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Clarification of guava juice by an ultrafiltration process: analysis on the operating pressure, membrane fouling and juice qualities

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Abstract

Fresh guava juice was clarified using ultrafiltration (UF) process on a laboratory scale in this study. The observation was undertaken to determine the effect of the operating pressure (OP) on the permeate flux (J) behaviour, the fouling mechanisms as well as the quality attributes of the guava juice i.e. pH, turbidity, colour, total soluble solids (TSS), total phenolic content (TPC) and ascorbic acid content (AAC). The clarification of guava juice was performed in a batch mode using a 100 kDa polymeric membrane in a dead-end module at an operating pressure OP of 1.0, 1.5, 2.0 and 2.5 bar. The results showed that a high OP resulted in high flux during the UF process. The flux-pressure curves exhibited no increase for an OP higher than 2.0 bar (P_{lim}), with a limiting flux (J_{lim}) identified at 17.22 kg/m^2/hr. Intermediate and total pore-blocking has been identified as the major fouling mechanisms in the process. The resulting juice after filtration showed a reduction of more than 97% turbidity with a lower TSS by 7 to 17%, compared to the fresh juice. The UF process permitted a good level of clarification with improvement in colour properties with a stable pH at 3.8. However, a 19 to 27% and 18 to 22% reduction of TPC and AAC, respectively were found in the filtered juice with respect to the fresh juice. For appropriate flux behaviour and juice quality attributes, the process UF should be conducted at 2.0 bar.

1. Introduction

Guava (*Psidium guajava* L.) fruit is very popular in many tropical and subtropical countries. This fruit is usually consumed fresh as it contains a high level of vitamin C and lycopene compared to orange fruit (Akesowan and Choonhahirun, 2013). Further, it is rich in vitamin A, omega-3 and -6 polyunsaturated fatty acids, dietary fibre, potassium, magnesium, and antioxidant pigments such as carotenoid and polyphenols (Akesowan and Choonhahirun, 2013). Due to its high potential in a health-promoting capacity, researchers and producers have made various explorations with regards to utilising this fruit for the development of different food products. One of the options is to promote guava as a healthy fruit juice.

However, similar to other typical fruit juices, guava juice contains macromolecules (100 to 1000 ppm) mainly pectin and other polysaccharides such as cellulose, hemicellulose that may affect the quality of the juice if it is stored for longer periods than a few days for commercial use (Bhattacharjee *et al.*, 2017). The colloids cause the juice to be cloudy as well as high in turbidity and viscosity which will reduce the consumer acceptance in some specific markets, either as pure guava juice or as mixtures with other juices (Ninga *et al.*, 2018). Hence, efforts have been made to clarify guava juice through enzymatic treatment using pectinase (Akesowan and Choonhahirun, 2013; Ninga *et al.*, 2018). However, this treatment may suffer a few drawbacks especially for industrial-scale applications such as the required processing conditions including temperature and pH that need to be closely monitored to ensure optimum enzyme reaction, and most of the enzymes are expensive to purchase or produce. In addition, improper disposal of the used enzymes may lead to environmental issues. Hence, a suitable processing method is needed to overcome these drawbacks by offering a feasible approach.

The membrane-based process offers an alternative to the conventional juice processing method e.g. enzymatic and heat treatment since it has many advantages such as

the absence of phase transition or chemical agents, enjoys mild operating conditions, is low cost and is easy when scaling up (Castro-Muñoz *et al.*, 2018). The membrane-based process is a method which selectively separates materials via pores and/or minute gaps in the molecular arrangement of a continuous structure (Bhattacharjee *et al.,* 2017). It is classified by pore size and by the separation driving force, which includes microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO) and nanofiltration (NF). Combination of membrane-based operations with other interesting applications have been suggested for replacement of conventional methodologies in fruit juice processing with most developed applications are related to the clarification and concentration of juices (Conidi *et al.,* 2018). The application of membrane processes for fruit juices has been extensively studied for the juices of apple, orange, pineapple and kiwifruit with the focus on different processing parameters (operating pressure, feed pH, feed concentration, crossflow velocity, temperature etc.) and juice quality attributes (clarity, color, pH, nutritional content etc.) (Bhattacharjee *et al.,* 2017). The advantages of using the membrane-based process are that it consumes lower energy which therefore reduces the operating cost, whilst allowing a significant improvement in the process efficiency and juice quality attributes such as colour, turbidity, and preservation of its natural bio-active compounds.

By considering its advantages, UF has great potential in guava juice processing. However, guava fruit has been minimally processed under industrial trials, and until now there have been no reports of processing guava juice by membrane technology. Thus, this study is aimed to explore the potential of applying the membrane-based process using ultrafiltration (UF) for guava juice clarification by observing its effect on the permeate flux behaviour, fouling mechanism and guava juice quality attributes. The information in this study will provide valuable insights for juice processing especially for the utilization of local guava fruit.

2. Materials and methods

2.1 Guava juice preparation

White guavas (*Psidium guajava* L.) of the GU8 variety which were fully-ripe and free from visual blemishes and bruises were purchased from a local market in Seri Kembangan, Malaysia. The fruits were washed with tap water, the skin peeled off and the fruit cut into small pieces. The peeled guavas were then processed using a juice extractor (PJ6900S, Pensonic, Malaysia). The guava fruit extract was filtered through a cheesecloth prior to centrifugation at 9000 rpm for

15 mins. The supernatant obtained was used as a feed for the ultrafiltration (UF) process.

2.2 UF experimental set-up and procedures

This process was carried out using a laboratory-scale membrane stirred cell unit (Amicon®, Millipore, USA) with a compressed air tank attached. The system was equipped with a polyethersulphone dead-end disc membrane with a molecular weight cut-off (MWCO) of 100 kDa, which has been reported to be suitable for clarification of natural juices and agro-food by-products (Castro-Muñoz *et al.*, 2018). The specification of the membrane used for the guava juice clarification in this study is shown in Table 1. Each UF experiment performed was executed with a capacity of 250 mL of juice at different operating pressures (OP) of 1, 1.5, 2 and 2.5 bar in order to find the limiting OP (OP_{lim}) that provided the maximum permeate flux for carrying out the batch concentration mode (Cassano *et al.*, 2007). The filtration process for each run was performed until it reached 80% of permeate recovery (PR) for the convenience of the process as described in Equation (1):

$$PR(\%) = \frac{V_p}{V_f} \times 100 \qquad (1)$$

Where V_f and V_p are the volume (g) of the feed and permeate, respectively. The performance of the UF process was measured in terms of the permeate flux (*J*) as described in Equation (2):

$$J = \frac{1}{A_m} \times \frac{\Delta W}{\Delta t} \qquad (2)$$

Where A_m is the effective membrane area (m^2) and ($\Delta W/\Delta t$) is the permeate weight ΔW collected over time Δt (kg.h^{-1}).

Table 1. The specifications of the membrane used for the guava juice clarification

Manufacturer	EMD Millipore Corporation
Configuration	Dead-end
MWCO (Da)	100,000
Membrane material	Polyethersulphon (PES)
Membrane area (m^2)	0.0032
Filter diameter (mm)	63.5

2.3 Modelling of the membrane fouling mechanism

In order to understand the fouling mechanism during the process, the flux decline was analysed through four types of fouling models, corresponding to cake formation, intermediate pore blocking, internal pore blocking and complete pore blocking phenomenon (Hermia, 1982). An explanation of each model is given below (Nor *et al.*, 2017):

Cake formation (n=0) occurs when particles form a gel layer over the membrane surface and can be

described by Equation (3):

$$J = J^* + (J_o - J^*)e^{(-k_a t)} \qquad (3)$$

Intermediate pore blocking (n=1) takes place when particles settle on other particles that have already been deposited on the membrane surface, which already block some pores and/or directly block an area of the membrane. It can be described by Equation (4):

$$J = \frac{J_o J^* e^{-k_b J^* t}}{J^* + J_o(e^{-k_b t} - 1)} \qquad (4)$$

Internal pore blocking (n=1.5) takes place when the particles enter the membrane pores and are deposited over the pore walls, reducing the membrane pore volume, as described by Equation (5):

$$\frac{1}{J^{1/2}} = \frac{1}{J_o^{1/2}} + k_c t \qquad (5)$$

Complete pore blocking (n=2) arises when particles block the membrane surface by means of pore sealing and can be described by Equation (6):

$$t = \frac{1}{K_d J^{*2}} ln\left[\left(\frac{J}{J_o}\frac{J_o - J^*}{J - J^*}\right) - J^*\left(\frac{1}{J} - \frac{1}{J_o}\right)\right] \qquad (6)$$

Where J_o is the initial permeate flux, J^* is the steady-state permeate flux and the k_a, k_b, k_c, and k_d in these models are constants.

The experimental data in this study was fitted to each model using the Solver function in Microsoft Excel 2013 (USA) to identify the fouling mechanism involved during the ultrafiltration process. Four optimisation runs were performed for each experimental flux profile by assigning n=0, 1, 1.5 and 2 where the residual sum of squares (RSS) between numerical predictions and experimental data for each run were compared for the lowest RSS to determine the main fouling mechanism.

2.4 pH, total soluble solids and turbidity measurement

The pH of the samples was determined using a pH meter model (Con 700, Oakton, USA). It was calibrated with a buffer solution of pH 4 and 7. The total soluble solids (TSS) were measured in terms of °Brix using a hand refractometer (PAL-3, Atago Co., Japan). Turbidity in the samples was determined using a microprocessor turbidity-meter (TN-100, Eutech Instrument, Singapore) and was calibrated with patron solution 0-1000 NTU.

2.5 Color measurement

The color properties were determined using a colorimeter (CS-2000, Konica Minolta, USA Data were expressed in terms of L* (lightness index), a* (redness-greenness) and b* (yellowness-blueness). Chroma is used to determine the degree of difference of a hue in comparison with gray color with the same lightness and is considered the quantitative attribute of colorfulness.

The chroma (c) and hue (h) were calculated using the following Equation 7 and 8:

$$c = (a^{*2} + b^{*2})^{1/2} \qquad (7)$$

$$h = \tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad (8)$$

2.6 Total phenolic content determination

The total phenolic content was determined colourimetrically with a Folin-Ciocalteau assay, which depended on the reduction of a Folin-Ciocalteau reagent by phenolic compounds under alkaline conditions. Some 0.3 mL of guava juice sample was added into 1.5 mL of 10% Folin reagent (10 mL Folin reagent diluted with 90 mL of distilled water) and 1.2 mL of 7.5% sodium carbonate, Na_2CO_3 (7.5 g of Na_2CO_3 in 100 mL of solution). The absorbance of the solution was measured at 765 nm with a Shimadzu UV-VIS spectrophotometer (Ultraspec 3100 Pro, Amersham Pharmacia Biotech, UK). The standard curve was established using gallic acid. The total phenolic content was expressed as a gallic acid equivalent in mg/L.

2.7 Ascorbic acid content determination

The sample was diluted with distilled water (1:1) prior to titration against dichlorophenolindophenol (DCPIP) solution. The endpoint of the titration was identified when a pink colour appeared, which lasted for at least 30 s. The mass of ascorbic acid (mg) in the sample was calculated based on the volume of titrated DCPIP solution.

2.8 Statistical analysis

The filtration of guava juice was carried out in duplicate, and all analyses were carried out in triplicate. The data was subject to examination for one-way analysis of variance (ANOVA) using Statistical Analysis System (SAS) software (Version 9.2, SAS Institute, USA). Significant differences between means were compared by a t-test at the 5% level of significance.

3. Results and discussion

3.1 Evaluation of flux behaviour

Figure 1(a) shows the behaviour of the permeate flux (J_p) as a function of time (*t*) at different operating pressures of 1, 1.5, 2, and 2.5 bar. Based on the graph, 1 bar OP exhibited the lowest initial flux (14.0 kg/m²/hr) and took the longest time to achieve 80% of the permeate recovery (PR), which was about 800 mins. In contrast, 2.5 bar OP resulted in the highest initial flux of 55.3 kg/m²/hr and completed the process in 220 mins. This finding was expected since the increase in permeate flux with pressure was due to the higher driving force across

the membrane (Nor *et al*., 2017), which was similar to other findings concerning juice filtration of kiwi fruit *(*Cassano *et al*., 2007) and xoconostle (Castro-Muñoz *et al*., 2018).
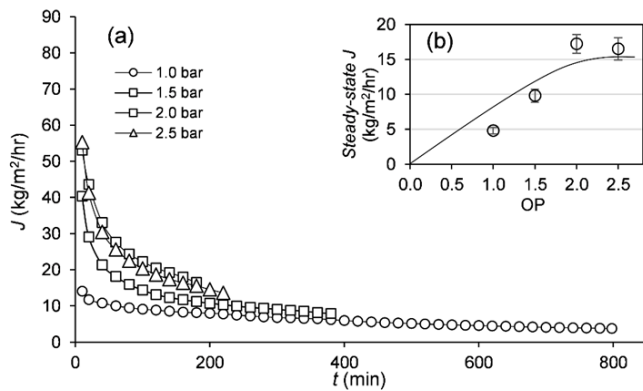

Figure 1. Permeate flux (J) profiles (a) J on the function of time (t) at different operating pressures (OP); (b) Steady-state J on the function of OP

Decreasing trends of the flux towards the end of the process up to the steady-state values were observed at all operating pressures as shown in Figure 1(a). There were three stages of flux decline in all the flux profiles. The first stage could be identified as a drastic reduction state that occurred during approximately the first 30 mins of the process. The second stage (minor flux reduction) was observed subsequently before the third stage (steady-state), where a non-variation of permeate flux as a function of time occurred until reaching the final permeate flux. The trends were strongly related to the fouling phenomenon taking place on the surface membrane during the filtration process. The gel polarisation phenomenon occurred when the feed passed through the membrane and left suspended solids behind. Subsequently, the rejected particles (suspended solids) started to deposit on the membrane surfaces to create fouling. Hence, the rate of flux decreased (Castro-Muñoz *et al*., 2018).

In general, the steady-state J_p increased with the increase of pressure from 1 to 2 bar, as shown in Figure 1(b). However, the steady-state J_p became independent of pressure after 2 bar of OP. The typical permeate flux showed a deviation from a linear flux-pressure behaviour as the pressure increased, and it became independent of pressure after reaching its limiting pressure, P_{lim} (Castro-Muñoz *et al*., 2018). The P_{lim} occurred when the permeate flux was not governed by the driving force, but it was governed by the fouling and polarisation-concentration phenomena *(*Cassano *et al*., 2007). At this point onwards, the fouling layer had consolidated itself, hence the prevailing forces could no longer facilitate in increasing the filtration rate, resulting in no significant change in the flux values. The limiting pressure gave the maximum permeate flux (known as the limiting flux, J_{lim}) produced by the driving force. In this study, the J_{lim} of 17.22 kg/m²/hr was observed at an OP of 2.0 bar where there was no significant rise of the permeate flux at a higher pressure. Hence, 2.0 bar pressure can be considered as the limiting pressure (P_{lim}) in this study.

3.2 Identification of mechanism responsible for flux decline

As fruit juices contain a noteworthy measure of macromolecules e.g., polysaccharides (pectins, cellulose, hemicellulose, and starch), dimness shaping segments (suspended solids (SS), colloidal particles, proteins, and polyphenols (Bhattacharjee *et al*., 2017), which will cause the formation of fouling, the control of the process parameters including pressure is necessary to minimise the impact on the flux performance. Table 2 shows the residual sum of squares (RSS) for the non-linear regression associated with various pore blocking models, i.e., cake formation (n=0), intermediate pore blocking (n=1), internal pore blocking (n=1.5) and complete pore blocking (n=2). The lowest RSS of each operating pressure (OP) indicates the best model to represent the experimental data, although there is a possibility that more than one mechanism may be involved (Nor *et al*., 2017). Based on Table 2, the most prominent fouling mechanism in the process is the intermediate pore blocking (n=1), except for the process at the higher OP of 2.5, which showed close RSS values between the n=1 and n=2 models (complete pore blocking).

The fouling mechanism that occurred on the membrane surface in this study evolved from an intermediate to a complete pore blocking condition depending on the operating pressure. This might be

Table 2. Residual sum of squares (RSS) for the non-linear regression of different fouling models in the UF process

Operating pressure (bar)	Pore blocking models							
	Cake formation (n=0)		Intermediate pore blocking (n=1)		Internal pore blocking (n=1.5)		Complete pore blocking (n=2)	
	K_a	RSS	K_b	RSS	K_c	RSS	K_d	RSS
1	0.0046	32.1471	0.0005	18.9331*	0.0004	54.0851	0.0002	2674192
1.5	0.0568	843.071	0.0011	311.199*	0.0022	2336.77	0.0001	89487.2
2	0.0442	512.653	0.0008	168.4934*	0.0015	1490.1	5.43x10⁻⁵	11312.6
2.5	0.0577	959.807	0.0009	417.1894	0.002	2153.63	5.43x10⁻⁵	406.919*

* The smallest RSS for each experimental data block

because, at a higher OP, more absorption of non-permeating molecules occurred on the membrane surface which subsequently led to the pores becoming blocked completely. Studies of the filtration of other fruit juices identified different fouling mechanisms, which were due to the natural compositions of the sample. For example, intermediate pore blocking followed with cake filtration represents the most competent combination of fouling mechanisms for the observed membrane flux decline in the clarification of pequi fruit juice (de Santana Magalhães *et al.*, 2018). However, for the clarification of kiwi juice the cake filtration fouling mechanism was predominant (Cassano *et al.*, 2008).

3.3 Evaluation of quality attributes of the clarified guava juice

3.3.1 pH and total soluble solids

Table 3 shows the pH and total soluble solids (TSS) of the samples at different operating pressures (OP) of the process. Based on Table 3, there are no significant differences in pH values ($p<0.05$) in the fresh (feed), clarified (permeate) and retained juice (retentate) at OP values of 1.0, 1.5, 2.0, and 2.5 bar. This result indicates that the ultrafiltration process does not affect the pH value of clarified guava juice. This finding is in agreement with previous studies of different fruit juices (Cassano *et al.*, 2008; Castro-Muñoz *et al.*, 2018).

Furthermore, the UF process has resulted in some reduction of TSS in the permeate of the guava juice as shown in Table 3. At 1 bar, there was a slight decrease in total soluble solids from 5.3 to 4.92 (7.1% TSS reduction) in the permeate when compared to the fresh guava juice (feed). The same condition was observed in other OPs where the TSS decreased by 14.4, 17.4 and 7.1% for an OP of 1.5, 2.0 and 2.5 bar, respectively. Although no obvious relationship between OPs and TSS reduction in the permeate, this result indicates that the UF process has managed to remove some of the suspended solids from the guava juice. It can be supported by the higher TSS values in the retentate of all samples compared to the feed, reflecting the retention of the soluble solids by the membrane. The inconsistency of TSS values in feed, permeate and retentate at different OP in this study occurred might be due to the variation of its initial value in the feed. The TSS generally consisted of low molecular weight compounds such as sugars (sucrose, glucose, and fructose), mineral salts and some organic acids (Castro-Muñoz *et al.*, 2018). The literature has reported similar findings in the juice clarification of Xoconostle (prickly pear) (Castro-Muñoz *et al.*, 2018) and kiwi fruit (Cassano *et al.*, 2007).

As the TSS were concentrated in the retentate stream, this leads to a decline in the flux during the process due to the fouling layers formed by a combination of suspended solids and adsorbed macromolecular impurities (Cassano *et al.*, 2007).

3.3.2 Turbidity and colour

Figure 2 shows the turbidity of the samples at the different OP of 1 to 2.5 bar. The turbidity of the clarified guava juice for all samples was drastically reduced when compared to the feed. The turbidity of the permeate after the UF process was almost completely removed, with all the filtered samples exhibiting a greater than 97% reduction of turbidity, resulting in higher clarity of the guava juice. Similar results have been reported for the clarification of banana, pineapple, blackberry, melon and apple juice through membrane filtration where the turbidity was greatly reduced in the permeate and was high in the retentate stream (Bhattacharjee *et al.*, 2017).
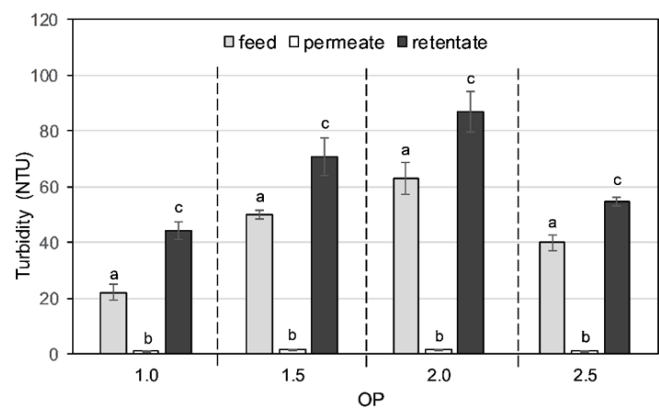

Figure 2. Turbidity of UF samples at different operating pressure (OP) (Different letters in the same section indicate the significant differences of $p < 0.05$)

The removal of turbidity can be associated with TSS reduction in the clarified juice. Generally, the turbidity considers the presence of fibres, suspended solids, high molecular weight carbohydrates and TSS (Castro-Muñoz *et al.*, 2018). Most of these non-permeating molecules were accumulated on the membrane surface during the process, causing high turbidity and TSS of the retentates

Table 3. Analysis of pH and TSS of the guava juice submitted to UF at different operating pressures

Operating pressure (bar)	pH			TSS (°Brix)		
	Feed	Permeate	Retentate	Feed	Permeate	Retentate
1	3.78±0.01[a]	3.81±0.01[a]	3.79±0.00[a]	5.30±0.28[a]	4.92±0.07[a]	5.48±0.306[a]
1.5	3.86±0.01[a]	3.88±0.00[a]	3.87±0.01[a]	7.15±0.85[a]	6.12±0.56[b]	7.60±0.94[a]
2	3.73±0.01[a]	3.73±0.01[a]	3.72±0.00[a]	6.30±0.19[a]	5.20±0.12[b]	7.65±0.78[a]
2.5	3.85±0.02[a]	3.87±0.00[a]	3.87±0.00[a]	7.25±0.33[a]	6.73±0.15[b]	7.97±0.28[a]

*Means (± SD) with the different letters are significantly different at $p < 0.05$ for each row of the section

and subsequently linked to the flux decay as discussed in the previous section.

The positive changes in terms of the physical aspects of the guava juice, including its turbidity, is important due to the high demand of consumers for the good appearance of the fruit juice. Clear fruit juice is more attractive to humans for consumption (Castro-Muñoz *et al.*, 2018). This attribute can be reflected in the colour properties of the juice. Figure 3 exhibits the colour changes of the guava juice before and after the UF process. The filtered guava juice looks "light" and "sparkling clear" compared to the feed and retentate. This can be further supported by the colour properties of the samples, represented by lightness/darkness (L*), greenness/redness (a*) and yellowness/blueness (b*), as shown in Table 4.
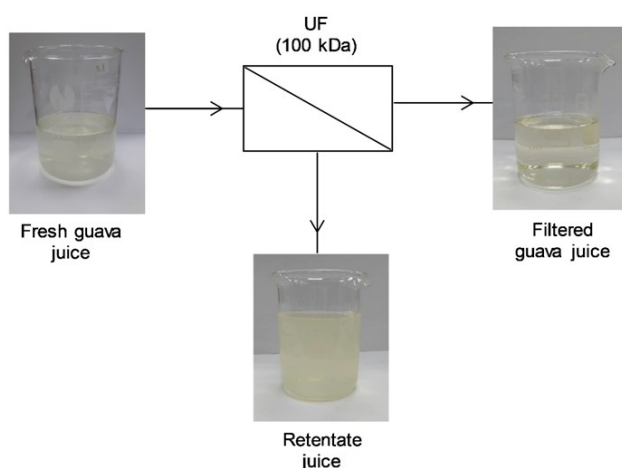

Figure 3. Guava juice samples by the ultrafiltration process

Based on Table 4, the permeate for all OP processes exhibited an increase in L* value compared to the feed. Meanwhile, the UF also managed to reduce the a* and b* values in all permeate, indicating that the clarified juice is lighter in colour with some degree of greenness and blueness. Further, the h° value for all the permeates also increased while the brightness (chroma) decreased after the filtration process, which indicated that the clarified juice behaved by moving in the direction of "clear" juice.

3.3.3 Total phenolic content (TPC) and ascorbic acid content (AAC)

Table 5 shows the total phenolic content (TPC) and ascorbic acid of the samples after the UF process at the different operating pressures (OP) of 1 to 2.5 bar. Overall, a reduction of TPC has been identified after the guava juice was filtered, with 19.7, 27.64, 20.4 and 24.52% reduction when the process was performed at an OP of 1.0, 1.5, 2.0 and 2.5 bar, respectively. Reductions in turbidity and total solids are desirable to obtain a clarified extract, but reductions in polyphenols compromise the nutrition quality of the extract (de Santana Magalhães *et al.*, 2019). The reduction of TPC in the permeate might be due to interaction with compounds rejected by the membranes (Castro-Muñoz *et al.*, 2018). For example, the loss of the phenolic compounds can be linked with the continuous action of polyphenol oxidases in the retentate (Cassano *et al.*, 2008). Variation in the initial TPC values in the feed has caused some inconsistencies of its values in the samples at different OP in this study. Nevertheless, based on the finding in this study, the TPC reduction may not be dependent on the variation of the OP. Although TPC reflects the antioxidant properties of the juice, it is also related to the astringency of the product. Hence, the TPC rejection in this study signifies that the astringency of the clarified juice has also been reduced, which might be a good alternative from the sensory perspective.

Table 4. Analysis of colour properties of guava juice submitted to UF at different operating pressures

Operating pressure (bar)	Samples	Colour				
		L*	a*	b*	Hue angle (°)	Chroma
1	Feed	31.05±0.29[c]	-0.05±0.00[a]	0.68±0.06[b]	-85.70[c]	0.23[b]
	Permeate	32.21±0.78[a]	-0.25±0.01[b]	0.22±0.07[c]	0.03[a]	0.06[c]
	Retentate	31.85±0.17[bc]	-0.14±0.17[a]	0.73±0.05[a]	-79.34[b]	0.28[a]
1.5	Feed	32.25±0.17[b]	-0.10±0.01[a]	0.56±0.02[b]	-90.05[b]	0.23[b]
	Permeate	33.91±0.32[a]	-0.28±0.03[c]	0.32±0.04[c]	0.16[a]	0.06[c]
	Retentate	32.05±0.02[b]	-0.12±0.08[b]	0.62±0.05[a]	-89.45[b]	0.28[a]
2	Feed	32.27±0.038[ab]	-0.14±0.16[a]	1.25±0.19[a]	-84.12[c]	0.80[b]
	Permeate	32.93±0.75[a]	-0.38±0.05[b]	0.26±0.21[b]	-22.43[a]	0.26[c]
	Retentate	31.80±0.08[c]	-0.18±0.09[a]	1.12±0.10[a]	-80.90[b]	0.64[b]
2.5	Feed	31.73±0.04[b]	-0.01±0.05[a]	0.85±0.13[ab]	-42.15[b]	0.38[b]
	Permeate	32.27±1.20[a]	-0.25±0.09[c]	0.50±0.04[c]	0.44[a]	0.16[c]
	Retentate	31.50±0.51[b]	-0.16±0.08[b]	1.05±0.10[a]	-74.94[c]	0.59[a]

*Means (± SD) with the different letters are significantly different at p < 0.05 for each row of the section

Table 5. Analysis of total phenolic content (TPC) and ascorbic acid content (AAC) of guava juice submitted to UF at different operating pressures

Operating pressure (bar)	TPC (mg/L)			AAC		
	Feed	Permeate	Retentate	Feed	Permeate	Retentate
1	100.43±3.78[a]	80.61±0.82[c]	92.61±1.25[b]	28.92±0.10[a]	22.49±1.52[c]	31.595±01.36[ab]
1.5	204.04±1.02[a]	147.64±1.54[c]	178.09±4.51[b]	30.52±0.76[a]	24.36±1.62[c]	27.846±0.12[ab]
2	212.14±5.68[a]	168.90±0.99[c]	197.01±1.33[b]	28.92±1.52[a]	23.56±1.52[b]	27.846±0.76[a]
2.5	131.96±1.85[a]	99.61±1.68[c]	122.95±2.66[b]	29.54±0.49[a]	24.10±0.76[b]	29.48±0.80[a]

*Means (± SD) with the different letters are significantly different at $p < 0.05$ for each row of the section

The ascorbic acid content (AAC) in white seeded guava fruit is known to be superior when compared to other fruits such as orange, banana, dragon fruit and star fruit. Hence, this study investigated the effect of the UF process on the AAC in the guava juice. Based on Table 5, the AAC in the permeate was found to be lower compared to the feed at all OP. The ACC reduced by 22.2, 20.2, 18.5 and 18.4% at an OP of 1.0, 1.5, 2.0 and 2.5 bar, respectively. Similar AAC reduction of 16.7% was observed in filtered kiwi fruit juice during the membrane filtration process as a result of oxidation during the filtration process (Cassano *et al.*, 2007). Similar to TPC, the AAC is believed to be unaffected affected by variations in the operating pressure.

4. Conclusion

Clarification of guava juice was achieved by a UF process, and insight was provided in terms of the flux profile at different operating pressures (OP), the fouling mechanism involved and the quality attributes of the juice. The permeate flux of the UF stages was found to be dependent on the OP, up to 2.0 bar, where no significant flux increase occurred at the higher pressure. Hence, 2.0 bar was determined as the limiting pressure of the process. For an OP less than 2.0 bar, intermediate pore blocking has been identified as the major fouling mechanism of the process, while total pore-blocking fouling predominated the UF at an OP of 2.5 bar. The UF process in this study permitted a good level of clarification by reducing the total soluble solids (TSS) and turbidity in the guava juice while maintaining the pH and enhancing the colour properties. However, due to oxidation and solute interactions, some reduction of the total phenolic content (TPC), and ascorbic acid content (AAC) were observed in the permeates with respect to the fresh juice. Nevertheless, from the sensory perspective, the reduction of TPC might be a good alternative since the astringency of the clarified juice was also expected to be reduced. Based on the permeation flux profiles and quality attributes of the guava juice, the best operating pressure of the UF process condition should be at 2.0 bar. Exploration of the clarification of guava juice through UF process can be further extended in the future by incorporating the enzymatic pre-treatment for higher processing efficiency.

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