

# Clarification of pomegranate juice using PSF microfiltration membranes fabricated with nano TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>

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## Abstract

Microfiltration (MF) membranes were fabricated using PSF/PEI (17/2 wt%) with TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles to enhance pomegranate juice clarification performance. The membrane performances were tested using dead-end filtration system. Membranes were characterized by Scanning Electron Microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), porosity, water contact angle, and pure water flux experiments. All MF membranes had higher porosity, pure water flux, and hydrophilicity. SEM images of the membranes proved the nanoparticle incorporation to the PSF/PEI matrix. The quality of clarified pomegranate juice samples using PSF/PEI nanocomposite membranes were better than that of clarified using both commercial and unmodified membranes. The highest performance for the clarification of pomegranate juice samples was obtained for 0.05% of Al<sub>2</sub>O<sub>3</sub> incorporated PSF/PEI membranes with the highest color (5,781 ± 4 PtCo), total soluble solid (16.2 ± 0.0 Brix), total phenolic content (2,642.1 ± 46.4 mg GAE/L), antioxidant activity (ABTS: 62.4 ± 0.2 TEAC/L, DPPH: 41.3 ± 0.0 TEAC/L) and total monomeric anthocyanin (100.7 ± 1.7 mg/L).

## Practical applications

Utilization of membrane technology in food industry has been increased rapidly in the past two decades. Due to their advantage in terms of saving color pigments, MF membranes are more suitable than UF ones for clarification of pomegranate juice. Incorporation of nanoparticles to the membrane matrix is one of the methods to increase the antifouling character and the strength of the membranes modified with hydrophilic polymers. There are some studies investigating the effect of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles on the properties of polymeric membranes. However, there are no reported data on the utilization of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanocomposite membranes for clarifying pomegranate juice. In this study, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> incorporated new generation PSF/PEI membranes were utilized in the clarification process of pomegranate juice for the first time in the literature. The results showed that Al<sub>2</sub>O<sub>3</sub> incorporation seems to be a good alternative for clarifying pomegranate juice with enhanced quality parameters.

## 1 | INTRODUCTION

The interest in red fruits are increasing due to their rich polyphenol content such as anthocyanins, flavonols, flavan-3-ols, benzoic, and hydroxycinnamic acid derivatives, which can provide free radical-scavenging property (Cassano & Drioli, 2014). Because of their inhibition effect of free radicals, red fruits are defined as anti-carcinogenic foods (Kozák et al., 2008). Pomegranate (*Punica granatum*) juice production attains huge interest among the red fruit juices because of its high phenolic and anthocyanin content, which increase its nutritional and health benefits (Cassano, Conidi, & Tasselli, 2015; Davarcı, Kadiroğlu, Dıblan, Selli, & Kelebek, 2019; Zhu, 2019). Phenolic compounds can interact with both protein and phenolic compounds and form small particles causing cloudy appearance, which is an undesirable property for clear beverages (Charlton et al., 2002; Davarcı et al., 2019). Clarification is the essential stage of clear juice production to obtain clear beverages and to prevent sediment formation during storage as well (Davarcı et al., 2019).

Conventional clarification methods applied in fruit juice industry is composed of many steps including enzymatic treatment (pectinization), cooling, flocculation (gelatin, silica sol, bentonite, and diatomaceous earth), decantation, centrifugation, and filtration. These conventional methods are time consuming, since flocculation step requires 6–18 hr to accomplish adequate sedimentation (Vaillant, Millan, Dornier, Decloux, & Reynes, 2001). In addition, there are some other drawbacks of using clarifying agents such as bentonite. Utilization of membrane technology in food industry has been increased in the last two decades and in juice industry, membrane separation process is more efficient than conventional clarification process as the organoleptic and nutritional properties are saved (Ghosh, Rana, Kumar, Pradhan, & Mishra, 2015). Besides, pressure-driven membrane processes allow fruit juice industry to decrease the operating time by eliminating the cooling, flocculation, decantation, and centrifugation steps applied in the conventional process. In addition disposal of the clarifying agents (used in conventional separation processes) leads to environmental pollution (Vaillant, Pérez, Acosta, & Dornier, 2008). Therefore, membrane separation processes are environmentally safe compared to conventional ones (Ahmad & Ahmed, 2014). In other words, membrane processes eliminate negative effects of fining agents in terms of nutritional value of product, process yield, and environmental effects.

Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) are the pressure-driven membrane separation processes used in food industry. In fruit juice industry, mainly microfiltration (MF) and ultrafiltration (UF) are used for the clarification process. The main difference between MF and UF is the pore size of the membranes. The pore size of MF membranes range from 0.1 to 10  $\mu\text{m}$ , whereas UF membranes have pore size of 0.01 to 0.1  $\mu\text{m}$ . This pore size difference affects which particles can get through the membrane and which particles can be rejected by the membrane. There are some studies related to pomegranate juice clarification with MF and UF membranes. In a research conducted by Cassano,

Conidi, & Drioli, 2011), pomegranate juice was clarified using UF membrane. They indicated that, suspended solids were completely removed in the clarification process, whereas soluble solid were passed through the membrane. In addition, UF membranes lead to removal of polyphenols and anthocyanin at the levels of 16.5% and 11.7%, respectively. Mirsaeedghazi, Emam-Djomeh, Mousavi, Aroujalian, and Navidbakhsh (2010) used MF for the clarification process of pomegranate juice using two different polyvinylidene fluoride (PVDF) membranes and indicated that turbidity and total soluble solid content of clarified juices obtained from membranes with pore sizes of 0.22  $\mu\text{m}$  were 3.21 NTU (nephelometric turbidity units) and 15.3°Brix, respectively. On the contrary, the same quality parameters were higher (14.78 NTU and 17.5°Brix) when a membrane with a higher pore size (0.45  $\mu\text{m}$ ) was used, indicating more particles passed through the membrane. Membrane fouling was also higher when the membrane having smaller pore size was used. In another study, Mirsaeedghazi et al. (2012) used both MF and UF membranes for pomegranate juice clarification. MF membranes resulted higher permeate flux, on the contrary, there were no significant differences between the UF and MF process in terms of clarified juice properties (i.e., turbidity, total soluble solid content, phenolic components, anthocyanins, antioxidant activities). However, the fouling was greater when UF membrane was used. Mirsaeedghazi et al. (2012) reported that, UF process does not have any advantage over MF process in terms of the pomegranate product quality, on the contrary, it has disadvantage in terms of fouling. Therefore, MF seems to be more suitable for the clarification of pomegranate juice (Mirsaeedghazi et al., 2012).

Fouling is a major drawback of the membrane processes as it cause a decrease in the flux, and therefore, an increase in energy consumption (Bhattacharjee, Saxena, & Dutta, 2017; Lipnizki, 2010). Increasing the hydrophilicity of the membranes by the modification of the membrane surface is one of the ways to overcome the fouling problem. The membrane surface can be modified using some hydrophilic polymers such as PVP (polyvinyl pyrrolidone), PEG (polyethylene glycol), PVA (polyvinyl alcohol), and PEI (polyethylenimine). The latter one is preferred due to its pore forming ability (Saki & Uzal, 2018); however, the pore forming ability of PEI can decrease the mechanical strength and selectivity of the membranes (Ba, Langer, & Economy, 2009). To overcome this problem, nanoparticles are incorporated to the membrane matrix (Baghbanzadeh, Rana, Lan, & Matsuura, 2016; Garcia-Ivars, Alcaina-Miranda, Iborra-Clar, Mendoza-Roca, & Pastor-Alcañiz, 2014; Madaeni & Ghaemi, 2007; Razmjou et al., 2012; Saleh & Gupta, 2012; Uzal, Ates, Saki, Bulbul, & Chen, 2017; Vatanpour et al., 2012; Wang, Su, Sun, Ma, & Jiang, 2006; Yang, Zhang, Wang, Zheng, & Li, 2007). In a previous study, we have also modified polysulfone (PSF)/PEI UF membranes with  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  nanoparticles and used them in the clarification of apple juice (Severcan, Uzal, & Kahraman, 2020). We demonstrated that, there is a big potential to use  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  incorporated nanocomposite UF membranes for the clarification of apple juice with enhanced performance in terms of both apple juice quality and process performance.

To the best of our knowledge, there has not been any study on the clarification of pomegranate juice using nanoparticle embedded membranes. In this study, we aimed to investigate the effect of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticle incorporation to the performance of PSF/PEI MF membranes during the clarification process of pomegranate juice. The fabricated MF membranes were characterized by Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FT-IR), contact angle, and porosity analysis. Moreover, the clarified pomegranate juice samples were characterized in terms of color, total soluble solid, turbidity, total phenolic content, antioxidant activity, and total monomeric anthocyanin content.

## 2 | MATERIALS AND METHODS

### 2.1 | Pomegranate juice samples

Pomegranate juice samples of both turbid (S1) and clarified (S2) were supplied from Döhler Inc. (Karaman, Turkey). The samples were stored at -18°C until analysis. Turbid pomegranate juice samples (S1) were subjected to clarification process using the membranes fabricated in this study. Clarified pomegranate juice sample (S2) obtained from Döhler Inc. was used for comparison. Turbidity and total soluble solid content of S1 were measured as 785 NTU (nephelometric turbidity units) and 14.0°Brix, respectively. Color, turbidity, and total soluble solid content of S2 were 5,111 Pt-Co, 1.4 NTU, and 14.0°Brix, respectively.

### 2.2 | Membrane fabrication

Nanocomposite PSF/PEI MF membranes were fabricated by using phase inversion method. The membrane matrix of MF membranes were adjusted according to Saki and Uzal's research (Saki & Uzal, 2018). For the fabrication of the MF membranes, 17 wt% PSF (polysulfone, MW 60,000, Acros Organics), 2 wt% PEI (polyethylenimine, MW 25,000, Sigma-Aldrich, USA), and different concentrations of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles (Nanografi, Turkey) (0.01 wt%, 0.03 wt%, 0.05 wt%) were mixed. The compositions of the membrane solutions are shown in Table 1. NMP (1-methyl-2-pyrrolidone,

**TABLE 1** Composition of the nanocomposite MF membranes used for pomegranate juice clarification

Substrate	PSF (wt%)	PEI (wt%)	TiO <sub>2</sub> (wt%)	Al <sub>2</sub> O <sub>3</sub> (wt%)
MF1	17	-	-	-
MF2	17	2	-	-
MFT1	17	2	0.01	-
MFT3	17	2	0.03	-
MFT5	17	2	0.05	-
MFA1	17	2	-	0.01
MFA3	17	2	-	0.03
MFA5	17	2	-	0.05

Merck, Germany) and DMF (N,N-dimethylformamide, Merck, Germany) solutions were added as solvent at a ratio of 70:30, respectively. Solutions were mixed at 400 rpm using a magnetic stirrer for 12 hr until homogenous mixtures are obtained. Then, the solutions were treated in an ultrasonic bath for at least 2 hr to remove the bubbles.

### 2.3 | Membrane characterization

#### 2.3.1 | Scanning electron microscopy (SEM) analysis

Scanning Electron Microscope (Zeis Evo LS10, Germany) was used at 3 kV and 5 kV to analyze the top surface and cross-section morphologies of the membranes, respectively. Membrane pieces were cut in 1 cm<sup>2</sup> for analysis. Before analysis, membrane samples were coated with platinum applying a JEOL JFC 1600 Autofine coater. Measurements were conducted on 50 different positions and average values were given as results. Magnification in a SEM was adjusted at 30,000 and 500 for surface and cross-section analyzes, respectively.

#### 2.3.2 | Porosity analysis

The membrane pieces (4 cm<sup>2</sup>) were immersed in ethanol for 2 hr, and then, were dried in an oven at 50°C overnight to remove the alcohol. The porosity ( $\epsilon$ ) of the membranes was calculated using Equation (1) (Lohokare, Bhole, Taralkar, & Kharul, 2011);

$$\epsilon = \frac{(W_i - W_f) / de}{\left(\frac{W_i - W_f}{dw} + W_f\right) / dp} \quad (1)$$

where,  $W_i$  is the weight of membrane (g) before ethanol immersion,  $W_f$  is weight of membrane (g) after drying,  $de$  and  $dp$  represents densities of ethanol (0.788 g/cm<sup>3</sup>) and polymer (1.24 g/cm<sup>3</sup>), respectively.

#### 2.3.3 | Water contact angle analysis

Attension-Theta-Lite tensiometer (Biolin Scientific, Finland) was used on the sessile drop mode to determine hydrophilicity of the membranes. For this purpose, 4  $\mu$ l of distilled water was dropped on the membrane surface, and contact angles between surface and water droplet were recorded. Measurements were conducted on three different points and results were given as average.

#### 2.3.4 | FT-IR analysis

FT-IR with ATR crystal (Thermo Nicolet Avatar 370, USA) was used to detect functional groups on the membrane surface and to

observe the changes in membrane surface chemically with addition of PEI and TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles. Prior to analysis, membrane samples were dried at 50°C for one night. Measurement was carried out at the interval 400–4000 cm<sup>-1</sup> wavelength. Each spectrum was received after 32 scans.

### 2.3.5 | Dead-end filtration

In MF clarification experiments, dead-end filtration system (Sterlich, HP4750, Washington, USA) with an effective membrane area of 14.6 cm<sup>2</sup> was used. The membrane samples were placed to the bottom of the reservoir that was filled with 250 ml of distilled water. The filtration pressure was maintained by a compressed N<sub>2</sub>. The filtration experiments were carried out at a stirring speed of 250 rpm, 25 ± 3°C. System pressure was set as 1.4 bar. Water permeate was collected in a graduated cylinder (25 ml) at certain interval and flux was calculated by using Equation (2);

$$J_w = \frac{V}{A \times t} \quad (2)$$

where,  $J$  is the water flux (L/m<sup>2</sup>h),  $V$  (L) is the permeate volume (L),  $A$  (m<sup>2</sup>) is the effective membrane area, and  $t$  (h) is the permeation time.

## 2.4 | Characterization of the pomegranate juice samples

### 2.4.1 | Color, turbidity, and total soluble solid content

Color values of the samples were measured spectrophotometrically according to the standard ASTM method No: 1209 (ASTM D1209-05, 2019) by measuring the absorbance at 465 nm (DR 6000, Hach, UK). Turbidity of the samples was determined using a turbidity meter (Thermo Scientific, Eutech TN-100, Singapore) at room temperature and expressed in nephelometric turbidity units (NTU). Total soluble solid content (\*Brix) of the samples were measured using a refractometer (DR-A1, Abbe ATAGO, Japan). All the analyses were repeated three times and the results were given as the average.

### 2.4.2 | Total phenolic content

Folin-Ciocalteu method described by Spanos and Wrolsdal (1990) was used to determine the total phenolic content of pomegranate juice samples. The samples were diluted at 1:10 ratio with distilled water before analysis because of its high phenolic content. According to this method, 900 µl of distilled water was mixed with 100 µl of diluted pomegranate juice samples in a glass tubes (16 × 100 mm) and 5 ml of Folin-Ciocalteu phenol solution (0.2 N, Merck, Germany) was added to the mixture. The tubes were capped immediately and

incubated in dark at room temperature for 8 min. At the end of the incubation, 4 ml of sodium carbonate (Anhydrous, Merck, Germany) solution (75 g/L) was added to the tubes and the capped tubes were incubated in dark at room temperature for 2 hr. After incubation, the absorbance value of the solutions was measured at 765 nm (UV-1800, Shimadzu, Japan). Gallic acid (Merck, Germany) was used as calibration reference standard (100–500 mg gallic acid/L methanol). Total phenolic content of the samples were expressed as mg gallic acid per liter of sample. All the analysis were repeated twice and the results were given as the average.

### 2.4.3 | Total antioxidant capacity

Total antioxidant capacity of the samples was determined by conducting two different methods; ABTS<sup>•</sup> radical-scavenging and DPPH radical-scavenging methods.

#### ABTS<sup>•</sup> radical-scavenging method

ABTS radical-scavenging activity was determined according to method of Re, Pellegrini, Pannala, Yang, and Rice-Evans (1999). Prior to the analysis, ABTS (3-ethylbenzothiazoline-6-sulfonic acid, Sigma-Aldrich, USA) solution (7 mM) and potassium persulfate (Merck, Germany) solution (2.45 mM) were mixed and incubated in dark at room temperature for 12–16 hr to form ABTS<sup>•+</sup> radical cation. The absorbance of ABTS<sup>•+</sup> solution was adjusted to 0.70–0.80 at 732 nm by diluting with 50% of ethanol (Merck, Germany) solution (vol/vol). Pomegranate juice samples were diluted at 1:70 ratio with 50% of EtOH before analysis to adjust the absorbance value between 0.300 and 0.600. Diluted samples (50 µl) were mixed with 3 ml ABTS<sup>•+</sup> solution and the absorbance was measured at 732 nm after 6 min (UV-1800, Shimadzu 1601, Japan). Inhibition percentage was calculated according to the Equation (3):

$$\text{Inhibition (\%)} = [1 - (A_{\text{sample}} - A_{\text{radical solution}})] \times 100 \quad (3)$$

where  $A_{\text{sample}}$  is the absorbance of the sample 6 min after ABTS<sup>•+</sup> solution addition,  $A_{\text{radical solution}}$  is the absorbance of ABTS<sup>•+</sup> solution. Trolox (6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Sigma-Aldrich, USA) was used as calibration reference standard (0.5–2.0 mM/50% of ethanol). The results were expressed as mmol trolox equivalent per liter of sample (mmol TEAC/L). All the analyses were repeated twice and the results were given as the average.

#### DPPH radical-scavenging method

Antioxidant activity of the samples were also analyzed using DPPH radical-scavenging method described by Anton, Gary Fulcher, and Arntfield (2009). According to this method, 200 µl of sample was mixed with 4 ml of DPPH (2,2-Diphenyl-1-picrylhydrazyl, Sigma-Aldrich, USA) solution (0.1 mM in methanol), then, the tubes were capped immediately and incubated in dark at room temperature for 30 min. At the end of the incubation, absorbance values of the samples were measured at 517 nm (UV-1800, Shimadzu, Japan). Trolox

(Sigma-Aldrich, USA) was used as the calibration reference standard (0.1–0.5 mM in 60% of methanol). The results were indicated in mmol Trolox equivalent per liter of sample (mmol TEAC/L). All the analyses were repeated twice and the results were given as the average.

#### 2.4.4 | Total monomeric anthocyanin pigment content

The total monomeric anthocyanin content of the samples was determined by using the pH-differential method (Wang & Xu, 2007). Samples (0.32  $\mu$ l) were mixed with 3.6 ml of two different potassium chloride buffer solutions (0.4 M, pH 4.5 and 0.025 M, pH 1.0). The samples were incubated for 30 min. At the end of the incubation the absorbance values of the samples were recorded at both 510 nm and 700 nm (UV-1800, Shimadzu 1601, Japan). Total monomeric anthocyanin content expressed in cyanidin-3-glucoside was calculated according to Equation (4);

$$\text{Total monomeric anthocyanin} \left( \frac{\text{mg}}{\text{L}} \right) = \frac{A \times \text{MW} \times \text{DF} \times 1000}{\epsilon \times l} \quad (4)$$

where, MW is the molecular weight of cyanidin-3-glucoside (449.2 g/mol), DF is the dilution factor,  $l$  is the length of light path (cm),  $\epsilon$  is the molar extinction coefficient for cyanidin-3-glucoside (26,900  $\text{L mol}^{-1} \text{cm}^{-1}$ ). DF and  $A$  values were calculated from Equations (5) and (6), respectively.

$$\text{DF} = \frac{V_{\text{sample}} + V_{\text{KCL buffer}}}{V_{\text{sample}}} \quad (5)$$

$$A = (A_{1,150} - A_{1,700}) - (A_{2,510} - A_{2,700}) \quad (6)$$

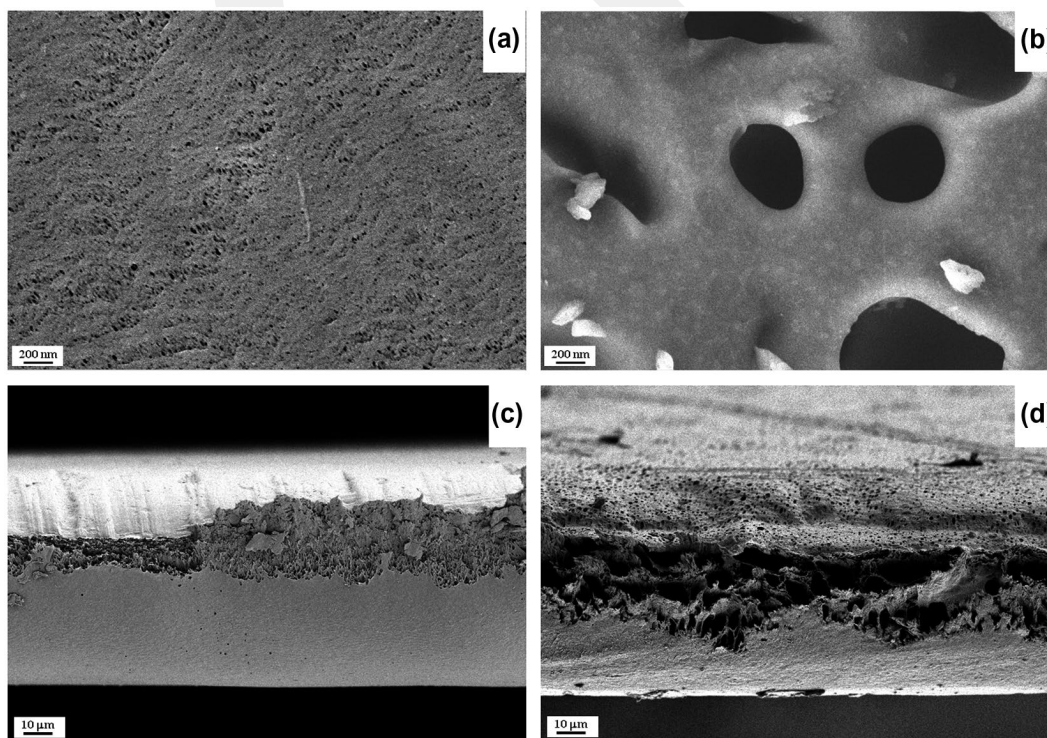
where  $A_{1,510}$  and  $A_{1,700}$  is the absorbance value for first buffer solution (pH 1.0) at 510 nm and 700 nm, respectively. Similarly  $A_{2,510}$  and  $A_{2,700}$  absorbance value for second buffer solution (pH 4.5) at 510 nm and 700 nm, respectively.

## 3 | RESULTS AND DISCUSSION

### 3.1 | Characterization of the membranes

#### 3.1.1 | Morphology

Membrane morphology is an important characteristics to evaluate the filtration performance of the membranes. To examine morphological changes related to the addition of PEI and nanoparticles ( $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$ ) to the PSF membrane matrix, the surface, and cross-section images were obtained by SEM. The surface and cross-section images of the PSF (MF1) and PSF/PEI (MF2) membranes are shown in Figure 1a,b, respectively. Pure PSF membrane (MF1) exhibited asymmetric structure with dense top layer (Figure 1a). This is also mentioned by Ganesh, Isloor, and Ismail (2013). As can be seen from Figure 1b, the membrane surface



**FIGURE 1** SEM images of PSF and PSF/PEI membranes (a) MF1 (17%PSF) (b) MF2 (17%PSF/2%PEI), (c) Cross-section of MF1 (17%PSF), (d) Cross-section of MF2 (17%PSF/2%PEI). Magnifications: 30 KX for (a) and (b); 500 X for (c) and (d)

structure is completely changed by addition of PEI to the membrane matrix and macro pores are observed on the surface of the PSF/PEI MF membrane (MF2). Pores on the surface of PSF/PEI MF membrane are much more intensive than those of pure PSF membrane. Cross section of MF1 had a dense structure (Figure 1c), on the contrary, pores were observed in the PSF/PEI MF membrane indicating the alteration in the membrane structure with the addition of PEI (Figure 1d). Similar observations were also observed in our previous study (Severcan et al., 2020).

Surface and cross-sectional SEM images of the PSF/PEI/TiO<sub>2</sub> (MFTs) membranes are given in Figure 2. As can be seen from the figure, with the addition of TiO<sub>2</sub> nanoparticles, finger-like pores are occurred and elongated between top surface and bottom surface of the MF membranes. Also, pore density of the membranes increased with addition of nanoparticles. PSF/PEI membrane (MF2) has larger pores but lower pore density than nanocomposite membranes (MFTs and MFAs). In addition, the pure PSF membrane (MF1) and PSF/PEI membrane (MF2) exhibited less and smaller inner apertures while PSF/PEI/TiO<sub>2</sub> membranes (MFTs) exhibited more and bigger inner apertures. Similar to our results, Cao, Ma, Shi, and Ren (2006) reported that pure PVDF membrane had less and smaller inner apertures, whereas TiO<sub>2</sub> incorporated PVDF membrane has more and bigger inner apertures. Bae & Tak (2005) and Yang et al. (2007) also investigated that the structure of the PSF membrane became more porous after the addition of TiO<sub>2</sub> nanoparticle.

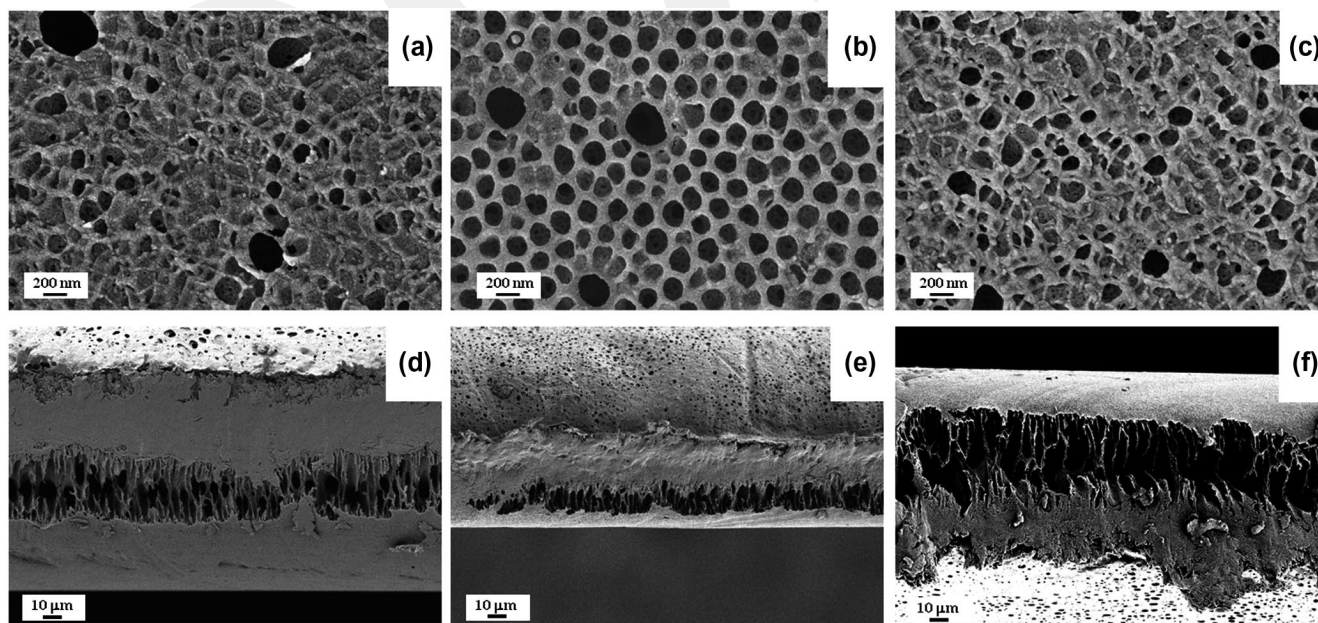
Surface and cross-sectional SEM images of the PSF/PEI/Al<sub>2</sub>O<sub>3</sub> (MFAs) membranes are given in Figure 3. Thin microporous top-layer and finger-like pores in sublayer for all nanocomposite membranes are observed in SEM images. According to some researches, this top layer and cross-section structure are indicated as typical asymmetric porous structure (Wang et al., 2012; Xu et al., 2014;

Zinadini, Zinatizadeh, Rahimi, Vatanpour, & Zangeneh, 2014). The morphologies of membrane surfaces indicated that the surface porosity increased with addition of nanoparticles. Also, the addition of nanoparticles leads to formation of sponge-like cross-section of the membranes. These lateral pores of the membranes provides to enhance the pure water fluxes and permeation (Zinadini et al., 2014). As can be seen from Figure 3d-f when Al<sub>2</sub>O<sub>3</sub> content increased, the width of finger-like structure increased.

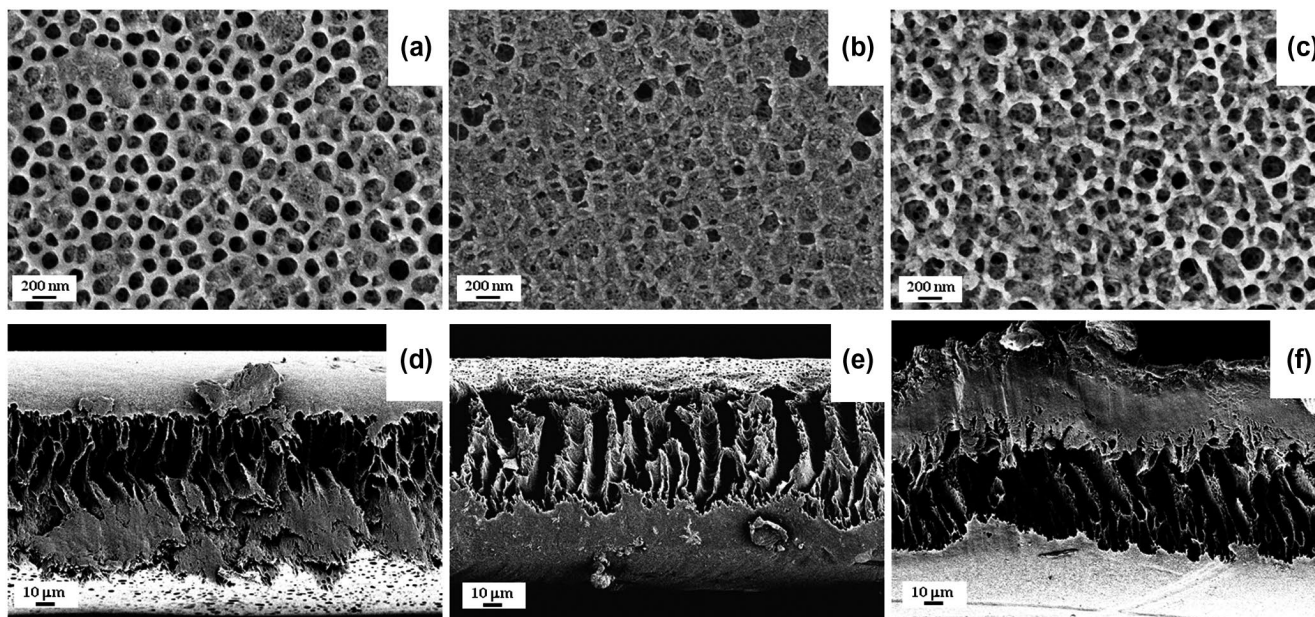
The finger-like porous structure of the nanoparticle embedded MF membranes was much wider than MF1 and MF2. Larger pore channel can be formed because of the rapid mass transformation during phase inversion (Zhao et al., 2013). The macro-void structure was altered by the modified with nanoparticles. This can be resulted from hydrophilic nature of the nanoparticles. During phase inversion, hydrophilic nature of nanoparticles leads to increase porosity as well as changes in macro-voids structure (Ganesh et al., 2013). These findings demonstrate that the addition of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles affect the membrane structure and morphology considerably.

### 3.1.2 | Porosity

Porosity values of the nanocomposite MF membranes are shown in Table 2. The pure PSF membrane (MF1) had the lowest porosity with 69.4% ± 2% because of its dense structure. Similar to our results, Genné, Kuypers, & Leysen, 1996) calculated porosity for pure PSF membrane (18 wt%) as 79%. Porosity of the membranes significantly increased with the addition of PEI and nanoparticles. This was also seen with the SEM images results (Figures 1-3). The porosity values of the TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> incorporated membranes were between 79.7%–83.5% and 77.3%–84.8%, respectively. Among the nanoparticle incorporated



**FIGURE 2** SEM images of PSF/PEI/TiO<sub>2</sub> membranes. (a) MFT1 (b) MFT3 (c) MFT5 (d) Cross-section of MFT1 (e) Cross-section of MFT3 (f) Cross-section of MFT5. T: TiO<sub>2</sub>; 1, 3, 5: 0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios. Magnifications: 30 KX for (a), (b), and (c); 500 X for (c), (d), and (e)



**FIGURE 3** SEM images of PSF/PEI/  $\text{Al}_2\text{O}_3$  membranes. (a) MFA1 (b) MFA3 (c) MFA5 (d) Cross-section of MFA1 (e) Cross-section of MFA3 (f) Cross-section of MFA5. A:  $\text{Al}_2\text{O}_3$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios. Magnifications: 30 KX for (a), (b), and (c); 500 X for (d), (e), and (f)

**TABLE 2** Porosity and contact angle results for pure PSF MF membrane, PSF/PEI MF membrane, and nanocomposite MF membranes

Membrane	Porosity (%)	Contact angle (°)
MF1	69.4 ± 2	94 ± 5
MF2	77.9 ± 3	86 ± 4
MFT1	83.5 ± 3	79 ± 5
MFT3	80.2 ± 3	76 ± 2
MFT5	79.7 ± 4	69 ± 1
MFA1	77.3 ± 3	79 ± 2
MFA3	80.4 ± 3	77 ± 4
MFA5	84.8 ± 4	72 ± 3

Note: MF2: 17%PSF/2%PEI; T:  $\text{TiO}_2$ ; A:  $\text{Al}_2\text{O}_3$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios.

membranes the one prepared with the addition of 0.05% of  $\text{Al}_2\text{O}_3$  nanoparticle (MFA5) had the highest porosity. There are some studies investigating the effect of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  addition on the porosity of the membranes. Ayyaru and Ahn (2018) modified PES membrane by addition of sulfonated  $\text{TiO}_2$  and they observed an increase in the porosity values from 68.4% ± 3% to 87.6% ± 4%. Also, Maximous, Nakhla, Wong, and Wan (2010) produced membrane using  $\text{Al}_2\text{O}_3$  nanoparticles and had higher porosity than unmodified membrane.

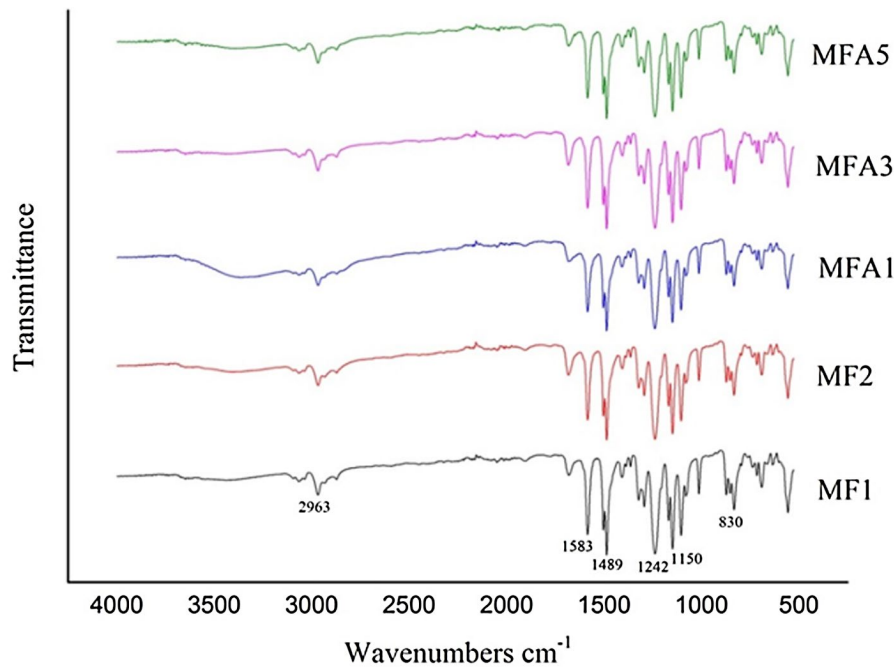
### 3.1.3 | Hydrophilicity

Hydrophilicity of the MF membranes were determined by contact angle measurement and contact angle results are shown in Table 2.

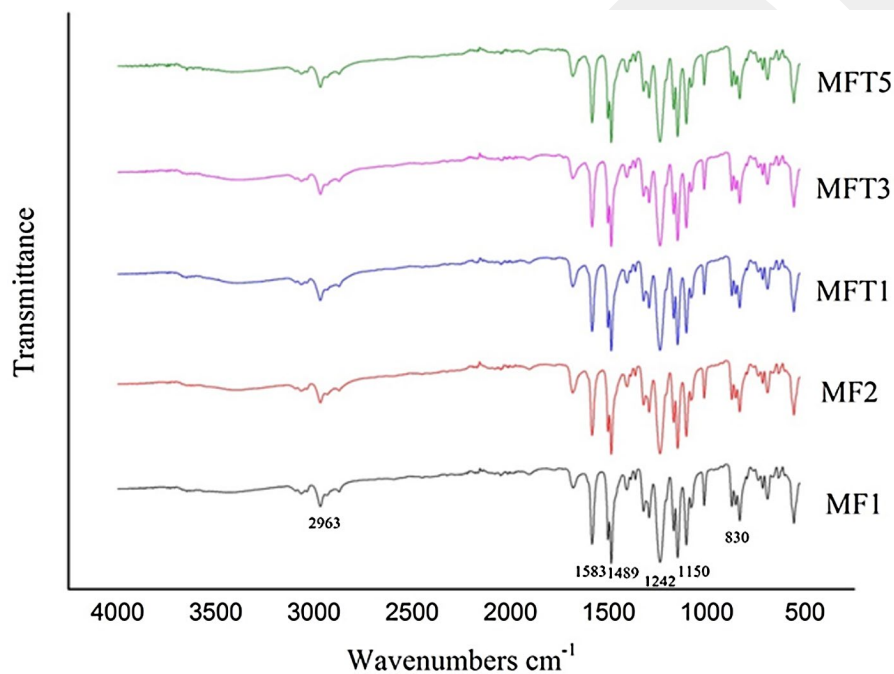
According to these results membrane MF1 had the highest contact angle value ( $94^\circ \pm 5^\circ$ ) with the lowest hydrophilicity. With the addition of PEI and nanoparticles contact angle values decreased, and thus, hydrophilicity of membranes increased. PEI has been proven to increase the hydrophilic property and positive charge of the membrane due to its high content of amine (Timpert et al., 2006). As the concentration of  $\text{TiO}_2$  increase in the membrane matrix, hydrophilicity increased. Among the membranes, the one prepared with 0.05% of  $\text{TiO}_2$  (MFT3) had the lowest contact angle ( $69^\circ \pm 1^\circ$ ), therefore, highest hydrophilicity. Similar to  $\text{TiO}_2$  incorporated MF membranes, increase in  $\text{Al}_2\text{O}_3$  concentration caused decreases in contact angle value, in other words increases in the hydrophilicity. Similar to our result, Uzal et al. (2017) also investigated a decrease in the contact angle value of the PSF membrane after  $\text{Al}_2\text{O}_3$  nanoparticle addition. Ng, Mohammad, Leo, and Hilal (2013) stated that the presence of inorganic oxide nanoparticles reduce the crystallinity of PSF and increase the amorphous portion. The increase in the hydrophilicity of the membranes might be attributed to this phenomenon.

### 3.1.4 | FT-IR

FT-IR spectrum of the  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  incorporated MF membranes are indicated in Figures 4 and 5, respectively. As can be seen from the figures, absorption peaks for pure PSF membrane (MF1) were detected as  $1,150 \text{ cm}^{-1}$  and  $1,167 \text{ cm}^{-1}$  (Phenyl-Carbonyl C-C stretching),  $1,242 \text{ cm}^{-1}$  (C-H stretching),  $1,537 \text{ cm}^{-1}$  (aromatic ring stretching),  $2,965 \text{ cm}^{-1}$  (asymmetric and symmetric  $\text{CH}_2$  stretching) (Avilés, Cauch, Moo-Tah, May Pat, & Vargas-Coronado, 2009; Khalid et al., 2015). According to these figures, there is no significant difference between



**FIGURE 4** FT-IR spectrum of pure PSF membrane, PSF/PEI membrane and  $\text{TiO}_2$  incorporated nanocomposite MF membranes. MF1: 17%PSF; MF2: 17%PSF/2%PEI; T:  $\text{TiO}_2$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios



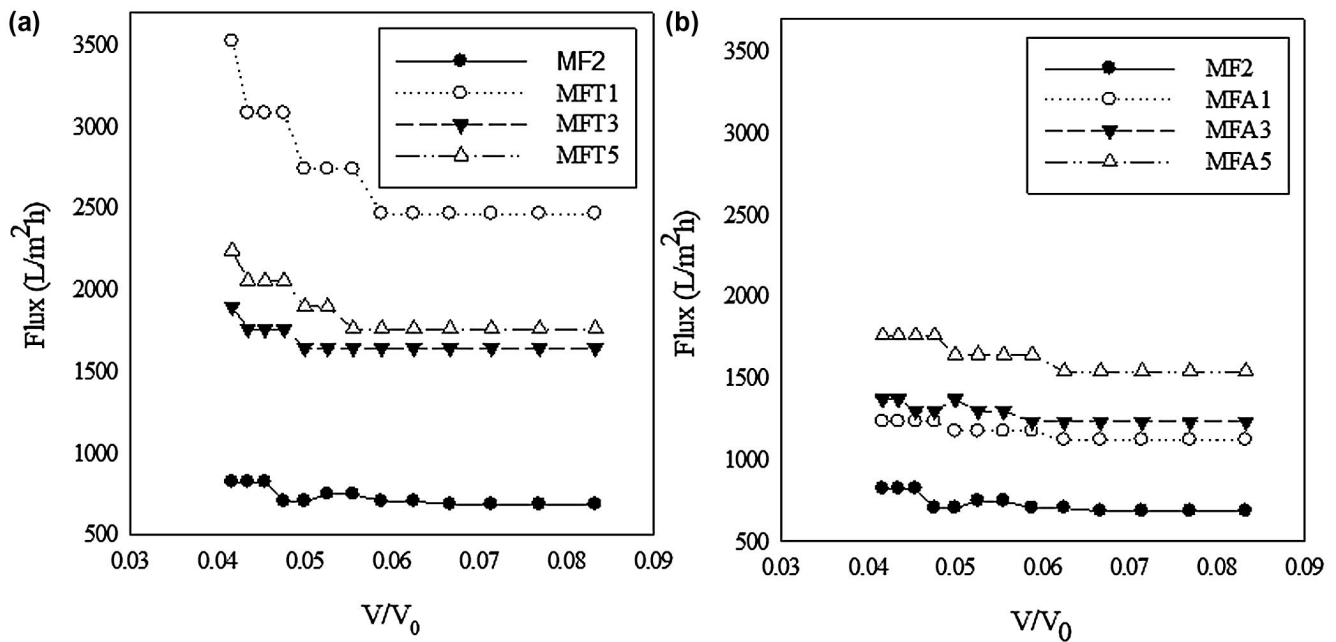
**FIGURE 5** FT-IR spectrum of pure PSF membrane, PSF/PEI membrane, and  $\text{Al}_2\text{O}_3$  incorporated nanocomposite MF membranes. MF1: 17%PSF; MF2: 17%PSF/2%PEI; A:  $\text{Al}_2\text{O}_3$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios

FT-IR spectrum results of the membranes. This may be resulted from very low concentration of nanoparticles.

### 3.1.5 | Pure water flux

The effect of nanoparticle addition ( $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$ ) on the performance of PSF/PEI MF membranes was analyzed in terms of pure water flux using dead-end filtration system. The pure water flux results of MF membranes prepared with the addition of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  nanoparticles (0.01%, 0.03%, and 0.05%) are shown in Figure 6a,b, respectively. Pure water flux of the membrane prepared with only

17% of PSF (MF1) was  $135 \text{ L/m}^2\text{h}$  (not shown in Figure 6), whereas pure water flux of the PSF/PEI MF membrane (MF2) was measured as  $959 \pm 34 \text{ L/m}^2\text{h}$ . As can be seen from Figure 6a,b, the addition of nanoparticles caused increases in pure water fluxes of the MF membranes. Among the MF membranes prepared with  $\text{TiO}_2$  nanoparticles (MFTs), the one prepared with the addition of 0.01% of  $\text{TiO}_2$  (MFT1) had the highest performance in terms of pure water flux ( $2,776 \pm 32 \text{ L/m}^2\text{h}$ ) (Figure 6a). As stated above, this membrane had the lowest contact angle value (Table 2) among the membranes indicating the highest hydrophilic character. Similar to our results, Li, Xu, Yang, Yu, and Liu (2009) investigated that the addition of  $\text{TiO}_2$  nanoparticles improved the performance of microporous PES membrane



**FIGURE 6** Pure water flux values of PSF/PEI and  $\text{TiO}_2$  (a) and  $\text{Al}_2\text{O}_3$  (b) incorporated nanocomposite MF membranes. MF2: 17%PSF/2%PEI; T:  $\text{TiO}_2$ ; A:  $\text{Al}_2\text{O}_3$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios

**TABLE 3** Color, turbidity, total soluble solid, total phenolic content, total antioxidant activity, and total monomeric anthocyanin results of pomegranate juice samples clarified by MF membranes

Membrane	Color (PtCo)	Turbidity (NTU)	Total soluble solid (Brix)	Total Phenolic content (mg GAE/L)	ABTS (mmol TEAC/L)	DPPH (mmol TEAC/L)	Total Monomeric Anthocyanin (mg/L)
MF2	4,879 ± 8	2.06 ± 0.07	10 ± 0.0	1,617.3 ± 12.8	27.2 ± 0.1	24.2 ± 0.0	50.1 ± 0.3
MFT1	5,475 ± 9	0.28 ± 0.01	16.2 ± 0.1	2,212.7 ± 14.6	57.4 ± 0.1	36.3 ± 0.1	92.2 ± 0.2
MFT3	5,245 ± 10	0.39 ± 0.01	16.2 ± 0.0	2,317.5 ± 12.8	55.6 ± 0.1	37.7 ± 0.3	86.2 ± 0.1
MFT5	5,069 ± 4.5	0.27 ± 0.03	15.47 ± 0.1	2,062.0 ± 8.1	33.3 ± 0.0	33.7 ± 0.2	75.1 ± 0.2
MFA1	5,403 ± 5.1	0.43 ± 0.01	16.0 ± 0.0	2,284.0 ± 32.2	48.8 ± 0.2	40.5 ± 0.1	90.7 ± 0.3
MFA3	5,245 ± 6	0.29 ± 0.05	15.5 ± 0.1	1,973.3 ± 6.8	42.8 ± 0.2	31.8 ± 0.3	86.7 ± 0.1
MFA5	5,781 ± 4	0.69 ± 0.06	16.2 ± 0.0	2,642.1 ± 46.4	62.4 ± 0.2	41.3 ± 0.0	100.7 ± 1.7
S2	5,111 ± 5.8	1.40 ± 0.08	14.0 ± 0.1	2,619.6 ± 66.4	43.0 ± 0.1	30.1 ± 0.3	77.2 ± 0.2
S1	-	785 ± 4	16.3 ± 0.1	3,799.7 ± 12.0	67.2 ± 0.3	46.9 ± 0.1	104.5 ± 0.2

Note: MF2: 17%PSF/2%PEI; T:  $\text{TiO}_2$ ; A:  $\text{Al}_2\text{O}_3$ ; 1, 3, 5:0.01, 0.03, 0.05 wt% nanomaterial incorporation ratios. S2: clarified pomegranate juice from Döhler Inc., S1: turbid pomegranate juice from Döhler Inc.

in terms of pure water flux. In addition, Wang, Wang, Wang, Huang, and Wang (2013) demonstrated that modification with  $\text{TiO}_2$  nanoparticles leads an increase in pure water flux from 70  $\text{L}/\text{m}^2\text{hbar}$  to 190  $\text{L}/\text{m}^2\text{hbar}$ .  $\text{TiO}_2$  nanoparticles, at even low concentration, are reported to enhance the inner structure, which led to more permeate flux (Cao et al., 2006).

The pure water fluxes of the MF membranes prepared with  $\text{Al}_2\text{O}_3$  nanoparticles (MFAs) increased as the nanoparticle concentration increased. The highest pure water flux among the MFAs was achieved with the MF membrane prepared with the addition of 0.05% of  $\text{Al}_2\text{O}_3$  (MFA5). This result was also compatible with the contact angle values of the membranes (Table 2). The MFA5 membrane having the highest flux value, had the lowest contact angle value among the  $\text{Al}_2\text{O}_3$  incorporated MF membranes. Our results are

comparable with available literature. Yan, Li, and Xiang (2005) modified PVDF (polyvinylidene fluoride) membrane with alumina ( $\text{Al}_2\text{O}_3$ ) at nano-scale and reported that the increase in  $\text{Al}_2\text{O}_3$  concentration caused an increase in the water flux. Addition of nanoparticles improved porosity, thereby increases pure water flux and permeability.

### 3.2 | Characterization of the clarified pomegranate juice

Color, turbidity, total soluble solid content, total phenolic content, total antioxidant capacity and total monomeric anthocyanin results of the pomegranate juice samples clarified using MF membranes are shown in Table 3. Turbid pomegranate juice (S1) and clarified

pomegranate juice (S2) samples supplied from Döhler Inc. were also analyzed for comparison and the results were shown in Table 3.

Color is an important parameter of pomegranate juice because visual property of the sample is a significant factor in terms of quality perception of consumers. Color, astringency, and bitterness of pomegranate juice are derived from the phenolic compounds of pomegranate juice (Roger, 2018). Producing pomegranate juice with stable color is the main problem required to be solved in pomegranate juice process (Alper & Acar, 2004). Turbid juice samples (S1) were excluded from the spectrophotometric color analysis because high-suspended solid content can cause misleading results. The color value of the clarified pomegranate juice supplied from Döhler Inc. (S2) was 5,111 PtCo, whereas the sample obtained using pure PSF (MF2) had a lower color value (4,879 PtCo). Most of the samples clarified using  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  incorporated nanocomposite MF membranes (MFTs and MFAs) had higher color values than that of S2. The MF membrane prepared with the incorporation of 0.05% of  $\text{Al}_2\text{O}_3$  (MFA5) nanoparticle caused higher color value (5,781 Pt-Co) among the others. According to Oziyci, Karhan, Tetik, and Turhan (2013) color of clear pomegranate juice is easily affected by clarification. Our results showed that the color of clarified pomegranate juice was generally better than that of the S2 sample (supplied from Dohler Inc.); which indicates the improvement effect of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  incorporated MF membranes on color properties.

Turbidity of raw pomegranate juice (S1) was measured as 785 NTU. The turbidity values of the clarified samples were lower than that of turbid pomegranate juice, as expected. The pomegranate juices clarified using unmodified PSF/PEI MF membrane (MF2) had the highest turbidity ( $2.06 \pm 0.07$  NTU) value. Modification of the membranes with nanoparticles ( $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$ ) caused decreases in the turbidity of the samples. All of the samples clarified using the membranes fabricated in this study had a turbidity value lower than 1 NTU (Table 3), which means at least 99.9% reduction in the turbidity was achieved. There are some studies in the literature investigating the effect of membrane processing on the turbidity of the pomegranate juice. In another study of Mirsaedghazi et al. (2010), the turbidity of the pomegranate juice decreased from 498 NTU to 15 NTU (96.9% reduction) when a commercial microfiltration membrane made of polyvinylidene fluoride with a pore size of 0.45  $\mu\text{m}$  was used. Higher reduction value (99.8%) in turbidity was reported by Mirsaedghazi et al. (2012). There are also some studies where various fining agents used before filtration process. Similarly, Erkan-Koç, Türkyılmaz, Yemiş, and Özkan (2015) used several clarifying agents and the highest reduction (98.8%) in the turbidity value was achieved when gelatin was used (from 534 NTU to 6 NTU). The new generation nanoparticle embedded MF membranes fabricated in this study showed superior performance, in terms of turbidity removal, compared to the results reported in the literature.

Total soluble solid content of the turbid pomegranate juice supplied from Döhler Inc. (S1) was measured as 16.3°Brix. Similar results were also indicated in the literature. Total soluble solid content of

unclarified pomegranate juice was reported as 16.09–16.52°Brix by Türkyılmaz, Tağı, Dereli, & Özkan, 2013). The total soluble solid content of the pomegranate juice clarified using the unmodified PSF/PEI MF membrane (MF2) had the lowest total soluble solid content. The total soluble solid content of the clarified pomegranate juice samples were between 16.0 and 16.2°Brix, however, clarified pomegranate juice obtained from Döhler Inc. (S2) had a lower total soluble solid content (14.0°Brix). After the clarification process with the MF membranes fabricated in this study, total soluble solid content of the samples seemed to decrease slightly, however, the decreases were not significant. Similar observations were also reported by (Cassano et al., 2011; Mirsaedghazi et al., 2010).

Phenolic compounds are essential ingredients of pomegranates as they contribute color and flavor (Oziyci et al., 2013). The total phenolic content of the turbid pomegranate juice (S1) is 3,799.7 mg GAE/L, however, the clarified pomegranate juice sample of Döhler Inc. (S2) had a lower total phenolic content of 2,619.6 mg GAE/L. Commercial membrane used by Döhler Inc. for pomegranate juice clarification caused 31.1% loss in total phenolic content of the sample. The new generation MF membranes fabricated with incorporating nanoparticles in this study showed similar performance with commercial membrane used by Döhler Inc. in terms of removal of total phenolic content of clarified pomegranate juice. The total phenolic content of the pomegranate juice sample clarified using nanoparticle incorporated MF membranes were lower than that of turbid pomegranate juice (S1) and the values were between 1973.3 and 2,642.1 mg GAE/L. In addition, unmodified PSF/PEI MF membrane (MF2) leads to the most total phenolic content loss (1617.33 mg GAE/L, 57.4% loss). However, the  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  nanoparticle incorporated MF membranes (MFTs and MFAs) caused less loss in total phenolic content of pomegranate juice. The lowest loss (30.5%) in total phenolic content was achieved when the membrane prepared with 0.05 wt  $\text{Al}_2\text{O}_3$  (MFA5) was used. This may be resulted from the increase in pore size of the membranes with the addition of  $\text{Al}_2\text{O}_3$  nanoparticles in membrane matrix (Reza, Mohades, & Homayoonfal, 2015). There are some studies related to the clarification of pomegranate juice using clarifying agents and/or membrane filtration. Mirsaedghazi et al. (2010) applied hydrophilic polyvinylidene fluoride (PVDF) with 0.22 and 0.45  $\mu\text{m}$  pore size for the clarification of pomegranate juice. The loss in total phenolic content was indicated as 50.5% and 34.9%, respectively. In another study, pomegranate juice was clarified using gelatin and bentonite as clarifying agents and commercial UF membrane; and the clarification process led to 25% loss in total phenolic content (Onsekizoglu, 2013).

Pomegranate juice have much more antioxidant activity than other fruit juices and beverages (Gil, Toma, Hess-pierce, Holcroft, & Kader, 2000). High phenolic compound of pomegranate juice is responsible for high antioxidant capacity in pomegranate juice (Kalaycioğlu & Erim, 2017; Mousavinejad, Emam-Djomeh, Rezaei, & Khodaparast, 2009; Seeram et al., 2008). Total antioxidant activities of the samples were analyzed with ABTS and DPPH radical-scavenging methods and results were shown in Table 3. According to these results, the ABTS antioxidant activity of the turbid pomegranate

juice (S1, 67.2 mmol TEAC/L) decreased by applying commercial membrane used by Döhler Inc. caused 36.9% loss. In addition clear juice obtained using unmodified PSF/PEI MF membrane (MF2) had the lowest total antioxidant capacity with 27.2 mmol TEAC/L. On the contrary, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> incorporated nanocomposite MF membranes exhibit superior performance in terms of antioxidant capacity. Among these nanocomposite MF membranes, the one prepared with the addition of 0.05% of Al<sub>2</sub>O<sub>3</sub> nanoparticle (MFA5) showed the best performance in terms of antioxidant capacity (62.4 mmol TEAC/L; 7.1% loss). There are some studies investigating the effect of clarifying agents on the antioxidant capacity of pomegranate juice. Erkan-Koç et al. (2015) clarified pomegranate juice using gelatin, casein, and albumin as clarifying agents and determined ABTS antioxidant activity loss values as 21.3%, 24.7%, and 17.2%, respectively. In another study, (polyether ketone) hollow fiber (HF) membrane clarification caused 17.8% decrease in ABTS antioxidant activity of pomegranate juice (Cassano et al., 2011). Onsekizoglu (2013) clarified pomegranate juice using gelatin, bentonite, and commercial UF membrane (30 kDa cut-off PVDF membrane) and total antioxidant capacity of pomegranate juice decreased by 16% after clarification. As can be seen from these results, clarifying agents caused more reduction of antioxidant capacity than the membranes fabricated in this study.

Similar to the results of ABTS antioxidant activity, clarification caused decreases in the DPPH antioxidant activity. The commercial membrane used by Döhler Inc. caused 35.8% loss in terms of DPPH antioxidant activity. In addition, clear juice obtained using unmodified PSF/PEI MF membrane (MF2) had the lowest total antioxidant capacity (24.2 mmol TEAC/L) and highest loss (48.4%). On the contrary, according to DPPH radical-scavenging analysis results TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanomaterial incorporated membranes exhibit superior performance in terms of clarifying pomegranate juice with high antioxidant capacity. DPPH antioxidant capacity of clarified pomegranate juices obtained using nanocomposite MF membranes ranges between 31.8 and 41.3 mmol TEAC/L. Among these fabricated nanocomposite MF membranes, the one prepared with 0.05% of Al<sub>2</sub>O<sub>3</sub> nanomaterial (MFA5) showed the best performance in terms of antioxidant capacity (41.3 mmol TEAC/L). Moreover, as the polyphenolic compounds act as antioxidant compounds (Candrawinata, Golding, Roach, & Stathopoulos, 2014), the highest total phenolic content and antioxidant content of the clarified pomegranate juice sample was obtained with the sample clarified using the same membrane (0.05% of Al<sub>2</sub>O<sub>3</sub>, MFA5). In addition, clarified pomegranate juice samples obtained using unmodified membrane (MF2), had the lowest phenolic content as well as total antioxidant content.

Anthocyanin pigment is responsible for red, purple, and blue color quality of many fresh and processed fruits. Color of anthocyanin pigment alters depending on pH, so total monomeric anthocyanin pigment content is determined by using "pH differential method." At pH 1.0 anthocyanin pigments are colored whereas at pH 4.5 anthocyanin pigment are colorless (Giusti & Wrolstad, 2001). Total monomeric anthocyanin content contribute

to the total antioxidant capacity and total phenolic content of pomegranate juice (Koroknai, Csanádi, Gubicza, & Bélafi-Bakó, 2008). Total monomeric anthocyanin content of clarified pomegranate juices were determined by pH differential method and shown in Table 3. After the clarification conducted by Döhler Inc. total monomeric anthocyanin content decreased with a loss of 26.1%. In addition, clear juice obtained using unmodified PSF/PEI MF membrane (MF2) had the lowest total monomeric anthocyanin pigment with 50.1 mg/L (52.1% loss). On the contrary, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanomaterial incorporated MF membranes exhibit superior performance in terms of clarifying pomegranate juice with high total monomeric anthocyanin pigment content. The anthocyanin content of the samples clarified using these membranes were between 75.07–92.20 mg/L and 86.66–100.74 mg/L, respectively. Among the clarified pomegranate juices, the one clarified using 0.05% of Al<sub>2</sub>O<sub>3</sub> nanomaterial incorporated MF membrane (MFA5) had the highest total monomeric anthocyanin content (100.7 ± 1.7 mg/L) and lowest anthocyanin loss (3.6%). Vardin and Fenercioglu (2003) used PVPP and gelatin for the clarification of pomegranate juice and total monomeric anthocyanin pigment content was measured as 68.8 mg/L (22.7% loss) and 83.7 mg/L (6.2% loss), respectively. Cassano et al. (2011) also indicated that clarification of pomegranate juice by using ultrafiltration leads decrease in total monomeric anthocyanin content at an extent of 11.7%. In another study, after clarification of pomegranate juice using gelatin and bentonite as clarifying agents and commercial UF membrane (30 kDa cut-off PVDF membrane) caused 15% loss in total monomeric anthocyanin content (Onsekizoglu, 2013).

## 4 | CONCLUSIONS

In this research, PSF/PEI MF membranes were fabricated with incorporating two different nanoparticles (TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>) and their performances in pomegranate juice clarification were evaluated. TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticle addition into PSF/PEI MF membrane matrix enhanced the membrane hydrophilicity, porosity, and pure water fluxes. Membrane morphology changed with the addition of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> nanoparticles, which proved by SEM analysis. Moreover, modification with nanoparticles leads to improve pomegranate juice clarification performance in terms of clarified juice quality. Furthermore, according to pomegranate juice characterization results, MFT1 had better performance among the TiO<sub>2</sub> incorporated membranes. However, 0.05% Al<sub>2</sub>O<sub>3</sub> incorporated PSF/PEI MF membrane exhibited the superior performance among the membranes, showing that Al<sub>2</sub>O<sub>3</sub> incorporation seems to be a good alternative for clarifying pomegranate juice with enhanced quality parameters.

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## CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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