Chemical and Sensory Characteristics of Fruit Juice

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The intake of fruit has a notable effect on the prevention of signs of aging, cardiovascular diseases, cataracts, and strokes, presenting anti-inflammatory, anticancer, antidiabetic, and neuroprotective properties. In addition, fruit juices are considered alternative food products, being developed as probiotic substrates as an alternative to dairy products. Because they are well accepted by consumers and have a high nutritional value with positive health effects, fruit juices are ideal vehicles for probiotics.

fruit processing fruit juice

1. The Chemical Composition of Fruit

It is recognized that fruit consumption constitutes a large contribution of macronutrients, micronutrients, phytochemicals, and structural carbohydrates [1][2][3] (**Figure 1**), resulting in health benefits. According to dietary guidelines, fruit intake decreases excessive oxidative stress, preventing chronic and metabolic diseases while also acting on energy intake [4].

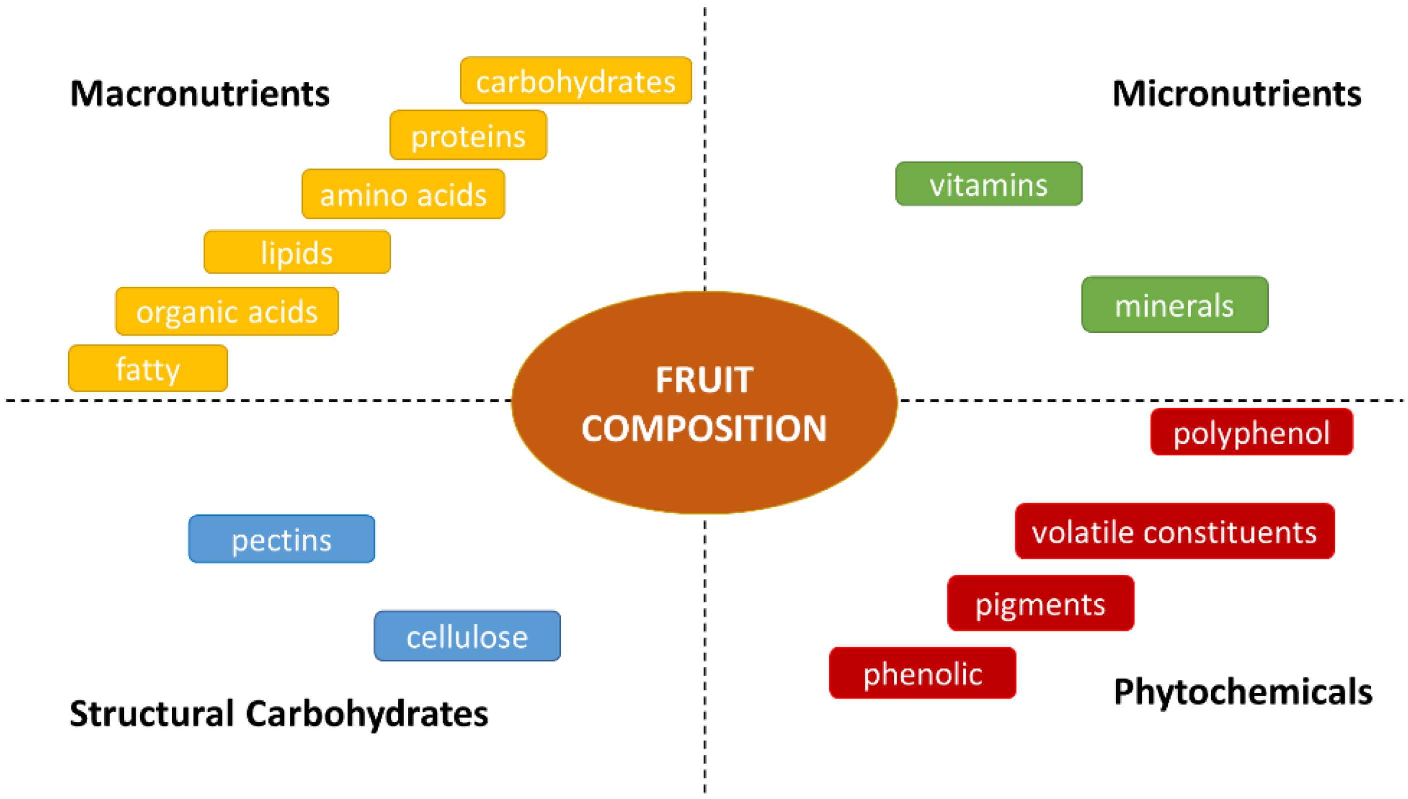

Figure 1. Fruit composition.

Indeed, fruits are recognized as fundamental sources of vitamins, minerals, dietary fiber, and antioxidants. Their nutritional value and sensory characteristics depend on species, variety, cultivation (conventional or biological), soil, climatic conditions, storage, transport, and shelf life. Currently, there is a tendency to combine different fruits to increase both the flavor and the contribution of nutritional qualities [5][6].

Fruits are important sources of vitamins and minerals, mainly vitamin C and the B complex, and precursors of vitamin A, as well as providing antioxidants [6][7].

Minerals are essential in human health as they affect the development of bones and teeth, in addition to being related to electrolyte and water balance, metabolic catalysts, oxygen binding, and hormonal functions [8]. Fruits can contain significant amounts of important minerals such as: potassium, particularly bananas, blackcurrants, and blackberries; magnesium, of which the highest content is recorded in blackberries; and iron, where the strawberry stands out. However, they are low in sodium and selenium. It is also observed that berries as a whole are an important source of minerals, of which the main minerals found are phosphorus, potassium, calcium, magnesium, and iron (**Table 1**).

Table 1. Mineral and vitamin composition of different fresh fruits.

Fruits	Minerals (mg/100 g of Fresh Weight)										Vitamins			References
	Ca	P	K	Mg	Na	Fe	Se	Cu	Mn	Zn	C	A	B6	B2	
Apple	6	11	107	5	1	120 [a]	0	30 [a]	40 [a]	40 [a]	4.6	3 [a]	-	-	[9]
Apricot	13	23	259	10	1	390 [a]	0.1 [a]	80 [a]	80 [a]	200 [a]	10	96 [a]	-	-	[9]
Banana	5	22	358	27	1	260 [a]	1 [a]	80 [a]	270 [a]	150 [a]	8.7	3 [a]	-	-	[9]
Blackberry	6–29	2–29 [d]	77–349	6–44.8	2–4 [d]	0.28–1.28	-	0.02–0.04 [d]	1.2–2.6 [d]	0.07–0.44	34–52	-	-	-	[1][6][9][10]
Blackcurrant	35–45 [d]	35–40 [d]	300–320 [d]	15–18 [d]	1.7–2.5 [d]	1.3–2.5 [d]	-	0.15–0.20	0.35–0.52	0.25–0.31	122.4–193.2	-	-	-	[6][11]

Fruits	Minerals (mg/100 g of Fresh Weight)										Vitamins				References
	Ca	P	K	Mg	Na	Fe	Se	Cu	Mn	Zn	C	A	B6	B2	
								[d]	[d]	[d]					
Blueberry	15–35 [d]	8.6	56–80 [d]	4.9	0.11–0.22 [d]	1.24	-	0.02–0.04 [d]	-	0.13	10–100	-	1999 [c]	216 [c]	[1][6][9][10]
Cherry	13	12.2–15	90.9–173	11–12.2	0	1.16	0	60 [a]	-	0.69	10–62.4	3 [a]	790 [c]	247 [c]	[1][9][10]
Clementine	30	21	177	10	1	140 [a]	10 [a]	40 [a]	20 [a]	60 [a]	48.8	-	-	-	[9]
Cranberry	15–30 [d]	1–4 [d]	24–30 [d]	3–7 [d]	4–6 [d]	0.16–0.4 [d]		0.13–0.2 [d]	0.3–0.10 [d]	0.02–0.04 [d]	10 [b]	-	606 [c]	69 [c]	[1][6]
Fig	35	14	14	17	1	370 [a]	0.2 [a]	70 [a]	130 [a]	150 [a]	2	7 [a]	-	-	[9]
Grapes	10	20	191	7	2	360 [a]	0.1 [a]	130 [a]	70 [a]	70 [a]	3.2	3 [a]	-	-	[9]
Litchis	5	31	171	10	1	310 [a]	0.6 [a]	150 [a]	60 [a]	70	71.5	0	-	-	[9]
Mango	11	14	168	10	1	160 [a]	0.6 [a]	110 [a]	60 [a]	90 [a]	36.4	54 [a]	0.1–0.16	0.02–0.1	[9]
Melon	9	15	267	12	16	210 [a]	0.4 [a]	40 [a]	-	180 [a]	36.7	169 [a]	-	-	[9]

Fruits	Minerals (mg/100 g of Fresh Weight)										Vitamins				References
	Ca	P	K	Mg	Na	Fe	Se	Cu	Mn	Zn	C	A	B6	B2	
Orange [a]	41	14	181	10	0 [b]	100 [a]	0.5 [a]	40 [a]	30 [a] [c]	70 [a]	53.2	11 [a]	- [d]	-	[9]
Papaya	20	10	182	21[12]	8	250 [a]	0.6 [a]	40 [a]	40 [a]	80 [a]	60.9	47 [a]	-	-	[9]
Peach	6	20	190	9	0	250 [a]	0.1 [a]	70 [a]	60 [a]	170 [a]	6.6	16 [a]	-	-	[9]
Pear	9	12	116	7	1	180 [a]	0.1 [a]	80 [a]	50 [a]	100 [a]	4.3	1 [a]	-	-	[9]
Pineaplle	13	8	109	12	1	290 [a] [14]	0.1 [a]	110 [a]	930 [a]	[13][14] 120 [a]	47.8	3 [a]	-	-	[9]
Plum	6	16	[15] 157	[5][13][16]	0	170 [a]	0	60 [a]	50 [a]	100 [a]	9.5	17 [a] [9]	-	-	[9]
Raspberry	1.14	5.7	71.8	15.9	0.5–1 [d]	1.06	-	-	1.5–2.0 [d]	.37	5–92.2	-	- [5][9][10]	-	[1][6][9][10]
Strawberry	2.2–16	6.6–24	51.2–153	13–15.9	1	410	0.4	50 [7]	390	140	5–90	1	1744 [c]	93 [c]	[1][9][10]
Watermelon	7	11	112	10 [17]	1	240	0.4	40	40	100	8.1	28	-	-	[9]

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Phenolic compounds are one of the major classes of secondary plant metabolites and are among the most abundant natural antioxidants in the diet. Fruit is one of the foods richest in polyphenols, contributing to about half of the total nutritional intake [18]. They are associated with the prevention of numerous pathologies associated with oxidative stress, acting as antioxidants, also exhibiting antibacterial, antitumor, antimalarial, and antiviral characteristics, among others [1][19]. The phenolic potential of fruits depends on many factors, of which genetic attributes, maturity stage, and growing conditions are of primary importance [1][20].

About 8000 different plant phenolic structures are known [21], which are divided into major families such as phenolic acids, flavonoids, and stilbenes [7][22]. In red fruits, most of the phenolics present belong fundamentally to two classes: phenolic acids and anthocyanins, although each species has its profile [1]. For example, blueberries are rich in quercetin and caffeic acid (31.0–83.0 and 2.0–27.35 mg/kg fresh weight, respectively) [23][24][25], while lingonberries are rich in *p*-coumaric and ferulic acid (37.6–251.1 and 16.2–221.7, respectively) [26][27].

Among the flavonoids, flavanols and proanthocyanidins are the most present in the human diet. In fruits, catechins are represented with high content in apricots and cherries [28][29]. Proanthocyanidins are particularly abundant in cranberries (418.8 mg/100 g fresh weight), blueberries (179.8–331.9 mg/100 g fresh weight), plums (215.9–256.6 mg/100 g fresh weight), apples (69.6–141 mg/100 g fresh weight), blackcurrants (147.8 mg/100 g fresh weight), and strawberries (145 mg/100 g fresh weight) [30]. Anthocyanins are also abundant in fruits, found mainly in the fruit skin. Anthocyanin content is related to the increasing color intensity as the fruit ripens [31][32]. Grapes are the main dietary source of anthocyanins. The monomeric anthocyanins in grape skin extracts were mainly malvidin, particularly the malvidin-3-glucoside (1.40–7.09 mg/g of skin and 0.62–6.09 mg/g of skin, respectively) [33].

Lignans are found in relatively low concentrations in various fruits, having a positive impact on the prevention of heart disease, mamma cancer, and osteoporosis [34]. The highest content of lignan is observed in pears (15.56 mg/100 g food), apricots (11.57 mg/100 g food), grapefruits (7.44 mg/100 g food), peaches (6.83 mg/100 g food), and strawberries (6.2 mg/100 g food) [35].

Stilbenes are rarely present in human food. *Trans*-resveratrol can be found in grape skins with well-known beneficial health effects [36][37], namely in the prevention of human cardiovascular diseases. The highest concentration of this phenolic compound was found in grape skin, with a higher concentration in the red compared to the white varieties [38].

The chemical composition of the fruit affects the sensory characteristics of the juice. According to Francis and Newton [39], aroma results from complex interactions of numerous chemical compounds. Essentially, the cultivar [40][41][42], agricultural practices (conventional vs. organic) [43][44], post-harvest treatments, and the different techniques used to extend the shelf life of fruit and fruit juices [45][46], lead to variations in their sensory characteristics. Several techniques can be used to preserve the shelf life of this type of product, including thermal and non-thermal processing methods. However, their use should prevent the loss of the sensory properties of the juice or limited effectiveness of the treatment, since, in the search for the development of differentiating products, the mixed fruit juices are an option responding to the consumer demand for new flavors with added nutritional value, better sensory characteristics, and more striking colors [47][48].

2. Juice Composition vs. Processing Technologies

The consumer demand for fruit juices is growing as they are a naturally rich source of bioactive compounds, however, their susceptibility to spoilage limits the shelf-life [49]. For this reason, the food industry is constantly searching for new processing technologies to extend the shelf life with a low impact on the fruit juice quality, as the consumers are now more conscious of health and diet [50][51]. To extend the shelf life of fruit juices, the most commonly used preservation process is thermal processing (pasteurization and sterilization). For example, apple juice is treated by HTST at 77 to 88 °C for 25 to 30 s [52] and orange juice by HTST at 90 to 95 °C for 15 to 30 s [53]. However, this process may promote undesirable quality changes in the juice composition and the sensory and nutritional values of the fruit juice [54].

For example, Vegara et al. [55] evaluated the influence of pomegranate juice pasteurized on anthocyanin stability and verified that the application of thermal treatments (65 and 90 °C for 30 or 5 s) diminished the percentage of anthocyanins in the polymeric form but increased the monomeric anthocyanins. Also, Aguilar-Rosas et al. [56] studied the high-temperature short time (HTST) pasteurization process (90 °C; 30 s) of apple juice and observed a decrease in the concentration of the total phenolic compounds (~32%), compared to the untreated juice.

Mena et al. [57] analyzed pomegranate juice before and after low-, mild- and high-temperature pasteurization (LTP, MTP, HTP, at 65, 80, and 95 °C, respectively, for periods of 30 or 60 s, and observed that the total anthocyanin concentration was different among thermally processed and untreated pomegranate juices, the lowest concentration being determinate in the control (untreated pomegranate juices), while the highest concentration of anthocyanins was found in the juice treated at 95 °C for 30 s.

Consequently, as consumers want fruit juices not only with extended shelf life but also with enhanced quality characteristics, researchers are looking for innovative non-conventional technologies such as high-pressure (HP), ultrasound (US), pulsed electric fields (PEF), ultraviolet-C radiation (UV-C), low-pressure plasma (LPP) and Ohmic heating (OH) (**Table 2**) to achieve the consumer demand for fruit juice with an extended shelf life, better quality, and an improved nutritional profile [51]. Recent studies reported a positive impact of non-thermal processing on juice quality [58][59]. Optimized non-thermal processing enhanced the content of the bioactive compounds in fruit juices and consequently their beneficial health effects [51][60].

Table 2. Thermal and non-thermal processing technologies of fruit juices.

Juice	Conditions	Effect	References
Pasteurization-Conventional heating			
Orange juice	95 °C, 1 min	Reduction of pectin methylesterase activities (88.3%)	[61]
	90 °C, 50 s	Sensory quality was the limiting factor for the shelf life of conventionally pasteurized juice, at 50 days	[62]
	90 °C, 30 s	Significant loss of the content of total carotenoid pigment	[63]
Pulsed electric field (PEF)			
Orange juice	35 kV/cm, 4 μs, 40 °C	8% loss of vitamin A, 1% loss of citric acid	[64]

Juice	Conditions	Effect	References
		no change in Brix, pH, vitamin C, and viscosity	
	40 kV/cm, 97 ms, 45 °C	PEF-processed juice retained more ascorbic acid, flavor, and color than thermally processed juice (90 °C/90 s) PEF-processed juice sensory evaluation of texture, flavor, and overall acceptability was ranked highest than thermally processed juice	[65]
	20 kV/cm, 25 µs	PEF treatments preserved the characteristic compounds associated with a fresh flavor (e.g., dl-limonene, β-myrcene, α-pinene, and valencene) more effectively than an intensive thermal treatment (121 °C/20 min)	[66]
Apple Juice	35 kV/cm, 94 µs	No change in natural color and Vitamin C	[67]
	35 kV/cm, 4 µs	pH, total acidity, phenolic and volatile compounds were less affected by PEF than by HTST treatment (90 °C /30 s)	[56]
	High-pressure processing (HHP)		
Orange juice	600 MPa, 4 min at 40 °C	High-pressure treatment led to lower degradation of ascorbic acid compared with pasteurization (80 °C/60 s)	[68]
	500 MPa, 5 min at 25 °C	2% loss of vitamin C, no change in Brix, pH, and color	[64]

Juice	Conditions	Effect	References
	400 MPa, 1 min at 40 °C	5%-8% loss of vitamin C, no change in Brix, pH, and color	[69]
	600 MPa, 15 min	93.4% retention rate of anthocyanin (cyanidin-3-glucoside); 85% retention rate of ascorbic acid	[70]
Lemon juice	450 MPa, 2, 5, or 10 min	Slight effects of HPP on the compounds and physicochemical properties	[71]
Apple juice	400 MPa, 10 min	High-pressure treated apple juice sensory quality was higher compared to pasteurization (80 °C, 20 min)	[72]
Strawberry juice	200–500 MPa, 20 min, 20 °C	No major changes in strawberry juice aromatic volatile profile composition after HP treatment. Changes appeared in the composition of aromatic compounds after sterilization (120 °C, 20 min)	[73]
Ultra-sonication (US)			
Orange juice	20 kHz, 1500 W, 10 min, 32–38 °C	No changes in pH, °Brix, and titratable acidity	[74]
	20 kHz, 1500 W, 8 min, 10 °C	Changes in color and ascorbic acid concentration during storage	[75]
Grapefruit juice	28 kHz, 30, 60, and 90 min, 20 °C	Improvement in the ascorbic acid, total phenolics, flavonoids, and flavonols. No changes in the pH, acidity, and °Brix value. Differences in the color values with overall quality improved	[76]
Cold plasma			

Juice	Conditions	Effect	References
Pomegranate juice	5 min; 4 cm^3; 0.75 dm^3/min	Pasteurization and plasma treatment resulted in total phenolic content increasing by 29.55% and 33.03%, respectively	[77]
	3 min; 5 cm^3; 0.75 dm^3/min	Anthocyanin content increased after cold plasma treatment by between 21% and 35% Higher anthocyanin stability	[78]
		Ultraviolet-C radiation (UV-C)	
Orange juice	>230 J/L	No changes in aroma and color 11% loss of vitamin C	[64]
	12–48 kJ/L	Ascorbic acid losses increased with the UV-C application No changes in total phenols and antioxidant capacity No changes in pH, total soluble solids, and titration acidity	[79]
Pomegranate juice	12–62 J/mL [83]	No changes in total phenol content No changes in pH, total soluble solids, and titration acidity	[80]
		Ohmic heating (OH)	
Watermelon juice	90 °C/15–60 s	No changes in lycopene High color stability	[81]

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Another example of non-thermal technology is the application of high-pressure (HP) and high hydrostatic pressure (HHP) processing on acid fruit juices. This technology is effective in the inactivation of microorganisms (meeting the Food and Drug Administration requirement of a 5-*log* reduction) and denaturation of diverse enzymes [84],

Juice	Conditions	Effect	References
		Decrease in total phenolic compounds	[86]
	95 °C/1, 3 and 5 min/voltage gradients of 10, 13.33, 16.66, 20 and 23.33 V/cm at 50 Hz	Voltage gradient and treatment time was statistically significant with change in pH and total color difference	[82]

of storage for 550 MPa during the 90 s. These results showed clearly that the color stability of pomegranate juice is dependent on the processing conditions. Orange juice showed an increase in flavanone after HPP processing (400 MPa, 40 °C, 1 min), compared to the untreated juice [54]. Also, Sánchez-Moreno et al. [88] and Oms-Oliu et al. [89] observed in orange juice treated with HP (400 MPa/40 °C/1 min) an enhancement in the concentration of naringenin by 20% and the concentration of hesperetin by 40%, compared with the untreated orange juice and the preservation of the orange juice sensory characteristics.

In addition, pulsed electrical field (PEF) processing, which applies short bursts of high voltage electricity for microorganism inactivation, has been successful in a variety of liquid products with relatively low viscosity and electrical conductivity such as orange juice and cranberry juice [90]. PEF has a high potential for microorganism inactivation and enzyme denaturation, extending the shelf life and preserving the nutritional, vitamin, aroma, and sensory characteristics due to the very short processing time and low processing temperature. Blueberry juice processed by HP (600 MPa/42 °C/5 min) and processed by PEF (36 kV/cm, 100 µs) stored refrigerated at 4 °C for 56 days, showed a 50% of ascorbic acid reduction in both unprocessed blueberry juices and in the PEF-treated juices at the end of the refrigeration time. However, HPP-treated blueberry juice better maintained the ascorbic acid content during the storage time with a reduction of 31%, and the anthocyanins in the blueberry juice treated with HP were also better preserved. Sánchez-Moreno et al. [88] considered that the PEF treatment did not modify flavanone content, but in general, the pasteurization process led to a diminished naringenin content (16.04%), with no modification in hesperetin. They also observed that even though the losses in total vitamin C were <9%, treatments with the higher temperatures (HPT) (90 °C/1 min), tend to show a greater reduction in the concentration of both forms of vitamin C. HP treatment (400 MPa/40 °C/1 min) led to an increase in carotenoid release (53.88%) and vitamin A value (38.74%). PEF treatment did not modify individual or total carotenoid content. Traditional thermal treatments did not have any effect on the total carotenoid content or on the vitamin A value. In apple juice, the treatment with PEF decreased the concentration of total phenolic compounds (~15%) compared to the untreated juice, however, this decrease was lower than that observed with thermal pasteurization, which decreased the phenolic compounds by 32% [56]. In summary, according to Sánchez-Moreno et al. [88], HP and PEF technologies were more effective than HPT treatment in preserving the bioactive compounds of orange juice. Likewise, Agcam et al. [91] showed that the total phenolic concentration of orange juice was enhanced after the PEF and thermal pasteurization treatments. Orange juice processed by PEF contained higher phenolic compound concentrations than those processed by the heat. The orange juice treated with PEF had more stable flavonoids and phenolic acids than those treated with thermal pasteurization. The PEF-treated samples had higher sensory scores than the heat-treated samples. Therefore, these authors suggested that the application of PEF processing to orange juice seems to be a promising alternative to thermal pasteurization to obtain an extended shelf life and better preservation of phenolic compounds and should be taken into consideration for industrial-scale production.

In recent times, cold plasma was considered suitable for use with fruit juices [92][93]. Therefore, cold plasma is accepted as a potential, novel, non-thermal technology for the quality improvement of fruit juices, and numerous research works have studied the application of cold plasma in fruit juices [60][78][94][95][96][97]. The treatment is performed under milder temperatures (< 70 °C), which contributes to the preservation of sensory characteristics and the maintenance of bioactive compounds in fruit juices [77]. Bursać Kovačević et al. [78], using a cold atmospheric gas-phase plasma in pomegranate juice, observed an increase in the concentration of anthocyanin between 21% and 35% compared to the untreated juice, which confirms that the cold plasma has a positive impact on anthocyanin stability. More recently, de Castro et al. [60] studied the application of cold plasma excitation frequency (200, 420, 583, 698, and 960 Hz) in the juice physicochemical properties. These authors concluded that after the application of this non-thermal treatment the content of ascorbic acid was increased by increasing the plasma excitation frequency. According to these authors, cold plasma application could be an interesting method to enhance the nutritional quality of fruit juices. It was also observed in diverse fruit juices, for example, strawberry juice, blackcurrant juice, and raspberry juice, that anthocyanins are stable to HP treatments, such as the application of cold plasma excitation frequency [58][59].

Several research works have been conducted on different fruit juices using ohmic heating which is also known as electrical resistance heating, such as the inactivation of microorganisms [98][99][100] and enzymes, for example, pectin methylesterase (EC.3.1.1.11) also called pectinesterase [61][101] and polyphenoloxidase, for minimizing enzymatic browning [81]. In orange juice treated with ohmic heating around 96% of the pectin methylesterase activity was reduced as observed by Demirdöven et al. [61]. In fruit juices, the use of ohmic heating to inactivate enzymes does not affect the juice flavor [102]. Hashemi et al. [103] compared different ohmic heating treatments (150, 200, and 250 V; 120 s; 99.4 °C) with the conventional heating process (90 °C; 15 min) for the inactivation of microorganisms in blended citrus juice (sweet lemon and orange). These researchers showed that the inactivation rate of pathogenic bacteria using ohmic heating increased by the increase of voltage from 150 to 250 V. Also, Darvishi et al. [104] studied the influence of ohmic heating on the concentration of black mulberry juice in comparison to the traditional heating treatment. Using ohmic heating the phenolic concentration of the juice was 3–4.5 times greater than if using traditional heating treatment.

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