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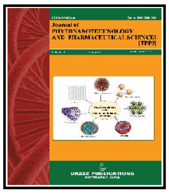

Review Article : Open Access

Effect of different food processing techniques on native antioxidants

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Abstract

Antioxidants are the natural molecules that help to neutralize harmful free radicals in our bodies linked to multiple illnesses, including diabetes, heart disease, and cancer. Generally, fruits and vegetables are considered as the ideal source of antioxidants like vitamin C, vitamin E, lycopene, flavonoids, *etc*., but some other plants source such as tea, coffee, beans, *etc*., are also rich in antioxidants. However, to meet the demands for convenient, cheaper, and readily available food, a number of conventional and novel food processing techniques are employed to transform the natural fresh foods into value added products including, jam, chutney, jelly, RTS beverages, pickles, candies, *etc*. While these processing methods bring about numerous advantages, such as improved convenience and preservation, they also have the potential to lead to the loss of essential naturally occurring food components, particularly bioactive compounds. A review discussing the effects of different processing methods on the natural antioxidants of food and their effect on health has been discussed hereunder.

1. Introduction

A balanced and nutritious diet is the cornerstone of good health. Cereal, pulses, milk, and fruits and vegetables make a balanced healthy diet. According to nutritional pyramid, eating 5 servings of fruits and vegetables in a day provide essential nutrients such as vitamins, minerals, fibre, and antioxidants which improves our immune system and helps in preventing many diseases such as diabetes, obesity, heart disease and even certain types of cancer. Among different nutrients, fruit and vegetables are denser in antioxidants as shown in Figure 1 (Aries *et al.,* 2022).

Antioxidants help to prevent the oxidation process. Antioxidants are compounds that scavenge free radicals in the human system by acting as a defense system to the body against the damages caused by free radicals and reactive oxygen species (ROS). Oxidation is a chemical reaction that can produce free radicals and ROS, which potentially causes serious damage to cells of the body (Mititelu *et al.,* 2020; Sharifi-Rad *et al.,* 2021). ROS are usually produced either by normal cell metabolism or exposure to external factors.They are subsequently responsible for premature ageing and various diseases like cardiovascular and degenerative diseases (cataracts, Alzheimer's disease, and cancer). There are two types of antioxidants, *i.e.*, endogenous (found in body itself) and exogenous (intake from outside such as food). Various sources of exogenous antioxidants with their mechanism are presented in Table 1. Natural antioxidants are found in varying category of food, including fruits, vegetables, tea, coffee, and other plant-based diets. Worldwide dietary recommendations include the consumption of fruits and vegetables as a strategy for disease prevention, provide macro as well as micronutrients and many phytochemicals along with their antioxidant properties (Ali *et al.,* 2021).

2. Antioxidants as pharmacological agents

Many biological processes such as breathing, metabolism of biomolecules, digestion, *etc*., take place in living body continuously, for the generation of energy which are responsible for producing harmful compounds such as free radicals, ROS, reactive nitrogen species (RNS), *etc*. (Pizzino *et al.,* 2017). Under stress conditions, formation of ROS and RNS is quite common phenomenon, that produces oxidative stress and irreversible alterations in cell due to redox imbalance. Oxidative stress is one of the major cause developments of damage in cell structures which includes changes in membrane structure, proteins, lipids, and DNA, *etc.* These types of damages alter the cell functions, leading to variety of cellular responses through the formation of secondary reactive species, affecting the health of cells. These secondary reactive spices play important role in development of chronic diseases in human being like cancer, cardiovascular, liver, and neurological disorders, *etc.,* as depicted in Figure 2 (Rudrapal *et al.,* 2022).

The defense mechanism of antioxidant comprises of different mechanisms that includes: (a) delaying or inhibiting free radicals' production, (b) free radical scavenging, (c) changing free radicals into less toxic compounds, (d) delaying the formation of secondary toxicactive species, (e) interrupting the chain propagation reaction (chain breaking antioxidants), (f) boosting the endogenous antioxidant defense system through synergism with other antioxidants and (g) chelating metal ions (Adwas *et al.,* 2019). The endogenous antioxidant defense system of the body is improved to reduce the undesirable effects of free radicals, ROS and RNS by supplementing,

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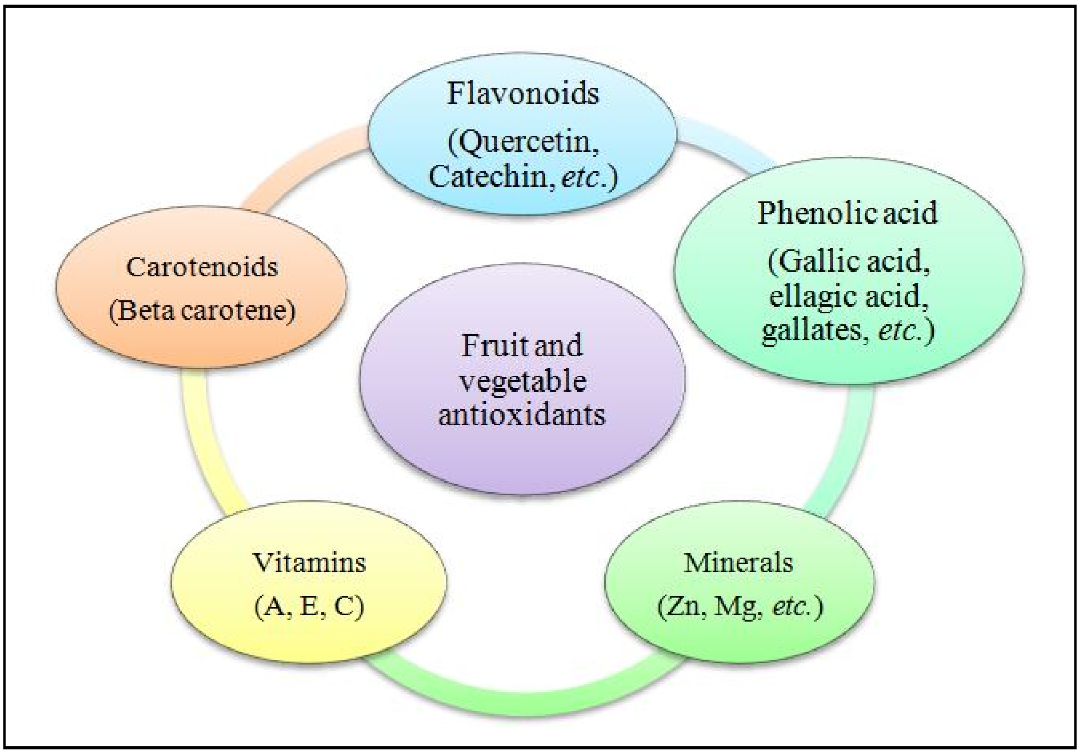

Figure 1: Various category of antioxidant present in fruits and vegetables.

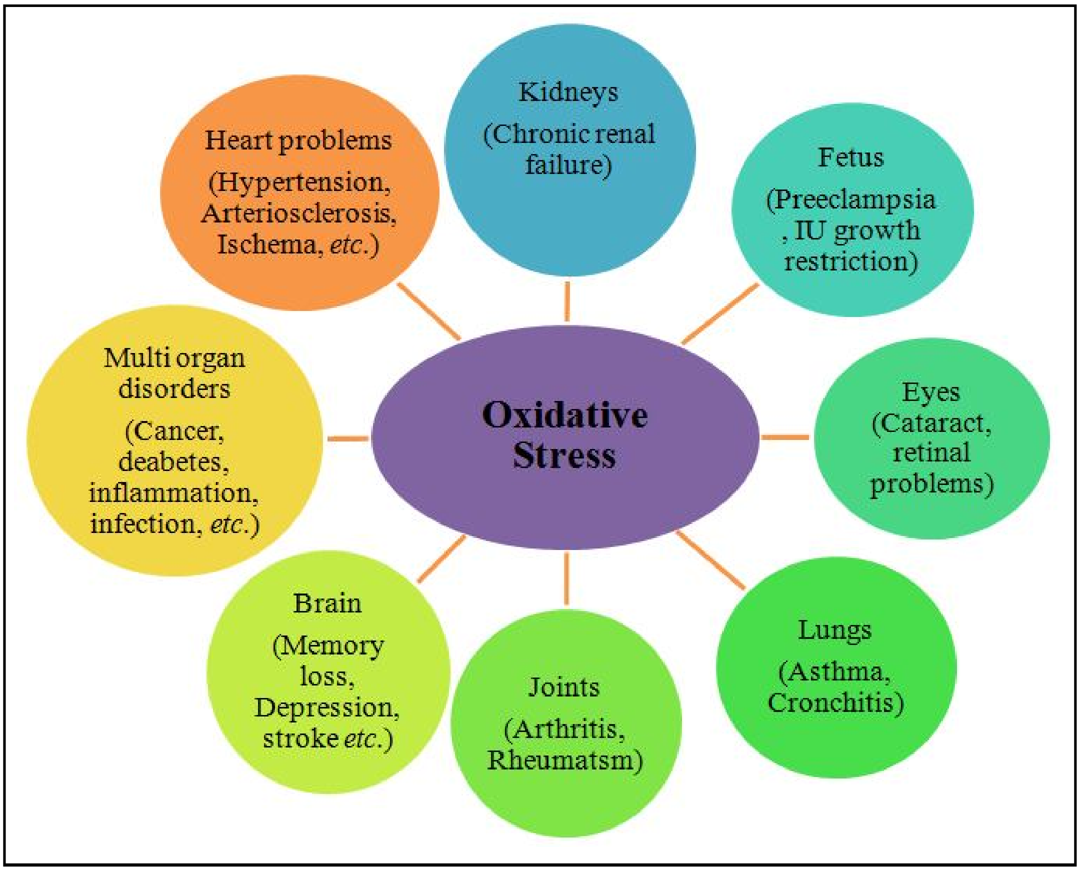

Figure 2: Oxidative stress-induced diseases in humans.

The exogenous natural antioxidants in the regular diet plan. However, screening of natural antioxidants with suitable medicinal properties is a big challenge because the activity of natural antioxidants to reduce oxidative stress depends on their chemical structures, bond dissociation enthalpies, redoxpotentials, and their effective concentrations at the reaction site with ROS and RNS (Stromsnes *et al.,* 2021). An ideal antioxidant should be readily absorbed by the body, have good eliminating capacity of ROS and RNS, and chelate metals at physiologically suitable concentrations (Rudrapal *et al.,* 2022).

Table 1: Antioxidant potentials of fruits, plants, and natural compounds

Sources	Antioxidant compound	Potential mechanism of action	References
Apple (*Malus domestica*)	Phenolics, flavonoids	Suppress tumor cells growth	Eberhardt *et al.* (2000)
Grape juice	Anthocyanins	Reduce oxidative damage to cells	Burin *et al.* (2010)
Berry	Anthocyanins	Health maintenance chemo-preventive	Loliger (1991)
Litchi (*Litchi chinensis*)	Vitamin C, niacin, riboflavin, thiamine, folate and β-carotene	Act as free radicals' scavenger	Sangeeta *et al.* (2023)
Guava (*Psidium guajava*)	Protocatechuic acid, ferulic acid, quercetin and guavin B, quercetin, gallic acid, and caffeic acid	Help in reducing oxidative stress and chelates free radicals	Upadhyay *et al.* (2019)
Ginger (*Zingiber officinale*)	phenols	Decrease lipid peroxidation	Stoilova *et al.* (2007)
Tomato (*Solanum lycopersicum*)	Lycopene, phenolics, flavonoids, vitamins C & E	Activate redox-sensitive regulatory mechanisms	Serio *et al.,* (2005)
Carotenoid-rich plants	β-carotene	Physical quenching appears to play a substantial role in protecting biological systems from oxygen free radical damage mediated damage; therate of the chemical process accounts for only 0.05% of the activity	Eberhardt *et al.* (2000)
Coriander (*Coriandrum sativum*)	Monoterpenoid, linalool	Inhibitory effect against radical-scavenging characteristics that is the concentration-dependent manner	Wangensteen *et al.* (2004)
Coffee brews	Polyphenols, melanoidins	Enhance active oxygen scavenging activity	Cammerer and Kroh (2006)
Walnut (*Juglans regia* L.)	Phenolics	Vital in obtaining a visible supply of chemicals having antibacterial activity and health-protective effects	Oliveira *et al.* (2008)
Sesame coat (*Sesamum indicum* L.)	Sesamin sesamolin	Cholesterol lowering, lipid metabolism regulation, blood pressure stabilization, and antitumor effects	Changa *et al.* (2002)
Curcuma longa	Curcumin I, curcumin II, curcumin III	Reduce lipid peroxidation	Cammerer and Kroh (2006)
Ginger (*Zingiber officinale*)	Phenols	Reduce lipid peroxidation	Stoilova *et al.* (2007)
Grain	Ferulic aciddiferulic acids	Consumption of high-fiber,whole-grain diets have been linked to a lower risk of cancerand coronary heart disease	Adom and Liu (2002)

3. Antioxidants from fruits and vegetables waste

Fruits and vegetables contain many health promoting nutrients and are consumed as raw, minimally, or semi processed, and as well as in completely processed form. The production and processing of fruits and vegetables are being increasing day-by-day with the growing population and changing diet habits to fulfill the demand of the growing population. But, post-harvest losses and industrial waste from fresh and processing fruit and vegetables industries are becoming a serious nutritional, economic, and environmental problem. Usually, 25-30% waste is generated from different processing operations of fruits and vegetables during processing (Eberhardt *et al.*, 2000). These wastes mainly consist of seed, skin, rind, and pomace, *etc.,* that can be considered as a good source of potentially valuable bioactive compounds, such as carotenoids, polyphenols, anthocyanin, dietary fibers, vitamins, enzymes, and essential oils.

In the past few decades, researchers have been struggling to generate methods and equipment to extract the valuable components from fruits and vegetables waste for getting the therapeutic benefits. Higher quantity of phenolic compounds and ascorbic acid have been reported in fruits and vegetable waste scalps or pomace rather than their pulp (Strati and Oreopoulou, 2011). Peels of the most fruits have 2-27 times more concentration of antioxidant than their pulpy portion

(Narashans *et al.,* 2018). Banana pulp consists of 232 mg/100 g of total phenol and this amount is just 25% of phenols present in banana peels (Eberhardt *et al.,* 2000). Similarly, cucumber peels have also been considered as a good source of flavonoids (Stoilova *et al.,* 2007). A significant number of bioactive compounds includes carotenes, tocopherols, terpenes, sterols, and polyphenols with strong antioxidant properties can be extracted from the tomato wastes (peels and seeds) (Olyad *et al.,* 2020). Many antioxidant compounds (carotenoids, phenolic compounds, vitamin C) are also present in mango peels, which possess storage preventive activities against many degenerative diseases, such as Alzheimer's disease, cataracts, cancer, and Parkinson's disease (Burin *et al.,* 2010). The fruit waste (skin, stem, and seeds) of wine industry contains many antioxidants that have been shown to prevent many degenerative processes and possess health-promoting effects. The waste produced after coffee processing consist approximately 6% polyphenols and 4% tannins that can be extracted and utilized for many purposes (Cammerer and Kroh, 2006). Antioxidant extracted from various fruits and vegetables waste are presented in Table 2. The antioxidant rich compounds extracted from the waste can be utilized by many food industries to develop functionally enriched foods, color, and flavour. The bioactive compounds from waste are also utilized by different pharmaceutical industries to prepare various medicines and by textile industry for extraction of natural colors. The management of waste for the production of various crucial bioactive components is an important step toward sustainable development (Narashans *et al.,* 2018).

Table 2: Antioxidants extracted from some fruits and vegetable wastes

Horticultural produce	Residue	Antioxidant	Reference
		Fruits	
Banana (*Musa paradisiaca* Linn.)	Unripe (green) fruit and peel	Phenols and flavonoids	Eberhardt *et al.* (2000)
Mango (*Mangifera indica*)	Peel, kernel	Gallic acid, ellagic acid, gallates, gallotannins, condensed tannins	Burin *et al.* (2010), Munoz-Espada *et al.* (2004)
Watermelon (*Citrullus lanatus*)	Peel, rinds	Citrulline, lycopene, flavonoids, and phenols	Cammerer and Kroh (2006)
Cucumber (*Cucumis sativus*)	Peel	Phenols, lavonoids, pheophytin, phellandrene, caryophyllene	Cammerer and Kroh (2006) Stoilova *et al.* (2007)
Potato (*Solanum tuberosum*)	Peel	Chlorogenic acid, cafeic acid, ferulic acid, and phenols	Nantitanon *et al.* (2010)
Coffee (*Coffea arabica*)	Coffee ground and residue	Polyphenols, tannins, and gallic acids	Adom and Liu, (2002) Cammerer and Kroh (2006)
Apple (*Malus domestica*)	Peel	Epicatechin, catechins, anthocyanins, quercetin glycosides, chlorogenic acid, hydroxycinnamates, phloretin glycosides, and procyanidins	Eberhardt *et al.* (2000)
Grapes (*Vitis vinifera*)	Skin and seeds	Coumaric acid, cafeic acid, ferulicacid, chloro-genic acid, cinnamic acid, neochlorogenic acid, p-hydroxybenzoic acid, protocatechuic acid, vanillic acid, gallic acid, proanthocyanidins, quercetin 3-o-gluuronide, quercetin, and resveratrol	Burin *et al.* (2010),
Guava (*Psidium guajava*)	Skin and Seeds	Catechin, cyanidin 3-glucoside, galangin, gallic acid, homogentisic acid, and kaempferol	Nantitanon *et al.* (2010)
Pomegranate (*Punica granatum*)	Peel and Pericarp	Gallic acid, cyanidin-3,5-diglucoside, cyanidin-3 -diglucoside, anddelphinidin-3, 5-diglucoside	Gil Mi (2010)
		Vegetables	
Carrots (*Daucus carota*)	Peel	Phenols, β-carotene	Nantitanon *et al.* (2010)
Tomato (*Solanum lycopersicum*)	Skin and Pomace	Carotenoids	Strati *et al.* (2011)

4. Changes occuringin antioxidants during food processing

Many studies deal with estimated losses of food nutrients, including antioxidants during food processing and only the residual concentration of antioxidants has been determined in most cases, rather than the total antioxidant presentin foods (Olyad *et al.,* 2020). It has been quite different, and sometimes even opposite, effects on the intrinsic antioxidant properties of foods that can occur during processing and storage.

4.1 Effect of thermal processing

Exposure of food components to temperatures above ambient conditions (during heat processing) is a major cause of detectable changes, not only in nutritional quality but also in antioxidant activity. Although, some processes involving higher temperatures are used in order to produce positive changes, especially of the sensory value, they often result in loss of nutritional quality, and in some cases, in loss of their resistance against lipidoxidation. The heating process generally involved pasteurization,baking, cooking, roasting, blanching, microwave heating, drying, *etc.* It is reported that heat treatment generally reduces the bioactive compounds in food (Ismail *et al.*, 2004), but in some cases such as in tea, it increases and are formed during heating (Manzocco *et al.*, 1998).

4.1.1 Changes during pasteurization

Pasteurization is the heat treatment given to food generally below boiling temperature. Losses of vitamins are a good marker of negative changes due to thermal destruction. Transformations of tocopherols (vitamin E) and loss of ascorbic acid (vitamin C) are used as an indicator of food quality and, therefore, the severity of pasteurization, blanching, or the length of cooking are the prime factors which affect the quality and efficacy of antioxidants.These losses are mainly due to thermal destruction, and to a lesser extent oxidation is also responsible. In fruit juices, the main cause of colour deterioration is enzymatic browning of polyphenolic compounds due to presence of polyphenol oxidase enzyme which can be inactivated by heat treatment. Many studies revealed that pasteurization of fruit juices normally decreased antioxidant activity. It is observed that under aerobic conditions, antioxidant activity is decreased by 64-79% in black chokeberry juice concentration depending on storage temperature and pH of the juice (Tomczak, 2007). Losses of antioxidants are minimized by deaeration and maintaining the pH and temperature of the pasteurization and storage as well. Moreover, the addition of antioxidants before or after processing is quite common. The effect of pasteurization temperature on antioxidant acidity of pomegranate juice was observed and found that low-temperature (65°C) pasteurized juice had the highest value for antioxidant retention as compared to medium (80°C) and high temperature (90°C) pasteurization (Warkina, 2020). Negligible effect was recorded in antiradical activities in orange juice after pasteurization at 90°C for 30 seconds (Sentandreu, *et al.*, 2007).

4.1.2 Changes during sterilization

Sterilization is the process which proceeds at higher temperatures than pasteurization. The intensity of the sterilization process is extremely high and results in significant change in the quality characteristics of the product as well as the elimination of microorganisms.However, these changes are usually more detrimental. In canned fruits and vegetables, substantial vitamin losses may occur in all water-soluble vitamins, particularly ascorbic acid, which is the most important antioxidant in these foods. Therefore, the presence of residual oxygen in the medium must be minimized. In some foods, ascorbic acid or other antioxidants are added to the brine or syrup. The reduction in antioxidant activity (from 91.98 to 27.57%) of fully ripe canned strawberries during 3 months of storage may be attributed due to the thermal degradation of naturally occurring antioxidants during canning (Naseem *et al.*, 2017) and due to the formation of early maillard reaction products with prooxidant properties (Nayak *et al.*, 2013). In canned fish, the oxidative stability of fish lipids is variably depending on the antioxidant content and stability of the filling medium (Roe *et al.*, 2013).The canning process causes loss of antioxidant capacity in the eel muscle due to the leaching of soluble components, such as vitamins and proteins, into filling medium and thermal damage during heat treatments (Limia *et al.*, 2021).

4.1.3 Changes during blanching

Commercial methods of blanching involve passing solid foods through an atmosphere of saturated steam or a bath of hot water so that only the water in both physical states is the carrier of heat. Rapid heating of the food material deactivates enzymes, such as lipoxygenases, which causes catalyzed lipid oxidation followed by partial degradation of natural antioxidants (Al-juhaimi *et al.*, 2018). The deactivation of polyphenol oxidases is also very useful for the protection of natural antioxidant compounds. Time length and temperature during blanching are the most crucial parameters to determine the quality of the final product. Microwave treatment before blanching to green asparagus is useful to stabilize the vitamin C and inactivation of peroxidase enzyme (Zheng and Lee, 2011). A similar finding is also reported in antioxidant activity of Brussels sprouts (Olivera *et al.*, 2008). Blanching of leafy vegetables can cause a 50% reduction in antioxidants, whereas boiling for 15 min cause an 82% loss of antioxidants in the water (Amin *et al.*, 2006). Previous studies revealed that short-time steam or water blanching is a suitable measure to ensure maximum polyphenol retention (Kaiser *et al.*, 2013). It is also proven that pretreatment like blanching caused the decrease in the antioxidant compound, anthocyanin, and betacyanin content, as well as radical scavenging capacity in fibre rich fruit powder prepared from peels of dragon fruit (Sengkhamparn *et al.*, 2013).

4.1.4 Changes during different methods of cooking

Different cooking methods (boiling, baking, frying, roasting, *etc.*) are applied for the conversion of inedible food to edible food which can usually lower the antioxidant content of food (Somsub *et al.*, 2007; Wachtel Galor *et al.*, 2008), but some cooking methods can improve the antioxidant capacity of selected vegetables. For example, cooking (boiling, steaming, microwaving) pumpkin pulp increased the total phenolic content and antioxidant properties. However, in tomato and sweet corn, cooking increased the total phenolic content but there was considerable loss of vitamin C (Dewanto *et al.*, 2002). Deep fat frying of food commodities in oil occurs at relatively high temperatures (170-180°C or even more) which enhances the destruction rate of antioxidants due to easier contact of frying oil with air (if frying oil starts foaming). However, the temperature of inner layers does not exceed 100°C, so antioxidants are preserved in inner parts of the food. But, the deep-fried foods are easily oxidized on further storage. Heat processing (boiling, steaming, microwaving) reduced the antioxidant capacity by 45% in fruit (cherry, plums, raspberry) jam after processing (Kim *et al.*, 2006), and vitamin C in tomato (Dewanto *et al.*, 2002) and tropical green leafy vegetables (Adefeghaand Oboh, 2011). However, these processing methods enhanced the antioxidant activity in red beetroot (Ravichandran *et al.*, 2013), tomato (Nayak *et al.*, 2015), and sweet corn (Dewanto *et al.*, 2002). The process of baking favours oxidation, but only in surface layers because inner parts are not heated to high temperatures (Poljsak *et al.*, 2021). Roasting is commonly used in culinary operations. Heat is applied through hot air and during these operations, outer layers of the material are heated to 120-200°C or even more, while inner layers do not exceed 100°C. The antioxidant compounds were liberated and increased in cashew nuts and peanuts after roasting at 130°C for 33 min. The temperature of roasting is an important parameter for fluctuation in the content of antioxidant components. Buckwheat flour roasted at 120°C for 40 min causes a 33% decrease in flavonoids (Zhang *et al.* 2010), whereas roasting at

160°C for 30 min decreases total flavonoids by 15.9%. This is because rutin in buckwheat is more stable to heat than other flavonoids compounds such as vitexin, isovitexin, homoorientin, and orientin (Zielinski *et al.* 2009). The reduction in phenolic content of barley was recorded as 8.5-49.6% after roasting at 280°C for 20 seconds (Sharma and Gujral, 2011). Soaking followed by roasting also enhanced the totalphenolic, flavonoid, and antioxidant contents in dry beans (Boateng *et al*., 2008). The antioxidant activity of red beet is also improved by 2-3 folds after roasting as compared to the raw sample (Ravichandran *et al*., 2013).

4.2 Changes in antioxidants during nonthermal processing

Nonthermal techniques provide promising alternative to thermal processing in which temperature applied to food do not exceed 50°C but it effectively reduces the detrimental effect of food that occur due to thermal processing (Al-juhaimi *et al*., 2018). Application of nonthermal techniques (irradiation, high pressure processing, pulse electric field, *etc.*) are increasing day-by-day to minimize the changes occurring in food during processing.

Food irradiation is commonly used technique for preservation of food to large extent by eliminating pathogenic microbes, which include both ionizing (2-7-kGy used in foods) and non-ionizing radiation (ultraviolet light). UV light of different intensities or types (A, B, and C) is applied, although UV-C is the most effective for food disinfection (Feng *et al*., 2013). In case of High-pressure processing (HPP) pressure applied to different food commodities ranges from 300-700 MPa mainly for inactivation of microbes and enzymes (Chawla *et al*., 2011). The sensory and nutritional characteristics of HPP-treated foods are generally identical to those of fresh foods because it affects all part of food equally (Rastogi *et al*., 2007). Another non-thermal technique which can be used in food for extension of shelf-life is pulsed electric field (PEF) in which electricity (20-80 kV/cm) is applied for a short time to a food product positioned between two electrodes whereas in ultrasound, sound waves of frequencies ranging from 20 kHz to 10 MHz are applied to food which creates cavitation for microbial destruction. The effect of various nonthermal techniques on antioxidant activities of different food are presented in Table 3.

Table 3: Effect of nonthermal processing methods on antioxidant activity of different food

Treatment with nonthermal technique	Effect on different antioxidants	References
0-20 kGy γ-Irradiation to pomegranate peel powder	Irradiation dose increased up to 10 kGy, the antioxidant activity of pomegranate peelpowder enhanced from 12.12 to 13.7 g TE/100 g due to the degradation of higher-molecular-mass tanninsand their conversion into simpler phenolic compounds such as tannic and gallic acids	Mali *et al*. (2012)
γ-Irradiation of 3 kGy to sun dried apricot	Increased free radical scavenging activity and overall antioxidant activity	Hussain *et al*.(2013)
γ -Irradiation at doses increasing from 0 to 5 kGy in black tea	No changes in antioxidant activity were observed	Fanaro *et al*.(2014)
Orange fruit treated with γ-Irradiation of 100 -700 Gy followed by 3 weeks of storage at 5°C	Total phenolic compounds and natural antioxidant were unaffected	McDonald *et al*. (2013)
Velvet bean seeds treated with different doses of irradiation	Free radical scavenging activity was enhanced due to reduction in electron spin resonance after irradiation	Bhat *et al*. (2007)
Irradiation treatment to carrot and kale juice	The antioxidant activity was increased in carrot juice while in kale juice it was decreased after irradiation	Song *et al*. (2006)
10 kGy γ -Irradiation to clove, nutmeg, and cinnamon	Total phenolic content in clove and cinnamon increased but not in nutmeg due to break down of tannins	Variyer *et al*. (1998)
Peach andnectarine fruits treated with UV-B irradiation for 12, 24, and 36 h	Antioxidant activity increased in peach fruit, whereas nectarine fruits were unaffected	Scattino *et al*. (2014)
Watermelon juice treated with UVC (2.7–37.5 J/ml) treatment followed by storage at 5 ± 1°C for 37 days	UVC treatment did not change the levels of bioactive compounds, which remained consistent until 25th day of storage after that the levels deteriorated in both treated and non-treated samples	Feng *et al*. (2013)
Treatment of tomatoes with different doses of irradiation	Lycopene content of tomatoes were enhanced due to red light treatment	Liu *et al*. (2009)
HPP-treated carrot and tomato purees	Non-significant decrease in antioxidant activity was observed	Patras *et al*. (2008)
HPP-treated orange juice	Slower degradation was recordedin ascorbic acid and anti-oxidant activity was higher as compared to pasteurized juice	Polydera *et al*. (2004)
HPP treatment of orange juice and mixed juice (orange + carrot) followed by storage at 4°C for 21 days	No significant changes were recorded	Fernandez-Garcia *et al*. (2000)
Apple juice treated with sonication before HHP	Significant increase in phenolic, ascorbic acid, and total antioxidant content and antiradical activity was observed	Abid *et al*. (2014)

Treatment of fermented rice bran with HPP combined with a complex enzymes	Higher production of ferulic acid and free amino acid content, which led to increased bioactivity	Kim and Han (2012)
Apricot nectar and gooseberry treated with 300-500 MPa pressure at 25°C for 5-20 min	Increase in antioxidant activity due to elevated pressure and application time	Huang *et al.* (2013)
Effect of HPP treatment on orange juice	HPP treatment led to an increase inthe content of naringenin (20.16%) and hesperidin (39.88%)	Sánchez-Moreno, *et al.* (2005)
High-intensity PEF treatment to watermelon juice	Better retention of lycopene and antioxidant capacity withincreasing PEF frequency and intensity	Oms-Oliu *et al.* (1993)
PEF treatment to strawberry juice	No significant changes were recorded	Odriozola-Serrano *et al.* (2008)
PEF treatment to apple pieces	Significantly increased the native polyphenol in juice (8.8 %)	Turk *et al.* (2012)
Blueberry juice treated with PEF at 36 kV/cm for 100 µs	Significantly increased the antioxidant compounds (ascorbic acid, total phenolics, and total anthocyanins)	Barba *et al.* (2012)
Cranberry bush puree treated with HPP (200, 400, and 600 MPa for 5 or 15 min) and PEF (3 kV/cm, 5, 10, and 15 kJ/kg)	Increment in total phenols, total flavonoids, and total anthocyanins which ultimately increased the antioxidant activity of the puree	Ozkan *et al.* (2021)
Pasteurization of apple juice with PEF	Observed the reduction of total phenolics compounds by 15% as compared to thermal pasteurization (32% reduction)	Aguilar-Rosas *et al.* (2007)
Thermo-sonication (40°C, for 5 min and 10 min; 50°C for 5 min and 10 min) treatment given to apple-grape juice blend	Increase in total anthocyanins (petunidin 3-O-glucoside, peonidin 3-O-glucoside,malvidin 3-O-glucoside, cyanidin 3-O-glucoside, delphinidin 3-O-glucoside,cyanidin 3,5-diglucoside, malvidin 3,5-diglucoside)was observed in ultrasonication treatment for 10 min	Aadil *et al.* (2020)
Ultrasonic treatment (0, 0.9, 1.8, 2.7, and 3.6 kJ/cm3) of Acai juice	Increase in total antioxidant capacity	de Souza Carvalho *et al.* (2020)

5. Conclusion

Thermal processing methods, including cooking, pasteurization, sterilization, and blanching, have long been used as fundamental techniques to safeguard food from spoilage and enhance its safety for human consumption. However, a notable drawback associated with these conventional approaches is the depletion of natural antioxidants present in the food. In recent times, non-thermal techniques have emerged as a more promising alternative; as they offer improved retention of antioxidants and, in some cases, may even enhance their activity and availability. Therefore, selection of optimal processing methods becomes crucial to ensure better retention of nutrients in fresh food commodities and their products in order to achieve not only the desired objectives of a food processing method, but also preserve the activity and quality of natural health-promoting constituents or bioactive compounds.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

References

Aadil, R.M.; Khalil, A.A.; Rehman, A.; Khalid, A.; Inam-ur-Raheem, M.; Karim, A. and Afraz, M.T. (2020). Assessing the impact of ultra-sonication and thermo-ultrasound on antioxidant indices and polyphenolic profile of apple-grape juice blend. Journal of Food Processing and Preservation, **44**:45-58. https://doi.org/10.1111/jfpp.v44.510.1111/jfpp.14406.

Abid, M.; Jabbar, S.; Hu, B.; Hashim, M.M.; Wu, T.; Wu, Z.; Khan, M.A. and Zeng, X. (2014). Synergistic impact of sonication and high hydrostatic pressure on microbial and enzymatic inactivation of apple juice. LWT Food Sci. Technol., **59**:70-76

Adefegha, A.S. and Oboh, G. (2011). Cooking enhances the antioxidant properties of some tropical green leafy vegetables. African J. Biotechnol., **10**:623-639.

Adom, K.K. and Liu, R.H. (2002). Antioxidant activity of grains. Journal of Agricultural and Food Chemistry, **50**:6182-6187.

Adwas, A.A.; Elsayed, A.; Azab, A.E. and Quwaydir, F.A. (2019). Oxidative stress and antioxidant mechanisms in human body. J. Appl. Biotechnol. Bioeng., **6**:43-47.

Aguilar, K.; Garvín, A.; Ibarz, A. and Augusto, P.E.D. (2017). Ascorbic acid stability in fruit juices during thermosonication. Ultrasonics Sonochemistry, **37**:375-381.

Ali, M.Y.; Sina, A.A.I.; Khandker, S.S.; Neesa, L.; Tanvir, E.M.; Kabir, A. and Gan, S.H. (2021). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. Foods, https://doi.org/ 10.3390/foods10010045.

Al-juhaimi, F.; Ghafoor, K.; Ozcan, M.M.; Jahurul, M.H.A.; Babiker, E.E.; Jinap, S.; Sahena, F.; Sharifudin, M.S. and Zaidul, I.S.M. (2018). Effect of various food processing and handling methods on preservation of natural antioxidants in fruits and vegetables. J. Food Sci. Technol., **55**:3872-3880.

Amin, I.; Norazaidah, Y. and Hainida, K.I.E. (2006). Antioxidant activity and phenolic content of raw and blanched Amaranthus species. Food Chem., **94**:47-52.

Arias, A.; Feijoo, G. and Moreira, M.T. (2022). Exploring the potential of antioxidants from fruits and vegetables and strategies for their recovery. Innovative Food Science and Emerging Technologies, **77**:102974. https://doi.org/10.1016/j.ifset.2022.102974

Barba, F.J.; Jager, H.; Meneses, N.; Esteve, M.J.; Frigola, A. and Knorr, D. (2012). Evaluation of quality changes of blueberry juice during refrigerated storage after high-pressure and pulsed electric fields processing. Innov. Food Sci. Emerg. Technol, **14**:18-24.

Bhat, R.; Sridhar, K.R. and Bhushan, B. (2007). Free radicals in velvet bean seeds (*Mucuna pruriens* L.) and their status after gamma irradiation and conventional processing. LWT Food Sci. Technol., **40**:1570-1577.

Boateng, J.; Verghese, M.; Walker, L.T. and Ogutu, S. (2007). Food Effect of processing on antioxidant contents in selected dry beans *(Phaseolus* spp. L.). LWT-Food Sci. Technol., **41**:1541-1547.

Burin, V.M.; Falcao, L.D.; Gonzaga, L.V.; Fett, R.; Rosier, J.P. and Bordignon-Luiz, M.T. (2010). Colour, phenolic content and antioxidant activity of grape juice. Food Science and Technology, **30**:1027-1032.

Cammerer, B. and Kroh, L.W. (2006). Antioxidant activity of coffee brew. European Food Research and Technology, **223**:469-474.

Changa, L.W.; Yena, W.J.; Huangb, S.C. and Duha, P.D. (2002). Antioxidant activity of sesame coat. Food Chemistry, **78**:347-354.

Chawla, R.; Patil, G.R. and Singh, A.K. (2011). High hydrostatic pressure technology in dairy processing: A review. J Food Sci Technol., **48**: 260-268.

De-Souza Carvalho, L.M.; Lemos, M.C.M.; Sanches, E.A.; da-Silva, L.S.; de-Araújo-Bezerra, J.; Aguiar, J.P.L. and Campelo, P.H. (2020). Improvement of the bioaccessibility of bioactive compounds from Amazon fruits treated using high energy ultrasound. Ultrasonics Sonochemistry, **67**: 105148. https://doi.org/10.1016/ j.ultsonch.2020.105148.

Dewanto, V.; Wu, X. and Liu, R.H. (2002). Processed sweet corn has higher antioxidant activity. J. Agric. Food Chem., **50**:4959-4964. doi:10.1021/jf0255937.

Dewanto, V.; Xianzhong, W.; Adom, K.K. and Liu, R.H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J. Agric. Food Chem., **50**:3010-3014, doi:10.1021/jf0115589.

Eberhardt, M.V.; Lee, C. and Liu, R. (2000). Antioxidant activity of fresh apples. Nature, **405**:903-904.

Fanaro, G.B.; Hassimotto, N.M.A.; Bastos, D.H.M. and Villavicencio, A.L.C.H. (2014). Effects of c-radiation on microbial load and antioxidant proprieties in black tea irradiated with different water activities. Radiat. Phys. Chem., **97**:217-222.

Fernandez-Garcia, A.; Butz, P. and Tauscher, B. (2000). Does the antioxidant potential of high pressure treated apple juice change during storage? High Press Res., **19**:543-550.

Feng, M.; Ghafoor, K.; Seo, B.; Yang, K. and Park, J. (2013). Effects of ultraviolet-C treatment in teflon oil on microbial populations and physico-chemical characteristics of watermelon juice. Innov. Food Sci. Emerg. Technol., **19**:133-139.

Gil, M.I. (2000). Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. Journal of Agricultural and Food Chemistry, **48**:4581-4589.

Huang, W.; Bi, X.; Zhang, X.; Liao, X.; Hu, X. and Wu, J. (2013). Comparative study of enzymes, phenolics, carotenoids and color of apricot nectars treated by high hydrostatic pressure and high temperature short time. Innov. Food Sci. Emerg. Technol., **18**:74-82.

Hussain, P.R.; Chatterjee, S.; Variyar, P.S. Sharma, A.; Dar, M.A. and Wani, A.M. (2013). Bioactive compounds and antioxidant activity of gamma irradiated sun-dried apricots (*Prunus armeniaca* L.). J. Food Compos. Anal., **30**:59-66.

Ismail, A.; Marjan, Z.M. and Foong, C.W. (2004). Total antioxidant activity and phenolic content in selected vegetables. Food Chem., **87**:581-586.

Kaiser, A.; Kammerer, D.R. and Carle, R. (2013). Impact of blanching on polyphenol stability and antioxidant capacity of innovative coriander (*Coriandrum sativum* L.) pastes. Food Chem., **140**:332-339.

Kim, D. and Han, D.G. (2012). High hydrostatic pressure treatment combined with enzymes increases the extractability and bioactivity of fermented rice bran. Innov. Food Sci. Emerg. Technol., **16**:191-197.

Kim, D.O. and Padilla Zakour, O.I. (2006). Jam processing effect on phenolics and antioxidant capacity in anthocyanin rich fruits: cherry, plum, and raspberry. J. Food Sci., **69**:395-400.

Limia, L.G.; Sanmartin, N.M.; Carballo, J.; Domínguez, R.; Lorenzo, J.M. and Martínez, S. (2021). Oxidative stability and antioxidant activity in canned eels: effect of processing and filling medium. Foods, **10**: 790. https://doi.org/10.3390/foods10040790.

Liu, L.H.; Zabaras, D.; Bennett, L.E.; Aguas, P. and Woonton, B.W. (2009). Effects of UV-C, red light and sun light on the carotenoid content and physical qualities of tomatoes during post-harvest storage. Food Chem., **115**:495-500.

Loliger, J. (1991). The use of antioxidants in food. In O.I. Aruoma and B. Halliwell (Eds.), Free radicals and food additives. Taylor and Francis. pp:129-150.

Mali, A.; Khedkar, K. and Lele, S. (2012). Effect of gamma irradiation on total phenolic content and *in vitro* antioxidant activity of pomegranate (*Punica granatum* L.) peels. Food Nutr. Sci., **2**:428-433.

McDonald, H.; Arpaia, M.L.; Caporaso, F.; Obenland, D.; Were, L.; Rakovski, C. and Prakash, A. (2013). Effect of gamma irradiation treatment at phytosanitary dose levels on the quality of 'Lane Late' navel oranges. Postharvest Biol. Technol., **86**:91-99.

Mititelu, R.R.; Pădureanu, R.; Băcănoiu, M.; Pădureanu, V.; Docea, A.O.; Calina, D.; Barbulescu, A.L. and Buga, A.M. (2020). Inflammatory and oxidative stress markers-mirror tools in rheumatoid arthritis. Biomedicine, **8**:125. https://doi.org/10.3390/biome dicin es8050125.

Manzocco, L.; Anese, M. and Nicoli, M.C. (1998). Antioxidant properties of tea extracts as affected by processing. LWT Food Sci Technol., **31**:694-698.

Nantitanon, W.; Yotsawimonwat, S. and Okonogi, S. (2010). Factors influencing antioxidant activities and total phenolic content of guava leaf extract. LWT- Food Science and Technology. **43**:1095-1103.

Narashans, A.S.; Sagar, S.P.; Sharma, S.; Yahia, E.M. and Lobo, M.G. (2018). Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. Comprehensive Reviews in Food Science and Food Safety, **17**:512-531.

Naseem, Z.; Gull, A.; Wani, S.M.; Massodi, F.A. and Ganaie, T.A. (2017). Changes in anthocyanin, total phenolic, antioxidant activity, texture and color of canned strawberry during storage. Journal of Postharvest Technology. **5**:79-88.

Nayak, B.; Liu, R.H. and Tang J. (2013). Effect of processing on phenolic antioxidants of fruits, vegetables, and grains: A review. Critical Reviews in Food Science and Nutrition, **55**:887-918.

Odriozola-Serrano, I.; Soliva-Fortuny, R. and Martýn-Belloso, O. (2008). Phenolic acids, flavonoids, vitamin C and antioxidant capacity of strawberry juices processed by high-intensity pulsed electric fields or heat treatments. Europ. Food Res. Technol., **228**:239-248.

Oms-Oliu, G.; Odriozola-Serrano, I; Soliva-Fortuny, R. and Martin-Belloso, O. (1993). Effect of high- intensity pulsed electric field processing condition on lycopene, vitamin C and antioxidant capacity of watermelon juice. Food Chem., **115**:1312-1319.

Olivera, D.F.; Vina, S.Z.; Marani, C.M.; Ferreyra, R.M.; Mugridge, A.; Chaves, A.R. and Mascheroni, R.H. (2008). Effect of blanching on the quality of Brussels sprouts (*Brassica oleracea* L. *gemmifera* DC) after frozen storage. J. Food Eng., **84**:148-155.

Oliveira, I.; Sousa, A.; Ferreira, I.C.F.R.; Bento, A.; Estevinho, L. and Pereira, J.A. (2008). Total phenols, antioxidant potential and antimicrobial activity of walnut (*Juglans regia* L.) green husks. Food and Chemical Toxicology, **46**:2326-2331.

Olyad, E.R.B.A.; Atomsa, D.; Chimdessa, M. and Gonfa, T. (2020). Determination of flavonoid contents and evaluation of *in vitro* antioxidant activities of the extract of selected citrus fruit peel. International Journal of Secondary Metabolite, **7**:8-18.

Ozkan, G.; Stübler, A.S.; Aganovic, K.; Drager, G.; Esatbeyoglu, T. and Capanoglu, E. (2021). Retention of polyphenols and vitamin C in cranberrybush puree (*Viburnum opulus*) by means of non-thermal treatments. Food Chemistry, **360:**129918.

Patras, A.; Brunton, N.; Da-Pieve, S.; Butler, F. and Downey, G. (2008). Effect of high pressure processing on antioxidant activity andinstrumental colour of tomato and carrot purees. Innov. Food Sci. Emerg. Technol., **10**:16-22.

Pizzino, G.; Irrera, N.; Cucinotta, M.; Pallio, G.; Mannino, F.; Arcoraci, V.; Squadrito, F.; Altavilla, D. and Bitto, A. (2017). Oxidative stress: Harms and benefits for human health. Oxid. Med. Cell. Longev., 8416763.

Poljask, B.; Kovac, V. and Milisav, I. (2021). Antioxidants, food processing and health. Antioxidants, **10**:433. https://doi.org/10.3390/antiox10030433.

Polydera, A.C.; Nikolaos, G.S. and Taoukis, P.S. (2004). The effect of storage on the antioxidant activity of reconstituted orange juice which had been pasteurized by high pressure or heat. Int. J. Food Sci. Technol., **39**:783-791.

Rastogi, N.K.; Raghavarao, K.S.; Balasubramaniam, V.M.; Niranjan, K. and Knorr, D. (2007). Opportunities and challenges in high pressure processing of foods. Crit. Rev. Food Sci. Nutr., **47**:69-112.

Ravichandran, K.; Saw, N.M.M.T.; Mohdaly, A.A.A.; Gabr, A.M.M.; Kastell, A.; Riedel, H.; Cai, Z.; Knorr, D. and Smetanska, I. (2013). Impact of processing of red beet on betalain content and antioxidant activity. Food Res. Int., **50**:670-675.

Roe, M.; Church, S.; Pinchen, H. and Finglas, P. (2013). Nutrient Analysis of fish and fish products-analytical report, Institute of Food Research: Surrey, UK.

Rudrapal, M.; Khairnar, S.J.; Khan, J.; Bin Dukhyil, A.; Ansari, M.A.; Alomary, M.N.; Alshabrmi, F.M.; Palai, S.; Deb, P.K. and Devi, R. (2022). Dietary polyphenols and their role in oxidative stress-induced human diseases: insights into protective effects, antioxidant potentials and mechanism(s) of action. Front. Pharmacol., **13**:806470.

Sánchez-Moreno, C.; Plaza, L.; Elez-Martínez, P.; De-Ancos, B. and Martín-Belloso, O. (2005). Impact of high pressure and pulsed electric fields on bioactive compounds and antioxidant activity of orange juice in comparison with traditional thermal processing. Journal of Agricultural and Food Chemistry, **53**:4403-4409.

Sangeeta, S.; Chopra, C.S.; Rai, S.; Ramachandran, P. and Hamid. (2023). Formulation and storage study of leather prepared from litchi (*Litchi chinensis* Sonn.) fruit affected with pericarp browning using response surface methodology (RSM). Ann. Phytomed., **12**:1-11.

Scattino, C.; Castagna, A.; Neugart, S.; Chan, H.M.; Schreiner, M.; Crisosto, C.H.; Tonutti, T. and Ranieri, A. (2014). Post-harvest UV-B irradiation induces changes of phenol contents and corresponding biosynthetic gene expression in peaches and nectarines. Food Chem., **163**:51-60.

Sengkhamparn, N.; Chanshotikul, N.; Assawajitpukdee, C. and Khamjae, T. (2013). Effect of blanching and drying on fiber rich powder from pitaya (*Hylocereus undatus*) peel. International Food Research Journal, **20**:1595-1600.

Sentandreu, E.; Navarro, J.L. and Sendra, J.M. (2007). Effect of technological processes and storage on flavonoids content and total, cumulative fast-kinetics and cumulative slow kinetics antiradical activities of citrus juices. European Food Research and Technology, **225**:905-912.

Serio, F.; Ayala, O.; Bonasia, A. and Santamaria, P. (2005). Antioxidant properties and health benefits of tomato. In: Recent progress in medicinal plants. **13**:161-182.

Sharifi-Rad, J.; Quispe, C.; Herrera-Bravo, J.; Akram, M.; Abbaass, W.; Semwal, P.; Painuli, S.; Konovalov, D.A.; Alfred, M.A.; Kumar, N.V.A.; Imran, M.; Nadeem, M.; Sawicka, B.; Pszczó³kowski, P.; Bienia, B.; Barbaœ, P.; Mahmud, S.; Durazzo, A.; Lucarini, M. and Calina, D. (2021). Phytochemical constituents, biological activities, and health-promoting effects of the *Melissa officinalis*. Oxidative Medicine and Cellular Longevity, 6584693.

Sharma, P. and Gujral, H.S. (2011). Effect of sand roasting and microwave cooking on antioxidant activity of barley. Food Res Int., **44**:235-240

Somsub, W.; Kongkachuichai, R.; Sungpuag, P. and Charoensiri, R. (2008). Effects of three conventional cooking methods on vitamin C, tannin, myo inositol phosphates contents in selected Thai vegetables. J. Food Compos. Anal., **21**:187-197.

Song, H.P.; Kim, D.H.; Jo, C.; Lee, C.H.; Kim, K.S. and Byun, M.W. (2006). Effects of gamma irradiation on the microbiological quality and antioxidant activity of fresh vegetable juice. Food Microbiol., **23**:372-378.

Stoilova, I.; Krastanov, A.; Stoyanova, A.; Denev, P. and Gargova, S. (2007). Antioxidant activity of a ginger extracts (*Zingiber officinale*). Food Chemistry, **102:**764-770.

Strati, I.F. and Oreopoulou, V. (2011). Effect of extraction parameters on the carotenoid recovery from tomato waste. International Journal of Food Science and Technology, **46**:23-29.

Stromsnes, K.; Lagzdina, R.; Olaso-Gonzalez, G.; Gimeno-Mallench, L. and Gambini, J. (2021). Pharmacological properties of polyphenols: bioavailability, mechanisms of action, and biological effects in *in vitro* studies, animal models, and humans. Biomedicines, **9**:1074.

Tomczak, D.W. (2007). Changes in antioxidant activity of black chokeberry juice concentrate solutions during storage. Acta Sci. Pol. Technol. Aliment., **6**:49-55.

Turk, M.F.; Vorobiev, E. and Baron, A. (2012). Improving apple juice expression and quality by pulsed electric field on an industrial scale. LWT Food Sci. Technol., **49**:245-250.

Upadhyay, R.; Dass, F.P.; Chauhan, A.K.; Yadav, P.; Singh, M. and Singh, R. (2019). Guava enriched functional foods: Therapeutic potentials and technological challenges. In: The role of functional food security in global health. DOI: https://doi.org/10.1016/B978-0-12-813148-0.00021-9.

Variyer P, Bandyopadhyay C, Thomas P (1998) Effect of gamma irradiation on the phenolic acids of some Indian spices. Int. J. Food Sci. Technol, **33**:533-537

Wangensteen, H.; Samuelsen, A.B. and Malterud, K.E. (2004). Antioxidant activity in extracts from coriander. Food Chemistry, **88**:293-297.

Wachtel Galor, S.; Wong, K.W. and Benzie, I.F.F. (2008). The effect of cooking on Brassica vegetables. Food Chem., **110**:706-710.

Warkina, G. (2020). Review on changes in bioactive composition of fruits during juice processing. Food Sci. and Nutri. Tech., **5**:1-9. DOI: 10.23880/fsnt-16000230.

Zheng, H. and Lee, H. (2011). Effect of microwave pretreatment on the kinetics of ascorbic acid degradation and peroxidase inactivation in different parts of green asparagus (*Asparagus officinalis* L.) during water blanching. Food Chem., **128**:1087-1093.

Zhang, M.; Chen, H.; Li, J.; Pei, Y. and Liang, Y. (2010). Antioxidant properties of tartary buckwheat extracts as affected by different thermal processing methods. LWT Food Sci. Technol., **43**:181-185.

Zielinski, H.; Mishalska, A.; Amigo-Benavent, M.; Del Castillo, M.D. and Piskula, M.K. (2009). Changes in protein quality and antioxidant properties of buckwheat seeds and groats induced by roasting. J. Agric. Food Chem., **57**:4771-4777.

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