Influence of Food Processing Operations on Vitamins

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Importance of Vitamins

Vitamins are organic compounds which cannot be synthesized in adequate quantities by humans and, therefore, must be supplied by our diet. Moreover, they have different regulatory functions that determine the development, physical efficiency, and health status of our body. To date, 15 vitamins have been recognized in human nutrition. Depending on their solubility, vitamins are either classified as water soluble or fat soluble vitamins (Katouzian and Jafari, 2016). As shown in **Table 1**, water soluble vitamins include vitamin C and the members of the vitamin B group, whereas fat soluble vitamins comprise vitamins A, D, E, and K; also included are the carotenoids that possess varying degrees of vitamin A activity (Pamela et al., 2005; Ball, 2005; Kim and Driskell, 2009).

Impact of Food Processing Operations on Vitamins

Technological processing applied in the food industry often includes many thermal and non-thermal processes. These processes can have either negative or positive effects on the food materials. Food-processing operations are primarily focused on inactivation of enzymes, food-borne pathogens, prolongation of shelf-life, improved digestibility and bioavailability of nutrients, including augmented antioxidants. In contrast, these processing operations can also bring some unintentional and undesired consequences, such as loss of certain vitamins (Van Boekel et al., 2010; Nayak et al., 2015). Furthermore, the rate of this reduction in vitamin content is influenced by a number of factors: heat, moisture, oxygen, pH, light, oxidising and reducing agents, presence of metallic ions (e.g. iron, copper), and presence of other vitamins (Ottaway, 1993).

Considering the increasing demand of consumers for nutritious and functional foods, manufacturers in the food industry have to develop preservation technologies to ensure that the nutrients of the foods are lost to a minimum. Clearly, different food processing operations such as pasteurization, sterilization, blanching, cooking, frying, high pressure processing, etc. have undesirable effects on vitamins. In this chapter, we will consider these processes in two classes: conventional food processes; and modern processes particularly the non-thermal ones.

Influence of Conventional Food Processing Operations on Vitamins

Vitamin degradation during heating is dependent on several factors such as the processing method, food type, oxygen, light, moisture, pH, the chemical matrix, type of vitamins, and active enzymes (Awuah et al., 2007; Leskova et al., 2006). A brief overview of studies considering the effect of conventional food processing on vitamins is discussed in this section. Although there are some investigations on the effects of food processing operations on the retention of vitamins, generally speaking, the literature in this field is scarce. More studies have been focused on vitamin C and vitamin B group. In fact, retention of vitamin C during various food processes is a model and control index which predicts the retentions of other vitamins too.

Table 1 Classification of the vitamins, their sources and associated anemias

Solubility	*Vitamins*	*Other names/forms*	*Food sources*	*Nutritional anemias*
Water-soluble	Vitamin C	Ascorbic acid	Tomatoes, strawberries, peppers, broccoli, citrus fruits	Scurvy
	Vitamin B_1	Thiamine	Pork, beef, yeast, whole grains, legumes	Beriberi, Wernicke-Korsakoff syndrome
	Vitamin B_2	Riboflavin	Meats, dairy products, enriched cereals, breads, green leafy vegetables	Dermatitis, Cheilosis, Glossitis
	Vitamin B_3	Niacin Nicotinic acid Nicotinamide	Yeasts, meats, poultry, fish, nuts, and enriched products such as cereals and grains.	Pellagra, Neurological symptoms
	Vitamin B_5	Pantothenic acid	Liver, yeast, meats, egg yolks, whole grains, potatoes, broccoli, mushrooms, and avocadoes	Burning foot syndrome
	Vitamin B_6	Pyridoxine Pyridoxal Pyridoxol Pyridoxamine	Meats, whole-grain products, vegetables, some fruits (e.g. banana), nuts, fortified cereals	Weakness, Sleeplessness, Cheilosis, Glossitis, Stomatitis, Microcytic
	Vitamin B_8	Biotin	Liver, egg yolks, soybeans, bakers and brewer's yeasts	Dermatitis, Glossitis, Loss of appetite, and nausea
	Vitamin B_9	Folic acid Folate	Green leafy vegetables, orange juice, dried beans, peas	Macrocytic Megaloblastic Neural tube Defects in the fetus
	Vitamin B_{12}	Cobalamin Cyanocobalamin Hydroxocobalamin	Meats, poultry, liver, whole milk, eggs, oysters, fresh shrimp, pork, chicken	Megaloblastic Pernicious Dementia Paranoia Depression
Fat-soluble	Vitamin A	Retinol, Retinal Retinoic acid (A_2) α-carotene β-carotene γ-carotene β-cryptoxanthin Echinenon	Meats, egg yolks, fortified food products, dark green leafy vegetables, yellowish-orange fruits and vegetables.	Night blindness Xerophthalmia Anorexia, Immune deficiencies, Follicular hyperkeratosis
	Vitamin E	α-Tocopherols β-Tocopherols γ-Tocopherols δ-Tocopherols α-Tocotrienol β-Tocotrienol γ-Tocotrienol δ-Tocotrienol	Polyunsaturated plant oils, almonds, peanuts	Sensitivity of erythrocytes to peroxide, Abnormal cellular membranes
	Vitamin D	Ergocalciferol (D_2) Cholecalciferol (D_3)	Self synthesis via sun light, fish and fish oils	Rickets Osteomalacia
	Vitamin K	Phylloquinone (K_1) Menaquinone (K_2) Menadione (K_3)	Green leafy vegetables, plant oils	Hemorrhagic syndrome

(Adapted from Leskova et al., 2006; Harvey and Ferrier, 2011; Kim and Driskell, 2009)

Vitamin C

Various conventional food processes have been investigated for their effects on the vitamin C content of different fruits and vegetables as shown in **Table 2**; almost all these investigations have reported to result in some losses of vitamin C. For example, it has been revealed that conventional food processing operations bring about significant decreases of vitamin C content of various foods, such as pasteurization of tomato (Capanoglu et al., 2008), orange (Gil-Izquierdo et al., 2002), guava (Ordóñez-Santos and Vázquez-Riascos, 2010), and strawberry (Klopotek et al., 2005). Blanching as a mild thermal processing has been determined to reduce vitamin C levels in parsley leaves by 47%–51% (Lisiewska and Kmiecik, 1997), and in broccoli by 40% (Wu et al., 1992). Abushita et al. (2000) also reported that during hot-break pulping of tomato, about 38% of its original ascorbic acid was lost, and further processing to produce tomato paste by vacuum evaporation resulted in losses of more than 16% of the ascorbic acid content (Abushita et al., 2000). Moreover, Al-Duais et al. (2009) reported the losses of ascorbic acid, in *Cyphostemma Digitatum* plant, 59% after sun drying.

Table 2 The influence of conventional food processing operations on vitamin C

Processing	*Product*	*Result*	*References*
Pasteurization (93 °C)	Tomato	50% ↓	Capanoglu et al. (2008)
Extrusion	Acha/Soybean Blends	No changes	Anuonye et al. (2010)
Blanching	Brocoli	40% ↓	Wu et al. (1992)
Boiling	Spinach	60% ↓	Rumm-Kreuter and Demmel (1990)
Steaming		46.5% ↓	
Pressuõre cooking		58% ↓	
Thermal treatment (88 °C for 2, 15, and 30 min)	Tomato	11%–29% ↓	Dewanto et al. (2002)
Sun drying	Cyphostemma	59% ↓	Al-Duais et al. (2009)
Boiling (10 min at 90 °C)	Spinach	40%–60% ↓	Gil et al. (1999)
Pasteurization	Red tomato	81% ↓	Georgé et al. (2011)
Mild pasteurization (75 °C/30 s)	Orange	12% ↑	Gil-Izquierdo et al. (2002)
Standard pasteurization (95°C/30 s)		19% ↑	
Concentration		2% ↓	
Freezing		2% ↓	
Standard pasteurization (95 °C/30 s)		58% ↓	
Convectional drying (50, 60, and 70 °C)	Sour cherry	71%–73% ↓	Horuz et al. (2017)
Hybrid drying (120, 150, and 180W coupled with hot air at 50, 60, and 70 °C)		63%–84% ↓	
Frozen	Brocoli	50%–55% ↓	Murcia et al. (2000)
Canned (30 min at 121 °C)		84% ↓	
Thermal treatment (Diffrent time and Temperatures)	Beet	1%–8% ↓	Jiratanan and Liu (2004)
Microwaved	Green peas	13% ↓	Hunter and Fletcher (2002)
Boiled		39% ↓	
Overcooked		61% ↓	
Blanching	Parsley	47%–51% ↓	Lisiewska and Kmiecik (1997)
Pasteurization	Strawberry	28%–35% ↓	Klopotek et al. (2005)
Pasteurization	Milk	20% ↓	Moltó-Puigmartí et al. (2011)
Blanching	Pepper	12% ↓	Martínez et al. (2005)
Freeze drying		3% ↓	
Frying		25% ↓	
Roasting		20% ↓	
Low pasteurization	Tomato pure'e	27% ↓	Sánchez-Moreno et al. (2006)
High pasteurization		27% ↓	
Freezing		2% ↑	
High pasteurization plus freezing		31% ↓	
Vacuum Drying			Reis et al. (2017)
50 °C	Litchi	32.78% ↓	
60 °C		25% ↓	
70 °C		34.17% ↓	
Blanching	Vegetables	89.1%–97.3% ↓	Mosha et al. (1995)
Cooking		80.1%–97.4% ↓	
Thermal processing	Pepper	75% ↓	Howard et al. (1994)
Heat Treatments	Milk	16.6%–29.7% ↓	Haddad and Loewenstein (1983)
Pounded and cooked	Cassava leaves	76.87% ↓	Achidi et al. (2008)
Ground and cooked		78.61% ↓	
Baking	Tomato	2%–62% ↓	Gahler et al. (2003)
Thermal treatments	Tomato	10.2%–29.4% ↓	Dewanto et al. (2002)
Boiling	Vegetables	51% ↓	Bureau et al. (2015)
Blanching	Sweetcorn,	10% ↓	Klein (1997)
	Green beans	20% ↓	
	Broccoli	30% ↓	
Pasteurization	Guava pulp	28.3% ↓	Ordóñez-Santos and Vázquez-Riascos (2010)
	Guava nectar	37% ↓	
Sundrying	Green Leafy Vegetables	6.5%–66.9% ↓	Babalola et al. (2010)
Blanching		64.5%–79.23% ↓	
Boiling		74.5%–91.5% ↓	
Squeeze-washing		89.6%–89.9% ↓	
Squeeze-washing with salt		90.5% ↓	
Squeeze-washing and boiling		94.9%↓	
Heat processing (Toasting)	Edible Winged Termite	16% ↓	Kinyuru et al. (2010)

(Continued)

Table 2 The influence of conventional food processing operations on vitamin C—cont'd

Processing	*Product*	*Result*	*References*
Heating (98 °C, 10 min) Freezing (−20 °C)	Apricots, Cherries, Nectarines, Peaches, Plums, Carrots	1.2–2.5 fold ↑ 1.6–2.5 fold ↑	Leong and Oey (2012)
Thermal processing by increasing nanoparticle concentration (70 °C)			
0%	Tomato juice	37.27% ↓	Jafari et al. (2017)
2%		34.41% ↓	
4%		33.66% ↓	

↓: decrease, ↑: increase.

Vitamin C is very susceptible to chemical and enzymatic oxidation during the processing, storage, and cooking of foods (Ball, 2006). It is clear that raw tomato contains more vitamin C than processed tomato, and there is a higher loss of this vitamin during the production of tomato concentrates than in tomato juice or whole canned tomatoes (Riso and Porrini, 2001). Results from some other studies have also indicated that vitamin C is destroyed mainly due to oxidation reactions and the heat applied in the presence of air during processing (Leoni, 2002). In addition to the effect of oxygen, such high temperature applications themselves cause oxidative stresses. On the other hand, losses of vitamin C are minimal when vegetables are cooked without any water, whereas maximum losses are associated with cooking in a large amount of water (Leskova et al., 2006). For example, Ordóñez-Santos and Vázquez-Riascos (2010) observed that the production of nectar and pulp from fresh guava decreased vitamin C (28.3%–37%). Consistent with these results, they indicated that the reduction of vitamin C is attributed primarily to the dilution effect generated by addition of water in the product. Another study showed that vitamin C losses during blanching were found to be 10% for sweetcorn, 20% for green beans and 30% for broccoli (Klein, 1997). It has been shown that harvest damage, cutting/slicing, particle size, and type of blancher (steam/water, rotary/cabin) are the main factors affecting the losses of vitamin C (Davey et al., 2000).

Babalola et al. (2010) showed that green leafy vegetables were affected by different processing methods. They reported that boiling (91.5%) and squeeze washing (94.9%) caused more loss than blanching (79.23%). Consequently, it is better to inactivate the oxidase enzyme that destroys vitamin C, blanching vegetables in hot water. Moreover, when comparing various cooking procedures for vegetables, Bureau et al. (2015) observed that boiling was the less suitable method, with a high loss of vitamin C, compared to steaming, microwaving or pressure cooking. Another study conducted by Dewanto et al. (2002) showed that after 2, 15, and 30 min of heating at 88 °C, the vitamin C content significantly decreased by 10.2%–29.4%. Similarly, baking at 220 °C of tomato, the vitamin C content significantly dropped by 2%–62% (Gahler et al., 2003). In addition, certain pretreatments such as thawing cause higher vitamin C loss. Therefore, frozen vegetables must not be thawed before cooking.

These investigations show that vitamin C is a heat unstable vitamin. The losses of vitamin C are primarily due to chemical degradation including oxidation of ascorbic acid to dehydroascorbic acid (DHAA), followed by hydrolysis of the latter to 2,3-diketogulonic acid. Afterwards, polymerization to form other nutritionally inactive products (Dewanto et al., 2002; Ordóñez-Santos and Vázquez-Riascos, 2010) occurs. In a more recent study, Jafari et al. (2017) investigated the effects of thermal processing by nanofluids on vitamin C retention of tomato juice. The results showed that increasing nanoparticle concentration from 0 to 2% and 4% could culminate in the slightly better retention of vitamin C due to shorter process times. On the other hand, Leong and Oey et al. (2012) reported 1.2–2.5 fold and 1.6–2.5 fold increases in vitamin C content of some fruits and vegetables following the heating and freezing, respectively. This study indicated that heating and freezing enhanced the stability of vitamin C, resulting in higher levels after processing compared to fresh. This was due to ascorbic acid oxidase inactivation during heating leading to L-AA protection towards enzymatic oxidation (Leong and Oey, 2012).

Vitamin E

Some selected studies considering the influence of conventional food processing on the retention of vitamin E has been summarized in **Table 3**. Generally, vitamin E in foods is predominantly represented by α-tocopherol. Capanoglu et al. (2008) compared values for the starting material in tomato paste and found that 22% of α-tocopherol was increased during thermal processing while 69% δ-tocopherol and 84% γ-tocopherol were also lost. Seybold et al. (2004) reported that homogenization and sterilization of tomatoes during tomato juice production resulted in significant losses in α-tocopherol. Also, extrusion process variables could affect this vitamin content. For instance, extrusion cooking was determined to decrease vitamin E levels in cereals by 63%–94% (Zielinski et al., 2001), and in buckwheat by 63% (Zieliński et al., 2006). Moreover, Thammapat et al. (2016) observed that the parboiling process significantly decreased the concentrations of α- and γ-tocopherols as compared to raw rice (18%–25%). Similarly, Stuetz et al. (2017) noted that concentrations of α-tocopherol were decreased in hazelnuts, almonds and walnuts (20%–54%). The effects of processing on the content of vitamin E in foods have been the subject of limited investigations. In another study, Murcia et al. (1999) observed that boiling, omelette, and microwaving of egg yolk led to a 21.63%, 53.24%, and 43.12% reduction in vitamin E activity, respectively. The possible explanations could be the formation of peroxides as intermediate products in the autooxidation

Table 3 The influence of conventional food processing operations on different vitamins (other than Vitamin C)

Processing	*Product*	*Vitamin*	*Result*	*References*
Pasteurization (93 °C)	Tomato	α-tocopherol	22% ↑	Capanoglu et al. (2008)
		β-tocopherol	128% ↑	
		δ-tocopherol	69% ↓	
		γ-tocopherol	84% ↓	
		β-carotene	36% ↓	
Extrusion	Buckwheat	Vitamin E	63% ↓	Zieliński et al. (2006)
Extrusion	Whole-grain (wheat, barley, rye, oat)	Vitamin E	63%–94% ↓	Zielinski et al. (2001)
Extrusion	Oats, maize maize + peas	Thiamin (B_1)	39%–77% ↓	Athar et al. (2006)
		Riboflavin (B_2)	14%–30% ↓	
		Niacin (B_3)	25%–40% ↓	
		Pyridoxine (B_6)	65%–82% ↓	
Extrusion	Acha/soybean blends	Riboflavin (B_2)	6% ↓	Anuonye et al. (2010)
		Pyridoxine (B_6)	86.36% ↓	
Thermal treatment (120 °C for 30 s)	Carrot juice	Vitamin A	49% ↓	Chen et al. (1995)
Sun drying	Digitatum plant	Vitamin E	22% ↑	Al-Duais et al. (2009)
High vacuum flame sterilization	Tuna flake	Thiamin (B_1)	45% ↓	Seet et al. (1983)
		Riboflavin (B_2)	16% ↓	
		Niacin (B_3)	14% ↓	
Pasteurization	Red tomato	β-carotene	8% ↓	Georgé et al. (2011)
Thermal treatment (various time and Temperatures)	Beet	Folic acid	23%–39% ↓	Jiratanan and Liu (2004)
Roasting (140 °C for 25 min or 160/170 °C for 15 min)	Nuts	Thiamine (B_1)	11%–84% ↓	Stuetz et al. (2017)
		Riboflavin (B_2)	−6 - 6%↑	
		Pyridoxine (B_6)	−4 – 22% ↑	
		α-Tocopherol	20%–54%↓	
Parboiling	Rice	Vitamin E	18%–25% ↓	Thammapat et al. (2016)
Pasteurization	Orange-carrot Juice	Vitamin A	7.8% ↑	Torregrosa et al. (2005)
Low pasteurization	Tomato pure’e	Vitamin A	6% ↑	Sánchez-Moreno et al. (2006)
High pasteurization			3% ↑	
Freezing			12% ↑	
High pasteurization plus freezing			12% ↑	
Boiling	Egg yolk	Vitamin E	21.63% ↓	Murcia et al. (1999)
Omelette			53.24% ↓	
Microwaving			43.12% ↓	
Blanching	Vegetables	Riboflavin	19%–23%↓	Mosha et al. (1995)
		Thiamine	10%–91% ↑	
			67.7%–85.6% ↓	
Cooking		Riboflavin	3%–87%↓ or 15%–27% ↑	
		Thiamine		
			29.3%–88.6% ↓	
Blanching	Vegetables	Vitamin A	32.5%–63.1% ↑	Mosha et al. (1997)
Cooking			68.6%–228.6% ↑	
Cooking	Egg yolk	cholecalciferol (D_3)	1%–6% ↓	Mattila et al. (1999)
	Mushroom	hydroxycholecalciferol (25-OH-D_3)	5%–11% ↓	
	Fish		1%–14% ↓	
		ergocalciferol (D_2)	2%–23% ↓	
		cholecalciferol (D_3)		
Water blanching	Lima bean	Vitamin B_6	19%–24% ↓	Raab et al. (1973)
Steam blanching			13%–17% ↓	
Thermal processing	Pepper	Provitamin A	25% ↓	Howard et al. (1994)
Dehydrating	Apricot	β-carotene	9.2% ↓	Bolin and Stafford (1974)
Shade drying			10.1% ↓	
Sun drying			30% ↓	
Heat Treatments	Milk	Thiamine	7.9%–11.9% ↓	Haddad and Loewenstein (1983)
		Riboflavin	0.9%–2.7% ↓	
Thermal Processing	Soymilk	Thiamine	25% ↓	Kwok et al. (1998)
		Riboflavin	29% ↓	

(Continued)

Table 3 The influence of conventional food processing operations on different vitamins (other than Vitamin C)—cont'd

Processing	*Product*	*Vitamin*	*Result*	*References*
Heat processing (Toasting)	Edible Winged Termite	Pyridoxine (B_6)	4% ↓	Kinyuru et al. (2010)
		Folic acid	37% ↓	
		Ascorbic acid	16% ↓	
		Niacin (B_3)	21% ↓	
		Riboflavin (B_2)	34% ↓	
		Retinol	30% ↓	
		α-Tocopherol	20% ↓	
Pounded and cooked	Cassava leaves	Thiamine (B_1)	35.14% ↓	Achidi et al. (2008)
		β-Carotene	6.76% ↓	
Ground and cooked	Cassava leaves	Thiamine (B_1)	38.95% ↓	Achidi et al. (2008)
		β-Carotene	5.29% ↓	
Boiling	Vegetables	Folate	68% ↓	Bureau et al. (2015)
		B-carotene	9% ↓	
Cooking	Boiled broccoli	Folate	53% ↓	Bassett and Sammán (2010)
	Boiled spinach		36% ↓	
	Boiled onion		10% ↓	
	Baked onion		37% ↓	
	Roasted liver		86% ↓	
	Fried hen egg		31% ↓	
	Boiled hen egg		2% ↓	
	Fried yolk		6% ↓	
	Boiled yolk		3% ↓	
	Boiled lentil		57% ↓	
	Boiled soybean		5% ↓	
	Boiled potato		26% ↓	
Fermentation	Kisra	Thiamine (B_1)	35% ↓	Mahgoub et al. (1999)
		Riboflavin (B_2)	16% ↑	
	Hulu-mur	Thiamine (B_1)	10% ↓	
		Riboflavin (B_2)	15% ↓	
Baking	Hulu-mur	Thiamine (B_1)	88.5% ↓	Mahgoub et al. (1999)
		Riboflavin (B_2)	48.4% ↓	
Pasteurization	Milk	Thiamine	< 10%↓	Chapman et al. (1957)
		Riboflavin	↔	
		Pantothenic acid	< 10%↓	
		Biotin	< 10%↓	
		Vitamin B_{12}	< 10%↓	
Sterilization		Thiamine	30%–50% ↓	
		Riboflavin	< 10%↓	
		Pantothenic acid	< 10%↓	
		Biotin	< 10%↓	
		Vitamin B_{12}	90%–100% ↓	
Ultra-high temperature processing		Thiamine	40%–50% ↓	
		Riboflavin	< 10%↓	
		Pantothenic acid	10%–15% ↓	
		Biotin	< 10%↓	
		Vitamin B_{12}	90%–100% ↓	
Evaporation		Thiamine	30%–40% ↓	
		Riboflavin	↔	
		Pantothenic acid	< 10%↓	
		Biotin	10%–15% ↓	
		Vitamin B_{12}	90% ↓	
Spray drying		Thiamine	10%–15% ↓	
		Riboflavin	< 10%↓	
		Pantothenic acid	< 10%↓	
		Biotin	10%–15% ↓	
		Vitamin B_{12}	35% ↓	

↓: decrease, ↑: increase, ↔: no changes.

of the fatty acids, destroying the oxidation sensitive vitamins such as vitamin E since it would react with the peroxides (Murcia et al., 1999).

Vitamin A

Similar to the observations for vitamin C, loss of β-carotene also varies depending on the type of vegetable (the matrix) as well as the processing method applied (**Table 3**). It has been reported that boiling and frying of Thai vegetables led to a 14% and 24% reduction in vitamin A activity, respectively (Speek et al., 1988). Moreover, according to Achidi et al. (2008), processing and cooking of cassava leaves caused minimal decrease in β-carotene content. Bolin and Stafford (1974) found that sun-drying (30%), shade-drying (10.1%), and dehydrating (9.2%) of apricot resulted in significant losses in β-carotene. Similarly, thermal processing of peppers resulted in a 25% decrease of total provitamin A activity (Howard et al., 1994).

On the other hand, Mosha et al. (1997) reported that the increase in vitamin A activities were in the range of 32.5%–63.1% for blanched vegetables, and 68.6%–228.6% for cooked vegetables. In another study conducted by Sánchez-Moreno et al. (2006), it was revealed no significant differences in vitamin A contents among low pasteurization, high pasteurization, freezing, high pasteurization plus freezing pur'ee samples in comparison with the untreated sample. As seen in the examples, more researchers have studied the effect of different methods of cooking and processing on the levels of both vitamin A and their vitamers in foods. These results show that vitamin A is sensitive to destruction by heat, light and oxygen. Moreover, thermal food processing can result in remarkable losses of vitamin A activity.

Vitamin B Group

Athar et al. (2006) reported a significant decrease in vitamin B_1 (39%–77%), vitamin B_2 (14%–30%), vitamin B_3 (25%–40%), and vitamin B_6 (65%–82%) in extruded food products. Similarly, Anuonye et al. (2010) indicated a 6% decrease in riboflavin (vitamin B_2) and 86.36% decrease in pyridoxine (vitamin B_6) after extrusion of Acha/soy bean blend. In another study, it was revealed that high vacuum flame sterilization of tuna flake led to a 14% reduction in vitamin B_3 (Seet et al., 1983). Jiratanan and Liu (2004) observed that thermal treatments of beet caused a 23%–39% decreases in folic acid. Al-Khalifa and Dawood (1993) indicated that Thiamin (vitamin B_1) was more sensitive to heat than was riboflavin. Moreover, the study reported that higher losses of thiamin occurred during roasting and deep-frying, while braising and microwave cooking resulted in lower losses. Bassett and Sammán (2010) investigated the retention of folate in foods after using different cooking processing. They reported that the folate retention was in the range 14%–99% according to both type of food and method of processing. Another study conducted by Achidi et al. (2008) concluded that thiamine losses from 35.14% to 38.95% occurred while processing cassava leaves. In a separate study, Kinyuru et al. (2010) observed that the toasting of frozen green vegetables, pyridoxine (B_6), folic acid, niacin (B_3), and riboflavin (B_2) was found to result in approximately 4%, 37%, 21%, and 34% losses, respectively.

Kwok et al. (1998) investigated effect of thermal processing on thiamine and riboflavin content in soy milk. They reported that thiamine was found to be much more heat sensitive than riboflavin. In another study, Mahgoub et al. (1999) noted that fermentation of kisra increased riboflavin (16%) but decreased thiamine (35%), whereas fermentation of hulu-mur reduced the levels of both riboflavin (15%) and thiamine (10%). Moreover, the same researchers observed that riboflavin was not affected by baking of kisra but thiamine level was markedly decreased. Hulu-mur baking caused reduction of both thiamine and riboflavin. These high losses may be attributed to the both long baking times and high baking temperatures. Chapman et al. (1957) reported that pasteurization (except riboflavin), sterilization, ultra-high temperature processing, evaporation (except riboflavin), and spray drying led to a decrease in all B complex vitamins. Furthermore, 7.9%–11.9% loss of thiamine and 0.9%–2.7% loss of riboflavin was observed on heat processing of milk (Haddad and Loewenstein, 1983).

Raab et al. (1973) showed that steam blanching (83%–87%) of lima beans may have somewhat improved retention compared to water blanching (76%–81%). Kōmura et al. (1990) investigated the effects of different cooking methods, including boiling, steaming, parching, frying on thiamine recovery and noted that the loss of thiamine was largest in boiling (70%), followed by parching (35%) and frying (30%). In a separate study, Mosha et al. (1995) investigated that effect of blanching and cooking processing on the retention of riboflavin and thiamine. They found a decrease in thiamine content by blanching (67.7%–85.6%) and cooking (29.3%–88.6%) of vegetables. This is explained by the water-soluble nature of the vitamin being leached out into the water. Moreover, the losses of thiamine content may have resulted from severity of heat treatment. The rate of thiamine degradation is accelerated by increase in temperature and pH (Kinyuru et al., 2010). In contrast, it has been shown that blanching and cooking resulted in a significant increase in riboflavin content in some vegetables (cowpea, peanut and pumpkin greens (10%–91%), whereas in amaranth and sweet potato leaves (19%–87%), a significant decrease was observed. These increases in riboflavin are supposed to result from an increased tissue breakdown and increased accessibility of the vitamin to the extracting solvent. Kwok et al. (1998) reported that riboflavin is more heat-stable than is thiamin, and its thermostability is independent of heating methods. Some other results have been briefly shown in **Table 3**.

The Influence of Modern and Non-thermal Food Processing Operations on Vitamins

Traditional thermal processing led to remarkable losses in nutritional quality as mentioned in the previous section. Considering the increasing consumer fresh-like products demands, food industries have directed their studies to the search for alternative processing technologies including UV light, high intensity light pulses, γ-irradiation, pulsed electric fields, radiofrequency electric fields, Ohmic heating, microwave heating, ultrasonication, high hydrostatic pressure, supercritical carbon dioxide, ozonation, and flash vacuum

(Jiménez-Sánchez et al., 2017). In general, it has been revealed that these technologies seem to be less detrimental than the thermal processing. In this section, the effects of modern and non-thermal food processing operations on retention of vitamins will be discussed and a brief overview of the relevant studies have been shown in **Table 4**.

Pulsed Electric Field Processing

Pulsed electric fields (PEF) have been developed during the last decades as an alternative to thermal pasteurization of liquid foods. A number of studies have shown high vitamin C retention after PEF processing compared to the thermal treatment (**Table 4**). For example, Odriozola-Serrano et al. (2008) reported that vitamin C retention just after treatment in heat treated tomato juice was 79.2%, whereas in PEF-processed juice, there was a 86.5% retention. Moreover, Elez-Martinez and Martin-Belloso (2007) reported that high intensity pulsed electric field (HIPEF) treated orange juice (87.5%–98.2%) and gazpacho (84.3%–97.1%) always showed a vitamin C retention higher than that of the heat-pasteurized products. Similarly, Elez-Martínez et al. (2006) showed that HIPEF-processing resulted in higher ascorbic acid content in orange juice (91.2%) than thermal pasteurization (82.8%).

In the study conducted by Salvia-Trujillo et al. (2011), they observed 99.5%–97.0% vitamin C retention after applying HIPEF treatment to the fruit juices. Sánchez-Vega et al. (2015) reported that HIPEF-treated broccoli juice exhibited greater relative content of β-carotene than the juice treated by heat. Similarly, Odriozola-Serrano et al. (2009) showed that β-carotene has been shown to substantially increase in PEF-processed tomato juices, whereas γ-carotene content is slightly depleted (3%–6%). Odriozola-Serrano et al. (2013) proposed that HIPEF processing could trigger the biosynthesis of carotenoids, resulting in an increment of some of them. On the other hand, Oms-Oliu et al. (2009) indicated that HIPEF processing of watermelon juice led to a 4%–60% reduction in vitamin C. According to these researchers, electric field strength, pulse frequency, pulse width, polarity and treatment time significantly affected vitamin C of watermelon juice. In contrast, Salvia-Trujillo et al. (2011) observed that HIPEF treatment did not affect the concentration of group B vitamins, but thermally treated beverages showed lower riboflavin (vitamin B_2) concentration.

High-pressure Processing

Similar to other non-thermal food processing operations, high-pressure processing (HPP) has a profound effect on the stability of vitamins in foods. For example, Barba et al. (2012) reported an increase of total tocopherol content (7%–28%) in orange juice-milk blend treated with HPP, mainly due to an increase in α-tocopherol content. These increases in α-tocopherol are supposed to result from an increased disruption of the chloroplasts where α-tocopherol is confined. Sánchez-Moreno et al. (2005) showed that HPP led to an increased vitamin A value (38.74%). Moreover, Sánchez-Moreno et al. (2006) showed that HPP of tomato puree showed the highest vitamin A value (39% ↑) among the samples. A possible explanation is this fact that HPP has the potential to enhance the reveal of vitamins from vegetables (Sánchez-Moreno et al., 2005, 2006). Toro-Funes et al. (2014) reported that

Table 4 The influence of non-thermal food processing operations on vitamins

Processing	*Product*	*Vitamin*	*Result*	*References*
High-intensity pulsed electric fields	Fruit juice	Niacin	↔	Salvia-Trujillo et al. (2011)
		Thiamine	↔	
		Riboflavin	↔	
Pulsed electric field	Broccoli juice	Vitamin C	25.4 ↓	Sánchez-Vega et al. (2015)
		β-carotene	30.5% ↑	
Pulsed electric field	Orange juice	Vitamin C	8.8% ↓	Elez-Martínez et al. (2006)
Pulsed electric field	Tomato juice	β-carotene	37% ↑	Odriozola-Serrano et al. (2009)
		γ-carotene	3%–6% ↓	
High intensity pulsed electric field	Orange juice	Vitamin C	10.7%–12.5% ↓	Elez-Martinez and Martin-Belloso (2007)
	Gazpacho		2.9%–15.7% ↓	
High-pressure processing	Orange juice−milk	Vitamin E	7–28% ↑	Barba et al. (2012)
		Vitamin D	↔	
Ultra-high-pressure homogenization	Almond beverage	α-tocopherol	83%–93% ↓	Toro-Funes et al. (2014)
High pressure processing	Orange juice	Vitamin A	38.74% ↑	Sánchez-Moreno et al. (2005)
High pressure processing	Tomato puree	Vitamin A	39% ↑	Sánchez-Moreno et al. (2006)
		Vitamin C	29.6% ↓	
High-pressure processing	Human milk	Vitamin C	1%–4% ↓	Moltó-Puigmartí et al. (2011)
		α-tocopherol	1%–6% ↓	
High-intensity pulsed electric field	Watermelon juice	Vitamin C	4%–60% ↓	Oms-Oliu et al. (2009)
Ultrasound treatment	Gooseberry juice	Vitamin C	24.4%–78.81% ↓	Ordóñez-Santos et al. (2017)
		Provitamin A	25%–96.24% ↑	
Ultra-high hydrostatic pressure	Strawberry coulis	Vitamin C	11% ↓	Sancho et al. (1999)
	Egg yolk		1.34% ↑	
High intensity pulsed electric field	Tomato juice	Vitamin C	13.5% ↓	Odriozola-Serrano et al. (2008)
High-intensity pulsed electric field	Orange-carrot juice	Vitamin A	6%–69% ↑	Torregrosa et al. (2005)
Ultrasound treatment	Tomato juice	Vitamin C	3.1%–39.3% ↓	Adekunte et al. (2010)

↓: decrease, ↑: increase, ↔: no changes.

ultra-high-pressure homogenization treatment of almond beverages led to a decrease in α-tocopherol content (83%–93%). On the other hand, Escobedo-Avellaneda et al. (2015) reported that higher vitamin C content than untreated controls were observed for high hydrostatic pressure-treated oranges. The researchers suggest that high hydrostatic pressure increases the release of vitamin C probably due to cellular disruption, making them more accessible for quantification. Similarly, Vega-Gálvez et al. (2012) reported that at 400 MPa, vitamin C showed the maximum retention (93%) and vitamin E increased compared with the initial value of the gel.

Ultrasound Processing

Ultrasound processing is a technology that has been extensively investigated in recent years. Studies on the influence of ultrasound processing suggests that it has beneficial effects on vitamin C level in some juices. For instance, Tiwari et al. (2009) showed that greater vitamin C (74.5%) retention was happened in sonicated orange juice. Moreover, Cheng et al. (2007) revealed that guava juice treated with both sonication and carbonation showed the highest ascorbic acid contents. Jabbar et al. (2015) reported a significant increase in ascorbic acid of carrot juice treated with ultrasound at 20 °C when compared with fresh untreated juice samples. Aguilar et al. (2017) reported that the ascorbic acid was retained in fruit juices after the ultrasound processing. Moreover, Cruz et al. (2008) suggested that the thermosonication treatment was found to be a better blanching process, since it inactivates watercress peroxidase at less severe blanching conditions and therefore retains higher vitamin C contents.

Rawson et al. (2011) found a higher retention of ascorbic acid at low ultrosound treatments. The higher retention level of ascorbic acid due to thermosonication treatment might be attributed to the milder heat processing as compared to heat treatment. Another reason could be that samples treated with thermosonication helped to eliminate the dissolved oxygen; thus it delayed ascorbic acid degradation (Anaya-Esparza et al., 2017; Cheng et al., 2007; Jabbar et al., 2015). In contrast, Ordóñez-Santos et al. (2017) reported that ultrasound processing of gooseberry juice was found to result in 24.4%–78.81% vitamin C and 25%–96.24% provitamin A losses. Adekunte et al. (2010) showed that the concentration of ascorbic acid in tomato juice ranged from 96.9% to 60.7%. Furthermore, Gamboa-Santos et al. (2013) showed that conventional blanching treatments at high temperature gave rise to carrots with retention of vitamin C (37.5%–85%) higher than blanching with US-probe (4%). It is possible that the degradation of ascorbic acid is attributed to oxidation processes generated during ultrasonic treatments. Moreover, hydrogen ions, free radicals, and hydrogen peroxide are created during the sonolysis of water molecules. Therefore, it could be related to oxidation reactions, enhanced by the interactions with them (Adekunte et al., 2010).

Strategies to Retain Vitamins During Food Processing Operations

Many studies considering the processing effects on vitamins showed that thermal treatments could adversely affect vitamins compared with non-thermal treatments. Therefore, protection of vitamin is an important task for food producers. In order to decrease degradation of vitamins, preparation of foods should be done according to appropriate procedures including avoiding overcooking; shortening cooking time; cooking with a minimum water, etc. Moreover, steaming, stirfrying, and pressure cooking bring about less vitamin losses than boiling or classical pan frying (Ball, 2005). Another promising approach for protecting vitamins can be micro/nano-encapsulation (Katouzian and Jafari, 2016). For example, Desai and Park (2005) reported that the vitamin C was found to be stable after encapsulation. Another study conducted by Abbasi et al. (2014) indicated that vitamin D_3 encapsulated in nanoparticles degraded less in the presence of oxygen. Assadpour et al., (2016a,b, 2017) and Assadpour and Jafari (2017) also reported that nanoencapsulation of folic acid within double emulsions could result in better protection of this vitamin resulting in more bioavailability of folic acid and targeted release in large intestine. Righetto and Netto (2006), furthermore, investigated the effect of the encapsulating materials on the stability of two sources of vitamin C, green West Indian cherry juice and synthetic ascorbic acid. They observed that the vitamin C of green West Indian cherry capsules was more stable than synthetic ascorbic acid. It has been shown that phenolic compounds present in the juice have an important role in vitamin C protection.

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