JA (2006) Effects of cooking methods on sensory qualities and carotenoid retention in selected vegetables. J Food Quality 29:445–457

Oerlemans K, Barrett DM, Suades BC et al (2006) Thermal degradation of glucosinolates in red cabbage. Food Chem 95:19–29

Onayemi O, Badifu GIO (1987) Effect of blanching and drying methods on the nutritional and sensory quality of leafy vegetables. Plant Food Hum Nutr 37(4):291–298

Osseyi ES, Wehling RL, Albrecht JA (2001) HPLC determination of stability and distribution of added folic acid and some endogenous folates during breadmaking. Cereal Chem 78:375–378

Padmavati K, Udipi SA, Rao M (1992) Effect of different cooking methods on beta-carotene content of vegetables. J Food Sci Technol India 29(3):137–140

Park YW (1987) Effect of freezing, thawing, drying, and cooking on carotene retention in carrots, broccoli and spinach. J Food Sci 52:1022–1025

Pellegrini N, Visioli F, Buratti S, Brighenti F (2001) Direct analysis of total antioxidant activity of olive oil and studies on the influence of heating. J Agric Food Chem 49(5):2532–2538

Peterson J, Dweyer J (1998) Flavonoids: dietary occurrence and biochemical activity. Nutr Res 18(12):1995–2018

Piironen V, Lindsay DG, Miettinen TA, Toivo J, Lampi AM (2000) Plant sterols: biosynthesis, biological functions and their importance to human nutrition. J Sci Food Agric 80:939–966

Pinheiro Sant'Ana HM, Stringheta PC, Cardoso Brandão SC, Monteiro Cordeiro de Azeredo R (1998) Carotenoid retention and vitamin A value in carrot (*Daucus carota* L.) prepared by food service. Food Chem 61:145–151

Podsedek A (2007) Natural antioxidants and antioxidant capacity of Brassica vegetables: a review. Food Sci Technol (LWT) 40:1–11

Pokorny J (1981) Browning from lipid-protein interactions. Progr Food Nutr Sci 5:421–428

Price KR, Bacon JR, Rhodes MJC (1997) Effect of storage and domestic processing on the content and composition of flavonol glucosides in onion (*Allium cepa*). J Agric Food Chem 45:938–942

Prosky L (1999) What is fibre? Current controversies. Trends Food Sci Technol 10:271–275

Puuponen-Pimia R, Hakkinen ST, Aarni M, Suortti T, Lampi AM, Eurola M, Piironen V, Nuutila AM, Oksman-Caldentey KM (2003) Blanching and long-term freezing affect various bioactive compounds of vegetables in different ways. J Sci Food Agric 83:1389–1402

Radwan S, Fawzy M, Salah H, Gamal S (1991) A comparative study on the deterioration of oils microwave and conventional way heating. Grasas Aceites 42(3):187–193

Rangkadilok N, Tomkins B, Nicolas ME, Premier RR, Bennett RN, Eagling DR, Taylor PWJ (2002) The effect of postharvest and packaging treatments on glucoraphanin concentration in broccoli (*Brassica oleracea var. italica*). J Agric Food Chem 50:7386–7391

Ranhotra GS, Keagy PM (1995) Adding folic acid to cereal-grain products. Cereal Foods World 40:73–74

Rastrelli L, Passi S, Ippolito F, Vacca G, Simone F (2002) Rate of degradation of alpha-tocopherol, squalene, phenolics, and polyunsaturated fatty acids in olive oil during different storage conditions. J Agric Food Chem 50(20):5566–5570

Regulska-IIow B, IIow R (2002) Comparison of the effects of microwave cooking and conventional cooking methods on the composition of fatty acids and fat quality indicators in herring. Nahrung-Food 46(6):383–388

Renard CMGC (2005) Effects of conventional boiling on the polyphenols and cell wallsof pears. J Sci Food Agric 85:310–318

Rice-Evans CA, Miller NJ (1996) Antioxidant activities of flavonoids as bioactive components of food. Biochem Soc Trans 24:790–795

Robards K, Antolovich M (1997) Analytical chemistry of fruits bioflavonoids. Analyst 122:11–34

Rodrigues AS, Rosa EAS (1999) Effect of post-harvest treatments on the level of glucosinolates in broccoli. J Sci Food Agric 79:1028–1032

Rodriguez R, Jimenez A, Guillen R, Heredia A, Fernandez-Bolaños J (1999) Turnover of asparagus cell wall polysaccharides during postharvest storage. J Agric Food Chem 47:4525–4531

Rodriguez R, Jimenez A, Fernández-Bolaños J, Guillen R, Heredia A (2006) Dietary fibre from vegetable products as source of functional ingredients. Trends Food Sci Tecnol 17:3–15

Rodriguez-Saona L, Barrett D, Selivonchick D (1995) Peroxidase and lipoxygenase influence on stability of polyunsaturated fatty-acids in sweet corn (*Zea mays L*) during frozen storage. J Food Sci 60(5):1041–1044

Rosa EAS, Heaney RK (1993) The effect of cooking and processing on the glucosinolate content: studies on four varieties of Portuguese cabbage and hybrid white cabbage. J Sci Food Agric 62:259–265

Rungapamestry V, Duncan AJ, Fuller Z, Ratcliffe B (2006) Changes in glucosinolate concentrations, myrosinase activity, and production of metabolites of glucosinolates in cabbage (*Brassica oleracea var. capitata*) cooked for different durations. Agric Food Chem 54(20):7628–7634

Rungapamestry V, Duncan AJ, Fuller Z, Ratcliffe B (2007a) Effect of cooking brassica vegetables on the subsequent hydrolysis and metabolic fate of glucosinolates. Proc Nutr Soc 66(1):69–81

Rungapamestry V, Duncan AJ, Fuller Z, Ratcliffe B (2007b) Effect of meal composition and cooking duration on the fate of sulforaphane following consumption of broccoli by healthy human subjects. Br J Nutr 97(4):644–652

Saghir S, Wagner KH, Elmadfa I (2005) Lipid oxidation of beef fillets during braising with different cooking oils. Meat Sci 71(3):440–445

Sahlin E, Savage GP, Lister CE (2004) Investigation of the antioxidant properties of tomatoes after processing. J Food Compost Anal 17:635–647

Sánchez-Muniz F, Viejo J, Medina R (1992) Deep-frying of sardines in different culinary fats. Changes in the fatty acid composition of sardines and frying fats. J Agric Food Chem 40:2252–2256

Sanz T, Salvador A, Fiszman SM (2007) Resistant starch (RS) in battered fried products: functionality and high-fibre benefit. Food Hydrocolloid. doi: 10.1016/j.foodhyd.2007.01.018

Sarhan MAI, El-Wakeil FA, Morsi MKS (1975) Chemical changes in sweet potatoes during cooking. Egypt J Food Sci 3(1/2):25–36

Scott J, Rébeillé F, Fletcher J (2000) Folic acid and folates: the feasibility for nutritional enhancement in plant foods. J Sci Food Agric 80:795–824

Seppanen C, Csallany A (2006) The effect of intermittent and continuous heating of soybean oil at frying temperature on the formation of 4-hydroxy-2-trans-nonenal and other alpha-, beta-unsaturated hydroxyaldehydes. J Am Oil Chem Soc 83(2):121–127

Shozen K, Ohshima T, Ushio H, Koizumi (1995) Formation of cholesterol oxides in marine fish products induced by grilling. Fish Sci 61(5):817–821

Silwood C, Grootveld M (1999) Application of high-resolution, two-dimensional H-1 and C-13 nuclear magnetic resonance techniques to the characterization of lipid oxidation products in autoxidized linoleoyl/linolenoylglycerols. Lipids 34(7):741–756

Simopoulos A (1999) Essential fatty acids in health and chronic disease. Am J Clin Nutr 70(3):560–569

Singh P, Kulshrestha K (2006) Studies on the effect of pretreatments on the preparation of carrot powder. J Food Sci Technol 43:145–147

Smith TK, Mithen R, Johnson IT (2003) Effects of Brassica vegetable juice on the induction of apoptosis and aberrant crypt foci in rat colonic mucosal crypts in vivo. Carcinogenesis 24:491–495

Sones K, Heaney RK, Fenwick GR (1984) An estimate of the mean daily intake of glucosinolates from cruciferous vegetables in the UK. J Sci Food Agr 35:712–720

Song L, Thornalley PJ (2007) Effect of storage, processing and cooking on glucosinolate content of Brassica vegetables. Food Chem Toxicol 45(2):216–224

Speek AJ, Speek-Saichua S, Schreurs WHP (1988) Total carotenoid and beta-carotene contents of Thai vegetables and the effect of processing. Food Chem 27(4):245–257

Stea TH, Johansson M, Jagerstad M, Frolich W (2006) Retention of folates in cooked, stored and reheated peas, broccoli and potatoes for use in modern large-scale service systems. Food Chem 101:1095–1107

Steinhart H, Rathjen T (2003) Dependences of tocopherol stability on different cooking procedures of food. Int J Vitam Nutr Res 73(2):144–151

Strack D, Wray V (1993) Anthocyanins. In: Harborne JB (ed) The flavonoids. Advances in research since 1986. Chapman and Hall, London

Sungpuag P, Tangchitpianvit S, Chittchang U, Wasantwisut E (1999) Retinol and beta carotene content of indigenous raw and home-prepared foods in Northeast Thailand. Food Chem 64:163–167

Sweeney JP, Marsh AC (1971) Effect of processing on provitamin A in vegetables. J Am Diet Assoc 59:238–343

Takagi S, Ienaga H, Tsuchiya C, Yoshida H (1999) Microwave roasting effects on the composition of tocopherols and acyl lipids within each structural part and section of a soya bean. J Sci Food Agric 79(9):1155–1162

Tatjana K, Terezija G, Milica K, Plestenjak A (2002) Dietary fibre content of dry and processed beans. Food Chem 80:231–235

Thebaudin JY, Lefebvre AC, Harrington M, Bourgeois CM (1997) Dietary fibres: nutritional and technological interest. Trends Food Sci Technol 8:41–47

Thompson KA, Marshall MR, Sims CA, Wei CI, Sargent SA, Scott JW (2000) Cultivar, maturity, and heat treatment on lycopene content in tomatoes. J Food Sci 65(5):791–795

Tothmarkus M, Sasskiss A (1993) Effect of cooking on the fatty-acid composition of silver carp (Hypophtalmichtis-Molitrix, V). Acta Alimentaria 22(1):25–35

Toor RK, Savage GP (2005) Antioxidant activity in different fractions of tomatoes. Food Res Int 38:487–494

Trowell HC, Southgate DAT, Wolever TMS, Leeds AR, Gassull MA, Jenkins DJA (1976) Dietary fiber redefined. Lancet 1:967

Uplike AA, Schwartz SJ (2003) Thermal processing of vegetables increases cis isomers of lutein and zeaxanthin. J Agric Food Chem 51:6184–6190

Vahteristo LT, Lehikoinen KE, Ollilainen V, Koivistoinen PE, Varo P (1998) Oven-baking and frozen storage affect folate vitamer retention. Food Sci Technol (LWT) 31:329–333

Vallejo F, Tomas-Barberan FA, Garcia-Viguera C (2002) Glucosinolates and vitamin C content in edible parts of broccoli florets after domestic cooking. Eur Food Res Technol 215:310–316

Vallejo F, Tomás-Barberán FA, García-Viguera C (2003) Phenolic compound contents in edible parts of broccoli inflorescences after domestic cooking. J Sci Food Agric 83:1511–1516

Vallejo F, Tomas-Barberan F, Garcia-Viguera C (2004) Health-promoting compounds in broccoli as influenced by refrigerated transport and retail sale period. J Agric Food Chem 51:3029–3034

Van den Berg H, Faulks R, Fernando Granado H, Hirschberg J, Olmedilla B, Sandmann G, Southon S, Stahl W (2000) The potential for the improvement of carotenoid levels in foods and the likely systemic effects. J Sci Food Agric 80:880–912

Vareltzis K, Koufidis D, Gavriilidou E, Papavergou E, Vasiliadou S (1997) Effectiveness of a natural Rosemary (*Rosmarinuss officinalis*) extract on the stability of filleted and minced fish during frozen storage. Food Res Tech 205(2):93–96

Veda S, Kamath A, Platel L, Begum K, Srinivasan K (2006) Determination of bioaccessibility of beta-carotene in vegetables by in vitro methods. Mol Nutr Food Res 50:1047–1052

Verkerk R, Dekker M (2004) Glucosinolates and myrosinase activity in red cabbage (*Brassica oleracea* L var *Capitata frubra* DC) alter various microwave treatments. J Agric Food Chem 52:7318–7323

Verkerk R, Krebbers B, Dekker MJ, Jongen WMF (1997a) Glucosinolates as contyributing factors in the quality of Brassica vegetables: stress-induced increase of indole

glucosinolates. In: Crop protection and food quality. University of Kent, Canterbury, pp 93–101
Verkerk R, van der Gaag MS, Dekker M, Jongen WMF (1997b) Effects of processing conditions on glucosinolates in cruciferous vegetables. Cancer Lett 114:193–194
Verkerk R, Dekker M, Jongen WMF (2001) Post-harvest increase of indolyl glucosinolates in response to chopping and storage of Brassica vegetables. J Sci Food Agric 81:953–958
Wang H, Murphy PA (1996) Mass balance study of isoflavones during soybean processing. J Agric Food Chem 44: 2377–2383
Wathelet JP, Mabon N, Foucart M, Marlier M (1996) Influence of blanching on the quality of Brussels sprouts (*Brassica oleracea* L cv *gemmifera*). Sci Aliment 16:393–402
Weesie RJ, Askin D, Jansen FJHM, de Groot HJM, Lugtenburg J, Britton G (1995) Protein-chromophore interactions in -crustacyanin, the major blue carotenoprotein from the carapace of the lobster, *Homarus gammarus* a study by 13C magic angle spinning NMR. FEBS Lett 362:34–38
Wennberg MS, Engqvist GM, Nyman EMGL (2003) Effects of boiling on dietary fibre components in fresh and stored white cabbage (*Brassica oleracez var capitata*). J Food Sci 68:1615–1621
Wennermark B, Ahlmen H, Jägerstad M (1994) Improved vitamin E retention by using freshly-milled whole-meal wheatflour during from-drying. J Agric Food Chem 42:1348–1351
Whelan J, Rust C (2006) Innovative dietary sources of n-3 fatty acids. Annu Rev Nutr 26:75–103
Wollenber E (1993) Flavones and flavonols. In: Harborne JB (ed) The Flavonoids. Advances in research since 1986. Chapman and Hall, London
Wyatt CJ, Perez-Carballido S, Mendez RO (1998) alpha- and gamma-Tocopherol content of selected foods in the Mexican diet: effect of cooking losses. J Agric Food Chem 46:4657–4661
Yamamoto Y, Imose K (1989) Changes in fatty acid composition in sardines (*Sardinops melanosticta*) with cooking and refrigerated storage. J Sci Vitam (Tokyo) 35(1):39–47
Yanar Y, Kucukgulmez A, Ersoy B, Celik M (2007) Cooking effects on fatty acid composition of cultured sea bass (*Dicentrarchus labrax*) fillets. J Muscle Foods 18(1):88–94
Yoshida H, Kajimoto G (1989) Effects of microave energy on the tocopherols of soybean seeds. J Food Sci 54:1596–1600
Yoshida H, Hirooka N, Kajimoto G (1991) Microwave heating effets on relative stabilities of tocopherols in oils. J Food Sci 56:1042–1046
Yoshida H, Takagi S, Mitsuhashi S (1999) Tocopherol distribution and oxidative stability of oils prepared from the hypocotyl of soybeans roasted in a microwave oven. J Am Oil Chem Soc 76(8):915–920
Yoshida H, Hirakawa Y, Abe S, Mizushina Y (2002) The content of tocopherols and oxidative quality of oils prepared from sunflower (*Helianthus annuus* L.) seeds roasted in a microwave oven. Eur J Lipid Sci Technol 104(2):116–122
Yoshida H, Tomiyama Y, Hirakawa Y, Mizushina Y (2006) Microwave roasting effects on the oxidative stability of oils and molecular species of triacylglycerols in the kernels of pumpkin (*Cucurbita* spp.) seeds. J Food Compost Anal 19(4):330–339
Zhang D, Hamauzu Y (2004) Phenolics, ascorbic acid, carotenoids and antioxidant activity of broccoli and their changes during conventional microwave cooking. Food Chem 88:503–509
Zia-ur-Rehman Z, Islam M, Shah WH (2003) Effect of microwave and conventional cooking on insoluble dietary fibre components of vegetables. Food Chem 80:237–240
Zia-ur-Rehman Z, Shah WH (2004) Domestic processing effects on some insoluble dietary fibre components of various food legumes. Food Chem 87:613–617