Effect of Membrane Clarification on the Physicochemical Properties of Fruit Juices: A Review

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ABSTRACT: *Fruit juices are important drinks, which are a rich source of water, vitamins, minerals, and other nutrients. Juice processing can affect its physicochemical properties and, therefore, change its nutrient value. One of the most important processes in juices is their clarification and concentration. Today, membrane processes such as microfiltration, ultrafiltration, nanofiltration, electrodialysis, membrane distillation, and osmotic distillation are used as new methods for concentrating and clarifying juices. The application of membrane processing has a significant effect on the physicochemical properties of juices such as pH, total solids, color, acidity, vitamins and minerals, phenolic compounds, and antioxidant activity. In this review, the effect of several membrane separation methods (microfiltration, ultrafiltration, nanofiltration, electrodialysis) on the physicochemical properties of fruit juices will be evaluated. Some membrane processes increase the pH of the juice and some do not change this parameter. The membrane clarification process reduces the Total Soluble Solid (TSS), turbidity, polyphenols, and antioxidant activity of fruit juices with different values. In addition, this process can completely remove the suspended solids from fruit juices. Most researchers have suggested that membrane clarification enhances the color value of juices. The effect of membrane processes on the number of organic acids and minerals depends on the type of juice, the type of membrane process, and the type of acid and minerals.*

KEYWORDS: *Clarification; Fruit juice; Microfiltration; Physicochemical properties; Ultrafiltration.*

INTRODUCTION

Consumption of fruits and vegetables prevents chronic diseases caused by oxidative stress. Fruit juices are nutritional products derived from fruits and are very popular in many countries [1]. There is ample evidence that fruit juice is part of a balanced diet that greatly reduces the risk of many diseases, including cancers, neurological diseases, and cardiovascular disease [2]. Although fruit juices are different in composition compared to their edible parts, they contain polyphenols, vitamins, and minerals extracted from fruits [3]. Fig. 1 shows the different stages of fruit juice processing.

Today, the high yield of juice extraction is an important goal in the juice industry. In many modern fruit and vegetable production processes, enzymes, especially pectinases, hemicellulases, cellulases, lacases, naranginases, and limoninases, are used as an important material to achieve greater performance and clarification. Pectinase is an enzyme that breaks down the pectic substances present in plant cell walls and reduces their effect on the final properties of the product, including color, turbidity and concentration [4. 5]. *Tasgin et al*. [6] reported that the immobilized pectin lyase is more effective than the free enzyme. On the other hand, some substances such as ascorbic acid, L-cysteine, Ca^{2+}, Cu^{2+}, Mn^{2+}, Mg^{2+}, Zn^{2+}, Hg^{2+}, Fe^{2+} and EDTA have been reported to significantly increase the enzyme activity in the production of fruit juices [7]. After juice extraction, a turbid drink is obtained due to the presence of water-insoluble fibers, colloid macromolecules including pectin, proteins, soluble-starch fractions, certain polyphenols, and their oxidized or condensed derivatives. Depending on the finished product, these substances must be eliminated partially or entirely to avoid further turbidity and precipitation and to improve sensory attributes (taste, smell, and color). Clarification alone can be performed by physicochemical methods, mechanical procedures, and their combinations [8].

Membrane technology is one of the approaches applied in this regard owing to high efficiency, low cost, low temperature, ease of scale-up and simplicity of operation [10]. Juice clarification, stabilization, depectinization and concentrations are the typical steps where membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been successfully utilized [11]. Fruit juices can be clarified by ultrafiltration (UF) and microfiltration (MF) [12, 13]. MF is a physical and pressure-driven filtration process in which a special pore-sized membrane (0.1-10 μm) is used for the separation of microorganisms and suspended particles at a transmembrane pressure of 1-3 bar. In the UF process, membranes with a pore size of 0.001-0.1 μm, molecular weight cut-off range of 1-10 kDa, and transmembrane pressure of 1-10 bar are used [14]. Reverse osmosis is a membrane separation process with a pore size of 0.0001- 0.001 μm in which a hydraulic pressure that is higher than the osmotic pressure of the solution is applied in such a way that permeation of water from high to low solute concentration occurs [15]. Nanofiltration (NF) is a pressure-driven process with a molecular weight cut-off range of 200-1000 Da that is between UF and RO. It is desirable processing for the fruit juice industry due to the improvement of aroma, regulation of sugar concentration, and treatment of wastewater [16].

Given that fruit juices are a rich source of nutrients, consumers expect the processing of this food to have little effect on their nutritional value and physicochemical properties. As a result, the effect of different processes on the physicochemical properties of fruit juices is desirable for its consumers. Because membrane processes are one of the most common processes applied to fruit juices, the effect of this processing on the physicochemical properties of fruit juices is of great value, but no comprehensive study has been conducted in this regard. Table 1 summarizes the changes of the important parameters in the membrane processes. Since various membrane processes with different characteristics are utilized in fruit juice processing, the changes in quality of juices are inevitable, therefore, the aim of this review is to investigate the effects of different membrane processes on physicochemical characteristics of fruit juices. This review is a comprehensive study in which the authors have tried to explain a general and complete view of the field to the reader.

EFFECT OF MEMBRANE PROCESS ON PHYSICOCHEMICAL PROPERTIES

Effect of membrane process on pH

A measure of the hydrogen ion activity is pH, typically in an aqueous solution. It is one of the most important physicochemical properties of fruit juices, which plays a significant role in fruit juice storage. This parameter can change during the membrane processing of fruit juices depending on the type of membrane process.

Fig. 1: Schematic of fruit juice processing [9].

Some membrane processes can increase the pH in fruit juices. For example, electrodialysis of passion fruit juice increased its pH from 2.9 to 4.0 [18]. The pH of cranberry juice also slowly raised from 2.51 to 2.66 by electrodialysis with bipolar membranes [19] and cellulose acetate membrane increased the pH of *Citrus limon* L. juice from 2.5 to 2.7 [20].

Some membrane processes do not have a significant effect on the pH of the juice. Selected fruit juices (peach, pear, apple and mandarin) were treated using ultrafiltration with a tubular sulphone membrane and reverse osmosis with tubular composite polyamide film. Evaluation of physicochemical properties of juices showed that the value of pH in peach, pear, apple and mandarin were 3.77, 3.71,

Table 1: The values of important structural characteristics of a membrane system [9, 17]

Process parameter	Variations
Types of Membrane	Asymmetric, Nonporous Dense, Electrically Charged, Isotropic Microporous, Ceramic, Metal, and Liquid
Diverse Membrane Separation Technologies	● Developed technologies (microfiltration, ultrafiltration reverse osmosis electrodialysis) ● Developing technologies (gas separation pervaporation, osmotic distillation, membrane distillation) ● To-be-developed technologies (facilitated transport)
Types of Module	Hollow fibers, Spiral wound, Plate and frame, Tubular
Preparation technique of membrane (less used)	Plasma polymerization, Reactive surface treatment, Dynamically formed membranes, Molecular sieve membranes, Microporous metal membranes by electrochemical etching
Foulant	General, Inorganic (scaling), Organics, Colloids (< 0.5µm), Biological solid

3.71, 3.80, respectively, and the change in pH during membrane treatment was not significant [9]. Similar results were observed during filtration of apple juice with a nylon nanofibrous membrane [21]. *Castro-Munoz et al.* [22] studied the effect of membrane clarification of Xoconostle juice on its physicochemical properties and observed no significant change in pH (≈ 3.85). Similar results have been reported in clarification of red beet juice with a cellulose ester membrane [12], blood orange juice by ultrafiltration [23] and pomegranate juice with both MF and UF [24, 25].

Effect of membrane process on the Total Soluble Solid (TSS) content

Various compounds are soluble in fruit juices and the most important of these compounds are sugars. The amount of these substances is measured using a parameter called the total Soluble Solid Content (TSS) [26]. TSS shows some important compounds in juices such as polysaccharides, proteins and colloidal materials. Therefore, its change indirectly shows changes in these valuable compounds. On the other hand, these compounds can form gels and accumulate on the membrane surface forming a secondary membrane which can reduce permeate flux [27].

The membrane clarification process reduces the Total Soluble Solid (TSS) of fruit juices with different values. *Mirsaeedghzi* & *Emam-Djomeh* [28] have observed that microfiltration reduced the TSS of bitter orange juice (from 5 Brix in fresh juice to 3 Brix in the clarified juice). Clarification of watermelon juice with MF causes 5% reduction in TSS [13]. A study done by *Castro-Muñoz et al.* [22] resulted in finding that ultrafiltration of Xoconostle fruit (*Opuntia joconostle*) juice rejected 10.17% of TSS, so filtered juice (TSS = 4.50 ˚Brix) conserved at least 89% of the initial TSS content of fresh juice (TSS = 5.01 ˚Brix) [22]. Filtration of enzyme treated Acai fruit juice with a Whatman No. 2 filter causes TSS reduction from 3.09 in fresh juice to 1.03 in filtered juice [27].

Some researchers concluded that the membranes with smaller pore size are more effective in reducing smaller soluble particles. For example, in the filtration of Jamun juice TSS content in permeate was reduced by reduction of membrane pore size [29]. However, *Mirsaeedghazi et al.* [24] achieved different results in clarification of pomegranate juice. They observed that changing the pore size of the membrane did not alter the amount of TSS decrease after juice clarification. In other words, clarification of pomegranate juice with UF and MF had the same effect on TSS content of treated juice, but an extra UF process applied to MF–treated juice causes a decrease in juice TSS as compared to the MF or UF process, individually [14].

Furthermore, for a membrane with a particular pore size, pressure has a positive effect on the TSS content. It can be concluded that pressure and membrane pore size have significant effects on TSS [29].

Effect of membrane processing on the suspended solids

Some compounds such as pectic substances, starch, cellulose, hemicelluloses, microorganisms, etc., are dispersed in the juices in the form of suspended solids [30]. These cause the appearance of the juices to become cloudy. A part of the juice-processing route is designed to remove this turbidity and make the juices clear. The most important reason for using membrane processes in fruit processing is their clarification. As a result, these processes will have a great impact on the amount of suspended solids that cause juice turbidity. Many studies have been conducted on the effect of membrane processes on the content of suspended solids in juices.

Quist-Jensen et al. clarified orange juice by UF, where his results showed that this process can remove all suspended solids, and produced a clear juice [31]. *Conidi et al.* concluded that UF treatment completely eliminates suspended solids and results in clear juice with clear red color in the clarification of pomegranate juice [32]. Similarly, *Abd-Razak et al.* utilized ultrafiltration (UF) flat sheet membranes that were made from regenerated cellulose, polyethersulphone and fluoropolymer with a Molecular Weight Cut-Off (MWCO) value of 10 kDa in order to isolate phytosterol compounds from orange juice. They observed that this membrane process can completely remove suspended solids from treated juice [33]. This result was matched with the results of *Cassano et al.* in membrane clarification of blood orange juice [34]. Additionally, a modified polyether ketone and polysulfone hollow fiber membrane was used to clarify pomegranate juice by *Cassano et al.* and their results reveled that suspended solids were totally removed [35]. These results are consistent with a study by *Mirsaeedghazi et al.* who reported that suspended solids in pomegranate juice were zero after membrane clarification [24].

Effect of membrane processing on the juice turbidity

As mentioned before, one of the main reasons for using membrane processing in the fruit juice industry is to reduce its turbidity [23]. The amount of turbidity reduction can be defined as a useful parameter to show the rate of clarification in fruit juices. Generally, there is a strong relationship between total soluble solids and turbidity. Turbidity is due to the presence of fibers, suspended solids, and high molecular weight compounds such as carbohydrate, minerals and organic acids in the juice [36]. As mentioned earlier, clarification has a strong effect on decreasing TSS. As suspended and soluble pectin and other suspended solids in fruit juice are removed by the clarification process, subsequently, TSS decreases. After the removal of suspended compounds and their accumulation in the retentate, the level of transparency of permeate increases [23]. Therefore, all researchers reported that membrane processing reduces fruit juice turbidity so it will be clarified. In some studies, the reduction in fruit juice turbidity after membrane clarification was very low. For example, according to *Castro-Munoz et al.* after clarification of Xoconostle fruit juice with UF (molecular weight cut-off of 100 kDa) 87.50% of turbidity was retained in clarified juice. High retention of turbidity in final product determines that a clarified Xoconostle juice is rich in its nutritional components but its turbidity is commercially high [22]. In contrast, some research has shown that fruit juice turbidity after membrane clarification is greatly reduced. For example, *Mirsaeedghazi et al.* study resulted in showing that the turbidity of pomegranate juice reduced more than 99% after its clarification with MF [24]. Amirasgari and Mirsaeedghazi have observed more than 90% reduction in the turbidity of red beet juice after clarification with MF, when the large particles were removed [12]. The use of magnetic field along with the membrane process in the clarification of pomegranate juice reduced the turbidity drop to about 72% [37].

Membrane pore size and transmembrane pressure are the two main factors affecting the rate of turbidity reduction. Jamun juice was clarified with microfiltration at different membrane pore sizes (0.1, 0.2 and 0.45 μm) and different transmembrane pressures (68.9, 103.3 and 137.8 kPa). The most reduction of turbidity was obtained when the membrane pore size was 0.1 μm. A membrane acts as a dynamic surface, which rejects particles based on their size. As reported, clarity of the filtered juice depends on the process pressure. Increasing process pressure increased the rate of decrease in turbidity in clear fruit juice. Maximum clarity of Jamun juice was observed at the transmembrane pressure of 137.89 kPa and the membrane pore diameter of 0.1 μm [29]. *Nourbakhsh et al*. [10] found contrary results in the membrane clarification of red plum juice. They mentioned that greater force applied on the juice results in more macromolecules being transferred from the membrane and, thus, to greater turbidity. They observed that as transmembrane pressure increases from the 0.5 to 2.9 bar the turbidity of red plum juice increased from 3650 to 4050 NTU. The Jamun juice has a fibrous texture that contains colloidal and suspended solids (proteins and polyphenols) that are rejected by the membrane and form cakes on the membrane surface; indeed, permeate turbidity decreases as a result of increase in membrane particle rejection; however, red plum juice has neither fibrous texture nor colloid particles [10, 29]. In membrane clarification of pomegranate juice by microfiltration and ultrafiltration, the effects of pore size and pressure on the rate of reduction of juicy turbidity were counteracted. That way, although membrane pore size in MF and UF are different (0.1–10 µm in MF and 0.01–0.1 µm in UF; [38], they had the same effect on turbidity of pomegranate juice after membrane clarification due to higher pressure of UF related to MF [24]. Sugar beet juice, on the other hand, showed a different behavior during membrane clarification as the results obtained by *Hakimzadeh et al.* showed that UF of microfiltered sugar beet juice could reduce its turbidity more than that obtained by MF alone. As a result, it can be expressed that in pomegranate juice, the particles remaining in the micro-clarified juice have a size distribution smaller than UF pore size that can easily pass through the membrane, and MF and UF had similar filtration efficiency [39].

Effect of membrane processing on juice color

Juice color is one of the most important qualitative parameters indicating characteristics such as fruit ripening, nutritional value, and quality of the juice, which affects consumer acceptance. If the consumer finds the desired color in the product offered, there will be more willingness to use it. In recent years, in order to improve consumer health, using natural color has become more common and since juices are a popular food among consumers, improving their color naturally is of particular importance [40]. Usually this qualitative parameter is measured with three indices a*, b* and L* indicating reddish color, yellowish color, and luminosity of the fruit juice, respectively. These parameters are measured using the Hunter lab or image processing after spectroscopy by a spectrophotometer.

Most researchers have suggested that membrane clarification enhances the color value of juices. According to Amirasgari and Mirsaeedghazi color parameters of red beet juice incresed after its membrane clarification. Increasing the L* value (from 3.3365 for fresh juice to 6.955 for clarified) indicates that luminosity of the juice increases after membrane clarification. Fresh juice had a* value of about 11.6 while it increased to 32.46 in the filtered juice. This means that microfiltration can increase the reddish color of this juice and reduce its green tint. Increasing the value of b* (from 2.33 to 9.50) determines that the yellowish color of red beet juice can increase after the clarification process; however, its bluish color decreases after this treatment [12]. *Toker et al.* [23] treated blood orange juice with ultrafiltration and showed that both color and clarity of the juice was increased due to the removal of suspended solids. In other words, the values of a*, b* and L* in ultrafiltrated juice have increased compared to those centrifuged. The authors also concluded that by reducing the size of the membrane pores, the color value increased and the maximum value of color was obtained for the juice clarified with the 30 kDa membrane. *Ghosh et al.* [29] obtained similar results after clarification of Jamun juice with ultrafiltration. They stated that the membrane pore size and the pressure have a significant effect on the chroma value, so that as the pressure of the clarification process increases, the lightness of Jamun juice increases. *Cesar et al.* obtained a different result on the effect of membrane clarification on the red color. They concluded that the lightness (L*) of Acai fruit juice increased after membrane clarification; however, red color pigments decreased due to the reduction of anthocyanins during juice clarification. The b* value shows a significant increase due to the reaction between polyphenolic compounds and furfurals or other aldehydes (as a product of the degradation of carbohydrate or ascorbic acid) that leads to the formation of brown pigments [27].

Li et al. evaluated the effect of clarification using ultrafiltration with the MWCO of 100 and 18 kDa on the color properties of mulberry juice. They concluded that using an ultrafiltration membrane with 100 kDa MWCO would lead to a 38% increase in redness with a slight change in luminosity. However, redness decreased by 75% with an 18 kDa membrane and luminosity increased by 57%. The increased redness of the juice was attributed to an increase in the amount of anthocyanins as a result of clarification by the 100 kDa membrane [41].

In a study carried out by *Castro-Munoz et al.* Xoconostle fruit (*Opuntia joconostle*) juice was clarified using a hollow fiber membrane 100 kDa. The results showed that the value of *b** decreased while an increase in *a** values was observed after membrane clarification. Moreover, h° decreased indicating an increase in redness induced by clarification [22]. Simultaneously, the brightness increased and the luminosity did not significantly change in Xoconostle juice and that was consistent with the results obtained by [41, 42].

In another study, chokeberry juice was clarified using microfiltration by ceramic membranes with different pore sizes (0, 0.2, 0.8, 1.4, 5 μm). It was expressed that L* increased after the microfiltration process which was attributed to the removal of dark color compounds such as anthocyanins in the juice. There was no significant difference in the effect of membrane size on L* value. However, the smaller the size of the membrane pores, the greater the value of a* and the lower the value of b*. It was indicative of greater removal extent of the compounds with yellow color than the red color compounds [43].

Ilame and Singh clarified Kinnow fruit juice with an ultrafiltration hollow fiber membrane with 10, 30 and 44 kDa MWCO. The results indicated that the value of L^* increased while the red pigments decreased because of reduction of β-carotene along with the pulp. The value of *b** in the treated juice showed a reduction due to the removal of yellow pigments such as α-carotene, β-carotene, zeta-antheraxanthin and β-cryptoxanthin [44].

Effect of membrane processing on the content of organic acids

Organic acids are the second most soluble solids in fruit juices. These compounds make up about 1% of the total weight of the juices. Citric and malic acids are the main organic acids found in fruit juices, but other acids such as ascorbic, isocitric, citramalic, galacturonic, shikimic, lactic, quinic, succinic, and fumaric acids are present in smaller amounts in various fruit juices [45]. The most important parameter affecting the passage of organic acids through membranes is their molecular weight. Table 2 shows the formula and molecular weight of the main organic acids in fruit juices.

Several studies have been conducted on the effect of fruit juice processing, including membrane processing, on organic acids. Organic acid content of untreated and ultra-filtrated *Citrus limon L. Burm cv Femminello comune* juice was evaluated by *Loizzo et al*. [20]. They recognized that the treated sample had significantly lower citric acid content than the untreated sample; however, the citric acid content was not significantly affected by transmembrane pressure (0.5–1.5 bar) [20]. In another work, Bagci investigated preclarification and ultrafiltration (UF) to obtain high quality pomegranate juice. A number of acids were detected using HPLC in fresh pomegranate juice; namely, citric acid, malic acid, quinic acid, and oxalic acid.

Table 2: The formula and molecular weight of the main organic acids in fruit juices.

Organic acid name	Formula	Monoisotopic molecular weight (Da)
Quinic acid	$C_7H_{12}O_6$	192
Tartaric acid	$C_4H_6O_6$	150
Ascorbic acid	$C_6H_8O_6$	176
Malic acid	$C_4H_6O_5$	134
Isocitric acid	$C_6H_8O_7$	192
Lactic acid	$C_3H_6O_3$	90
Malonic acid	$C_3H_4O_4$	104
Succinic acid	$C_4H_6O_4$	118
Citric acid	$C_6H_8O_7$	192
Fumaric acid	$C_4H_4O_4$	116
Glutaric acid	$C_5H_8O_4$	132
Maleic acid	$C_4H_4O_4$	116
Shikimic acid	$C_7H_{10}O_5$	174

The results showed that the pre-clarification and ultrafiltration had no effect on the content of organic acids, and it seems that the low molecular weight of organic acids makes it easier for them to cross the UF membrane [25]. Furthermore, *Veleirinho et al*. examined the effect of conventional clarification using filtering aids, ultrafiltration and nanofibrous polyethylene terephthalate membranes on the content of organic acids of apple juice. They concluded that the content of malic and oxalic acids was not significantly affected by clarification [46]. *Fuenmayor et al*. indicated that filtration of apple juice by nylon nanofibrous and commercial polyamide membranes reduced the content of malic acid. They also found that very small amounts of malic acid may be absorbed into the nylon nanofibrous and commercial polyamide membranes [21]. The effect of microfiltration of pomegranate juice on the content of organic acids was studied by *Colantuono et al.* and their results showed that microfiltration resulted in a decrease of 8.8%, 31.2%, 20.6% and 37.6%, in citric acid, malic acid, tartaric acid and quinic acid, respectively ($P \leq 0.05$) [47]. Similarly, *Mirsaeedghazi et al*. and *Cassano et al*. reported that microfiltration led to a decrease in organic acids compared to fresh juice [24, 48]. *Loizzo et al*. [20] used a 100 kDa cellulose acetate membrane to investigate

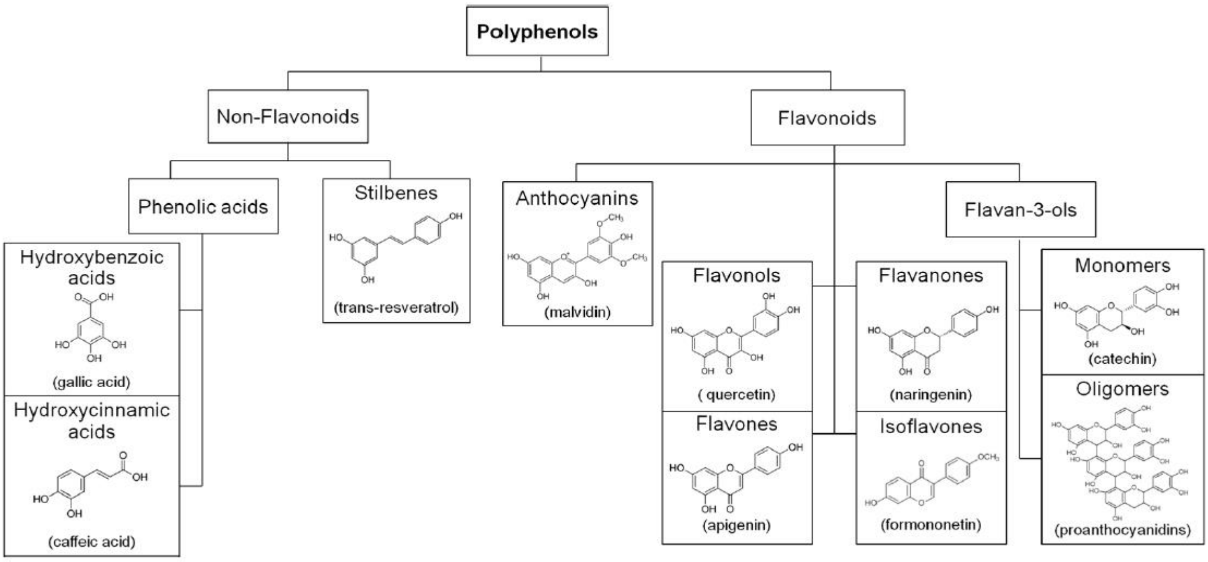

Fig. 2: The structures of important polyphenols in fruit juices [49].

the effect of ultrafiltration (UF) of *Citrus limon L. Burm. cv Femminello comune* juice at various transmembrane pressures (05–1.5 bar) on the content of ascorbic acid. They found that the content of ascorbic acid in untreated juice was 30.8±2.7 mg/100 ml, which did not significantly change in treated juice (27.7±3.1 to 29.4±3.0 mg/100 ml at 0.5 to 1.5 bar, respectively). *Chhaya et al.* [13] studied the effect of microfiltration of watermelon juice on the content of ascorbic acid at different pressures (136.5, 204.7 and 276 kPa) and different stirring speeds (1200, 1400 and 1600 rpm). They observed that the content of ascorbic acid was similar in treated and untreated juices. Moreover, they found that the content of ascorbic acid was not significantly affected by transmembrane pressure and stirring speed. Mirsaeedghazi and Emam-Djomeh demonstrated that microfiltration of bitter orange juice reduces the content of ascorbic acid due to the sensitivity of ascorbic acid to oxidation during the clarification process [28]. *De Oliveira et al.* [11] evaluated the effect of clarification of passion fruit juice with tubular ceramic and hollow fiber polyimide membranes on its nutritional value. They reported that in the tubular membrane, transmembrane pressure helps the permeation of vitamin C, while the permeation of vitamin C is not affected by the transmembrane pressure in the hollow fiber [11].

In general, researches have shown that the rate of change of organic acids during the membrane process of juices depends on several parameters such as the type of acid, the type of juice, the type of membrane process and the type of membrane material used, and the same behavior cannot be observed for all of them.

Effect of membrane processing on the content of phenolic compounds

Polyphenols are important compounds in food that contain several phenolic functional groups in their structure. Polyphenols are divided into two groups, flavonoids and non-flavonoids. Fig. 2 shows some important polyphenols and their structures [49]. The main polyphenol compounds in fruit juices are phenolic acids, flavonoids, anthocyanins and tannin, which have a very important effect on consumer health [50].

Some polyphenols can protect against diseases similar to Alzheimer's and dementia. They prevent neurotoxicity and lead to a neuroprotective effect against neurodegenerative diseases like Parkinson's, Alzheimer's, and Huntington's disease. Phenolic compounds may prevent systemic and/or localized inflammation and decrease cancer risk, specially colon, prostate, epithelial, endometrial, and breast cancers. Polyphenols improve ventricular health, reduce platelet activity, modulate enzymes, and have anti-inflammatory effects, and lower blood pressure, thereby increasing overall vascular health. They can block cholesterol oxidation to reduce LDL and lower risk of cardiovascular disease. Some polyphenols are associated with both the prevention and management of type 2 diabetes and have anti-obesogenic effects leading to improved weight loss and maintenance. In addition, a number of polyphenols have protein-binding properties that can inhibit starch, lipid, and protein digestion in the gastrointestinal tract [51]. Therefore, preserving these compounds is very important in fruit juice processing. Various studies have been conducted on the effect of membrane processes on the polyphenol compounds of fruit juices.

Blood orange juice was concentrated by ultrafiltration with polyethersulfone membranes (30, 50 and 100 kDa). The results showed that ultrafiltration reduced the content of total phenolic compounds and the highest reduction was achieved during clarification by the 30 kDa membrane. It was declared that some polyphenols in blood orange juice are probably associated with other components which were rejected by the membranes with a smaller cut off [23]. *Cassano et al.* [48] found that ultrafiltration of pomegranate juice results in rejection of 16.5% of polyphenols. *Cassano et al.* also used hollow fiber polyether ketone and polysulfone membranes to clarify pomegranate juice. The polyether ketone membrane exhibited higher polyphenols and flavonoids rejections (32.6 and 33.4%, respectively) than polysulfone membranes (25.1 and 24.1%, respectively) [35]. The results were in accordance with the findings of *Mirsaeedghazi et al.* in the clarification of pomegranate juice using mixed cellulose esters (MCE) flat-sheet membranes with pore sizes of 0.1 and 0.025 μm. It has been suggested that high concentrations of macromolecules such as pectin on the membrane surface lead to a gel layer that acts as an additional layer with fine porosity [24]. Therefore, some permeable compounds, such as low molecular weight polyphenols and sugars, may be trapped by this active layer of deposited solutes [52].

Onsekizoglu et al. used ultrafiltration for membrane clarification of apple juice. They confirmed that clarification using ultrafiltration with a 10 kDa MWCO membrane led to a reduction of total polyphenolic content. Using a hollow fiber membrane for clarification of Xoconostle fruit juice resulted in slight reduction of polyphenols [42]. It was pointed out that membranes with high MWCO (100 kDa) could not reject polyphenols, and these compounds are usually recovered in juice [22]. Moreover, possible interactions between membrane and solute results in the adsorption of polyphenols at the membrane surface [53]

Effect of membrane processing on the antioxidant activity

Antioxidant compounds reduce the severity of lipid peroxidation that occurs during food processing and storage, and can reduce the mutagenesis caused by oxidative stress in humans. Free radicals can damage human cells, causing some diseases, such as heart disease and cancer. Natural antioxidants can protect human cells from the effects of free radicals produced. The most important compounds that cause antioxidant properties in fruit juices are phenolic compounds such as phenolic acids, flavonoids, and anthocyanins [54]. The amount of these compounds with antioxidant properties can change during food processing, including membrane processes.

Amirasgari and Mirsaeedghazi [12] clarified the red beet juice using microfiltration and concluded that the antioxidant activity reduced due to a decrease in total phenolic compounds and betacyanins and betaxanthins. *Castro- Muñoz et al.* used 100 kDa hollow fiber membranes for clarification of Xoconostle fruit (*Opuntia joconostle*) juice. They reported preservation of 84% of the initial antioxidant activity and slight decrease in polyphenols and betalains [22]. *Citrus limon* juice was subjected to ultrafiltration using a 100 kDa cellulose acetate membrane at different transmembrane pressures (05–1.5 bar). It was observed that ultrafiltration had no negative effect on the antioxidant activity of juice and the highest level of flavonoid content and antioxidant activity was observed in the 1.5 bar [20]. Similar results were obtained by *Destani et al.* in which hollow fiber polyethersulfone membrane with MWCO of 100 kDa was used for treatment of blood orange juice and the rejection of phenolic compounds was 0.4-6.9% indicating a good antioxidant activity [55].

Effect of the membrane processing on the mineral content of fruit juices

Fruit juices are rich sources of minerals and the most important of these are sodium, calcium, magnesium, potassium and phosphorous. The preservation of these mineral compounds during food processing is very important because of their importance in human nutrition.

The most important membrane process that can affect the minerals in juices is electrodialysis.

Faucher et al. studied the effect of electrodialysis (ED) with bipolar membranes on mineral content of cranberry juice. They found that the content of mineral cations such as calcium, potassium, magnesium and sodium was not affected by ED, while phosphorus and chlorine were reduced after ED treatment. They concluded that the migration of phosphorus and chlorine ions occurs through the anion-exchange membrane because they have negative charge [19]. It has been reported that potassium can migrate through the anion-exchange membrane during ED treatment (180 min) [56]. *Serre et al.* studied the effect of some membrane processes on the minerals of cranberry juice. They found that the concentration of potassium ion decreased significantly during 6 h treatment with bipolar and anion-exchange membranes, however, the concentration of sodium, calcium and magnesium ions remained unaffected. They concluded that the high migration of potassium ion could be attributed to its high electrophoretic mobility as the most abundant ion in cranberry juice. Furthermore, they found that the potassium concentration of cranberry juice significantly decreased after treatment with bipolar and ultrafiltration membranes, while the concentration of sodium ions increased significantly. They also observed a significant decrease in potassium concentration of cranberry juice (from 600 ± 40 to 340 ± 40 ppm) at a rate of 1.5 ppm/min after juice treatment with bipolar and ultrafiltration membranes, while there was a significant increase in the recovery solution from 840 ± 30 to 1650 ± 220 ppm at a rate of 4.5 ppm/ min. An increase in the concentration of sodium ions in cranberry juice and the recovery solution was also observed. Due to the presence of sodium ions in the electrode rinsing solution, these ions pass through bipolar membranes. Concerning the cation exchange and ultrafiltration membranes configuration, the concentration of potassium ion was not affected by this treatment, while the concentration of calcium and sodium ions increased during cranberry juice treatment due to the notable migration of these ions through the cation exchange and the ultrafiltration membranes. They concluded that ultrafiltration (UF) membranes have larger pore than ionic membranes, so all mineral ions (sodium, calcium, magnesium, potassium and phosphorus ions) can easily penetrate UF. In general, it seems that the mineral content of juice is affected by various factors such as membrane type, pore size, membrane charge, juice type, process time, type of mineral and their charge [56].

CONCLUSIONS

The technique of membrane filtration in comparison with traditional filtration techniques in fruit juice processing has some advantages such as reducing energy consumption, easy increase of production, and high product quality. However, utilization of membrane technology for clarification and concentration of fruit juices affects their physicochemical properties. The effect of membrane processes on the pH rate varies. Some processes, such as electrodialysis, increase the pH, but most membrane processes do not have a significant effect on the pH value. Researches have shown that membrane processes reduce TSS in juices. The amount of TSS reduction is sometimes affected by the membrane pore size but in some cases, it is not. Suspended solids were reduced after membrane processing of fruit juices due to the barrier effect of the membrane against large particles. This change is consistent with changes in turbidity in juices, so that membrane processes greatly reduce turbidity in juices and make them clarified. Researches showed that some process parameters affect the rate of turbidity reduction during juice processing. The effect of membrane technology on organic acids, mineral content and the content of phenolic compounds depends on the type of membrane and pore size, type of compound and processing conditions. For example, ultrafiltration reduced citric acid in *citrus limon* juice, but this process could not change citric acid in pomegranate juice. As a general conclusion, it can be noted that most membrane processes will reduce organic acids. Similar results were observed regarding the effect of membrane processes on polyphenolic compounds. The Fig. S1 provides an overview of the effectiveness of membrane clarification on the physicochemical properties of fruit juices.

Therefore, it is suggested that the future of research on the application of membrane processes in fruit juice processing, select the type and parameters of the process that lead to stability of quality value and increase the efficiency of the permeate flux.

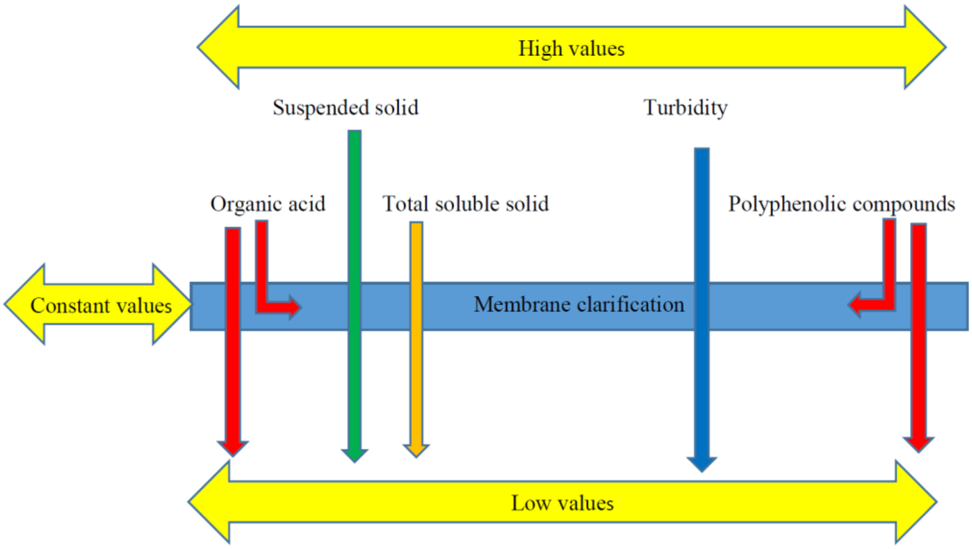

Fig. S1: An overview of the effectiveness of membrane clarification on the physicochemical properties of fruit juices.

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