Review

Chemical and Sensory Characteristics of Fruit Juice and Fruit Fermented Beverages and Their Consumer Acceptance

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Abstract: Recent social, economic, and technological evolutions have impacted consumption habits. The new consumer is more rational, more connected and demanding with products, more concerned with the management of the family budget, with the health, origin, and sustainability of food. The food industry over the last few years has shown remarkable technological and scientific evolution, with an impact on the development and innovation of new products using non-thermal processing. Non-thermal processing technologies involve methods by which fruit juices receive microbiological inactivation and enzymatic denaturation with or without the direct application of low heat, thereby lessening the adverse effects on the nutritional, bioactive, and flavor compounds of the treated fruit juices, extending their shelf-life. The recognition of the nutritional and protective values of fruit juices and fermented fruit beverages is evident and is attributed to the presence of different bioactive compounds, protecting against chronic and metabolic diseases. Fermentation maintains the fruit's safety, nutrition, and shelf life and the development of new products. This review aims to summarize the chemical and sensory characteristics of fruit juices and fermented fruit drinks, the fermentation process, its benefits, and its effects.

1. Introduction

The current trend in the food industry is to develop new products that present quality and food safety characteristics, responding to the needs and preferences of consumers. When adopting a more sustainable lifestyle, consumers are increasingly demanding, giving preference to natural, healthier, innovative, and tastier products with nutraceutical and sustainable characteristics and with a minimum amount of chemical preservatives and/or processing technologies [1,2]. As such, the sustainable development of the functional food market is increasingly evident, in which fruit juices and fermented fruit beverages begin to occupy a prominent place [3]. According to Corbo et al. [4], in 2008, the food industry presented an expected growth of between 2–3%, with the functional food market presenting an expectation of approximately 10%. This fact could be explained partially by the growing number of lactose-intolerant consumers, dairy allergies, the preference for products with low cholesterol content, and the growing trend of vegetarianism, which leads consumers to avoid the consumption of dairy drinks [5–7]. Also, the tendency of consumers to avoid highly sugary products is not insignificant in the valorization of functional food and beverages [8]. Several studies have been carried out highlighting the beneficial health effects of integrating fruit into the human diet as a supply of dietary nutrients and bioactive compounds, including dietary fiber, vitamins, minerals, polyphenols,

flavonoids, monoterpenes, and bioactive peptides [8–11]. Thus, the intake of fruit has a notable effect on the prevention of signs of aging, cardiovascular diseases, cataracts [12], and strokes [13], presenting anti-inflammatory, anticancer, antidiabetic, and neuroprotective properties [11,14,15]. In addition, fruit juices are considered alternative food products, being developed as probiotic substrates in recent years 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 [16,17].

Considering the extremely perishable nature of the fruits, finding new technologies for conservation and processing has become a focus for innovation in the food industry. Processing fruit to obtain juices or nectars is a means to transform perishable products into storable and marketable products, adding economic value to the fruit, avoiding waste, and minimizing losses that may occur during the marketing of the fresh product [18]. Fermentation is one of the oldest food processing technologies. As early as the Paleolithic and Neolithic eras, foods such as bread and wine were consumed [3]. Without the need for highly developed technologies, fermentation occurs spontaneously and naturally through the action of microorganisms present in or added to the substrates. Probiotics are non-pathogenic live microorganisms, and their selection is extremely important in the fruit fermentation process due to the biochemical changes they promote in the initial product [10]. Fermentation consists of the action of microorganisms on the raw material in a biotransformation process in which carbohydrates are transformed into organic acids or alcohols [19,20]. There are numerous fermentation techniques and microorganisms used in this process [21]. However, while there is diversification, four main fermentation processes can be considered: acetic, alkaline, alcoholic, and lactic fermentation [22]. The microorganisms involved in fermentation can be bacteria, yeasts, and molds [10]. Sometimes the microbial species involved in fermentation are not known and may even belong to multiple species. In fermented fruit beverages, the microorganisms used are mainly lactic acid bacteria (LAB), such as *Lactobacillus plantarum*, *Lactobacillus brevis*, *Lactobacillus rhamnosus*, *Lactobacillus acidophilus*, *Lactobacillus casei*, *Leuconostoc mesenteroides*, *Leuconostoc citreum*, *Leuconostoc fallax*, *Leuconostoc kimchi*, *Pediococcus pentosaceus*, *Pediococcus acidilactici*, *Weissella confusa*, *Weissella cibaria*, but also yeast, and acetic acid bacteria [8,10,13].

Thus, changes in the nutritional value, sensory characteristics, and microbial safety of the product are a consequence of the fermentation process. This is a technology that, according to several authors [3,10,23], has great advantages due to the improvement of food taste, food safety, and shelf life, with an increase in its nutritional properties by the production of interesting active principles. This review highlights the chemical and sensory characteristics of fruit juices and fermented fruit drinks, the fermentation process, its benefits, and its effects. The acceptance of fermented beverages by consumers will also be considered.

2. Fruit Juices

2.1. The Chemical Composition of Fruit

It is recognized that fruit consumption constitutes a large contribution of macronutrients, micronutrients, phytochemicals, and structural carbohydrates [15,24,25] (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 [26].
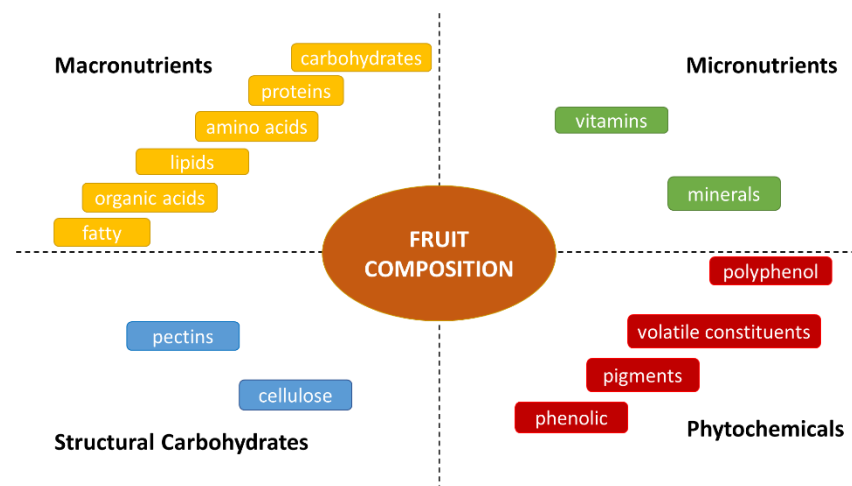
Figure 1. Fruit composition.

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 [27,28].

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 [10,28].

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 [29]. 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).

Without the ability to synthesize vitamins, these minerals are essential for the proper functioning of the human body due to their antioxidant potential [30]. Ascorbic acid, or vitamin C, exists mainly in red fruits, such as strawberries, cherries, red raspberries, black raspberries, blackberries, cranberries, and blueberries, with a higher incidence in black currants, oranges, and papayas, which also register considerable levels of vitamin C. Vitamin A is not found abundantly in fruits, with a few exceptions, such as mangos, papayas, melons, and even watermelons. Vitamin B6 (riboflavin) is not present in large amounts in fruits, but appears in appreciable amounts in blueberries, cherries, strawberries, cranberries, and plums (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]	-	-	[31]
Apricot	13	23	259	10	1	390 [a]	0.1 [a]	80 [a]	80 [a]	200 [a]	10	96 [a]	-	-	[31]
Banana	5	22	358	27	1	260 [a]	1 [a]	80 [a]	270 [a]	150 [a]	8.7	3 [a]	-	-	[31]
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	-	-	-	[15,28,31,32]
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 [d]	0.35–0.52 [d]	0.25–0.31 [d]	122.4–193.2	-	-	-	[28,33]
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]	[15,28,31,32]
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]	[15,31,32]
Clementine	30	21	177	10	1	140 [a]	10 [a]	40 [a]	20 [a]	60 [a]	48.8	-	-	-	[31]
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]	[15,28]
Fig	35	14	14	17	1	370 [a]	0.2 [a]	70 [a]	130 [a]	150 [a]	2	7 [a]	-	-	[31]
Grapes	10	20	191	7	2	360 [a]	0.1 [a]	130 [a]	70 [a]	70 [a]	3.2	3 [a]	-	-	[31]
Litchis	5	31	171	10	1	310 [a]	0.6 [a]	150 [a]	60 [a]	70	71.5	0	-	-	[31]
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	[31]
Melon	9	15	267	12	16	210 [a]	0.4 [a]	40 [a]	-	180 [a]	36.7	169 [a]	-	-	[31]
Orange	41	14	181	10	0	100 [a]	0.5 [a]	40 [a]	30 [a]	70 [a]	53.2	11 [a]	-	-	[31]
Papaya	20	10	182	21	8	250 [a]	0.6 [a]	40 [a]	40 [a]	80 [a]	60.9	47 [a]	-	-	[31]
Peach	6	20	190	9	0	250 [a]	0.1 [a]	70 [a]	60 [a]	170 [a]	6.6	16 [a]	-	-	[31]
Pear	9	12	116	7	1	180 [a]	0.1 [a]	80 [a]	50 [a]	100 [a]	4.3	1 [a]	-	-	[31]
Pineaplle	13	8	109	12	1	290 [a]	0.1 [a]	110 [a]	930 [a]	120 [a]	47.8	3 [a]	-	-	[31]
Plum	6	16	157	7	0	170 [a]	0	60 [a]	50 [a]	100 [a]	9.5	17 [a]	-	-	[31]
Raspberry	1.14	5.7	71.8	15.9	0.5–1 [d]	1.06	-	-	1.5–2.0 [d]	.37	5–92.2	-	-	-	[15,28,31,32]
Strawberry	2.2–16	6.6–24	51.2–153	13–15.9	1	410	0.4	50	390	140	5–90	1	1744 [c]	93 [c]	[15,31,32]
Watermelon	7	11	112	10	1	240	0.4	40	40	100	8.1	28	-	-	[31]

Units: [a] µg/100 g fresh weight (FW); [b] mg/100 g dry weight; [c] µg/100 g of fresh weight; [d] mg/100 g edible portion.

The benefits of a diet rich in dietary fiber have long been known [34,35], namely in physiological responses to satiety, gastrointestinal tract physiology [35], lower risk of colorectal cancer, lower total and LDL cholesterol, and cardiovascular disease [36]. The term dietary fiber consists of polysaccharides (cellulose, hemicellulose, pectins, gums, mucilages) and lignin [27,34,37]. The fiber content in the fruit ranges from 1 to 3.17 g/100 g FW, with pears and figs showing the highest amounts, 3.1 and 2.9 g/100 g FW, respectively [31]. The red fruits were recorded to possess lower fiber contents, where the cranberries present the highest fiber content (35.7 mg/100 g FW), followed by the raspberries (5.8–6.5 mg/100 g FW) and the blackberries (4.5–5.3 7 mg/100 g FW) [27,31,32].

Glucose, sucrose, and fructose are the main sugars in the fruits, and although there are significant variations in their amount, according to Septembre–Malaterre et al. [10], the number of sugars in the fruit can vary between 5 and 22% of fresh weight, with citrus fruits among those with the lowest percentage of sugars and bananas with the highest. Mikulic–Petkovsek et al. [38] determined that fructose and glucose are the main sugars present in red fruits; not detecting sucrose in blackberry and raspberry fruits.

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 [39]. 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 [15,40]. The phenolic potential of fruits depends on many factors, of which genetic attributes, maturity stage, and growing conditions are of primary importance [15,41].

About 8000 different plant phenolic structures are known [42], which are divided into major families such as phenolic acids, flavonoids, and stilbenes [10,43]. In red fruits, most of the phenolics present belong fundamentally to two classes: phenolic acids and anthocyanins, although each species has its profile [15]. For example, blueberries are rich in quercetin and caffeic acid (31.0–83.0 and 2.0–27.35 mg/kg fresh weight, respectively) [44–46], while lingonberries are rich in *p*-coumaric and ferulic acid (37.6–251.1 and 16.2–221.7, respectively) [47,48].

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 [49,50]. 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) [51]. 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 [52,53]. 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) [54].

Lignans are found in relatively low concentrations in various fruits, having a positive impact on the prevention of heart disease, mamma cancer, and osteoporosis [55]. 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) [56].

Stilbenes are rarely present in human food. *Trans*-resveratrol can be found in grape skins with well-known beneficial health effects [57,58], 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 [59].

The chemical composition of the fruit affects the sensory characteristics of the juice. According to Francis and Newton [60], aroma results from complex interactions of numerous chemical compounds. Essentially, the cultivar [61–63], agricultural practices (conventional vs. organic) [64,65], post-harvest treatments, and the different techniques used to extend the shelf life of fruit and fruit juices [66,67], 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 [68,69].

2.2. 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 [70]. 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 [71,72]. 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 [73] and orange juice by HTST at 90 to 95 °C for 15 to 30 s [74]. However, this process may promote undesirable quality changes in the juice composition and the sensory and nutritional values of the fruit juice [75].

For example, Vegara et al. [76] 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. [77] 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. [78] 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 [72]. Recent studies reported a positive impact of non-thermal processing on juice quality [79,80]. Optimized non-thermal processing enhanced the content of the bioactive compounds in fruit juices and consequently their beneficial health effects [72,81].

For example, Linhares et al. [82] compared the composition, stability, and bioactive compounds of juices produced with different processing technologies, thermal technologies such as high-temperature short time (HTST), ultrahigh temperature (UHT), and non-thermal technologies such as high power ultrasound (US), UV-pulsed-light and low-pressure plasma (LPP). These authors showed that all the juices produced with non-thermal processes increased the sugar content (glucose and fructose), and the amino acid betaine, except for the juices produced by the combination of the ultrasound process followed by low-pressure plasma (US.LPP). On the other hand, the juices produced by HTST and UHT showed higher concentrations of fatty acids and phenolic compounds. Also, the effects of ultrasound treatments on the quality of grapefruit juice were studied by Aadil et al. [83], and it was observed that all grapefruit juice samples were sonicated for 30, 60, and 90 min leading to an improvement in the total phenolic, flavonoids, and flavonol. These outcomes suggested that this non-thermal processing technology might be well applied at an industrial scale for the processing of grapefruit juice. Also, UV-C technology has been

demonstrated to obtain microbiologically safe fruit juices with a low negative impact on final product quality [84].

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 [85], without loss of vitamins, pigments, and compounds related to sensory characteristics [86]. High-pressure (HP) processing is preferred to thermal processes in terms of holding phenolic compounds. HP and HHP treatment at moderate temperature is described to have an insignificant effect on the anthocyanin concentration of diverse red fruit juices, as well as the flavor, taste, and color changes being minimal [87]. However, these authors also showed that the bioactive content of red fruit reduced with the intensity of the treatment in terms of processing time and pressure level. Varela-Santos et al. [88] evaluate the effect of HHP processing (350–550 MPa for 30, 90, and 150 s) on the concentration of anthocyanins, phenolic compounds, and color of pomegranate juice during 35 days of storage at 4 °C. These authors showed that HHP juice processing has a perceptible effect on the total color difference (ΔE) between untreated and treated samples, and the highest color difference was observed at day 35 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 [75]. Also, Sánchez-Moreno et al. [89] and Oms-Oliu et al. [90] 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 [91]. 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. [89] 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% [77]. In summary, according to Sánchez-Moreno et al. [89], HP and PEF technologies were more effective than HPT treatment in preserving the bioactive compounds of orange juice. Likewise, Agcam et al. [92] 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 [93,94]. 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 [1,81,95–98]. 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 [99]. Bursać Kovačević et al. [96], 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. [81] 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 [79,80].

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 [100–102] and enzymes, for example, pectin methylesterase (EC.3.1.1.11) also called pectinesterase [103,104] and polyphenoloxidase, for minimizing enzymatic browning [105]. In orange juice treated with ohmic heating around 96% of the pectin methylesterase activity was reduced as observed by Demirdöven et al. [103]. In fruit juices, the use of ohmic heating to inactivate enzymes does not affect the juice flavor [106]. Hashemi et al. [107] 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. [108] 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.

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%)	[103]
	90 °C, 50 s	Sensory quality was the limiting factor for the shelf life of conventionally pasteurized juice, at 50 days	[109]
	90 °C, 30 s	Significant loss of the content of total carotenoid pigment	[110]

Table 2. *Cont.*

Juice	Conditions	Effect	References
	Pulsed electric field (PEF)		
Orange juice	35 kV/cm, 4 μs, 40 °C	8% loss of vitamin A, 1% loss of citric acid no change in Brix, pH, vitamin C, and viscosity	[111]
	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	[112]
	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)	[113]
Apple Juice	35 kV/cm, 94 μs	No change in natural color and Vitamin C	[114]
	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)	[77]
	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)	[115]
	500 MPa, 5 min at 25 °C	2% loss of vitamin C, no change in Brix, pH, and color	[111]
	400 MPa, 1 min at 40 °C	5%-8% loss of vitamin C, no change in Brix, pH, and color	[116]
	600 MPa, 15 min	93.4% retention rate of anthocyanin (cyanidin-3-glucoside); 85% retention rate of ascorbic acid	[117]
Lemon juice	450 MPa, 2, 5, or 10 min	Slight effects of HPP on the compounds and physicochemical properties	[118]
Apple juice	400 MPa, 10 min	High-pressure treated apple juice sensory quality was higher compared to pasteurization (80 °C, 20 min)	[119]
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)	[120]
	Ultra-sonication (US)		
Orange juice	20 kHz, 1500 W, 10 min, 32–38 °C	No changes in pH, °Brix, and titratable acidity	[121]
	20 kHz, 1500 W, 8 min, 10 °C	Changes in color and ascorbic acid concentration during storage	[122]
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	[83]
	Cold plasma		
Pomegranate juice	5 min; 4 cm³; 0.75 dm³/min	Pasteurization and plasma treatment resulted in total phenolic content increasing by 29.55% and 33.03%, respectively	[99]
	3 min; 5 cm³; 0.75 dm³/min	Anthocyanin content increased after cold plasma treatment by between 21% and 35% Higher anthocyanin stability	[96]

Table 2. *Cont.*

Juice	Conditions	Effect	References
		Ultraviolet-C radiation (UV-C)	
Orange juice	>230 J/L	No changes in aroma and color 11% loss of vitamin C	[111]
	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	[123]
Pomegranate juice	12–62 J/mL	No changes in total phenol content No changes in pH, total soluble solids, and titration acidity	[124]
		Ohmic heating (OH)	
Watermelon juice	90 °C/15–60 s	No changes in lycopene High color stability Decrease in total phenolic compounds	[105]
	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	[125]

3. Fruit Juice Fermented Beverage

The production of fermented beverages using fruits other than grapes, such as oranges, mangos, raspberries, pineapples, apples, pears, apricots, peaches, cherries, bananas, and papayas increased in the last years. The explanations for this are the usage of fruit with a lower quality standard for natural eating, overproduction, and the development of fermented beverages with flavors and aromas typical of the fruits utilized. According to Lopez et al. [126], fruit wines are undiluted alcoholic beverages, produced with fruits other than grapes, which are tastier, more nutritious, and lighter alcoholic drinks as they retain the maximum amounts of the nutrients existing in the fruits. Fruit fermented beverages go through a period of fermentation and aging, and generally have an alcohol percentage between 5% and 13%, and 2–3% of sugars [127]. Fruit fermented beverages are characterized by peculiar aromatic notes, phenolic composition, antioxidants, alcohol content, and other parameters.

3.1. Alcoolic, Acetic and Lactic Fermentation

3.1.1. Alcoholic Fermentation

Many fruits are consumed fresh, but it is not unusual that large quantities are wasted during harvest, due to climate fluctuations and improper handling (inadequate storage, transport, and microbial infections). The food industry tries hard to extend the shelf life of fruits so that they can be consumed all over the world, year-round [128]. Therefore, the exploitation of ripe fruits or their juices in the production of fermented beverages is an attractive way of utilizing surplus and over-ripe fruits. Fermentation also helps to enhance the nutritional value of beverages, allowing: (i) the preservation through acidification/alcohol production; (ii) the alteration of chemical nature and sensory properties of fruit; (iii) the improvement in the efficacy of some bioactive constituents; and (iv) the enhancement of nutritional value of foods and beverages [129,130].

Wine and cider, obtained from grape and apple juice fermentation, respectively, are well-known drinks, mainly fermented by yeasts, and during the process alcohol, esters, aldehydes, terpenes, and acids are produced [131]. Besides wine and cider, many other fermented fruit juices are made from fruits [132]. Today, an increasing number of other fruits are available for the production of fermented fruit juices [129]. Table 3 lists some examples of fermented fruit juices, indicating the first published works in which they were mentioned.

Table 3. Examples of some fermented fruit juices. The first published works in which they were mentioned are also referenced.

Fruit Image	Fruit Name	References
	Apricot (*Prunus Armeniaca* L.)	A stone fruit. Due to the various advantages of apricot, the development of apricot, non-alcoholic, fermented fruit juices has good potential for commercialization [133,134]
	Apple (*Malus domestica*)	Due to the high fructose content in apple juice, the evaluation and selection of a fructophilic yeast strain could be significant to the apple fermented alcoholic fruit juice industry [135]
	Banana (*Musa sapientum* L),	Due to its high sugar content, banana is suitable for the production of fermented banana juice called banana wine, an alcoholic drink [136]
	Clementines (*Citrus reticula Blanco*)	Clementine fermented alcoholic fruit juice [137]
	Elderberry (*Sambucus nigra* L.)	Elderberry fermented fruit has a moderate ethanol concentration, intense red coloration, and higher pH value compared to most red wines
	Jabuticaba (*Myrciaria jaboticaba*)	The taste of the jabuticaba pulp was described as subacid to sweet, similar to grapes [138]. Fermentation of jabuticaba pulp produces an alcoholic fruit juice
	Kiwi (*Actinidia deliciosa* and *Actinidia chinensis*)	Fermented alcoholic juice from kiwifruit (Chinese gooseberry, Actinidia chinensis Planch) [139]
	Lychee (*Litchi chinensis* Sonn)	Lychee fermented juice (Chinese: lychee wine, lìzhījiǔ), is a full-bodied Chinese dessert wine (alcoholic fruit juice) made of 100% lychee fruit [140]
	Pineapple (*Ananas comosus*)	Pineapples contain a good sugar proportion which makes them suitable for fermentation [141], giving a pleasant alcoholic juice
	Raspberry (*Rubus idaeus* L.)	Fermented juices from raspberries present specific acid and sugar contents (pH 3.6 and 14.5 °Brix) that make them suitable for fruit wine production [142,143], an alcoholic fruit juice

The microorganism used to ferment the fruit juices and produce the fermented fruit beverages is usually a strain of *S. cerevisiae* species [129] or *S. cerevisiae* var. bayanus. The latter was used by Mena et al. [144] to produce a pomegranate juice fermented beverage.

Non-*Saccharomyces* yeasts, such as *Hanseniaspora uvarum*, *Hanseniaspora opuntiae*, *Hanseniaspora occidentalis*, *Pichia kudriavzevii*, and *Torulaspora delbrueckii* have been selected as candidates for an orange juice fermented beverage with higher volatile compounds concentration, odor active values, and sensory evaluation scores [145]. More recently, *Kluyveromyces marxianus*, *Zygosaccharomyces rouxii*, and *Pichia kluyveri*, studied by Gschaedler et al. [146] showed an increase in ethanol production in cider, when nutrients were added, obtaining more than 80 g/L of ethanol and showing that these yeasts have potential in the fermentation of apple juice. The use of non-*Saccharomyces* yeasts in co-inoculation (*Torulaspora delbrueckii*, *Lachancea thermotolerans*, and *Saccharomyces cerevisiae*) on apple mash fermentation was also studied for the production of Pálinka, a Hungarian fruit spirit [147]. According to the results obtained by Fejzullahu et al. [148], single and mixed cultures showed similar characteristics during mash fermentation and mixed cultures revealed a significantly higher concentration of volatile compounds and pleasant sensory attributes, compared to those exhibited by the pure culture of *S. cerevisiae*.

The presence of *Saccharomyces* and non-*Saccharomyces* yeast in fermented fruit juices also makes these drinks potential vehicles for probiotic microorganisms. *S. boulardii*, demonstrated above as able to ferment pomegranate juices [144], has the potential to inhibit pathogen growth [149]. *S. boulardii* can also degrade pathogen toxins, modulate intestinal microbiota, preserve normal intestinal physiology, and increase secretory IgA (sIgA) levels [150].

3.1.2. Lactic Acid Fermentation

Lactic acid fermentation (LAB) has been one of the oldest techniques to extend the shelf life of perishable foods [13] and is a valuable substitute for the bio-preservation of fruits and fruit juices. Single-fruit, blended smoothies, or fruit juices that can be fermented by LAB are healthy alternatives to promote fruit consumption [151,152]. Moreover, the scientific interest in the strategy of lactic acid fermented juices and the study of their probiotic properties have increased in the last years [150].

Lactic acid fermented foods and drinks have been produced for thousands of years due to their healthy features, and are well accepted by consumers [130]. Lactic acid fermentation leads to the synthesis of organic acids, carbon dioxide, ethanol, diacetyl, hydrogen peroxide, fatty acids, phenyl-lactic acid, and bacteriocins, all with antagonistic proprieties [153,154].

The fermented drinks may be obtained by "spontaneous" fermentation, by autochthonous lactic acid bacteria present in the raw material. The most usual strains are *Enterococcus* spp., *Fructobacillus* spp., *Lactobacillus* spp., *Leuconostoc* spp., *Pediococcus* spp., and *Weissella* spp. under anaerobic conditions [150], and moderate temperature (25–35 °C). Controlled fermentation using *Lactiplantibacillus plantarum*, *Lacticaseibacillus rhamnosus*, *Lactobacillus gasseri*, and *Lactobacillus acidophilus*, are safer, easier to replicate, more reliable, and provide standardization and constant quality of the final products [130,152,154]. Among the desirable technological traits, lactic acid bacteria starter cultures for fruit-based drinks should grow rapidly, ferment diverse carbohydrate substrates, acidify the juice, even at low pH values and temperature, and should also tolerate and/or metabolize phenolic compounds [130]. Additionally, LAB enhances nutrient bioavailability and guarantees complete fermentation. Most of the starter cultures can synthesize antimicrobial compounds foodborne pathogens and spoilage microorganisms [130]. Regarding sensory attributes, LAB is expected to synthesize aroma and flavor compounds, or their precursors, such as acetic acid, esters, ketones, alcohols, and terpenes, producing fermented juices with pleasant flavors and without off-flavors. Also, LAB may increase the antioxidant activity of the matrix, and be able to produce or release bioactive compounds such as peptides, vitamins, amino acids, and phenolics [8,152,154,155].

Some examples of fruit juices fermented with LAB are red dragon fruit (*Hylocereus polyrhizus*) beverages where a total of 21 isolates of LAB were isolated and characterized. They belonged to the genus of *Enterococcus*, namely: *Enterococcus faecalis* or *Enterococcus durans* [156]; fermented noni (*Morinda citrifolia* L.) fruit juice, is considered one of the health-promoting beverages, fermented by *Lactobacillus plantarum* SK15 [157]; and blueberry juices fermented by lactic acid bacteria isolated from fruit environment. *Lactobacillus plantarum* LSJ-TY-HYB-T9 and LSJ-TY-HYB-T7, and *Lactobacillus fermentum* LSJ-TY-HYB-C22 and LSJ-TY-HYB-L16 were possible candidates to produce fermented fruit juices, including blueberry juice [158]. Functional lactic acid bacteria can thus be used to produce fruit juices with reduced sugar levels, which is expected to be beneficial for human health [159].

3.1.3. Acetic Acid Fermentation

Acetic Acid Bacteria (AAB) are mostly known for their use in the production of vinegar, vitamin C, and cellulose [160]. AAB is responsible for the production of vinegar, including fruit vinegar. The production of fruit vinegar is a way of making use of fruit by-products, frequently employed by the food industry since extra or second quality fruit can be used without compromising the quality of the final product [161]. For producing vinegar, a

two-stage fermentation process is needed. The first stage is the conversion of sugars into ethanol by yeasts. Usually, this biological process is done by *Saccharomyces* species. The second stage is the oxidation of ethanol by acetic acid bacteria (*Acetobacter* and *Gluconobacter* species). Nevertheless, the focus of this review is the fruit juices and not the vinegar, a culinary condiment. According to the literature, in juices or juice-like products, acetic acid fermentation is only found in kombucha.

Kombucha is a fermented beverage that sensorially resembles carbonated cider, presenting a sweet, and slightly sour flavor [162]. It is obtained from sweetened black or green tea, via a symbiotic relationship named SCOBY (symbiotic culture of bacteria and yeast, a consortium of acetic acid bacteria, lactic acid bacteria, and osmophilic yeasts) [163]. The SCOBY association, also known as "tea fungus", in the form of a cellulosic biofilm, transforms the sugar and tea components into bioactive compounds with probiotic effects. The main bacteria in "tea fungus" are AAB, mainly species from the genera *Acetobacter* (*Acetobacter aceti*, *Acetobacter pasteurianus*, *Acetobacter nitrogenifigens*), *Gluconacetobacter* (*Gluconacetobacter* sp A4, *Gluconacetobacter sacchari*, *Gluconacetobacter oxydans*), and *Komagataeibacter* (*Komagataeibacter xylinus*, *Komagataeibacter kombuchae*) [164]. AAB is part of the relatively stable bacterial community in kombucha and is responsible for the oxidation of ethanol which leads to the production of acetic acid. Other secondary metabolites such as gluconic acid (from glucose), glucuronic acid (from glucose; detoxifying properties), and D-saccharic acid-1,4-lactone (from glucose; radical-scavenging; some *Gluconacetobacter* species) are also produced [164]. The main yeasts found in kombucha are *Saccharomyces* sp., *Zygosaccharomyces kombuchaensis*, *Torulopsis* sp., *Pichia* spp., *Brettanomyces* sp. [165], and *Zygosaccharomyces bailii* [166]. Several lactic acid bacteria have also been isolated [165]. After fermentation, the kombucha chemicals include the following: sugars; tea polyphenols; organic acids; fiber; ethanol; amino acids; essential elements (Cu, Fe, Mn, Ni, and Zn); several vitamins such as vitamin C, and B vitamins; carbon dioxide; antibiotic substances; and hydrolytic enzymes [167,168].

Recently, alternative raw materials have been suggested for the production of kombucha, for example, fruit or vegetable juices and cocktails, plant infusions, or milk [162]. For fruit-based drinks, there is reference to Salak kombucha in the literature. Salak or "snake fruit" is a fruit growing in a palm from the *Arecaceae* family in Indonesia. Salak kombucha is obtained following 14 days of "tea fungus" fermentation of the salak juice [169]. The same procedure can be applied to other fruits, producing delicious colorful drinks.

4. Sensory Characteristics and Consumer Acceptance of Fruit Juice and Fermented Fruit Beverages

The parameters that define the quality of a drink are positive attributes such as the following: color and overall appearance; taste properties, including flavor, mouth persistence, and aftertaste; olfactory properties, such as aroma, odor, orthonasal and retronasal; and tactile properties, such as mouth feel, body, and absence of contaminants (odors and strange flavors). Among the negative attributes are discoloration, foaming, sedimentation, gas, unpleasant smell (particularly of ketone or vinegar), bitterness, and astringency.

The fruit juice thermal treatments lead to substantial modifications of the final product qualities. Although microbial and chemical safety is prevalent during fruit juice processing, the sensory attributes are also important. The attributes such as color or tactile properties are very important for both the first acceptance and regular purchasing of the products. Therefore, the sensory quality of fruit juices plays an important role in consumer satisfaction. Thermal treatments are the most commonly used in fruit juice processing, but they tend to induce negative changes to the nutritional and sensory characteristics of the juices [170]. The pasteurized samples were significantly less desirable in terms of odor, color, cloudiness, acidity, overall flavor, and overall likeness. Therefore, emerging non-thermal processes are applied to maintain the quality, however, to reduce the color degradation and browning in fruit juice, the optimization of the processing parameters is necessary. For example, HP

treatment is a non-thermal treatment that has been described to inactivate microorganisms through membrane disruption and it preserves nutritional value with a reduced effect on fruit juices quality and sensory characteristics as lower molecular weight compounds, such as volatile compounds, pigments, and some vitamins are not changed, since covalent bonds are not affected by pressure [171]. Also, Aguilar-Rosas et al. [77] showed that PEF processing (4 μs, 35 kV/cm, and 1200 pps) maintained the volatile compounds responsible for apple juice flavor and color more than heat treatment, with 7% and 8.4% reduction of hexanal and hexyl acetate, respectively, unlike heat treatment which eliminated these compounds. Sensory analysis showed that the taste and flavor of fruit juices processed by PEF were preferred to thermally processed juices. The researchers Khandpur and Gogate [172] evaluated the quality of ultrasound orange juice concerning taste, smell, and mouth sensation and found that the ultrasound-treated juice was the most acceptable for consumers and was identical to the fresh unprocessed fruit juices. The positive effect of the ultrasound treatment is attributed to the removal of oxygen. After non-thermal treatments, juices showed the lowest variation in hedonic scores, if compared to the untreated juice [173].

Fermented fruit juices may have high acidity, making them unpleasant for consumers. Muhialdin et al. [174] added another approach that was followed by dragon fruit juices. Freeze-dried fruit juice (FDFJ) was added to fresh juice at different ratios, to reduce the acidity. A total of five samples at the mixture ratios 1:9, 2:8, 3:7, 4:6, and 0:10, were tasted by 65 random consumers (37 males and 18 females). The results showed a high preference among the random consumers for the sample containing FDFJ and fresh juice at a ratio of 1:9. However, the mixing ratio of 1:9 did not show a significant difference from the fresh juice.

The suitability of a mixture of juices from jicama, winter melon, and carrot as a raw medium to produce probiotic juice by strains of *Lactobacillus plantarum* and *Lactobacillus acidophilus*, was studied by Do and Fan [175]. Besides other parameters, their sensory acceptability was also investigated. Three versions of the fermented vegetable juice mixtures were served to judges. The judges indicated that they liked the color and texture of juices in all formulations and acceptance of the probiotic vegetable juice mixtures was in the range of five to eight on a nine-point hedonic scale. Moreover, the sensory quality was improved positively by sucrose addition or adding tropical fruit juices or multi-fruit juice (10% *v/v*).

The applicability of different LAB. strains (*Lactobacillus plantarum* (WJ-LP), *L. rhamnosus* (WJ-LR), *L. casei* (WJ-LC), *L. brevis* (WJ-LB), and *Pediococcus pentosaceus* (WJ-PP)) was evaluated recently in watermelon juice [176]. The sensory quality of fermented juices was evaluated by tasters that rated the overall liking using a nine-point hedonic scale This scale was also used to evaluate other sensory attributes such as appearance, aroma, sweetness, flavor, consistency, acidity, and color. Then, using the check-all-that-apply (CATA) test tasters checked all applicable sensory terms that described the sample from a list provided. At the end of the work, it was found that the lab strains significantly imprinted flavor characteristics which cause tasters to prefer *L. brevis* and *P. pentosaceus* fermented juices. These juices were the least penalized, had a higher purchasing power, and were associated with 'watermelon flavor', 'natural taste', 'sweet', and 'watermelon color' terms.

Due to their nutritional benefits, fermented beverages have become an influential player in the beverage industry. Kasron et al. [177] identified consumer acceptance and willingness to pay for fermented drinks in Malaysia. The field survey conducted showed that 54% of respondents knew about functional foods and 55% of these were aware of functional foods based on fruits. The survey also found that 30% of respondents had taken fermented drinks before. However, health issues are not the only reason why people consume fruit juices and their derivatives. Skąpska et al. [178], when studying "the development and consumer acceptance of functional fruit-herbal beverages", found that the main motivation for purchasing was their sensory acceptance, even if the consumers were informed of their potential health benefits. In their study, Skąpska et al. [178] also established that Aronia beverages were the most accepted and could find buyers when

introduced to the market. The other beverages (made with rugosa rose, acerola, sea buckthorn, or cranberry) were poorly or not accepted by the majority of the tasters, despite information on the pro-health effects of the products. The beverages were rated slightly higher by women than men and by people aged 25–34. Fermented beverages using selected lactic acid bacteria in the fermentation of various fruit juices, resulted in some cases in fruit beverages with enhanced nutritional and sensorial characteristics.

In addition, consumer paired preference tests were performed by Cordelle et al. [179] to establish the influence of gender and age on preferences for orange juice, and additionally to determine the reproducibility of consumer-liking patterns over repeated evaluation with 917 consumers. The outcomes of this research showed that neither gender nor age significantly affects consumer preferences for orange juice.

5. Final Remarks

Several studies have shown that fruit juices and fermented fruit beverages are commercially promising products. With great demand and acceptance by consumers, they are used not only as healthy drinks but also as therapeutic products, given their nutraceutical properties.

Moreover, due to the perishable nature of fruits, new technologies for conservation and processing are a demand in the food industry. Processing the fruits to obtain juices, nectars, or even fermented beverages is a valuable way to transform unpreserved products into storable products, adding economic value, avoiding waste, and minimizing losses that may occur during the marketing of the fresh products.

With consumer demand for new, healthy, and functional products produced sustainably, and the development of the technologies involved, it is expected that fermented beverages will position themselves in a prominent place in the functional food market. Nevertheless, it is important to consider the consumer sensory acceptability of this kind of juice as most of them, after fermentation, may gain some sensory attributes less pleasant to the consumers, such as excessive acidity. However, the sensory characteristics of fermented juices are highly dependent on the microorganisms used in the fermentation processes along with the selected processing techniques.

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