Effect of kiwifruit variety on the efficiency of ultrafiltration pretreatment during its juice membrane concentration with nanofiltration

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Abstract

Kiwifruit is widely consumed all over the world due to its nutritional compounds. It is recommended to prevent many types of diseases. The thermal concentration requires high temperatures, which destroy heat-sensitive compounds. Membrane processes are a suitable alternative to thermal processes due to the absence of high temperatures, simplicity, and lower cost. In this research, the juice of four varieties of kiwifruit, including Hayward, Abbott, Monty, and Allison, was clarified by ultrafiltration, and the permeate flux was measured at different pressures and flow rate. The results showed that the highest permeate flux was obtained at 2 bar and 20 mL/s. Also, Abbott and Allison had the highest and lowest product yield, respectively. The ultrafiltration permeate was treated by nanofiltration and the concentration value was investigated at different volume concentration factors (VCF). The results showed that by increasing the VCF to 4, the concentration of the target nutrient compounds begins in most varieties. Polyphenolic compounds, flavonoids, and antioxidant properties especially in Abbott and Hayward has increased about seven times. Hayward was seen to have the highest increase in polyphenolic compounds. The Hermia model showed that the cake formation mechanism was the dominant fouling mechanism in most of the processes.

Keywords: Concentration; Juice; Kiwifruit; Nanofiltration; Ultrafiltration

Introduction

Kiwi fruit *(Actinidia deliciosa)*, which was first introduced in Greece in 1973, is widely consumed worldwide due to its high nutritional value [1-2]. Kiwifruit juice consumption is strongly recommended due to its high nutrient components such as high levels of vitamin C, polyphenols, and flavonoids, which make it rich in antioxidant activity. These beneficial components can reduce heart diseases and prevent various types of cancers. Moreover, kiwifruit juice can enhance the human immune system and protect DNA against oxidation [1-4]

There are four important varieties of kiwifruit, including Hayward, Abbot, Monty, and Allison, which are the best choices for commercial-scale applications [5].

Kiwifruit juice should be clarified before its concentration due to the presence of suspended particles that increase the juice's turbidity. Microfiltration (MF) and ultrafiltration (UF) have been proven to be desirable processes for juice clarification due to their high efficiency, low cost, and ease of use [6]. On the other hand, thermal concentration destroys sensitive and functional components of fruit juices such as vitamin C and polyphenols during the process. Therefore, replacing novel technologies instead of traditional thermal methods not only can be useful in maintaining the nutritional value of fruit juices, but can also be effective in saving energy consumption, while the membrane process is a completely environmentally friendly method. Reverse osmosis (RO), nanofiltration (NF), osmotic distillation (OD), and membrane distillation (MD) are useful membrane processes that can successfully concentrate juices at low temperatures and thus preserve the juice nutritional value [7].

There are several researches to investigate the treatment of kiwifruit juice using the membrane process. Cassano et al., [2] used an integrated membrane process (UF and OD) to clarify and concentrate kiwifruit juice and produce highly nutritious kiwifruit concentrate. Hamzah & Leo [8] separated protein from kiwifruit juice by UF. It was found that protein separation by cellulose acetate membrane is very effective compared to traditional methods. Ilame and Satyavir [9] studied the membrane process of various fruit juices including kiwifruit juice and evaluated some physicochemical properties such as pH, total soluble solid content, and total titratable acidity. They announced that for juice clarification and concentration, the membrane process has many advantages, including enhanced product quality and reduced energy consumption compared to the evaporation process. However, they emphasized that the fouling phenomenon and membrane cost should be considered. Conidi et al. [10] studied the quality of kiwifruit juice clarified by modified Poly Ether Ketone hollow fiber membranes (UF system). They concluded that the clarified juice was free of suspended particles and also bioactive compounds such as ascorbic, malic, citric acids and polyphenol compounds were well preserved during the clarification process.

Several studies show that the fruit variety can affect the composition of its juice. For example, the physicochemical properties of different varieties of kiwifruit (Hayward, Abbott, Monty, Allison, and Red Kiwi) were evaluated. This research showed that Allison has the least total soluble solid and the most titratable acidity [11]. Similar studies have been conducted on other fruits. For example, Markowski et al. [12] compared the compositions of two varieties of pear juice, *Conference* and *Alexsander Lucas.* They concluded that the production method and the variety have a significant effect on the physicochemical properties of pear juice. According to the authors *Conference* had better turbidity characteristics than *Alexsander*. In general, it has been proven that the variety of fruit can affect the juice composition and its physical properties, therefore it is predicted that the variety can affect the efficiency of the process during the membrane processing.

In previous studies, the efficiency of the nanofiltration process in kiwi juice concentration and the effect of the ultrafiltration pretreatment on this efficiency were not evaluated. In particular, the effect of the kiwi variety on the efficiency of its membrane concentration by nanofiltration has been a topic that has a research gap. On the other hand, there is no research conducted on using UF as a pretreatment for improving NF efficiency to concentrate nutritional composition in four different kiwifruit juice varieties including Hayward, Abbot, Monty, and Allison.

Therefore, in the current work, different varieties of kiwifruit juice were concentrated using NF after pretreatment with UF. The effect of fruit variety on the efficiency of the membrane process was evaluated and the fouling mechanism was studied. Also, the content of titratable acidity, turbidity, pH, total soluble solids, total phenolic compounds, total flavonoid compounds, and antioxidant properties of feed and retentate were studied.

Materials and methods

Sample preparation

Four ripe kiwifruit varieties including Hayward, Abbott, Monty, and Allison were prepared from the local market (Salmanshahr, Iran). The average total soluble solids (TSS) of the fruits was between 11-13 °Brix. They were washed, peeled manually, and then their juice was extracted by a juicer (Parskhazar, P610, Iran). A clean cloth sieve was used to remove large pieces of juice and it was stored in polyethylene terephthalate bottles at -20°C till further analysis.

Membrane process

The lab scale UF unit with polysulfone membrane (MWCO of 20 kDa) and NF unit with polyamide membrane (MWCO of 400 Da) both 5.5 × 3.5 centimeters were used to clarify and concentrate kiwifruit juice, respectively (Tasfieh Sanati Ab Sharif, Iran). Kiwifruit juice was pumped from the feed tank to the flat sheet module (8.5 × 6 × 2 centimeters) by a positive displacement pump (C.C.K., model RO 50, Taiwan). The permeate was collected in the permeate tank and the retentate was returned to the feed tank. The transmembrane pressure was measured using two pressure meters before and after the membrane module, and the feed flow rate was manually controlled by a valve in the retentate path. Transmembrane pressure was controlled by a bypass system at different feed flow rates (Fig. 1).

Theory

The permeate flux (Jp, $kgm^{-2}s^{-1}$) was calculated according to Eq. 1.

$$J_p = \frac{\Delta m}{A \times t} \quad (1)$$

where Δm, A, and t are the permeate weight (kg), the membrane active surface (m^2), and time (s), respectively (Table 1).

The volume concentration factor (VCF), which indicates the amount of the product in UF and the concentration value in NF, was calculated with Eq. 2.

$$VCF = \frac{\text{Feed volume}}{\text{Feed volume} - \text{Permeate volume}} \quad (2)$$

The feed flow rate was measured manually by using a graduated cylinder and a timer.

Hermia's model was used to identify the main mechanism of the fouling phenomenon. According to this model:

- Standard blocking is dominant when the t/v versus t curve is linear.
- Cake formation is dominant when the t/v versus v is linear.
- Intermediate pore blocking is the dominant mechanism when the curve of Ln (t) versus v is linear [13].

On the other hand, the permeate flux of pure water before and after the juice process was measured to evaluate the fouling index (FI) according to Eq. 3 [14].

$$FI = 1 - \frac{\text{Water permeate flux after process}}{\text{Water permeate flux before process}} \times 100 \quad (3)$$

Evaluation of the physicochemical properties

The size of suspended particles was evaluated by a particle size analyzer (HORIBA-SZ100, USA). The pH was determined using a pH meter (827pH Lab-Metrohm, SWISS) at 25℃. A handheld refractometer (ATAGO, HSR-500, JAPAN) was used to determine the total soluble solid (TSS) and the results were expressed as °Brix. The total turbidity was measured using a turbidity meter (TU-2016, TAIWAN) at 25℃. The total acidity was determined by titration of 2.5 g of juice with NaOH (0.1 N) until pH reached 8.1 and data was expressed as g citric acid / 100 mL of kiwifruit juice.

The content of total phenolic compounds was determined using the Folin-Ciocalteau method with a slight modification. 0.5 mL of kiwifruit juice was mixed with 1.5 mL of double deionized water, 0.25 mL of Folin-Ciocalteau, and 0.5 mL of sodium carbonate solution (7.5% w/v). After 30 min incubation in the dark medium at 25 °C, the absorbance was measured at 765 nm using a spectrophotometer (Perkin Elmer, Lambda 25, USA). The total phenolic content was expressed as mg gallic acid/100 mL kiwifruit juice [1].

The content of total flavonoid compounds was measured using the aluminum chloride colorimetric method with some modifications. 0.5 mL kiwifruit juice was mixed with 70 µL sodium nitrite solution (5%). After 5 min, 0.15 mL aluminum chloride (10%) was added to the sample, and the mixture was incubated for 5 min at 20 °C and then was mixed with 1.3 mL double distilled water and 0.5 mL sodium hydroxide (1M). The absorbance of the final solution was measured using a spectrophotometer (Perkin Elmer, Lambda 25, USA) at 415 nm, and the results were expressed as mg catechin in 100 mL kiwifruit juice [1].

Total antioxidant activity was determined using the DPPH solution. 0.1 mL of kiwifruit juice was mixed with 3 mL of DPPH solution (2 mg in 50 mL methanol). The mixture was incubated for 20 min at 25 °C, then its absorbance was measured using a spectrophotometer (Perkin Elmer, Lambda 25, USA) at 517 nm (Wang et al., 2019). Total antioxidant activity was measured by Eq. 3.

$$DPPH\,(\%inhibition) = \left(\frac{Abs_0 - Abs_1}{Abs_0}\right) \times 100 \qquad (4)$$

where Abs0 and Abs1 are blank and sample absorbance, respectively.

To measure vitamin C, 100 g of kiwifruit juice was mixed with 30 mL of oxalic acid in a 500 mL flask to prevent oxidation of vitamin C. Then, 1 mL of potassium permanganate (100 µg/ mL) was added to 10 mL of the sample, and after keeping it for 5 minutes, its absorbance was measured by a spectrophotometer (Perkin Elmer, Lambda 25, USA) at 530 nm. The content of vitamin C was reported as mg ascorbic acid per L kiwifruit juice [15].

Results and Discussion

Effect of the membrane process on the physicochemical properties of kiwifruit juice

Different varieties of kiwifruit juice were treated using ultrafiltration and the physicochemical properties of feed, permeate, and retentate were considered. On the other hand, the permeate of UF was concentrated using NF to VCF=4, and the physicochemical properties of feed and retentate and their ratio were investigated.

The results showed that Monty and Allison had the highest and the lowest pH, respectively, and the pH value did not change during UF (Table 2). The results showed that the amount of titratable acidity in different varieties had an opposite trend of pH so Allison had the highest acidity and Monty the lowest. This finding is consistent with the findings of Zolfaghari et al. [16]. On the other hand, the acidity after the UF process decreased in all varieties, but there is a similar acidity value in permeate and retentate, which indicates that acidic compounds are trapped in the cake layer and not concentrated in the retentate (Table 2). The study of juice turbidity showed that Allison and Monty had the highest and lowest turbidity, respectively, and the value of this parameter decreased drastically in all varieties after the UF process. The moderate increase in turbidity of retentate showed that the compounds causing the juice's turbid appearance, such as suspended particles, were concentrated in the retentate and also trapped in the cake layer (Table 2). The results were consistent with the findings of Parvarie et al. [5]. The evaluation of the total soluble solid content showed that Allison had the highest soluble solid content and Abbott and Monty had the lowest content, which was consistent with the findings of Zolfaghari et al. [16]. Also, the results showed that the amount of total soluble solids during ultrafiltration decreased in permeate and retentate, which is due to being stuck in the membrane cake layer (Table 2).

Evaluation of flavonoid compounds showed that Monty had the highest flavonoid content and Hayward had the lowest content. The content of flavonoids in all varieties decreased after the UF treatment of juice. The results showed that the reduction of flavonoids occurs both in permeate and retentate (Table 2). Therefore, it can be concluded that the main part of this component is trapped in the cake layer formed on the membrane surface. Almost similar results were obtained in the study of polyphenolic compounds. Thus, Monty has the highest polyphenol content and after membrane treatment of all varieties with UF, the amount of this component decreased both in permeate and retentate (Table 2). Cassano et al. [17] obtained a similar result in the clarification of pomegranate juice.

Evaluation of the antioxidant property of different varieties of kiwifruit juice showed that Monty has the highest antioxidant value and Hayward has the lowest antioxidant content. It can be attributed to the highest content of polyphenol and flavonoid content in Monty, which creates a high antioxidant value in this variety. The results showed that the amount of antioxidant properties decreased after the UF process, which can be caused by the oxidation of vitamin C during the process and its destruction, as well as a significant decrease in polyphenols and flavonoids (Table 2). Cassano et al. [2] who produced high-quality kiwifruit juice by membrane processes, reached similar results for antioxidant properties. Also, Zolfaghari et al. [16] introduced Allison and Monty as the varieties that have the highest antioxidant properties due to high amounts of vitamin C.

The permeate of the UF process was concentrated with the NF unit to VCF=4 and the changes in the physicochemical properties of the feed, retentate, and their ratio were studied.

The results showed that the pH did not change during the NF process or a slight decrease was observed in Hayward and Monty (Table 2). Arriola et al. [18], who investigated the ability of nanofiltration to concentrate nutrients in watermelon juice, also came to the same conclusion that pH decreases with increasing VCF. On the other hand, a slight decrease in the titratable acidity of kiwifruit juice was observed in the retentate of the NF process (Table 2), which is probably due to the entrapment of acidic compounds in the cake layer on the membrane surface.

The evaluation of turbidity showed that this parameter increased in retentate after the NF process due to the rejection of suspended particles by the membrane (Table 2). The highest increase in turbidity in retentate was observed in Monty due to its large particles, which can cause a thicker cake layer on the membrane surface (Fig. 2). Hayward had the lowest turbidity ratio, and this can be attributed to its small particle size (Fig. 2) and its low fouling index, which will be explained later. Molaee Parvarei et al. [6], indicated a similar result in evaluating the effect of the membrane process on the physicochemical properties of fruit juices.

The TSS changes were the opposite of the turbidity changes, so that the Monty had the highest turbidity reduction, and the Hayward variety had the least turbidity reduction for a reason similar to what was mentioned for turbidity (Table 2).

Total polyphenol compounds and flavonoids increased with increasing the VCF (Table 2). The results showed that at the maximum VCF tested (VCF=4), the amount of polyphenols and flavonoids increased in Hayward and

Abbott, which can be concluded that the concentration of these nutrients occurred in these two varieties. However, no concentration of polyphenols and flavonoids was observed in Allison and Monty, which can be attributed to their high particle size and fouling index of about 90%. These factors can cause the cake layer to thicken on the membrane surface, and these compounds are trapped in this cake layer due to their large size and do not enter the retentate. Arend et al. [19], who investigated the concentration of polyphenolic compounds in strawberries by NF, reached a similar result regarding the concentration of phenolic compounds [19] Also, Pruksasri et al. [20] were able to concentrate the phenolic compounds of apple juice by NF process. Arriola et al. [17] reported that NF can concentrate the nutrient compounds in watermelon juice. They concluded that with increasing the VCF, the amount of flavonoid compounds in watermelon juice increased [18].

The antioxidant properties of fruit juices are responsible for their anti-cancer properties. Evaluation of antioxidant properties of different varieties of kiwifruit juice during the NF process showed that this parameter increased in the retentate of Hayward and Abbott. However, no increase in the antioxidant properties in the retentate of Allison and Monty was observed (Table 2). The main reason for the increase in antioxidant value in the retentate of Hayward and Abbott was the concentration of polyphenols and flavonoids in the retentate during the NF process. For further evaluation, the content of vitamin C was studied. The results showed that the highest amount of increase in antioxidant properties in retentate is related to the Abbott variety, which also had the highest concentration of vitamin C in retentate (up to 16 mg/l). But in the Monty, which had the least increase in antioxidant properties, this vitamin decreased to 5.09 mg/l after the NF process, which could be due to its oxidation. Arriola et al. [18] studied the potential of NF for the concentration of bioactive compounds in watermelon juice and obtained a similar result for vitamin C concentration.

Effect of variety type on the permeate flux and VCF during ultrafiltration of kiwifruit juice

Different varieties of kiwifruit juice were clarified using UF and their permeates were concentrated by the NF process. The results showed that the permeate flux during the UF process depends on the type of variety. To investigate more clearly, VCF in ultrafiltration of different varieties of kiwifruit juice was studied and it was concluded that Abbott and Allison had the highest and lowest VCF, respectively (Fig. 3). Evaluation of fouling mechanism showed that cake formation and standard blocking were the main fouling mechanisms during the UF process of Abbott and Allison varieties, respectively (Table 2).

Evaluation of particle size in different varieties showed that Allison has the biggest particle size and Abbott has the smallest one (Fig. 2). This finding was consistent with the results of VCF; so the variety with the biggest particle size, which probably causes the least fouling, produced the lowest VCF and permeate flux and vice versa.

Effect of feed type on the efficiency of nanofiltration of kiwifruit juice

The effect of feed type on the permeate flux and volume concentration factor (VCF) during nanofiltration (NF) of kiwifruit juice was evaluated. For this purpose, fresh kiwifruit juice and the permeate of the ultrafiltration process were treated by NF under the same process conditions. The results showed that when the feed was permeate of UF, the permeate flux and VCF of NF were higher than when the fresh fruit juice was used in all varieties (Fig.4). Most suspended particles were removed by UF, so higher permeate flux and VCF were observed due to less fouling phenomenon and thinner cake layer on the membrane surface during NF process. But fresh fruit juice is full of suspended particles, so when it was used as NF feed, a large number of particles moved to the membrane surface in the first minutes and a thick layer of cake was formed, resulting in a decrease in permeate flux and VCF immediately [21].

Evaluation of the fouling index showed that the NF process of UF permeate reduces the fouling index compared to the NF process of fresh juice (Fig. 5). The greatest difference between the fouling index of UF permeate juice and fresh juice was observed during the membrane treatment of Hayward, which also showed the highest difference in permeate flux and VCF (Fig. 4).

Effect of variety type on the NF efficiency of kiwifruit juice

The permeate of the ultrafiltration process of different varieties of kiwifruit juice was concentrated using the NF process and permeate flux and VCF were evaluated. In all the experiments, a significant decrease in the permeate flux was observed at the beginning of the process due to concentration polarization and fouling phenomenon. The evaluation of VCF showed that Abbott had the highest VCF and Allison had the lowest value (Fig. 6). The reason for such results was the highest particle size in Allison and the smallest one in Abbott (Fig. 2), which probably caused high fouling during NF process of Allison and low fouling during NF process of Abbott. To study the intensity of the flux drop in different varieties, the average of the ratio of permeate flux in 50-60 min to the permeate flux in 1-2 min was calculated and the results showed that this ratio was the highest in the Hayward and the lowest in the Monty (Fig. 6). Evaluation of the fouling index (FI) showed that Hayward, which had the highest ratio, had the lowest FI and Monty has the highest FI (Fig. 7), which is consistent with the data obtained about the ratio of permeate flux in 50-60 min to the permeate flux in 1-2 min.

Evaluation of fouling mechanism showed that cake formation is the main fouling mechanism in NF process of most varieties, when the feed used was UF permeate; but the NF process of fresh kiwifruit juice caused intermediate blocking as the main fouling mechanism (Table 3).

Conclusion

From the present research, it can be concluded that the use of integrated membrane process including UF followed by NF was a successful method for producing kiwifruit juice concentrate containing high amounts of nutrient compounds and antioxidant value. On the other hand, to start the concentration of nutrient compounds, a minimum VCF equal to 4 should be provided in the nanofiltration process.

Ease of use, energy saving and avoiding nutritional values loss are some of the advantages of using membrane processes.

The use of UF as a pretreatment for the clarification of kiwifruit juice is significantly effective in reducing fouling due to separating large molecules from juice and thus increasing the permeate flux in the NF process during concentration process.

Abbott which had the smallest particle size, had the highest product yield in both UF and NF processes, unlike Allison, which had the largest particle size and the lowest product yield. Cake formation was the dominant fouling mechanism during UF and NF processes of most varieties; but membrane process of Allison caused standard blocking fouling mechanism. On the other hand, some varieties have more nutritional value than others at the beginning of the process, so they will also show more nutritional value at the end of the concentration process.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Tables' caption

Table 1. Nomenclature

Tables 2. The effect of ultrafiltration and nanofiltration on the physicochemical properties of different varieties of kiwifruit juice

Table 3. Effect of the process type on the main fouling mechanism

Nomenclature	**Referred to**
MF	Microfiltration
UF	Ultrafiltration
NF	Nanofiltration
RO	Reverse Osmosis
OD	Osmotic Distillation
MD	Membrane Distillation
Δm	Permeate weight (kg)
A	Membrane active surface (m^2)
t	Time (s)
VCF	Volume concentration factor
Jp	Permeate flux
FI	Fouling index
MWCO	Molecular weight cutoff
TSS	Total soluble solid
DPPH	2,2-Diphenyl-1-picrylhydrazyl
Abs0	Blank absorbance
Abs1	Sample absorbance

Table 1

Variety	Sample	Physicochemical property						
		pH	Titratable acidity (g Citric acid/100 g sample)	Turbidity (NTU)	Total soluble solids (Brix)	Total flavonoids (mg catechin / mL sample)	Total polyphenols (mg Gallic acid / 100 g sample)	DPPH inhibition (%)
Ultrafiltration process (UF)								
Abbott	Feed	3.8^{Ba}	1.47^{Ca}	560.66^{Db}	11^{Ca}	2.06^{Ca}	0.08^{Ca}	57.99^{Cc}
	Permeate	3.9^{Ba}	0.34^{Cb}	0.16^{Bc}	3^{Bb}	0.18^{Bc}	0.01^{Bc}	13.27^{Ca}
	Retentate	3.9^{Ba}	0.40^{Cb}	712.33^{Ba}	3^{Bb}	0.99^{Bb}	0.05^{Bb}	39.28^{Cb}
Hayward	Feed	3.63^{Ca}	2.05^{Ba}	580^{Bb}	13.03^{Ba}	1.30^{Da}	0.09^{Ba}	47.96^{Dc}
	Permeate	3.5^{Ca}	0.98^{Ab}	19.84^{Ac}	5.06^{Ac}	0.63^{Ac}	0.01^{Bc}	13.16^{Cb}
	Retentate	2.8^{Db}	1.06^{Bb}	729.33^{Ca}	6^{Ab}	0.67^{Cb}	0.04^{Cb}	6.89^{Db}
Allison	Feed	3.5^{Da}	2.36^{Aa}	803.33^{Ab}	17.5^{Aa}	2.14^{Ba}	0.09^{Ba}	78.68^{Ba}
	Permeate	3.5^{Ca}	0.73^{Bb}	0^{Dc}	5^{Ac}	0.16^{Cc}	0.03^{Ac}	97.38^{Ac}
	Retentate	3.53^{Ca}	0.81^{Ab}	1206^{Aa}	6^{Ab}	0.54^{Db}	0.06^{Ab}	87.35^{Ab}
Monty	Feed	3.9^{Ab}	1.44^{Ca}	338.33^{Db}	11^{Ca}	2.22^{Aa}	0.09^{Aa}	84.63^{Ab}
	Permeate	4^{Aa}	0.35^{Cb}	2.75^{Bc}	3^{Bb}	0.19^{Bc}	0.01^{Bc}	76.28^{Ba}
	Retentate	4^{Aa}	0.40^{Cb}	1093.33^{Ba}	3^{Bb}	1.06^{Ab}	0.06^{Ab}	72.30^{Ba}
Nanofiltration (VCF = 4, Feed = the permeate of UF)								
Abbott	Feed	3.93^{Ba}	0.76^{Ba}	29.44^{Bb}	5^{Ca}	0.196^{Ab}	0.019^{Ba}	19.56^{Db}
	Retentate	3.93^{Aa}	0.51^{Bb}	318^{Aa}	2^{Cb}	0.230^{Ba}	0.020^{Ba}	40.88^{Ca}
	$\frac{Retentate}{Feed}$	1^{A}	0.66^{A}	10.79^{B}	0.4^{B}	1.175^{C}	1.088^{B}	2.09^{A}
Hayward	Feed	3.73^{Ca}	0.75^{Ba}	54.66^{Ab}	6^{Ba}	0.153^{Cb}	0.012^{Ba}	44.54^{Bb}
	Retentate	3.6^{Bb}	0.38^{Cb}	265^{Ba}	3.5^{Ab}	0.252^{Aa}	0.025^{Ca}	85.98^{Ba}
	$\frac{Retentate}{Feed}$	0.96^{B}	0.51^{B}	4.84^{D}	0.58^{A}	1.641^{A}	2.011^{A}	1.93^{B}
Allison	Feed	3.63^{Ca}	1.32^{Aa}	31.45^{Bb}	7.5^{Aa}	0.184^{Ba}	0.059^{Aa}	92.68^{Ab}
	Retentate	3.63^{Ba}	0.64^{Ab}	250.66^{Ca}	3^{Bb}	0.150^{Aa}	0.044^{Aa}	95.12^{Aa}
	$\frac{Retentate}{Feed}$	1^{A}	0.48^{C}	7.96^{C}	0.4^{B}	1.397^{B}	0.751^{C}	1.02^{C}
Monty	Feed	4.1^{Aa}	0.64^{Ca}	10.48^{Cb}	4Da	0.187^{Ba}	0.020^{Ca}	38.45^{Ca}
	Retentate	3.93^{Ab}	0.42^{Bb}	120Da	1^{Db}	0.174^{Ca}	0.015^{Da}	35.70^{Db}
	$\frac{Retentate}{Feed}$	0.95^{C}	0.66^{A}	11.44^{A}	0.25^{C}	0.932^{D}	0.763^{C}	0.92^{D}

Table 2

Process/Variety	R^2 of different Hermia's models with the linear curve			Main fouling mechanism
	Ln(t) vs. v	**t/v vs. t**	**t/v vs. v**	
Ultrafiltration of kiwifruit juice				
Abbott	0.8868	0.9176	<u>0.9437</u>	Cake formation
Hayward	<u>0.8528</u>	0.4276	0.4243	Intermediate blocking
Allison	<u>0.8734</u>	0.8377	0.8590	Intermediate blocking
Monty	0.8805	0.8635	<u>0.8922</u>	Cake formation
Nanofiltration of fresh juice				
Hayward	<u>0.9272</u>	0.0039	0.0121	Intermediate blocking
Nanofiltration of UF permeate				
Abbott	0.9306	0.9491	<u>0.9897</u>	Cake formation
Hayward	<u>0.8657</u>	0.7878	0.8033	Intermediate blocking
Allison	0.9288	0.9615	<u>0.9945</u>	Cake formation
Monty	0.9301	0.9480	<u>0.9894</u>	Cake formation

Table 3

Figures' caption

Fig 1. Schematic of membrane unit

Fig 2. The graph of the average particle size of different varieties of kiwi juice (the same letters in each graph means that there is no significant difference at the 95% level)

Fig 3. Effect of variety type on the permeate flux of ultrafiltration of kiwifruit juice

Fig 4. Effect of feed type on the permeate flux and volume concentration factor (VCF) during the NF process of kiwifruit juice

Fig 5. Fouling index diagram of different varieties of kiwi juice in the nanofiltration process (the same letters in UF permeated feed and fresh feed in different varieties mean there is no significant difference at the 95% level.)

Fig 6. Effect of variety type on permeate flux and VCF of Kiwifruit juice in the NF process

Fig 7. Fouling index in different varieties of kiwi juice (the same letters in each diagram means there is no significant difference at the 95% level.)

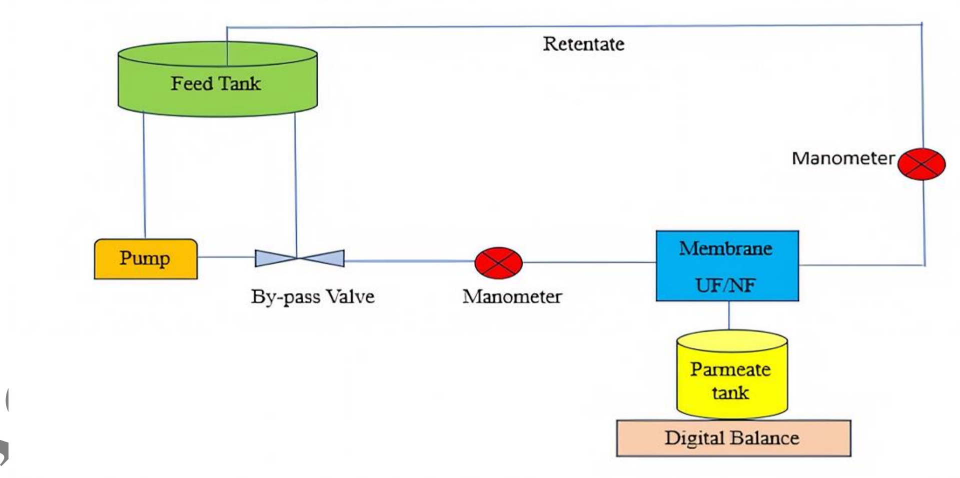

Fig. 1

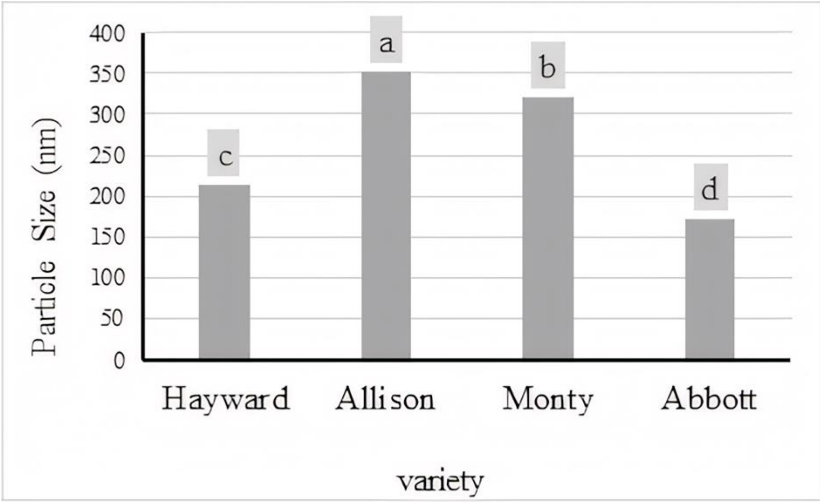
Particle Size (nm)
400
350
300
250
200
150
100
50
0
a
b
c
d
Hayward
Allison
Monty
Abbott
variety

Fig. 2

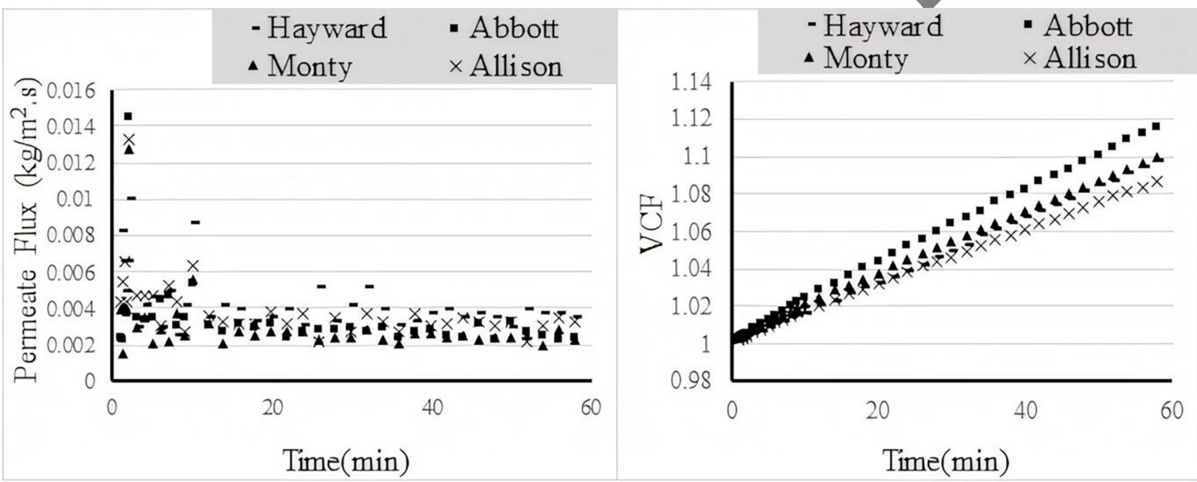
Hayward
Abbott
Monty
Allison
Permeate Flux (kg/m².s)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
20
40
60
Time(min)
VCF
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
Time(min)

Fig. 3

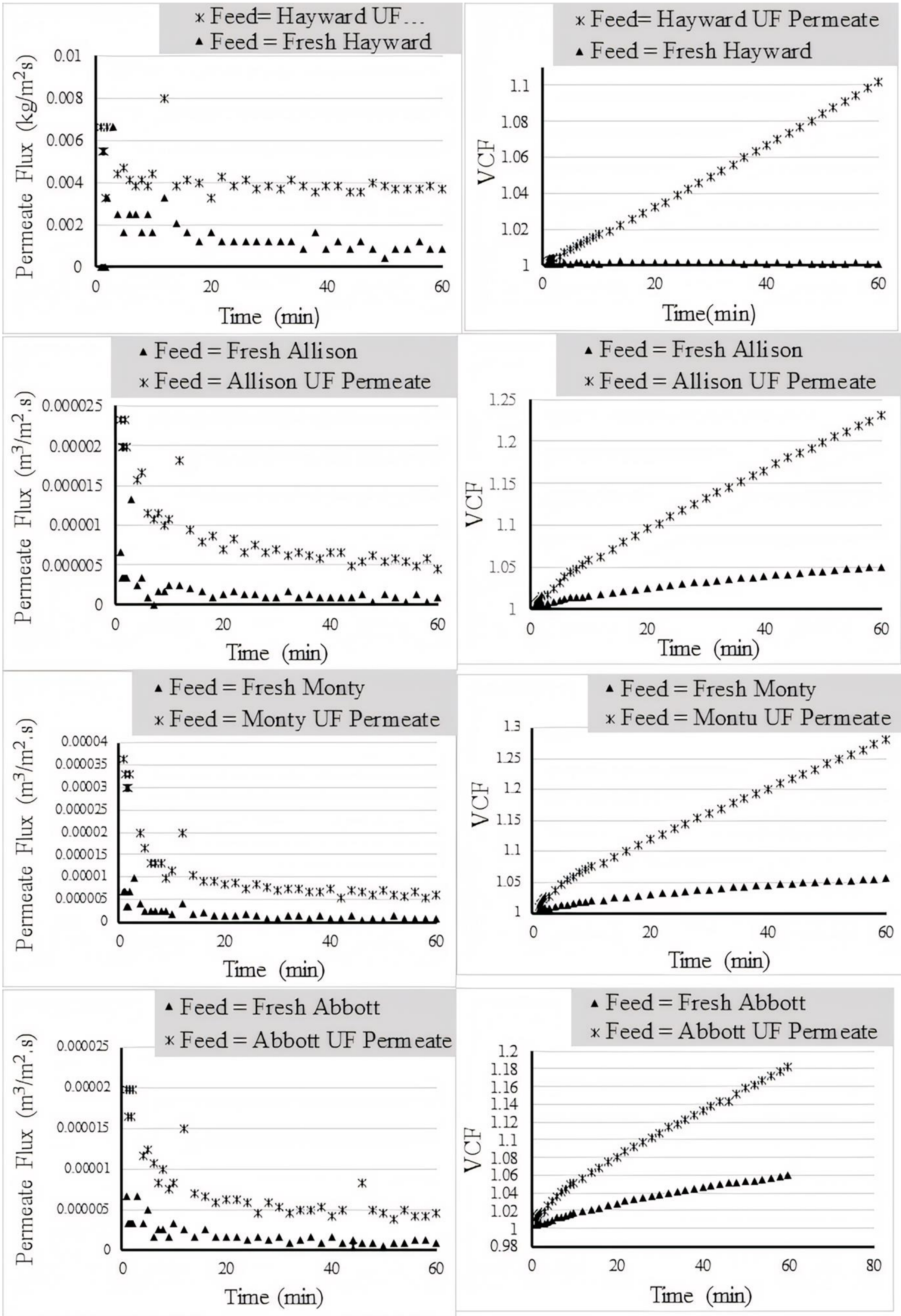
Feed= Hayward UF…
Feed = Fresh Hayward
Permeate Flux (kg/m2s)
0.01
0.008
0.006
0.004
0.002
0
0
20
40
60
Time (min)
Feed= Hayward UF Permeate
Feed = Fresh Hayward
VCF
1.1
1.08
1.06
1.04
1.02
1
0
20
40
60
Time(min)
Feed = Fresh Allison
Feed = Allison UF Permeate
Permeate Flux (m3/m2.s)
0.000025
0.00002
0.000015
0.00001
0.000005
0
0
20
40
60
Time (min)
Feed = Fresh Allison
Feed = Allison UF Permeate
VCF
1.25
1.2
1.15
1.1
1.05
1
0
20
40
60
Time (min)
Feed = Fresh Monty
Feed = Monty UF Permeate
Permeate Flux (m3/m2.s)
0.00004
0.000035
0.00003
0.000025
0.00002
0.000015
0.00001
0.000005
0
0
20
40
60
Time (min)
Feed = Fresh Monty
Feed = Montu UF Permeate
VCF
1.3
1.25
1.2
1.15
1.1
1.05
1
0
20
40
60
Time (min)
Feed = Fresh Abbott
Feed = Abbott UF Permeate
Permeate Flux (m3/m2.s)
0.000025
0.00002
0.000015
0.00001
0.000005
0
0
20
40
60
Time (min)
Feed = Fresh Abbott
Feed = Abbott UF Permeate
VCF
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0
20
40
60
80
Time (min)

Fig. 4

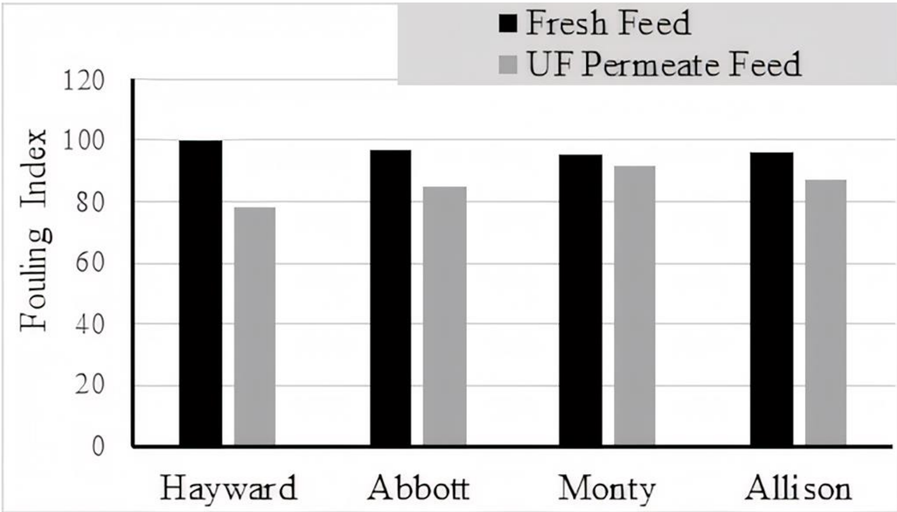
Fresh Feed
UF Permeate Feed
Fouling Index
120
100
80
60
40
20
0
Hayward
Abbott
Monty
Allison

Fig. 5

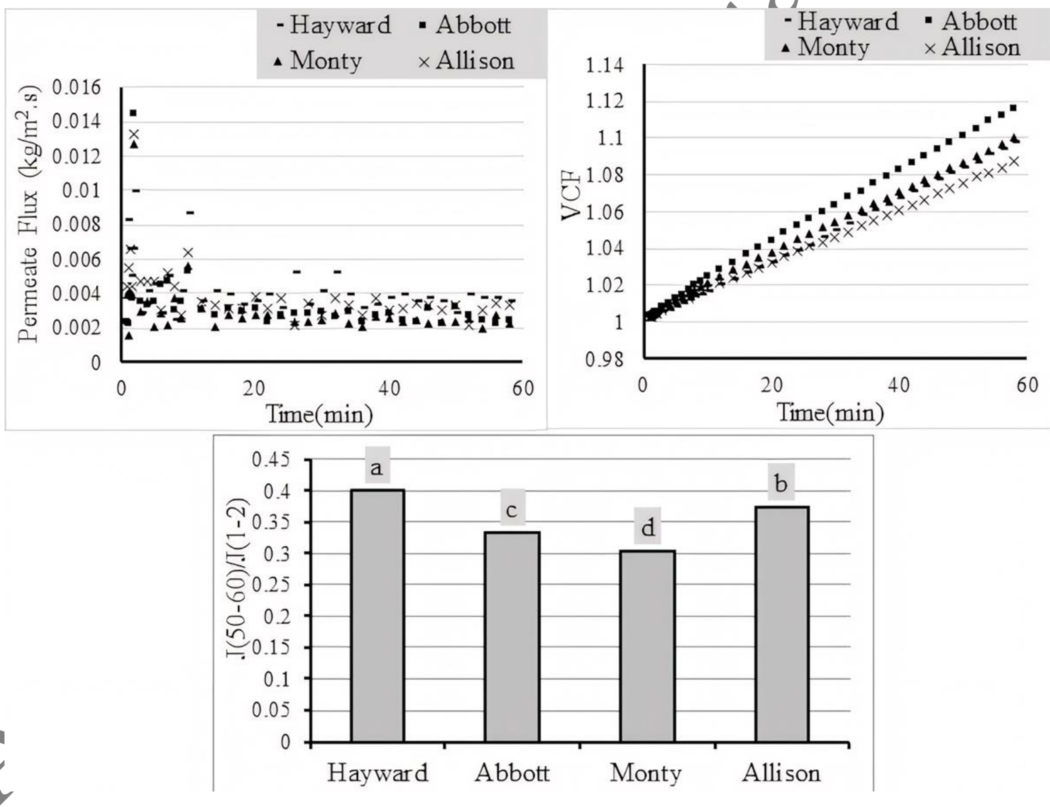
Hayward
Abbott
Monty
Allison
Permeate Flux (kg/m².s)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
20
40
60
Time(min)
Hayward
Abbott
Monty
Allison
VCF
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0
20
40
60
Time(min)
J(50-60)/J(1-2)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
a
c
d
b
Hayward
Abbott
Monty
Allison

Fig. 6

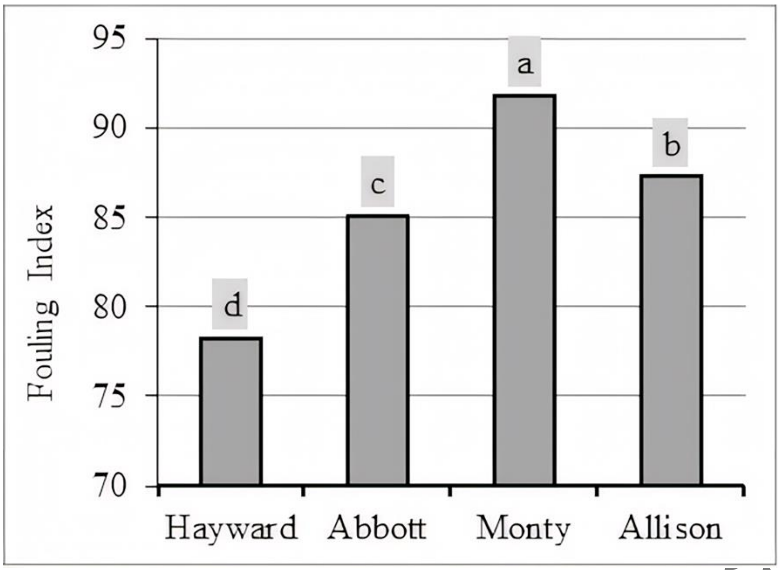

Fig. 7

Authors' biographies

Amir Pourmoradian was born on September 3, 1999, in Tehran. He received his bachelor's degree in Food Science and Engineering from Islamic Azad University and his master's degree in the same field from the University of Tehran. He is PhD student of Food Science and Technology at Tarbiat Modares University.

Hossein Mirsaeedghazi was born on August 25, 1979 in Tonekabon. He received his bachelor's degree in Food Science and Engineering from Ferdowsi University of Mashhad and his master's and doctorate degrees in the same field from the University of Tehran. He joined the University of Tehran as a faculty member in 2010 and has been working at this university since then in the specialized field of membrane processes in fruit juice processing. For up-to-date information, you can refer to the following link:

https://scholar.google.com/citations?user=3y5tC1gAAAAJ&hl=fa&oi=ao

Seyyed Abbas Mousavi was born on 1976 in Sari. He received his bachelor's, master's and doctorate degrees in Chemical Engineering from the University of Sharif. He joined the University of Sharif as a faculty member in 2008. For up-to-date information, you can refer to the following link:

https://scholar.google.com/citations?user=fXkAoUEAAAAJ&hl=en