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Effect of Pre-treatment on Aggregation, Biochemical Quality and Membrane Clarification of Pomegranate Juice

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Abstract: Pomegranate (*Punica granatum* L., Punicaceae) is the most popular tropical non-citrus fruits, mainly because of their attractive aroma, refreshing flavour and Brix/acid ratio. The research was carried out on the physicochemical analysis and membrane clarification of pomegranate juice after pretreatment. Pretreatment of pomegranate juice was performed using egg albumin with different concentrations and observed that 2 g/L concentration gave effective removal of colloidal substances of both juices. The biochemical analysis of pomegranate juice after pretreatment revealed the that of TSS, colour intensity, browning index, turbidity, titrable acidity, pH, viscosity, total antioxidant activity, total phenolic content, total anthocyanin content, reducing sugars, non-reducing sugars, total sugars and colour as 12.985%, 7.695, 4.726, 0.751%, 0.784%, 4.753, 2.326 cP, 37.221 mg/g, 57.225 (mg of GAE/g of dry material), 12.461 mg/100mL, 5.754%, 2.671%, 8.425% and 3.842, respectively. There were significant differences among all the treatments of pomegranate juice. Permeate flux generally declined with time for both microfiltration (MF) and ultrafiltration (UF). However, increase in permeate flux was achieved with increase in TMPs and feed flow rates. The permeate flux was high during MF of pomegranate juice than UF. The decrease in pore size and MWCO also decreased the permeate flux. In MF and UF of pomegranate juice, the initial fluxes were high but gradually decreased.

Keywords: Membrane clarification, Microfiltration, Ultrafiltration, Egg albumin, Permeate flux, MWCO, Pore size

Pomegranate is an important fruit crop grown in India. It is originated in Iran and extensive pomegranate farming is done in the Mediterranean countries like Spain, Morocco, Egypt, Iran, Afghanistan, and Baluchistan. India ranks first in pomegranate cultivation in the world. Ganesh, Bhagwa, Ruby, Arakta and Mridula are the important commercial cultivars. Maharashtra is leading with 147.9 thousand ha area with annual production of 1789 thousand MT and productivity of 12.10 MT/Ha. Andhra Pradesh and Telangana states record the productivity of pomegranate with 14.69 and 13.36 MT/Ha, respectively. India ranks sixth in the production of pineapple among the world countries.

Pomegranate (*Punica granatum* L., Punicaceae) is the most popular tropical non-citrus fruits, mainly because of their attractive aroma, refreshing flavour and Brix/acid ratio. This juice have been used in fruit based beverages individually, in the form of mixture or combined with other fruit juices. As an ingredient, the concentrated juice from pomegranate blends well with other aromas of fruits resulting in a pleasant product with a competitive market price. Pomegranate, mainly produced in the middle east have a number of nutritional and health benefits and is a potential source of anthocyanins, ellagic acid, phytoestrogenic flavonoids, tannins and organic acids, some of which are antioxidants. Further, as reported in biological studies, pomegranate juice is rich in anti-atherosclerotic and anti-atherogenic compounds which have been shown to reduce blood pressure and low density lipoprotein oxidation (Aviram and Dornfeld 2001). Due to these characteristics and increasing public awareness about nutritional food, the demand for the pomegranate fruit has significantly increased in the last years. Consequently, many industries producing pomegranate fruit juice as well as pharmaceutical companies extracting health beneficial compounds from the fruits have been developed. There is a worldwide increasing tendency for the consumption of tropical fruits, juices and fruit drinks due to the interest in ready to consume healthy products. Fruit juices are liquid foods that provide vitamins, sugars, mineral compounds and water. Consumers have individual preferences for specific appearance, consistency and flavor characteristics. Traditional methods of processing fruits limit the possibility to retain freshness as much as possible and its health-beneficial compounds. For instance, conventional juice clarification processes are based on the use of clarifying agents (gelatin, bentonite, diatomaceous earth, etc.) which create serious problems on the juice quality and freshness. Similarly, the concentration of fruit juices by thermal evaporation results in color degradation and reduction of most thermally sensitive compounds. Membrane technology is an alternative to produce a juice with good nutritional characteristics as it does not destroy the vitamins and other nutrients. It is also an alternative because of its operational advantages such as mild temperature, ease of scale-up and simplicity.

Introduction of membrane processing enables production of additive-free juices with high quality and natural fresh like taste. Juice clarification, stabilization, depectinization and concentration are typical steps in which membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) can be potentially utilized. Clarification based on membrane processes, particularly UF and MF, have replaced conventional clarification, resulting in elimination of chemical clarifying agents and simplified process for continuous production. Purpose of the membrane processing is to remove suspended solids as well as haze-inducing and turbidity causing substances to obtain a clear juice after storage. Keeping in view of the above points, a study was undertaken on membrane processing of pomegranate juice after pretreatment with egg albumin. The study also constituted the analysis of physicochemical characteristics of juice and establishing operational parameters to achieve high permeate flux.

MATERIAL AND METHODS

Pomegranate of (cv. *Ganesh)* variety were obtained from local market, Bapatla, Guntur dist. Andhra Pradesh. These varieties were chosen as a good juice. Sodium Benzoate, egg albumin powder, glass bottles of 250 mL were procured from National Scientific, Guntur, Andhra Pradesh. The fruits procured were properly sorted to discard fruits of mechanical damage while transportation. Pomegranate fruits were peeled, seeds were collected and juice was extracted.

Pre-treatment on aggregation and clarification of pomegranate juice: The pomegranate juice of was used to determine the effect of pre-treatment on aggregation and clarification parameters. The pre-treatment was performed using a fining agent called egg albumin. The juice was subjected to four concentration levels *i.e.,* 0.25, 0.5, 1 and 2 g/L and effect of pretreatment was analysed. After the collection of juice, the egg albumin powder was added and mixed thoroughly. The juice samples were muslin cloth filtered and centrifuged at 4000 rpm (2147 g) for 5 min (Domingues et al 2011). The supernatant was used for biochemical quality analysis to determine the effect of pretreatment. The concentration of egg albumin which resulted in better clarification was determined by biochemical quality analysis. This concentration was subsequently used for pre-treatment of both pineapple and pomegranate juices in all the experiments. The pre-treatment was performed to remove the colloidal substances present in the juices. Colloids can decrease the permeate flux during filtration of the juice due to presence of pectinases, cellulase, hemicellulase, xylanase, carbohydrase, glucanase or arabinose. Removal of aggregates of these species via pretreatment may increase the permeate flux due to the reduction in the size of the particles and the subsequent decrease in viscosity (Valero et al 2014). The results of the biochemical analysis were expressed statistically with complete randomised block design (CRD). The details of independent and dependent variables for pretreatment on aggregation and clarification of juices were as shown below

Independent variables	Dependent variables
Concentrations of egg albumin: 0.25, 0.5, 1 and 2 g/L	Total soluble solids (TSS)
	pH
	Turbidity
	Viscosity
	Titrable acidity
	Colour
	Colour intensity
	Browning index
	Total antioxdant activity (TAA)
	Total phenolic content (TPC)
	Total anthocyanin content (TAC)
	Reducing and non-reducing sugars
	Total sugars

The pre-treated pomegranate juice with egg albumin was subjected to physicochemical analysis. Total soluble solids (TSS) of juice were measured by Refractometer (ATAGO make, range 58-90%) and expressed in terms of % Brix. The pH measurement was performed using a digital pH meter (Systronics digital pH meter 355). The colour intensity was measured using a Systronics PC based Double Beam Spectrophotometer at absorbance of 510 nm. Similarly, Browning index was expressed as the ratio of 420 nm to 520 nm using Systronics PC based Double Beam Spectrophotometer (Valero et al 2014). The turbidity and color was also measured using Systronics PC based Double

Beam Spectrophotometer at absorbance of 700 nm and 420 nm respectively. The turbidity values of both juices were measured according to the procedure given by Valero et al (2014).Titrable acidity of both juices are determined by the procedure of AOAC (2005). Titrable acidity is expressed as the amount of free acid mainly as anhydrous citric acid present in fruit, conveniently in g acid per 100 g or 100 ml.

$$\% \text{ acidity} = \frac{a \times b \times c \times d \times 100}{e \times w \times 1000} \quad (1)$$

where, a = titre value (volume of 0.1N NaOH)

b = Normality of the alkali (0.1N), c = volume made up, d = equivalent weight of the acid, w = weight or volume of sample taken (g or ml) , e = aliquot

Viscosity of the fruit juice was determined by using Digital Viscometer (Brookfield, Model: DV1MLV). Lane and Eynon method (Ranganna, 1986) was used for determination of total, reducing and non – reducing sugars.

$$\text{Reducing sugars \%} = \frac{\text{(factor (0.052)×dilution ×100)}}{\text{(titre×wt. of sample)}} \quad (2)$$

$$\text{Total sugars \%} = \frac{\text{(factor (0.052)×dilution ×100)}}{\text{(titre×wt. of sample)}} \quad (3)$$

Non-reducing Sugars % = Total Sugars – Reducing Sugars (Ahmmed et al 2015)

The antioxidant assay was estimated by ferric reducing antioxidant power method using ascorbic acid as standard and total Phenolic content by Folin Ciocalteu's method using gallic acid as standard (Kametkar et al 2014). Anthocyanins are water soluble phenolic glycosides belonged to flavonoid pigments having C_{15} skeleton of flavones as basic structural unit.

$$\text{Total O.D./100 ml} = \frac{\text{O.D. ×Volume made up ×100}}{\text{ml of juice taken}} \quad (4)$$

$$\text{Total anthocyanin (mg/100 ml)} = \frac{\text{Total O.D./100 ml}}{87.3} \quad (5)$$

Membrane clarification of pomegranate juice: Membrane clarification (MF and UF) of pomegranate juice after pretreatment was carried out at Dr. N.T.R. College of Agricultural Engineering, Bapatla in hollow fibre membrane module setup (Model: HFM – 01, Technoquips Seperation Equipments, Kharagpur). The term membrane processing in this thesis is essentially clarification of juices using membranes.

Hollow fibre membrane module setup: The schematic of hollow fiber membrane set up is shown in Figure 1 and Plate 1. The heart of the setup is the hollow fiber module (F). The feed is drawn by the booster pump (C) and fed to the module by 6 mm polyurethane tube via a Perspex flange. Two pressure gauges in the range of 0 to 60 psi (4.1364 bars) are attached to the upstream and downstream of the module. A22.5*cm* needle valve (J) of stainless steel has been fitted in the retentive line after the module. This valve is used for fine tuning of pressure and flow rate through the module. A rotameter (K) of range 0 to 50 L/h is attached to the retentive line and the retentive stream is recycled back to the feed tank (A). A bypass line is connected from the pump to the feed tank and 15 cm stainless steel needle valve (B) is attached to the bypass line. The permeate flows through a 5 mm polyurethane pipe into permeate collector (G). By controlling the bypass valve (B) and retentive valve (J), one can control the flow rate and the trans membrane pressure drop across the module, independently. The trans membrane pressure drop is the arithmetic average of the readings in the pressure gauges E and I. The physical dimension of the setup is 70 mm in length, 48 mm in width and 65 mm in height. The weight of the setup is approximately 10 kg. One power point of domestic line 220 V is required to run the pump.

where,

A: Feed tank, B: Bypass valve, C: Booster pump, D: Short piece, E: Upstream pressure gauge (0 – 4.21 kg/cm^2(60 psi)), F: Hollow fibre module, G: Permate collector, H: Short piece, I: Downstream pressure gauge (0 – 4.21 kg/cm^2(60 psi)), J: Pressure valve (Needle type), K: Rotameter (0 – 50 Lph)

Membrane processing of pomegranate juice was carried out in the membrane module setup with different hollow fibre

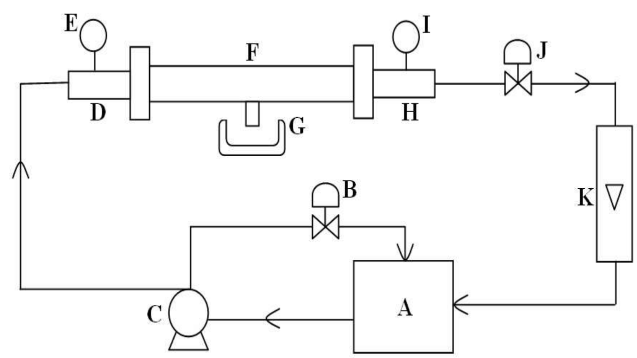

Fig. 1. Schematic diagram of the hollow fibre membrane module setup

Plate 1. Hollow fibre membrane setup

cartridges. The container was filled with 250 mL of juice. The operation was done in total recycle mode. The suction, retentate, by-pass lines were kept in feed solution and continuous operation was carried out. The permeate was collected at permeate line separately. All microfiltration (MF) and ultrafiltration (UF) experiments were carried out at trans membrane pressures (TMPs) of 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi). The pore sizes of hollow fibre cartridges used for microfiltration and ultrafiltration experiments were 0.1 and 0.2 μm and 120, 70, 44 and 120 kDa (MWCO), respectively. The permeate was collected at regular intervals of time and tabulated. Initially the membranes were compacted at 1.0342 bar 15 psi, 30 Lph with distilled water for 2 hours in total recycle mode. The technical specifications of MF and UF membrane were given in Table 1 and Table 2, respectively. Further, pure water flux data was collected both for MF and UF membranes using distilled water. After each run, the set up was flushed with distilled water and then cleaned with 0.1 N hydrochloric acid (HCl) for 30 mins in total recycle mode according to the washing protocol given by the manufacturer. After thorough washing, the permeability of the cartridges was analysed to measure the change in permeability of the hollow fibres. All the experiments were conducted in triplicate at room temperatures (30±2 °C). After every experiment, the membranes were cleaned properly and stored in the 1% formalin solution for future use.

Permeate flux was calculated as

$$J^* = \left(\frac{1}{A}\right) \times \left(\frac{dv}{dt}\right) \qquad (6)$$

Where, J*= Permeate flux (L/h m^2), A= Area of the membrane (m^2), dv= Volume of flow rate (L), dt= Time of flow rate (h)

The permeate collected was stored in glass bottles. The experiments were performed according to the different conditions laid down in the Table 3 and analysed to obtain high permeate flux.

RESULTS AND DISCUSSIONS

Pre-treatment of pomegranate juice: In pomegranate juice after the pre-treatment, 2 g/L concentration level recorded highest removal of colloidal substances. There was a decrease in all the constituents of the juice. However, the decrease of constituents was not high to loose the essential components of juice. Pomegranate juice resulted in effective decrease in constituents at 2 g/L concentration of egg albumin. The decrease in complex colloidal components might increase in permeate flux of the juice decreasing the fouling colour intensity of pomegranate juice. This was in accordance with Mirsaeedghazi et al (2010). The pomegranate juice presented a significant decrease in all the biochemical attributes as the concentration level of egg

Table 3. Operating variables for microfiltration and ultrafiltration of pomegranate juices

Operating variables	
Membrane poresizes:	MF - 0.1 and 0.2 μm UF – 120, 70, 44 and 10 kDa
Transmembrane pressures (TMP):	0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi)
Crossflow Velocities/ Feed flow rates:	0.024 m/s (20 Lph), 0.037 m/s (30 Lph) and 0.049 m/s (40 Lph)

Table 1. Technical specifications of MF membranes

Membrane material	Pore size (μm)	Water permeability as claimed by the manufacturer (m / Pa.s)
Poly acrylonitrile (PAN) (Make: M/s Technoquips seperations equipments Pvt.Ltd., Kharagpur)	0.2	53.4×10^{-11}
Poly acrylonitrile (PAN) (Make: M/s Technoquips seperations equipments Pvt.Ltd., Kharagpur)	0.1	44.5×10^{-11}

Table 2. Technical specifications of UF membranes

Membrane material	Pore size (kDa)	Water permeability as claimed by the manufacturer (m / Pa.s)
Poly SuLphone (PS) (Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur)	120	29.7×10^{-11}
Poly SuLphone (PS) (Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur)	70	24.3×10^{-11}
Poly SuLphone (PS) (Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur)	44	20.5×10^{-11}
Poly SuLphone (PS) (Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur)	10	13.4×10^{-11}

albumin increased which enhanced the filtration process while membrane processing by high permeates flux.

Browning index decreased in pomegranate juice upon using egg albumin as pre-treatment (Valero et al 2014). Pomegranate juice recorded the low BI values. BI values were high prior to the pre-treatment in non- clarified juice. Similarly, Alper et al (2005) also observed decrease in browning degree for non-clarified juice. A decrease of 49.1% was obtained with gelatine and bentonite combined conventional fining. Browning index values observed as 4.726 for pomegranate juice in 2 g/L concentration level of egg albumin.

The turbidity values decreased as the concentration level increased. The highest clarity was obtained with 2 g/L egg albumin. Similarly turbidity was also decreased with addition of PVPP and bentonite and increased the clarity of the juices (Valero et al 2014, Samreen et al 2020). Titrable acidity (TA) values decreased as the concentration of egg albumin increased. The pH values increased in pomegranate juice. The TA for pomegranate juice was 0.784% expressed as citric acid. Similarly, the pH of pomegranate juice was 4.753. The results were best for 2 g/L concentration level of egg albumin. However, there was a significant difference among all the concentration levels of egg albumin. Similar, results were recorded by Alighourchi et al (2009). Initially the concentration level 0.25 and 0.5 g/L did not show any significant difference in the values. They were approximately same in terms of pH of both the juices (Molina et al 2009).

Viscosity of the juices decreased with increase of concentration level of egg albumin. The mean values of viscosity of pomegranate juice at 2 g/L concentration level were recorded as 2.326±0.05 cP. There was a significant decrease in viscosity of pomegranate juice at different concentration levels of egg albumin. As the pomegranate juice is very light juice with less colloidal substances, the decrease of viscosity was recorded. The antioxidant activity decreased as the concentration level of egg albumin increased. The highest decrease was observed in 2 g/L egg albumin of pomegranate juice as 37.2218 mg/g. The centrifugation and clarification process might aid to the decrease in the antioxidant activity of the juice. Similar results were recorded by Vegara et al (2013) in terms of pomegranate juice. The results pertaining to antioxidant activity obtained in this study were not in accordance to Valero et al (2014) where the antioxidant activity increased upon increase of concentration level of egg albumin.

Total phenolic content of the juice also significantly decreased with increase of concentration level of egg albumin. Similar results were obtained by Valero et al (2014) in decrease of total phenolic content with 2 g/L egg albumin. The decrease of phenolic content might be due to the changes in the different clarification techniques with egg albumin. Total anthocyanin content decreased as the concentration of egg albumin in clarification increased. There was no significant difference for pomegranate juice at 0.25 and 0.5 g/L of egg albumin. The anthocyanin significantly decreased for 1 and 2 g/L egg albumin. Anthocyanin compounds are labile and undergo degradative

Table 4. Biochemical characteristics of pomegranate juice after pretreatment with different concentrations of egg albumin

Property	Concentration of egg albumin (g/L)			
	0.25	0.5	1	2
Total soluble solids (%)	13.783 ± 0.01	13.453 ± 0.010	13.156±0.010	12.985±0.010
Colour intensity	7.765±0.010	7.744±0.021	7.714±0.010	7.695±0.010
Browning index	6.944±0.010	5.926±0.015	5.483 ±0.015	4.726±0.015
Turbidity	0.781±0.050	0.775±0.050	0.768±0.020	0.751±0.050
Titrable acidity (%)	1.184±0.020	1.155±0.010	0.927±0.010	0.784±0.050
pH	4.036±0.015	4.23± 0.02	4.583±0.050	4.753 ± 0.050
Viscosity (cP)	4.826±0.010	4.105±0.010	3.557±0.010	2.326±0.050
Total antioxidant activity (mg/g)	42.521±0.010	40.251±0.010	38.532±0.020	37.221 ± 0.066
Total phenolic content (mg of GAE/g of dry material)	79.416±0.010	76.844±0.588	75.143±0.030	57.225±0.050
Total anthocyanin content (mg/100 mL)	14.493±0.010	13.971±0.050	13.257±0.010	12.461±0.050
Reducing sugars (%)	7.202±0.017	5.992±0.011	5.853±0.010	5.754±0.010
Non-reducing sugars (%)	4.052±0.050	4.833±0.050	3.8±0.05	2.671±0.010
Total sugars (%)	11.254±0.011	10.825±0.050	9.653±0.010	8.425±0.010
Colour	3.994 ±0.010	3.994±0.010	3.895±0.010	3.842± 0.010

F_{tab} = 4.0661

reactions. There are many variations in the stability of the structure of anthocyanins. Anthocyanins remain stable in dried form than in state of high water activity.

Reducing sugars significantly decreased in pomegranate juice. The highest decrease was recorded to 2 g/L concentration level egg albumin. The mean values of decrease obtained for pomegranate was recorded as 5.754%. Similarly, the decrease was obtained for total sugars and non - reducing sugars. A slight increase was observed in non - reducing sugars in pomegranate juice at 1 g/L egg albumin concentration. The increase might be achieved because of conversion of some sugars during hydrolysis. Total sugars significantly decreased in pomegranate juice as the concentration level increased. The decrease of total sugars was achieved due to conversion into simpler sugars while hydrolysis in pomegranate juice.

The colour values significantly decreased for pomegranate juice. Anthocyanins are phenolic compounds responsible for pomegranate juice colour. As, the phenolic content of the juices were in decreasing trend, the anthocyanins also decreased in juices. This might be the reason for the decrease of colour in juice as anthocyanins decreased. The loss of anthocyanin pigments occurred because of addition of egg albumin as it is sequestering agent it removes the colloidal substances in flocks which might have reduced the pigments in turn aided to decrease in colour of juice. Vardin and Fenercioglu (2003) recorded the same decrease with the use of gelatine addition and natural sedimentation. The 2 g/L egg albumin was the best concentration level as flocculating agent to remove the colloidal substances and this was utilized as pre-treatment prior to membrane processing of pomegranate juice to increase permeate flux and reduce fouling.

Membrane processing of pomegranate juice and establishing operational parameters to achieve high permeate flux: The pomegranate fruit juice was collected after pre-treatment with egg albumin. According to the pre-treatment analysis, the best concentration was observed at 2 g/L egg albumin. The pomegranate juice after pre-treatment with egg albumin was refrigerated for further membrane processing. In membrane processing, both Microfiltration (MF) and Ultrafiltration (UF) hollow fibre cartridges were used for clarification of pomegranate juice. The different combinations of membrane pore sizes, trans membrane pressures and flow rates were given in table 4.

MF of pomegranate juice: Pomegranate juice after pretreatment with egg albumin was subjected to membrane processing using microfiltration with membrane pore sizes of 0.2 and 0.1 µm. The permeate flux declined with time on both the membranes (Fig. 2 and 3). As the membrane pore size increased, the permeate flux increased. Similarly, the increase in TMP also increased the permeate flux (L/m^2h). The increase in feed flow rate also resembled the same increase in permeate flux. The highest permeate flux 125.523 L/m^2h was for 20 psi pressure and 40 Lph flow rate. Similar results were obtained for pomegranate juice clarified by 0.1µm membrane pore size (Fig. 3). The flux decreases sharply initially due to membrane fouling and gradually thereafter and finally attains a steady state value. Similar results were obtained by Rai et al (2006) for mosambi juice and Karmakar et al (2017) for coconut water. The difference in steady state values for both the pore sizes was marginal. Similar results were observed during MF of Tomato juice (Bottino et al 2002). The processing time increased there was a decline in permeate flux probably because of deposition of colloidal substances while clarification on membrane surface. These colloidal substances offer resistance to flow of permeate which leads to fouling. Fouling may have occurred due to pore narrowing by smaller particles that may have accumulated on the pore walls (Chilukuri et al 2001, Samreen et al 2020) or by pore plugging. High amount of permeate flux was obtained for 0.2 µm pore size probably because of its larger pore size. High fluxes were recorded due to pre-treatment with egg albumin at 2 g/L concentration as large floccs of colloidal substances were removed.

UF of pomegranate juice: Ultrafiltration (UF) of pomegranate juice was carried out with four different hollow fibre membranes with different molecular weight cut off (MWCO) *i.e.,* 120, 70, 44 and 10 kDa, trans membrane pressures 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi) and three flow rates 20, 30, 40 Lph. After pretreatment with egg albumin at 2 g/L concentration, pomegranate juice was subjected to membrane processing. It was observed through the biochemical quality analysis that large colloidal substances present in the juice was removed in the form large floccs as egg albumin is a good flocculating agent. The permeability of UF membranes was determined using distilled water at different pressures prior to the ultrafiltration of pomegranate juice.

120 kDa MWCO membrane: Pomegranate juice when subjected to UF treatment, there was decline in the permeate flux of juice (Fig. 4). The highest flux was obtained at high feed flow rates and high trans membrane pressures. Highest rate of permeate flux obtained was 111.721 L/m^2 h. The permeate flux gradually declined and reached a steady state value after prolonged duration of processing (Bottino et al 2002). The lowest value of permeate flux (7.448 L/m^2h) was obtained at 20 Lph, 5 psi trans membrane pressures.

However, the permeate flux during UF with 120 kDa MWCO was lesser than both MF 0.1 and 0.2 µm membranes. This might be because of the tighter asymmetric membrane structure of UF compared to MF. Probably, the reason for good permeate flux after long duration of filtration process might be the formation of secondary layer. The secondary layer would have given slightly higher and more sustainable flux because of the permeability of the layer. However, there was gradual decline in flux as the duration of processing increased because of formation of fouling on the membrane surface and also might be because of pore narrowing or pore clogging (Chilukuri et al 2001).

70 kDa MWCO membrane: Highest flux obtained for 40 Lph flow rate and 20 psi trans membrane pressure was about 99.388 L/m^2 h (Fig. 5). The lowest flux obtained for 20 Lph flow rate, 5 psi (0.3447 bars) TMP was about 7.297 L/m^2 h. The permeate flux decreased as the duration of filtration was increased. The TMP and flow rate were the driving forces to increase the permeate flux. The values of permeate flux for 20 psi (1.37890 bar) were high compared to all the remaining TMPs. Similarly lowest values of permeate flux were for 5 psi (0.3447 bar) TMP. All the permeate flux values gradually decreased and attained steady state values in the range from 7.297 to 20.179 L/m^2 h for low to high TMPs. Similarly, decline of permeate flux was observed by Cassano et al (2011) during pomegranate juice clarification.

The decline in permeate flux might have occurred because of concentration polarization on the membrane surface. The concentration polarization might have occurred because of the some colloids which could not be removed in the pre-treatment process of egg albumin. These colloids might adhere to the membrane surface causing plugging of pores. This in turn could have reduced permeate flux of the juice. The fouling might be predominant because of the tighter membrane pore size where easy clogging of membrane would have taken place. Initially high amount of flux rates were achieved because of the high TMPs and flow rates but gradually the permeate flux decreased. The increased flux rates initially might also because clean membrane in which the pores were unclogged.

44 kDa MWCO membrane: The pomegranate juice clarification was also performed with 44 kDa MWCO membranes at different trans membrane pressures and flow rates. The membrane permeability of the 44 kDa membrane was verified with different TMPs. The membrane permeability for 44 kDa Poly sulphone (PS) membrane was 18.3×10^{-11} m^3/m^2s Pa (Fig. 6). The calculated membrane permeability was in accordance with the membrane permeability given by the manufacturer in operational details of equipment (20.5×10^{-11} m^3/m^2 s Pa). During the membrane processing of pomegranate juice with 44 kDa MWCO membrane, the permeate flux declined gradually. The range of permeate flux obtained was from 94.143 to 5.031 L/m^2h. The decrease in permeate flux was probably due to concentration polarization by sediments of pomegranate which could not be removed while aggregation process with egg albumin.

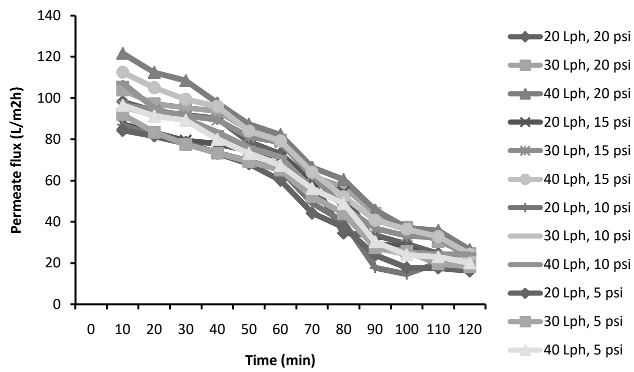

Fig. 2. Flux decline during MF of pomegranate juice using 0.2 µm pore size membrane at different TMPs and feed flow rates

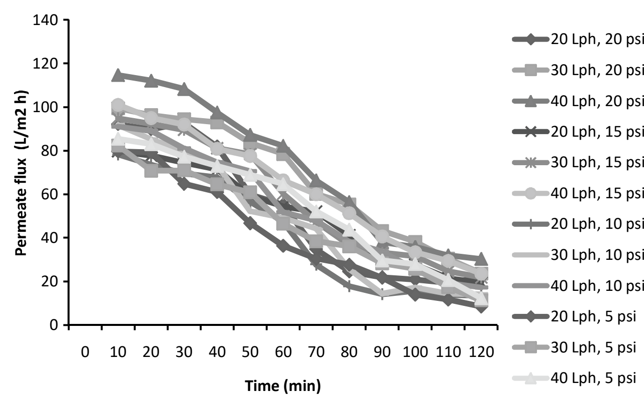

Fig. 3. Flux decline during MF of pomegranate juice using 0.1 µm pore size membrane at different TMPs and feed flow rates

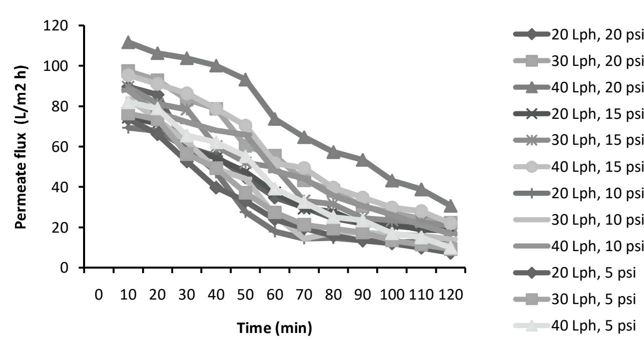

Fig. 4. Flux decline during UF of pomegranate juice using 120kDa MWCO membrane at different TMPs and feed flow rates

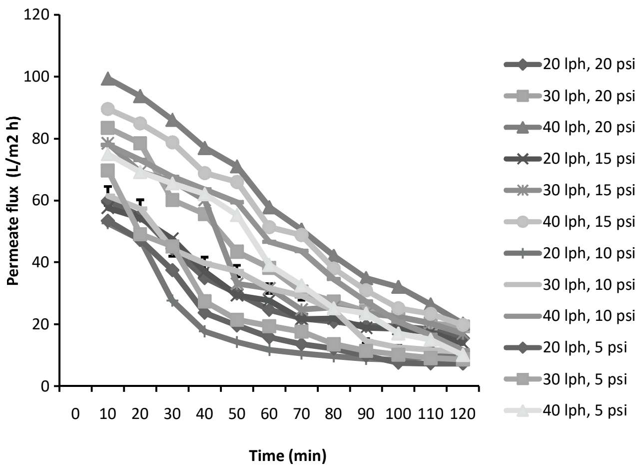

Fig. 5. Flux decline during UF of pomegranate juice using 70 kDa MWCO membrane at different TMPs and feed flow rates

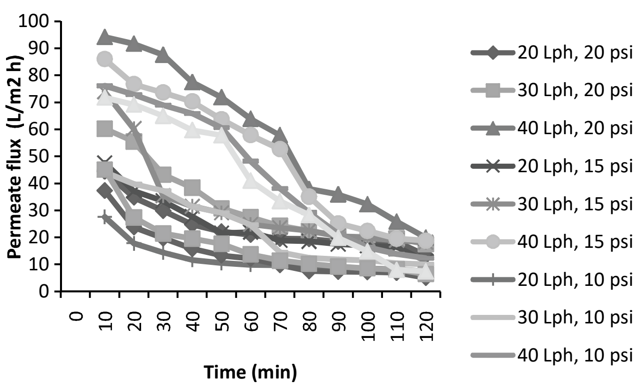

Fig. 6. Flux decline during UF of pomegranate juice using 44 kDa MWCO membrane at different TMPs and feed flow rates

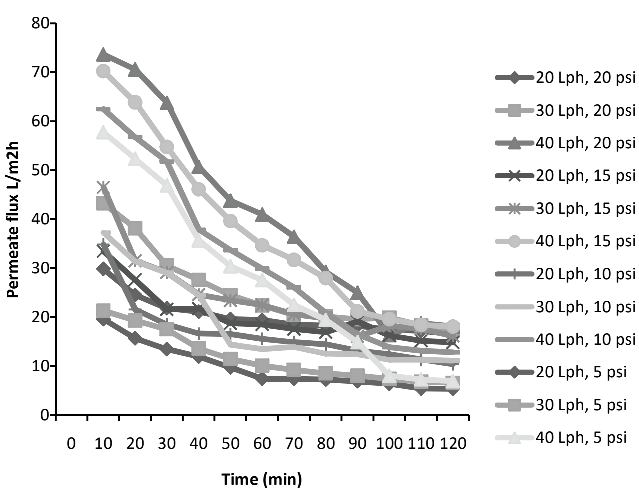

Fig. 7. Flux decline during UF of pomegranate juice using 10 kDa MWCO membrane at different TMPs and feed flow rates

10 kDa MWCO membrane: The decline in flux was observed in 10 kDa MWCO membrane (Fig. 7). The permeate flux obtained for 10 kDa MWCO membrane was low compared to the 44 kDa MWCO membrane. The lowest permeate flux was recorded among all the membranes. This might be because of tighter membrane where the possibility of chances of fouling was high. Smaller solute particles left after removal of the colloidal particles in the juice could cause pore narrowing.

CONCLUSIONS

Pre-treatment of pomegranate juice was performed using egg albumin at different concentrations and observed that 2 g/L concentration gave good results in removal of colloidal substances of both juices. Optimum concentration of flocculant *i.e.,* 2 g/L of egg albumin has been found to effectively remove the colloids. The TSS, colour intensity, browning index, turbidity, titrable acidity, pH, viscosity, total antioxidant activity, total phenolic content, total anthocyanin content, reducing sugars, non-reducing sugars, total sugars and colour. The characteristics were analyzed in permissible limits. Permeate flux declined with time in both MF and UF. However, increase in permeate flux was achieved with increase in TMPs and feed flow rates. The permeate flux was high for MF than UF. The decrease in pore size also decreased the steady state permeate flux.

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