USING FORWARD OSMOSIS CONCENTRATION TO RETAIN THE SENSORIAL AND PHYSICOCHEMICAL ATTRIBUTES OF APPLE CIDER

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by

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ABSTRACT

This study investigated the feasibility of using forward osmosis (FO) concentration to retain the sensorial and physicochemical attributes of refrigerated apple cider, as well as the effect of pectinase on FO processing and consumer acceptability. Apple cider was concentrated from approximately 10 °$Brix$ to 50 °$Brix$ at 20 °C with (FO-P) or without (FO-NP) the addition of pectinase to optimize FO performance. The concentrated apple cider was stored frozen at –18 °C before diluted back to 13 °$Brix$ and compared to the original cider (C). Samples FO-NP and FO-P were successfully concentrated using FO. The apparent water flux decreased over processing time, which ranged from 4.5 h to 4.98 h, while soluble solids content (SSC) and concentration factors increased. The physicochemical examination of C, FO-NP, and FO-P indicated no significant difference in pH, water activity, SSC, and titratable acidity but minor changes in turbidity and color properties. The sensory test showed no significant but relatively higher preference ranking for FO-P group. There were no significant differences regarding any specific sensorial attributes, thus FO seems a viable process to retain cider quality. Future work on the study of osmotic agents and scaling up is recommended.

BIOGRAPHICAL SKETCH

Junyi Chen was born and raised in Hangzhou, Zhejiang, China as the only daughter from Jian Chen and Huifang Xu. She graduated from the No. 2 High School of Hangzhou, Zhejiang in 2012 and continued her study as an undergraduate in Zhejiang University, Zhejiang, where she found her interest in Food Science. She transferred to Cornell University in 2014 as a junior and obtained her Bachler' Degree in Food Science from both Cornell University and Zhejiang University in 2016.

After graduation, she deferred her admission to Cornell University MPS program and spent one year seeking her passion in the field of Food Science. During this year, she interned in Intercontinental Hotel Hangzhou as a member of Club Lounge and obtained her PAID scuba diving license at the same time. She got the chance to talk to different people and figured out her enthusiasm in improving the quality of fruit juice using novel processing technologies.

Soon, she returned to Cornell University and joined Dr. Olga Padilla-Zakour's lab in 2017 as an MPS student. During the MPS study, Junyi worked on the research of concentrating apple cider using forward osmosis. After the completion of this degree, she will return to China and work as a marketing analyst in Nongfu Spring, Hangzhou.

To my beloved parents, Mr. Chen and Mrs. Xu, who have been loving me and supporting me for 24 years.

To my boyfriend, Minjie, who has been encouraging me for pursuing what I love.

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Finally, and most importantly, huge thank you to my parents and grandparents. Without your love and support for these years, I would not be able to complete my education. To my boyfriend, thanks for encouraging me and supporting me for pursuing my dream. To my friends, thank you for being by my side for all the good times and bad times.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

FO: Forward Osmosis

RO: Reverse Osmosis

C: Unconcentrated Apple Cider, control

FO-NP: Forward Osmosis Concentrated Apple Cider without Pectinase

FO-P: Forward Osmosis Concentrated Apple Cider with Pectinase

SSC: Soluble Solids Content

OA: Osmotic Agent

I. Introduction

I.1. Fruit (Apple) Juice and Fruit (Apple) Juice Market

Fruit is an extraordinary source of carbohydrates, minerals, vitamins, carotenoids, and polyphenols with the potential of reducing the risk of several chronic diseases, such as cardiovascular disease, cancer, and neurodegenerative disorders (Vauzour et al, 2010). By the definition of Merriam-Webster (2018), fruit is "the usually edible reproductive body of a seed plant; especially one having a sweet pulp associated with the seed." According to Food and Agriculture Organization of the United Nations (FAO) (2018), the global production of fresh fruit has grown from 13.6 million metric tons in 1990 to 33.25 million metric tons in 2016, which accounts for a significant portion of the world's agriculture output.

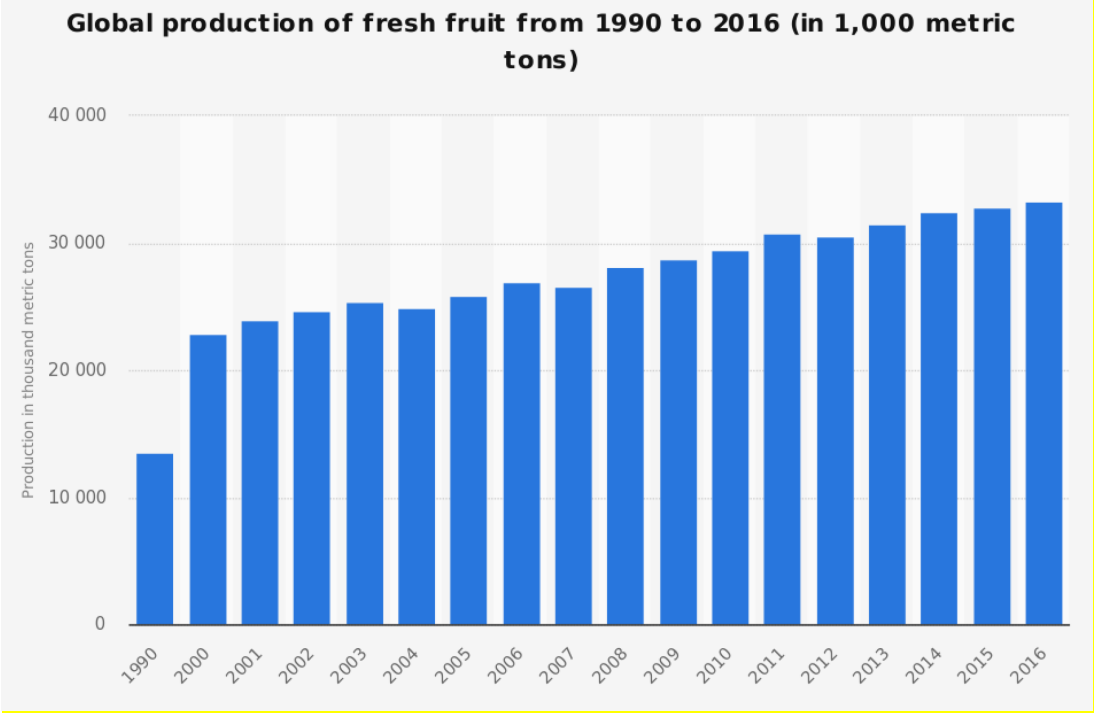

Figure 1. Global Production of Fresh Fruit from 1990 to 2016 (in 1,000 metric tons). (From Statista. Feb 28, 2018. https://www.statista.com/statistics/262266/global-production-of-fresh-fruit/)

However, fruit production is limited by their respective geographical zones and production seasons. Due to the perishable characteristic of fruits, the consumption of fresh fruits in areas geographically far apart or during the off-season is either costly or impracticable. To overcome the short-life of fresh fruit, scientists have been developing different technologies to process fruit into different products like dried fruit, canned fruit, frozen fruit, jam, and fruit juices. Among those processed fruit products, fruit juices account for 75% of the whole production chain, and the revenue in the juice segment of the United States reached US $9,943m in 2017 (Statista, 2018).

Apple ranks the third among the top 10 fruit types by global production volume (Rabobank, 2018). And New York State, which is the second-largest apple production state in the United States, produces 29.5 million bushels of apples annually (USDA, 2018). Forty seven percent of annual production is processed into apple products, including apple juice and cider. According to the New York Apple Association (2018), there are around 694 commercial apple producers in the state and they offered more than 17,500 jobs related to apple production directly and indirectly. Therefore, apple and apple juice will be appropriate research objects regarding the application of novel concentration technology for commercial fruit juice.

I.2. Apple Juice Manufacture

The sensorial and nutritional quality of the final fruit juice product is closely related to processing and storage condition. Figure 2 shows a typical fruit juice extraction process. The washing step aims to reduce not only the level of physical and chemical contamination but also microbial counts of the fruit. Due to the diverse nature of the fruit, harvesting season, storage condition, and maturity stage, washing methods are adapted to fit each product line respectively. The most economical and easy fruit washing machine that is gradually adopted in the food

industry involves the equipment of soft nylon brushes along the moving direction of washing conveyer. As fruits move, the brushes revolve and remove potential physical, chemical and biological debris on the surface of the fruits (Mushtaq, 2018).

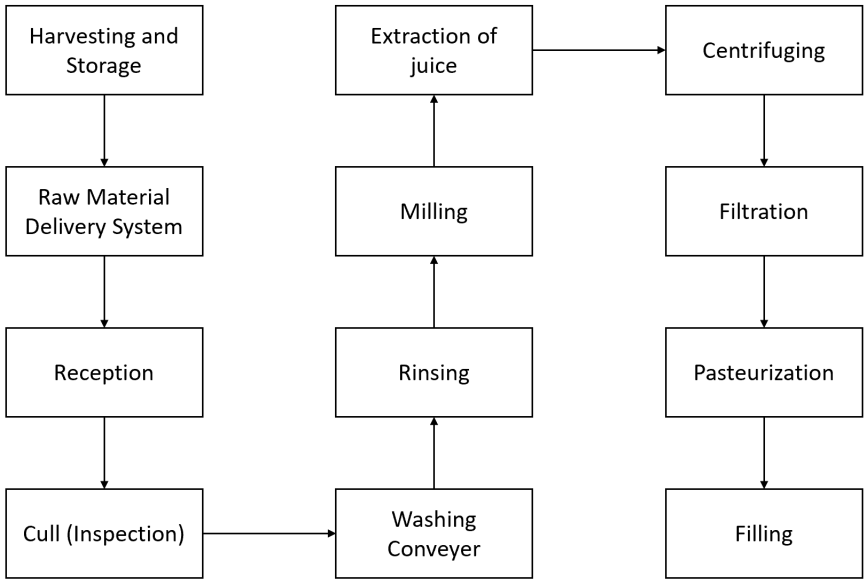

Figure 2. Manufacturing process flowchart of apple juice (adapted from Mushtag (2018) – Outline of the typical steps involved in the extraction of fruit juice)

Patulin is a commonly found mycotoxin in raw apples. On fallen apples, especially those that have been damaged by physical impacts, animals, and excessive handling, the growth of fungi produces high levels of patulin. If these apples are produced into apple juice or cider, the patulin levels in the final juice product may be high enough to be a health concerning chemical hazard to the consumer. The patulin level limitation determined by FDA in single strength apple juice is 50 micrograms per kilogram (USFDA, 2004). Conventionally, apples are visually inspected and rotting or moldy apples are manually removed to ensure the patulin level in the final product is within the criteria. Some producers may test the patulin level in the final product.

After culling, washing and rinsing, healthy apple is milled to break the whole apple into small pieces. This unit operation helps in distributing the apple pomace and increasing liquid

mobility within the pomace. The extent of milling impacts the final quality of apple juice as well as the efficiency of production. Excessive fine pomace slows down the speed of filtration or increases the solids content in the final product and impairs the mouthfeel; while too large particles increase difficulties to extraction and reduce the productivity. In most apple juice/cider industry, apples are conveyed into cylindrical mills, which are equipped with screw-like blades, and cut into pieces (Mushtaq, 2018).

Presses are typical equipment for juice and pomace separation. The selection of appropriate technology is based on not only the nature of the product but also the scale and the design of the plant. Rack and cloth press is an old technology. The apple pulp is wrapped into cloth screen and piled against each other between the wooden or stainless rectangular frames. As force is applied onto the frame, the pulp is squeezed to release apple juice. However, this press is labor and time consuming and is gradually been replaced in the modern plant (Mushtaq, 2018). Flottweg Separation Technologies came up with the latest belt press. The belt press is a continuous operation that loads the apple mesh onto a screen belt while a couple of rollers apply pressure to the apple pomace cake and extract juice from the pomace. As recommended by Flottweg Separation Technologies, this technology increases not only yields but also efficiency (FlottwegAG, 2012).

The juice is then centrifuged and filtered to remove suspended solids in the juice. Besides, the following pasteurization step is required to reduce the pertinent microbial pathogen count in juice by 5-log. After all these steps, the juice is ready for filling and distribution.

I.3. Fruit (Apple) Juice Concentrate

As most fruits' production is limited by their geographical and seasonal attributes, fruits have been processed into different products, including fruit juice, to enjoy their perishable flavor. Among different fruit juice types, natural single-strength juices are defined as the unaltered and unconcentrated natural juice. The distribution of natural single-strength juices represents large volumes thus their packaging, storage or transportation is hardly feasible from an economic point of view (Adnan, Mushtag, and Islam, 2018).

To solve these problems, the juice is concentrated by physically removing major part of the water present in the juice to reduce the volume, and the final product is called "fruit juice concentrate." Besides lowering distribution cost, concentration process also reduces water activity, which mitigates nonenzymatic browning and elongates fruit juice shelf life (Toribio, Nunes, and Lozano, 1984). However, as the concentration of fruit juice increases, it cannot mimic the sensorial, nutritional, and physicochemical attributes of the corresponding natural single-strength juice since the majority of nutrients and flavoring compounds are sensitive to processing conditions (Adnan et al., 2018).

I.4. Apple Juice Concentrate Manufacture

The concentration methods for apple cider can be classified into thermal concentration and nonthermal concentration. Thermal concentration methods include evaporation and freeze concentration, while the nonthermal concentration methods usually means membrane filtration and hydrate separation technology.

I.4.1.Thermal Concentration Technologies

Evaporators are a conventional equipment for fruit juice concentration. Water present in the juice is heated or sometimes boiled and evaporated into vapor form. The physical state of the

solvent is determined by both temperature and pressure, and the boiling point of solvent can be decreased by applying vacuum, which saves energy and some nutrients as well as flavoring compounds. One of the most typical evaporators is the multi-stage evaporator. In this system, the energy that is released during condensation of vapor is used to heat the next stage, which is under lower pressure than the previous stage. This pattern can be repeated several times and 4 to 6-stage evaporators are most commonly used by the food industry (Zimmer, Haverland, and latz, 2016). However, during the evaporation process, certain nutrients are destroyed, nonenzymatic browning is intensified, and some volatile flavoring compounds are transferred into vapor. This impairs the nutritional and sensorial quality of the juice even if they are diluted back to the original concentration.

As consumers' demand for high-quality juice increases, the development of another thermal concentration method called freeze concentration is of interest, where water is crystallized and separated from the juice. There are two ice crystal formation patterns used in the industry. The first one involves the growth of ice nuclei at super low temperature and short time, the growth of ice nuclei as it enters the recrystallizer, and the final separation of ice crystals from solution. The second system grows layers of ice crystals parallel to each other on the cold surface of the heat exchanger (Sánchez, Ruiz, Auleda, Hernández, and Raventós, 2009). Although freeze concentration is able to retain the high quality of fruit juice, the high equipment cost, difficult operation control, low energy conversion efficiency, and high solute inclusion rate makes this technology only applicable for high-value juice products (Adnan et al., 2018).

I.4.2.Nonthermal Concentration Technologies

Thermal concentration has been proved to influence the quality of juice, and scientists are developing new nonthermal concentration technologies. These technologies are mainly

membrane-based technologies, such as forward osmosis (FO), reverse osmosis (RO), and osmotic evaporation. Osmosis is defined as "the movement of the solvent (such as water) through a semipermeable membrane (as of sugar) into a solution of higher concentration that tends to equalize the concentrations of solute on the two sides of the membrane (Osmosis, 2018)." FO and RO are osmotic processes that separate water from dissolved solutes through a semipermeable membrane. However, the driving force for forward osmosis is an osmotic pressure gradient, which is the concentration difference between the feed and the osmotic agent; while the driving force for RO is the pressure applied on the feed side. Other than osmotic concentration, osmotic evaporation is driven by the partial pressure gradient in the vapor phase using a hydrophobic microporous membrane (Vaillant, Jeanton, Dornier, O'Brien, Reynes, and Decloux, 2001).

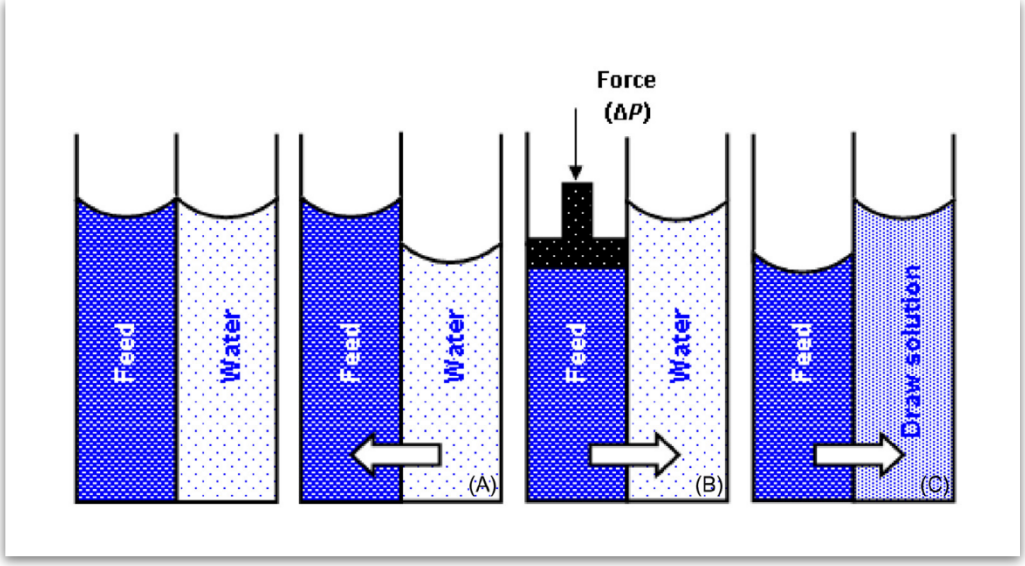

Figure 3 Movement of water during (A) osmosis, (B) reverse osmosis, (C) forward osmosis. the arrows show the direction of water movement (Rastogi, 2018).

I.5. Reverse Osmosis

Reverse osmosis is a pressure-driven osmosis process that exerts force on the feed side and creating a hydraulic pressure that is higher than the osmotic pressure differential and counteracts the natural osmosis. This technology allows juice to be concentrated at room temperature without changing the physical phase of neither the solvent nor the solids. In consequence, the nutritional and sensorial quality of the juice is highly retained. When compared to single- or triple-stage evaporators, RO saves 1/30 to 1/10 energy and makes it more competitive in current energy-oriented society. However, the maximum concentration for RO is 25-30 °Brix, and its application for viscous or high solid content liquid is limited by the reduced permeate flux (Navin, 2018).

I.6. Forward Osmosis

Forward osmosis is developed based on the principle that water transfer through a semipermeable hydrophilic membrane from diluted feed to concentrated osmotic agent (OA).

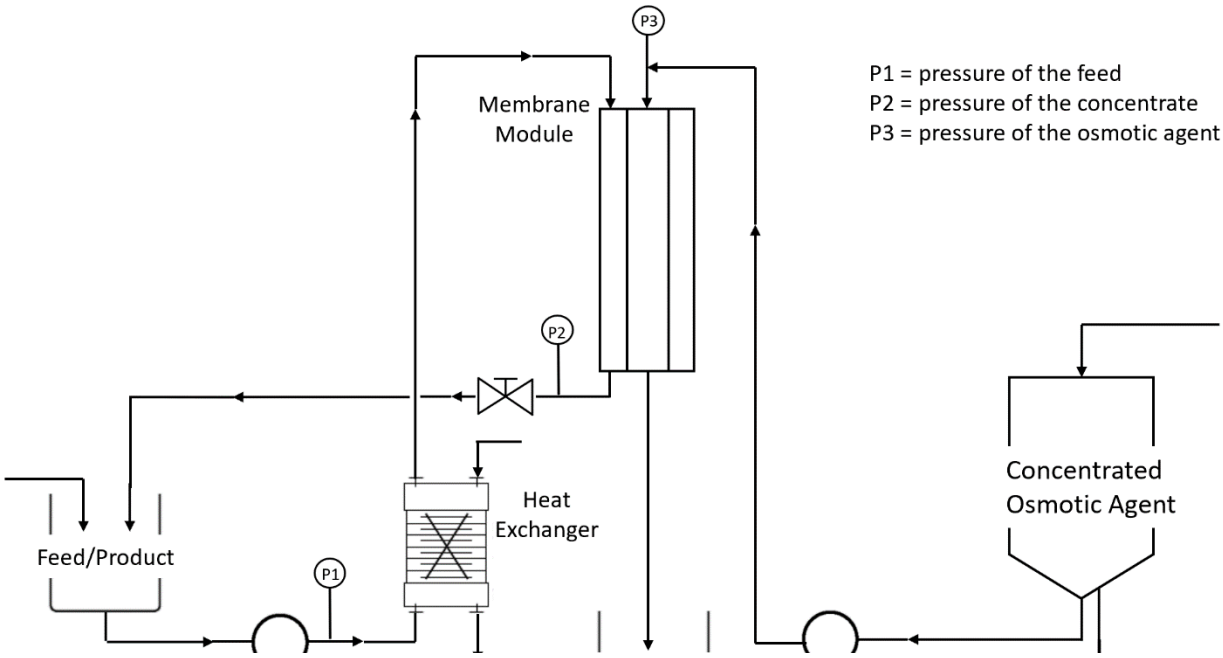

Figure 4 Schematic diagram of the lab scale forward osmosis unit. (Adapted from Ederna SAS, evapEOs® - FO mode micro pilot unit user manual by Emile)

Therefore, FO is an osmotic potential differential-driven osmosis process. It is also known as "direct osmosis," "engineered osmosis," or "manipulated osmosis (Navin, 2018)."

Figure 4 shows a schematic diagram of a lab scale FO unit. The product and the draw solution of higher concentration are loaded into the feed tank and concentrated OA tank respectively. The feed and the concentrated OA are pumped into the membrane column co-currently. The difference in flow rate of the two streams is controlled within the limitation specified by the membrane manufacturer. Due to the effect of heat on the product quality and the influence of the processing temperature on the permeate flux, the temperature of the system is controlled through a heat exchanger. The concentrated product is recycled back to the feed tank, while the diluted OA is gathered in a holding tank.

FO has the advantages of saving energy, minimizing fouling, retaining more nutritional compounds, reducing flavoring and coloring substances loss and higher maxima concentration than RO (Navin, 2018).

I.7. Osmotic Agent

The osmotic agent should have a high enough concentration than the feed to exert an osmotic pressure but also food grade safe at the same time. The solute for preparing OA should be water-soluble, and the price needs to be low enough to ensure sufficient availability. NaCl, $CaCl_2$, $KHCO_3$, $MgCl_2$, $MgSO_4$, $NaHCO_3$, $CaCl_2$, and $MgCl_2$ have been proven to be eligible OA solutes.

Potassium lactate, with formula $KC_3H_5O_3$, is a sugar fermented product. It is commonly stored and distributed as a solution with 60% solids content. Has been approved by the FDA as

one of the food additives for meat and poultry product, potassium lactate solution is food grade and can be used as OA (USFDA, 2006).

I.8. Pectinase

The performance of FO can be influenced by the nature of the product. Apple juice is a good source of pectin, which is a soluble dietary fiber. Pectin can be digested by an enzyme called pectinase and removed from the juice (Kashyap, Vohra, Chopra, and Tewari, 2001). The presence of pectin makes the juice cloudy as pectin suspends in the juice and provides a thick mouthfeel, while the removal of pectin makes the juice clear and light. As the healthy eating trend goes on, consumers now have a preference for pectin-included apple juice (apple cider) over pectin-removed apple juice (apple juice) (Reiser, 1987).

The presence of pectin not only has an impact on the nutritional and sensorial quality of the apple juice but also raises the resistance for water movement and increases the rate for membrane fouling during FO, therefore, reduces the water flux.

I.9. UV Pasteurization

Foodborne disease, which is mainly caused by pathogens from under-processed food, is one of the biggest food safety concerns. To ensure the safety of their products, food industries have been dealing with thermal treatment for years and the typical temperature and time combination for food pasteurization is 60 °C to 100 °C for specified seconds or minutes. However, during heat treatment, some heat-sensitive nutrients, flavoring, and coloring compounds are destroyed by excessive energy and therefore impair the quality of the product.

As consumer's demand for the higher quality product increases, nonthermal pasteurization methods such as ultraviolet (UV) radiation has been developed recently. The US Food and Drug Administration (1997) specified a minimum 5-log reduction of pathogen for juice products. And the application of UV light as an alternative pasteurization method for juice was approved by FDA an detailed in a report of the Institute of the Food Technologies. The report also indicates the minimal exposure of 14 mJ/cm^2 in all parts of the apple cider/juice to reach required microbial inactivation. The efficacy of UV pasteurization in apple cider and apple juice has been proved by Duffy, Churey, Worobo, and Schaffner (2000), Gabrial (2012), Quintero-Ramos, Churey, Hartman, Barnard, and Worobo (2004), and Wright, Sumner, Hackney, Pierson, and Zoecklein (2000).

I.10. Current Studies and Applications of Forward Osmosis

Propper, Camirand, Nury, and Stanley (1966) first tested the possibility of FO using RO membranes. It was then demonstrated that the flavoring and aroma quality of the raspberry juice concentrate produced using FO can best resemble that of the single-strength raspberry juice compared to the evaporation-concentrated product (Wrolstad, McDaniel, Durst, Micheals, Lampi, and Beaudry,1993). In 1994, Herron et al. developed a new FO with several osmotic concentration cells and an osmotic concentration apparatus and successfully concentrated different fruit juices using this new FO system. Petrotos et al. (1998) tested the effect of different processing parameters on the performance of FO while concentrating tomato juice. They were able to conclude that 1) among six different OAs (sodium chloride brine, calcium chloride brine, calcium nitrate brine, sucrose solution, glucose solution, and polyethylene 400 solutions), sodium chloride solution is the most effective; 2) increasing OA concentrating results in increased osmotic fluxes and reduced overall mass transfer coefficient; 3) raised temperature has

a positive influence on the performance of FO; 4) within a certain range, the water flux is negatively correlated with the thickness of the membrane. The concentration of pineapple juice using FO carried out by Babu et al. (2006) indicated several similar phenomena. Nayak and Rastogi (2010) successfully concentrated large-scale of anthocyanin extract 54 times by FO, which demonstrated higher stability, lower browning index, and less conversion of hydroxycitric acid lactone (HCA) to lactone form than the thermal-concentrated sample. FO also showed excellent operation when dewatering press liquor from orange juice production waste, which represents a slurry substance with great fouling potential (Garcia-Castello and McCutcheon, 2011).

The application of FO has been limited to laboratory scale and there is no study on the concentration of apple cider using FO. Therefore, the aim of this study was to investigate the feasibility of using F.O. concentration to retain the sensorial and physicochemical attributes of apple cider, as well as the effect of pectinase on FO processing and consumer acceptability.

II. Materials and Methods

II.1. Frozen pressed apple cider and pectinase

The frozen 100% pure apple cider was produced and pasteurized by the Cornell Department of Food Science (Plant #36-1038, Ithaca, NY, U.S.) on March 3rd, 2018. The apples used for processing were from New York State.

The food grade pectinase used for enzyme treatment and membrane cleansing was Rapidase®Pressl (DSM Food Specialties, BV, Netherland), which was stored at 4-8 °C. The pectin removed sample set was treated with pectinase (0.001%) at room temperature for 1 hour.

II.2. Forward osmosis unit

Figure 4 is the schematic diagram of the batch bench-scale FO unit (Evapeos - Ederna, Toulouse, France). The feed was pumped through a centrifugal pump from a 14 L feed tank into the membrane module. The temperature of the feed was controlled by a countercurrent plate heat exchanger (PROO13, AGC Engineering, U.S.) at 20 °C. On the other side, 60 °Brix OA was pumped from a vessel into the membrane module in co-current mode. The concentrated feed was recycled back into the feed tank, while the diluted OA was collected in a vessel. The concentrated and diluted OA vessels were placed on scales, whose reading were recorded by Realterm (VA Software, U.S.). The pressure of the concentrate, the feed, and the concentrated OA were measured by pressure gauges (EN 837-1, Baumer, Switzerland) connected at each side. A concentrate valve and drain valve were equipped to adjust pressure and drain the product.

II.3. Forward osmosis membrane

The membrane used during FO was provided by Ederna (Toulouse, France). The membrane is a spiral-wound cellulose triacetate membrane, with an outside diameter of 63 mm, a length of 530 mm, and a filtration area of 0.5 m^2.

After each FO process the membrane was cleaned in the following sequence:

a. Circulate DI water for 2 min and drain. Repeat at least 3 times.
b. Circulate Ultrasil 110 solution (1:1000 dilution, pH ≥ 8) for 15 min and drain.
c. Circulate DI water for 2 min and drain. Repeat at least 3 times.
d. Circulate pectinase solution (0.001%) for 1 hour at pH 4 - 5.
e. Circulate DI water for 2 min and drain. Repeat at least 3 times.
f. Circulate 0.4% citric acid solution for 15 min and drain.
g. Circulate DI water for 2 min and drain. Repeat at least 3 times.

h. Circulate 1% hydrogen peroxide solution for 30 min and drain.

i. Circulate DI water for 2 min and drain. Repeat at least 3 times.

j. Circulate DI water for 2 min and drain. Repeat at least 3 times.

k. Circulate 0.5% sodium metabisulfite solution for 2 min and save it in the system.

II.4. Osmotic agent

The OA used for FO is Ultralac KL 60 from Hawkins (Roseville, MN, U.S.), which is composed of 60% potassium lactate and water. The solution is concentrated to 60 °Brix by vacuum evaporation and cooled down to room temperature before each run.

II.5. Experimental design

Frozen fresh apple cider was thawed in a walk-in cooler for two days and prefiltered to remove insoluble solids before each experiment trial. One set of unconcentrated samples served as control (C); one set of samples was concentrated using FO (FO-NP); one set of samples was treated with pectinase for 1 hour at room temperature before FO concentration (FO-P). The initial soluble solids content (SSC) of the sample was recorded as the start point. During the FO process, the SSC of circulated feed was checked by refractometer every 15 min until it reached 50 °Brix. To ensure the safety and quality of apple cider concentrate, it was kept in the freezer below -18 °C. After storage, the concentrate was thawed in the refrigerator for 1 hour and diluted with DI water to 11 °Brix for sensory and physicochemical examination. Samples for sensory evaluation were pasteurized using UV light.

II.6. UV pasteurization

A commercial UV pasteurizer (CiderSure 3500, FPE Inc., NY, U.S.) was used for pasteurizing the apple cider at room temperature. The UV pasteurizer was set at 254 nm using a

turbulent flow regime to apply a constant dose of 14 mJ/cm^2 in all parts of the product to ensure a minimal 5-log pathogenic reduction (Usaga, Padilla-Zakour, and Worobo, 2016).

II.7. Physicochemical characteristics

The measurements for each characteristic per sample were done in triplicate.

II.7.1. pH, water activity, and soluble solids content (SSC) measurement

pH meter (Orion 3 star pH benchtop, Thermo, U.S.) was used for pH measurement. It was calibrated using pH 4 and pH 7 buffer (VWR chemicals, PA, U.S.). Dew Point Water Activity Meter (4TE, Aqua Lab, U.S.) was used for water activity measurement. SSC was measured using pocket digital refractometer (30050, Sper Scientific, China).

II.7.2. Titratable acidity measurement

Titratable acidity of each sample was measured using compact titrator (G20, Mettler Toledo, Switzerland), which was calibrated using pH 4 and pH 7 buffers (VWR chemicals, PA, U.S.).

II.7.3. Turbidity measurement

Turbidimeter (model 2100P, HACH, U.S) was used for turbidity measurement. It was calibrated using < 0.1 NTU and 800 NTU standards (Stablcal Formazin Standard, HACH, U.S.) The samples were placed in a glass sample cell and shaken well before each measurement.

II.7.4. Color analysis

Color components (a, b, and L) of each sample were determined by HunterLab colorimeter (UltraScan VIS, HunterLab, U.S.). The samples were loaded in a 1.0 ×1. 0 × 4.0 cm clear glass cell. Sensor USVIS1454 is connected to the device under reflectance specular

excluded mode to measure the appearance and appearance difference as seen by human eye. The illuminant was ejected at an angle of 8 °from the perpendicular to the sample surface through a 1-inch port plate with glass (Hunter Associates Laboratory, 2008).

II.8. Sensory evaluation

One hundred panelists were recruited from the Cornell Sensory Center database and scheduled through doodle poll as well as on-site check-in as there was no pre-screen requirement unless participants were allergic or intolerant to apple juice. The panelists included both male and female, ages 18+. Sensory evaluation was carried out following the guidelines and policies of the Cornell Institutional Review Board for Human Participants.

The sensory evaluation was conducted by the Cornell Sensory Center (Ithaca, NY, U.S.). All the samples were served under room temperature in a 5 oz clear plastic cup, which were coded with 3-digit random numbers and covered with clear plastic lid. One hundred panelists were asked to evaluate the appearance, aroma, flavor, purchase intent, and preference ranking of the samples on either 9-point scales or Just About Right (JAR) scales. The principle and technology behind FO were introduced to the panelists at the end of the test, and panelists were asked to reintroduce the concepts of FO or the FO concentrated product in their own words.

II.9. Statistical Analysis

All treatments were done in triplicate. Physicochemical data analysis were carried out by JMP® (SAS Institute, NC, U.S.) using one-way repeated measurements ANOVA at 5% significance level. Results were expressed as mean ± standard deviation.

JAR and 9-point scale scales sensory data were analyzed using Cochran's q test and ranking data was analyzed using Friedman two-way analysis of variance by ranks through RedJade® (Curion, CA, U.S.). Results were expressed as mean ± standard error.

III. Results and discussion

III.1. FO concentration process

Figure 5 shows the water flux over time for concentrating apple cider using FO with 60°Brix OA (potassium lactate). At the beginning of each test, there was a sharp increase in water flux as the system was building up. The trials with pectin reached the maximum flux value (at 0.15 h, 0.27 h and 0.30 h for FO-NP#1, FO-NP#2, and FO-NP#3) faster than the trials without pectin (at 0.77 h, 0.87 h, and 1.33 h for FO-P #1, FO-P#2, and FO-P#3). This phenomenon may be explained by the inconsistent breakdown of pectin. The main particle in the FO-NP samples that might deposit on the membrane is intact pectin, while that for FO-P samples are pectin particles of different sizes. Attaining near steady state in a sample with uniform particle size is faster than that for sample with uneven particle size. After this increase, the flux declines steadily. This trend was also observed by Nayak and Rastogi (2010) as well as Petrotos et al. (1998) when concentrating anthocyanin extract and tomato juice. They were also able to find that the reduction in water flux is related with the reduction of driving force due to the decreasing concentration difference between feed and OA, and the reduction of the overall mass transfer coefficient due to the increased juice viscosity.

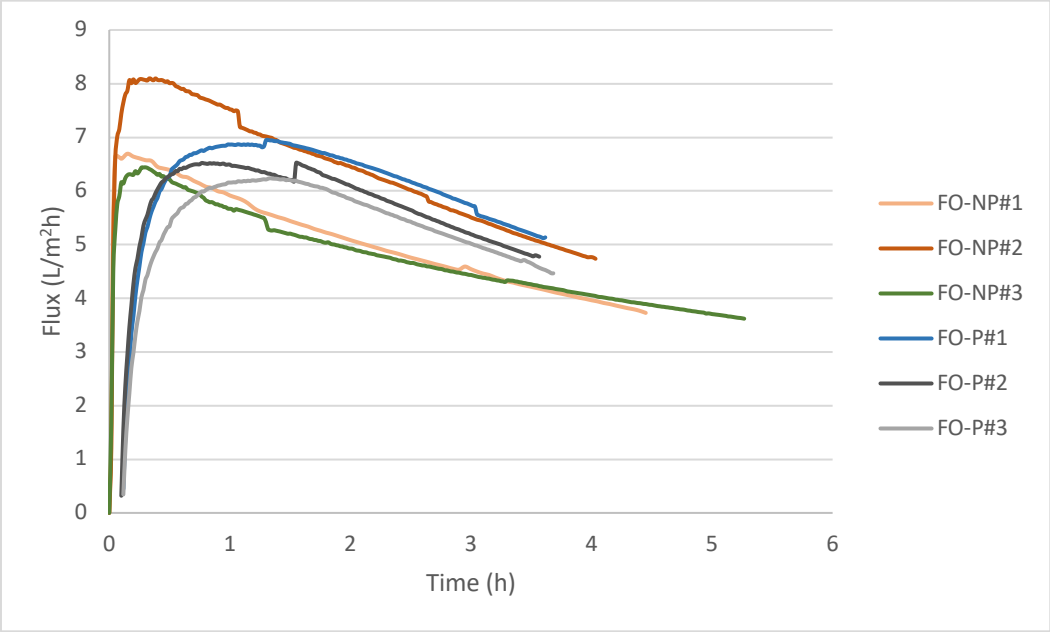

Figure 5 Flux performance during forward osmosis concentration of apple cider. FO-NP means samples concentrated using FO without pectinase, FO-P means samples concentrated using FO with pectinase. Experimental conditions: the pressure of feed at 1.0 Bar at the beginning of the process and gradually increased to 2.0 at the end of the process; the pressure of concentrate at 1.0 ± 0.2 bar; the pressure of 60 °Brix OA at 0.7 ± 0.05 bar; temperature 20°C.

The average water flux for FO-NP#1, FO-NP#2, and FO-NP#3 were 4.95, 6.36, and 4.73 L/m2h, and that for FO-P #1, FO-P#2, and FO-P#3 were 6.11, 5.75, and 5.38 L/m^{2}h. Although this trend was not significant (P=0.5, α=0.05), the average water flux of samples with pectin was lower than in samples without pectin. Figure 6 shows the average water flux of the two treatments at every 30 min time point. With greater error bar, FO-P treatment showed higher water flux than FO-NP treatment, which can be explained by the higher mass transfer resistance due to the presence of pectin. Garcia-Castello and McCutcheon (2011) found that pectin is the primary reason for membrane fouling during orange peel press liquor FO process.

It was noticed that the color and density of visible suspended solids of each original fresh apple cider samples were different. The solids content of original apple cider with a denser color should be higher even after prefiltration, which may be the reason for a greater average water flux for FO-NP#2,which had a lighter color.

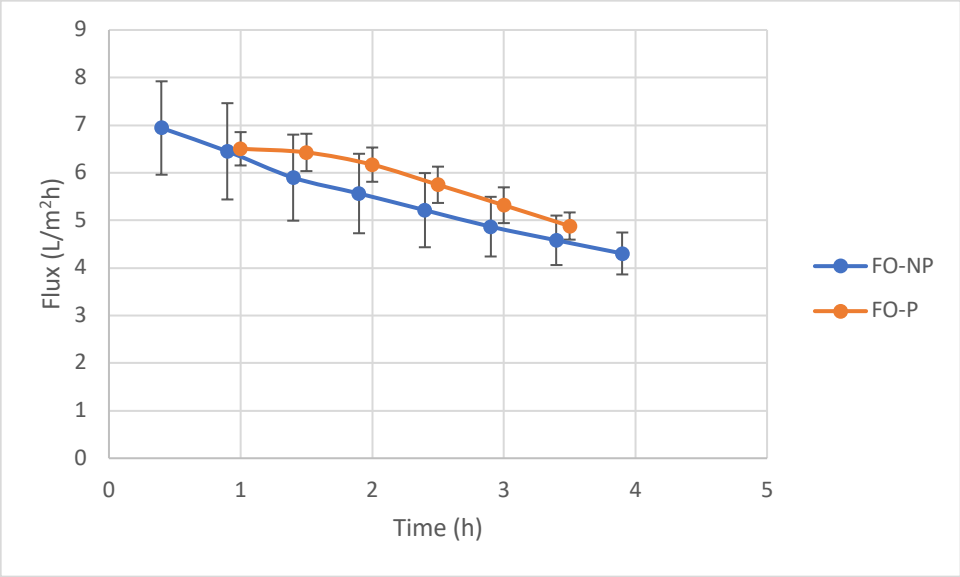

Figure 6 Average Flux performance during forward osmosis concentration of apple cider. FO-NP means samples concentrated using FO without pectinase, FO-P means samples concentrated using FO with pectinase. Experimental conditions: the pressure of feed at 1.0 Bar at the beginning of the process and gradually increased to 2.0 at the end of the process; the pressure of concentrate at 1.0 ± 0.2 bar; the pressure of 60 °Brix OA at 0.7 ± 0.05 bar; temperature 20°C.

The SSC and concentration factor increased over time as shown in figure 6 and figure 7. A similar trend was shown in Petrotos (2010) and his colleagues' research. The processing times for samples with pectin (FO-NP#1, FO-NP#2, and FO-NP#3) were 4.45 h, 3.88 h, and 4.98 h, and that for samples treated with pectinase (FO-P #1, FO-P#2, and FO-P#3) were 3.6 h, 3.5 h, and 4.16 h. Although not significant ($P=0.1$, $\alpha=0.05$), there was a trend that the processing time for samples without pectin was shorter than that for samples with pectin, which is coherent with greater average permeate flux for pectinase treated trials. The initial SSC of each test varied within the range of 9.2 to 14.5, and the final concentration factor varied from 3.4 to 5.4 in line with the initial SSC.

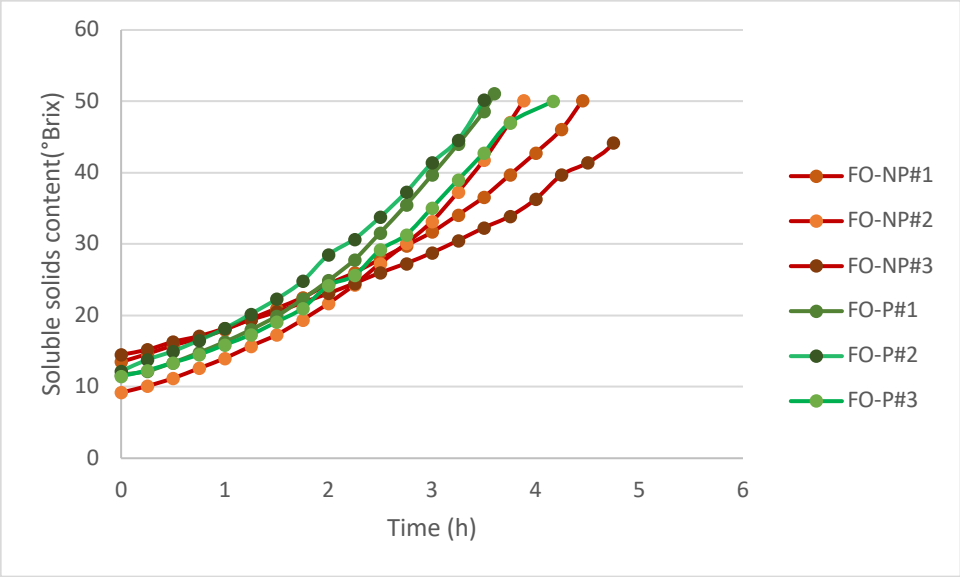

Figure 7 Soluble solids content of apple cider over time during forward osmosis concentration. FO-NP means samples concentrated using FO without pectinase, FO-P means samples concentrated using FO with pectinase. Experimental conditions: the pressure of feed at 1.0 Bar at the beginning of the process and gradually increased to 2.0 at the end of the process; the pressure of concentrate at 1.0 ± 0.2 bar; the pressure of 60 °Brix OA at 0.7 ± 0.05 bar; temperature 20°C.

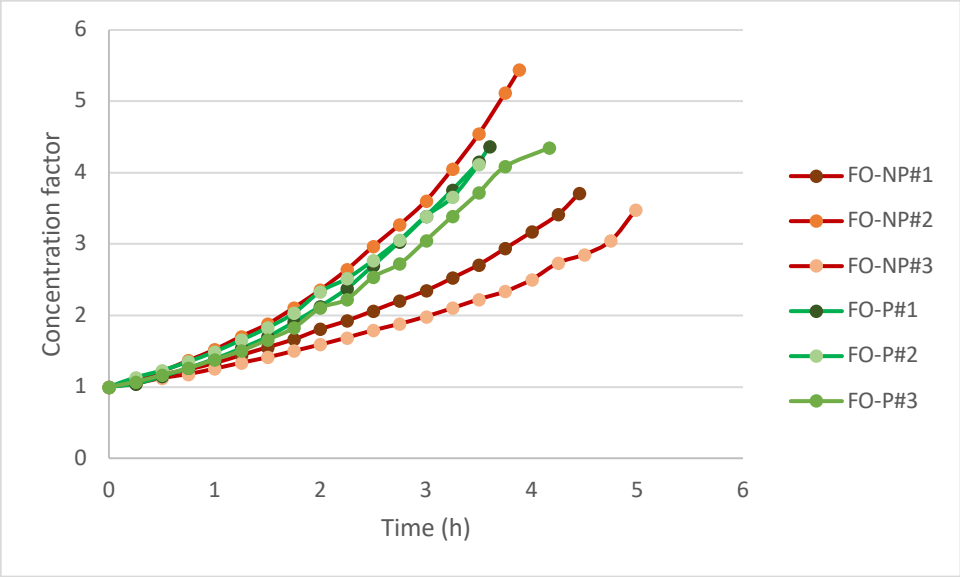

Figure 8 Concentration factor of apple cider over time during forward osmosis concentration. FO-NP means samples concentrated using FO without pectinase, FO-P means samples concentrated using FO with pectinase. Experimental conditions: the pressure of feed at 1.0 Bar at the beginning of the process and gradually increased to 2.0 at the end of the process; the pressure of concentrate at 1.0 ± 0.2 bar; the pressure of 60 °Brix OA at 0.7 ± 0.05 bar; temperature 20°C

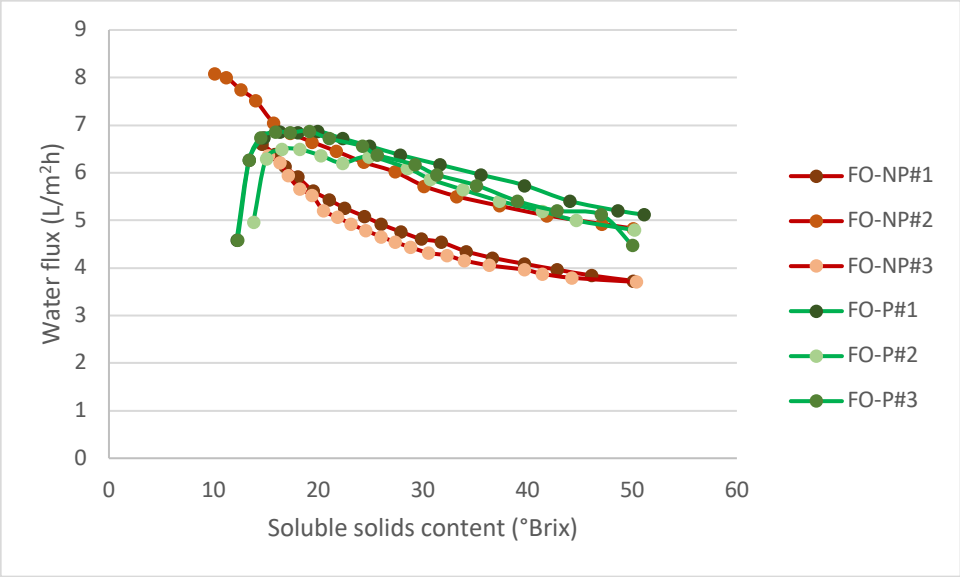

Figure 9 Relationship between water flux and soluble solids content of apple cider during forward osmosis concentration. FO-NP means samples concentrated using FO without pectinase, FO-P means samples concentrated using FO with pectinase. Experimental conditions: the pressure of feed at 1.0 Bar at the beginning of the process and gradually increased to 2.0 at the end of the process; the pressure of concentrate at 1.0 ± 0.2 bar; the pressure of 60 °Brix OA at 0.7 ± 0.05 bar; temperature 20°C

Figure 8 shows the relationship between water flux and SSC. The water flux of samples with pectin decreased as SSC increased; while the water flux for samples without pectin increased sharply at the low SSC and decreased steadily after reaching the peak. This is corresponding with the flux performance over time as the sample treated with pectinase take more time to reach stable conditions in the filtration system. In addition, it is apparent that after stabilization the overall water flux of samples with pectin is lower than that for samples without pectin.

III.2. Comparison of physicochemical properties

The physicochemical properties of the concentrated samples were comparable to that of the original apple cider. There were no significant differences in soluble solids content, pH, titratable acidity, and water activity between each group. The turbidity of pectinase treated group (FO-P) was significantly lower than the untreated group (FO-NP), which means the removal of

pectin intensified the clarity of apple juice. Group FO-NP and FO-P were significantly lighter and more intense in green hue than group C as they have a higher L value and a lower a value, which can be explained by the removal of pectin as well as the loss of coloring compounds that were suspended by the pectin. This result is coherent with the conclusion from Wrolstad et al. (1993), and Nayak et al. (2010), where the physicochemical attributes of reconstituted raspberry juice and anthocyanin extract were very close to that of original samples.

Table 1 Physicochemical properties of apple cider before and after forward osmosis. The value is expressed in mean ± standard error, α = 0.05. C means the group of samples that is not concentrated; FO-NP means the group of samples that is once concentrated using FO; FO-P means the group of samples that is once pectinase treated and concentrated using FO. For each attribute, values with the same letter show no significant differences.

Treatment	C	FO-NP	FO-P
°Brix	11.10 ± 0.11	11.03 ± 0.07	11.02 ± 0.03
pH	3.59 ± 0.07	3.67 ± 0.05	3.73 ± 0.02
TA (mol/L)	0.026 ± 0.003	0.024 ± 0.002	0.022 ± 0.001
a_w	0.988 ± 0.000	0.991 ± 0.001	0.988 ± 0.001
Turbidity	$6.1\times10^2 \pm 1.4\times10^{2a,b}$	$5.0\times10^2 \pm 0.9\times10^{2\ a}$	$3.5\times10^2 \pm 0.4\times10^{2\ b}$
Color-L	44.2 ± 0.4^a	48.6 ± 0.5^b	50.4 ± 0.5^b
Color-a	8.0 ± 0.3^a	6.6 ± 0.4^b	6.3 ± 0.4^b
Color-b	52.5 ± 2.4	52.1 ± 1.5	53.2 ± 0.7

Overall, most of the physicochemical attributes of the FO concentrated apple cider and juice were retained, with minor changes of the attributes that were related to the appearance of the apple cider.

III.3. Comparison of sensorial properties

Although the 100 panelists showed no preference between the control and the processed samples, there was a significant preference for the (FO-NP) compared to the once treated with pectinase (FO-P) sample, indicating a better response for the less processed cider.

Table 2 Sensory preference ranking of control apple cider(C), sample once concentrated with (FO-P) or without (FO-NP) pectinase.

	C	FO-NP	FO-P
Panelists	100	100	100
Rank 1	29%	45%	26%
Rank 2	41%	36%	23%
Rank 3	30%	19%	51%
Rank Sum	201	174	225
Post Hoc	AB	A	B

According to figure 10, there were no significant differences in the appearance, clarity, aroma, flavor, and overall like perception, but it is worth mentioning that the mean scores for the pectinase treated sample (FO-P) were generally lower than the other two based on the 9-point scale.

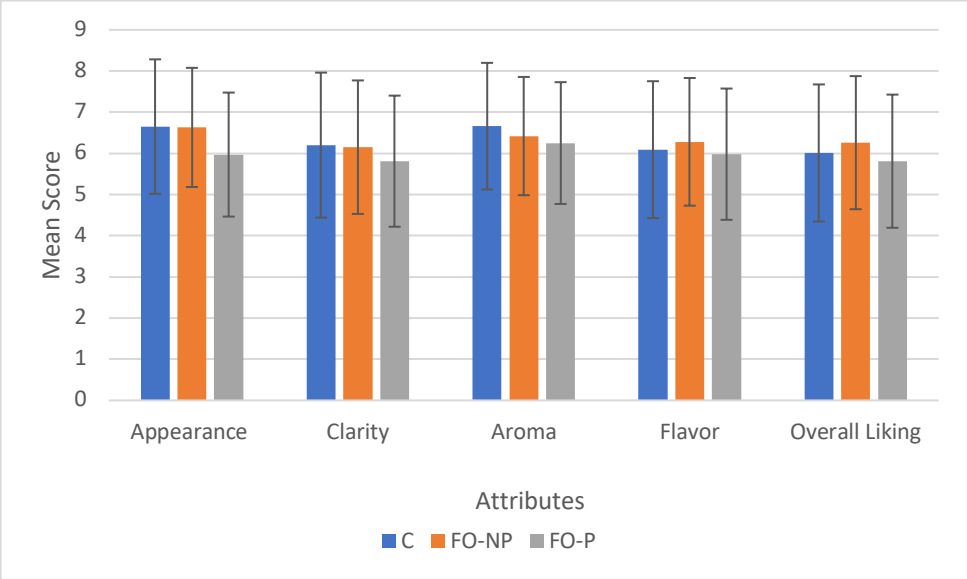

Figure 10 Sensory evaluation of control apple cider(C), sample once concentrated with (FO-P) or without (FO-NP) pectinase on a 9-point scale.

Figure 11 shows the mean score and standard error for some specific attributes of the samples on a JAR scale. There were minor differences between each sample, which were not significant.

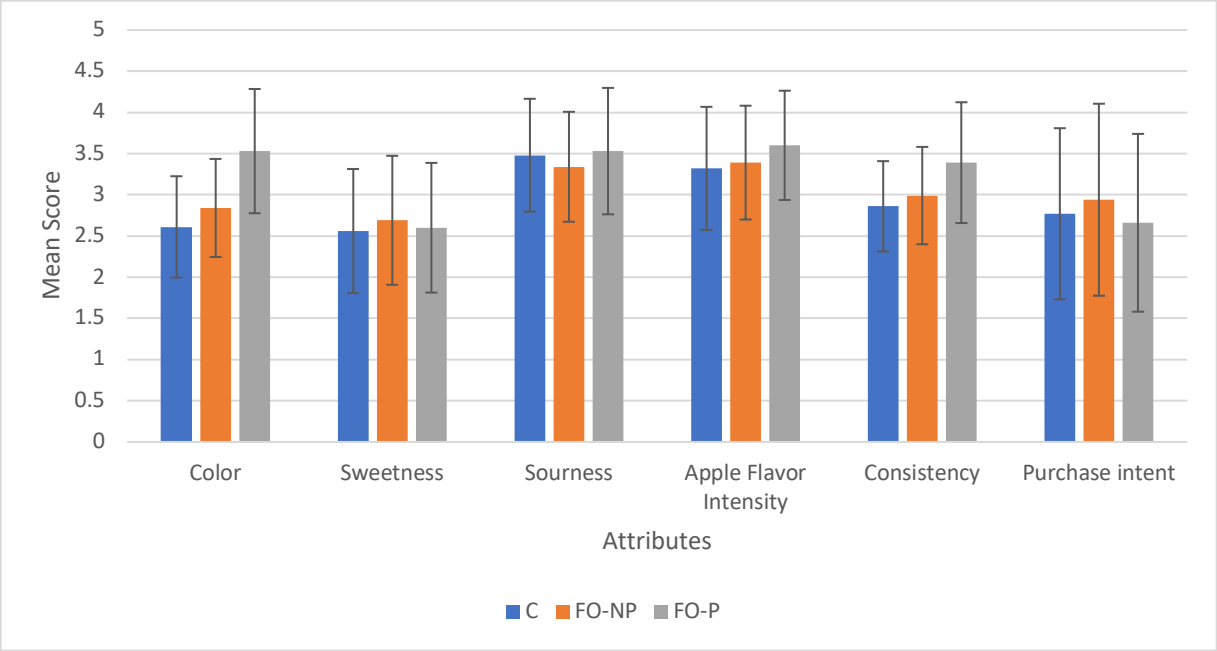

Figure 11 Sensory evaluation of control apple cider(C), sample once concentrated with (FO-P) or without (FO-NP) pectinase on a JAR scale.

Wrolstad et al. (1993) had the similar conclusion that the FO concentrates had no significant difference when compared to single-strength juice. They further evaluated the sensorial characteristics of FO concentrates, evaporation-concentrated samples and three commercial samples, where they found that the flavor and aroma of FO concentrated sample was closer to the single-strength juices.

IV. Conclusion

This study demonstrated the feasibility of concentrating apple cider using a benchtop lab scale forward osmosis unit from approximately 10 °Brix to 50 °Brix, and the addition of pectinase can make the process more efficient without affecting the overall acceptability of the reconstituted cider/juice. Most of the physicochemical attributes of the fresh cider are retained through the FO concentration, even when pectinase treatment is performed. In addition, there is no significant difference regarding the sensory attributes of FO concentrated apple cider and

(clear) apple juice. Overall, it is possible to concentrate apple cider using FO to produce a high-quality cider that is comparable to fresh.

Future work should study the possible migration of OA into the FO juice, the production and proper selection of OA based on the nature of product, and the scaling up to adapt the operation to a pilot plant and commercial application.

Reference

1. Adnan, A., Mushtaq, M., Islam, T. (2018). Chapter 12 - Fruit Juice Concentrates. *Fruit Juices*, ISBN 9780128022306.
2. Babu, B. R., Rastogi, N. K., & Raghavarao, K. S. M. S. (2006). Effect of process parameters on transmembrane flux during direct osmosis. *Journal of Membrane Science*, 280(1-2), 185-194.
3. Duffy, S., Churey, J., Worobo, R. W., & Schaffner, D. W. (2000). Analysis and modeling of the variability associated with UV inactivation of Escherichia coli in apple cider. *Journal of food protection*, 63(11), 1587-1590.
4. FlottwegAG. "Apple Juice Production with the Flottweg Belt Press." YouTube, 30 Mar. 2012, www.youtube.com/watch?v=OCQ0k4zWllo&t=225s.
5. "Fruit." *Merriam-Webster.com*. Merriam-Webster, n.d. Web. 29 June 2018.
6. Gabriel, A. A. (2012). Inactivation of Escherichia coli O157: H7 and spoilage yeasts in germicidal UV-C-irradiated and heat-treated clear apple juice. *Food Control*, 25(2), 425-432.
7. Garcia-Castello, E. M., & McCutcheon, J. R. (2011). Dewatering press liquor derived from orange production by forward osmosis. *Journal of Membrane Science*, 372(1-2), 97-101.
8. Herron, J. R., Beaudry, E. G., Jochums, C. E., & Medina, L. E. (1994). *U.S. Patent No.* 5,281,430. Washington, DC: U.S. Patent and Trademark Office.
9. Hunter Associates Laboratory. (2008). EasyMatch QC 4.70and above user's manual. Manual Version 2.2. www.hunterlab.com
10. Statista Market Forecast. (2018). Juices - United States. Retrieved from https://www.statista.com/outlook/20030000/109/juices/united-states#
11. Kashyap, D. R., Vohra, P. K., Chopra, S., & Tewari, R. (2001). Applications of pectinases in the commercial sector: a review. *Bioresource technology*, 77(3), 215-227.
12. Mushtaq, M. (2018). Extraction of Fruit Juice. *Fruit Juices,*131-159. doi:10.1016/b978-0-12-802230-6.00008-4
13. Nayak, C. A., & Rastogi, N. K. (2010). Forward osmosis for the concentration of anthocyanin from Garcinia indica Choisy. *Separation and Purification Technology*, 71(2), 144-151.
14. "Osmosis." *Merriam-Webster.com*. Merriam-Webster, n.d. Web. 23 July 2018.
15. Petrotos, K. B., Tsiadi, A. V., Poirazis, E., Papadopoulos, D., Petropakis, H., & Gkoutsidis, P. (2010). A description of a flat geometry direct osmotic concentrator to concentrate tomato juice at ambient temperature and low pressure. *Journal of food engineering*, 97(2), 235-242.
16. Petrotos, K. B., Quantick, P., & Petropakis, H. (1998). A study of the direct osmotic concentration of tomato juice in tubular membrane–module configuration. I. The effect of certain basic process parameters on the process performance. *Journal of Membrane Science*, 150(1), 99-110.
17. Popper, K., Camirand, W. M., Nury, F., & Stanley, W. L. (1966). Dialyzer concentrates beverages. *Food Eng*, 38(4), 102-104.
18. Quintero-Ramos, A., Churey, J. J., Hartman, P., Barnard, J., & Worobo, R. W. (2004). Modeling of Escherichia coli inactivation by UV irradiation at different pH values in apple cider. *Journal of Food Protection*, 67(6), 1153-1156.
19. Rabobank (2018). World Fruit Map 2018. *Utrecht*, Janurary 2018.
20. Rastogi, N. K. 2018. Chapter 13 - Reverse Osmosis and Forward Osmosis for the Concentration of Fruit Juices. *Fruit Juices*. ISBN 9780128022306.

21. Reiser, S. (1987). Metabolic effects of dietary pectins related to human health. *Food technology*.
22. Sánchez, J., Ruiz, Y., Auleda, J. M., Hernández, E., & Raventós, M. (2009). Freeze concentration in the fruit juices industry. *Food Science and Technology International*, 15(4), 303-315.
23. Toribio, J. L., Nunes, R. V., & Lozano, J. E. (1984). Influence of water activity on the nonenzymatic browning of apple juice concentrate during storage. *Journal of Food Science*, 49(6), 1630-1631.
24. Usaga, J., Padilla-Zakour, O. I., & Worobo, R. W. (2016). UV Tolerance of spoilage microorganisms and acid-shocked and acid-adapted Escherichia coli in apple juice treated with a commercial UV juice-processing unit. Journal of food protection, 79(2), 294-298.
25. Unites States Department of Agriculture (USDA) (2018). Noncitrus Fruits and Nuts 2017 Summary. *National Agriculture Statistics Service*, 1948-2698.
26. US Food and Drug Administration (USFDA). (1997). Fruit and vegetable juice beverages: notice of intent to develop a HACCP program, interim warning statement, and educational program. 21 CFR part 120. *Fed. Regist*, 62, 45593-45596.
27. US Food and Drug Administration (USFDA). (2000). Kinetics of microbial inactivation for alternative food processing technologies. A Report of the Institute of Food Technologists. https://www.fda.gov/downloads/food/foodborneillnesscontaminants/ucm545175.pdf
28. US Food and Drug Administration (USFDA). (2004). Guidance for industry: Juice HACCP hazards and controls guidance first edition; final guidance.
29. US Food and Drug Administration (USFDA). (2006). Food additive status list. *Revised as of April,* 1.
30. Usaga, J., Padilla-Zakour, O. I., & Worobo, R. W. (2016). UV Tolerance of spoilage microorganisms and acid-shocked and acid-adapted Escherichia coli in apple juice treated with a commercial UV juice-processing unit. *Journal of food protection*, 79(2), 294-298.
31. Vaillant, F., Jeanton, E., Dornier, M., O'Brien, G. M., Reynes, M., & Decloux, M. (2001). Concentration of passion fruit juice on an industrial pilot scale using osmotic evaporation. *Journal of Food Engineering*, 47(3), 195-202.
32. Vauzour, D., Rodriguez-Mateos, A., Corona, G., Oruna-Concha, M. J., & Spencer, J. P. (2010). Polyphenols and human health: prevention of disease and mechanisms of action. *Nutrients*, *2*(11), 1106-1131.
33. Wright, J. R., Sumner, S. S., Hackney, C. R., Pierson, M. D., & Zoecklein, B. W. (2000). Efficacy of ultraviolet light for reducing Escherichia coli O157: H7 in unpasteurized apple cider. *Journal of Food Protection*, 63(5), 563-567.
34. Wrolstad, R. E., McDaniel, M. R., Durst, R. W., Micheals, N., Lampi, K. A., & Beaudry, E. G. (1993). Composition and sensory characterization of red raspberry juice concentrated by direct‐osmosis or evaporation. *Journal of Food Science*, 58(3), 633-637.
35. Zimmer, E., Haverland, H., & Latz, M. (2016). Energetically optimized concentration of fruit juices. *Fruit processing: journal for the fruit processing and juice producing european and overseas industry*, (5), 178-183.

Chapter 2: Future Work and Recommendations

I. Selection of Osmotic Agent and Transmembrane Migration

The only osmotic agent that was used in this study was potassium lactate, however, the selection of different osmotic agent had been proven to influence the performance of forward osmosis. Sodium chloride, calcium chloride, calcium nitrate, sucrose, glucose and polyethylene glycol solutions have been used as osmotic agents for concentrating tomato juice by Petrotos, Quantick, and Petropakis (1998). It was found that salt solution had better permeate flux performance than glucose solution and polyethylene glycol solution. Besides, NaCl showed highest transmembrane flux (3.10 kg/m^2h) among all the salts.

Babu, Rastogi, and Raghavarao (2006) had similar conclusion. However, as they further studied the effect of mixed osmotic agents, they indicated that the addition of sodium chloride into sucrose solution increased the permeate flux (from 0.28 to 1.13 l/m^2h) and sodium chloride migration (up to 1.28%); the addition of sucrose into sodium chloride solution increased permeate flux (from 0.89 to 1.18 l/m^2h) and decreased sodium chloride transmembrane migration (from 1.87% to 0.58%).

Therefore, tests of different osmotic agents as well as the combination of different solutes for osmotic medium in the concentration of apple cider should be further studied to optimize the FO performance. Although the migration of osmotic agent was not evaluated in this study, it should be quantified in the future to ensure the safety and quality of the final product.

II. Membrane and Module Conditions

The membrane that was used in this study is designed to withstand a maximum feed-concentrate pressure difference of 0.7 bar. As the apple cider is concentrated to 50 °Brix, the

difference in feed and concentrate pressure reaches this limitation, which makes the further concentration impossible. Therefore, the maximum concentration of apple cider is limited by the parameters of the membrane.

The thickness of the membrane is also found to influence the performance of FO. With the same active layer, the thickness of the membrane is negatively correlated with the water flux (Petrotos et al., 1998; Herron, Beaudry, Jochums, and Medina, 1994). Thus, it is recommended to explore the performance of membrane with different thickness and module to find an optimal one.

III. Processing Parameters Optimization

Several studies have investigated the relationship between OA concentration and FO performance. There is a linear correlation between these two parameters that water flux increases as OA concentration increases due to greater osmotic pressure at higher OA concentration. However, the increase of osmotic agent concentration resulted in the decrease of overall mass transfer coefficient due to the increase of viscosity at higher concentration (Petrotos et al, 1998). In addition, Babu et al. (2006) pointed out that sodium chloride transmembrane migration increases from 1 to 2% as sodium chloride concentration increases from 6 to 26% (w/w). Therefore, it will be meaningful to explore an ideal OA concentration with the optimal high permeate flux, high overall mass transfer coefficient, and low OA migration combination.

Another important parameter for FO is processing temperature. As the temperature rises, the transmembrane flux and overall mass transfer coefficient increase, which results in a better membrane performance (Petrotos et al, 1998). Babu et al. (2006) revealed a 78% increase in water flux with an increase in temperature from 25 to 45°C. This can be explained by the

decreased viscosity of solution and increased diffusion coefficients due to increased temperature. However, the increase of temperature over certain range could result in deteriorated product quality and increase the microbial risks.

IV. Scaling Up

The successful application of FO in the industry requires scaling up of the process. However, the difficulty in designing appropriate full-scale membrane and the lack of an economic recovery method for diluted osmotic agent limited the large-scale research of FO.

Flat sheet membranes are the only current commercially available large-scale module that can be piled up to 1700 membranes by plate-and-frame system. However, in a continuous flow FO system, the feed needs to be recirculated at the permeate side, which make the construction of flat sheet membranes more complicated. Besides, the maximum acceptable hydraulic pressure at this setup is relatively low due to the lack of adequate membrane support, which requires more accurate operation control. Another limitation is the low packing density with greater space, higher capital and labor costs (Cath, Childress, and Elimelech, 2006).

The recovery of diluted OA was accomplished by vacuum evaporation in this study, which increased the energy and capital cost to FO process. When determining the energy conversion efficiency of FO, the energy consumed through OA recovery should be included as well. But finding a low cost, high availability and safe OA that can be reconcentrated easily is still a challenge for scientists. Although the energy consumption of FO during food processing is not study at this point, McGinnis and Elimelech (2007) calculated the energy requirements of ammonia–carbon dioxide forward osmosis desalination. FO saves around 72% to 85% energy on an equivalent work basis compared to thermal desalination methods. Mazlan, Peshev, and

Livingston (2016) compared the energy requirement of FO and RO during desalination. The energy consumption for FO desalination based on different types of OA and recovery method used was found to show no significant difference with that for RO desalination. Therefore, finding an effective and efficient osmotic agent is one of the key points in the application of FO.

References

1. Babu, B. R., Rastogi, N. K., & Raghavarao, K. S. M. S. (2006). Effect of process parameters on transmembrane flux during direct osmosis. Journal of Membrane Science, 280(1-2), 185-194.
2. Cath, T. Y., Childress, A. E., & Elimelech, M. (2006). Forward osmosis: principles, applications, and recent developments. Journal of membrane science, 281(1-2), 70-87.
3. Herron, J. R., Beaudry, E. G., Jochums, C. E., & Medina, L. E. (1994). U.S. Patent No. 5,281,430. Washington, DC: U.S. Patent and Trademark Office.
4. Mazlan, N. M., Peshev, D., & Livingston, A. G. (2016). Energy consumption for desalination—A comparison of forward osmosis with reverse osmosis, and the potential for perfect membranes. Desalination, 377, 138-151.
5. Petrotos, K. B., Quantick, P., & Petropakis, H. (1998). A study of the direct osmotic concentration of tomato juice in tubular membrane–module configuration. I. The effect of certain basic process parameters on the process performance. Journal of Membrane Science, 150(1), 99-110.

Appendix

Table 3 Water flux and soluble solids content (SSC) over time from different forward osmosis concentration processes of apple cider

P#1			P#2			P#3			NP#1			NP#2			NP#3		
Flux	Time	SSC	Flux	time	SSC	Flux	time	SSC	Flux	Time	SSC	Flux	Time	SSC	Flux	Time	SSC
$L/(m^2*h)$	(h)	°Brix	$L/(m^2*h)$	(h)	°Brix	$L/(m^2*h)$	(h)	°Brix	$L/(m^2*h)$	(h)	°Brix	$L/(m^2*h)$	(h)	°Brix	$L/(m^2*h)$	(h)	°Brix
0	0	13.5	0	0	9.2	0	0	14.5	0	0	11.7	0	0	12.2	0	0	11.5
6.608	0.25	14.6	8.08	0.25	10.1	6.368	0.25	15.2	4.592	0.25	12.2	4.96	0.25	13.8	4.592	0.25	12.3
6.392	0.5	15.8	8.008	0.5	11.2	6.216	0.5	16.3	6.272	0.5	13.4	6.288	0.5	15	6.272	0.5	13.4
6.139	0.75	16.8	7.744	0.75	12.6	5.9413	0.75	17.1	6.741	0.75	14.8	6.496	0.75	16.5	6.7413	0.75	14.5
5.916	1	18	7.52	1	14	5.668	1	18.2	6.864	1	16.3	6.492	1	18.2	6.864	1	15.9
5.619	1.25	19.5	7.053	1.25	15.7	5.5232	1.25	19.4	6.845	1.25	18	6.365	1.25	20.2	6.8448	1.25	17.3
5.44	1.5	21	6.835	1.5	17.3	5.2053	1.5	20.5	6.877	1.5	19.9	6.205	1.5	22.3	6.8773	1.5	19.1
5.259	1.75	22.5	6.647	1.75	19.4	5.0674	1.75	21.8	6.72	1.75	22.3	6.338	1.75	24.8	6.72	1.75	21
5.084	2	24.4	6.454	2	21.7	4.926	2	23.1	6.56	2	24.9	6.098	2	28.5	6.56	2	24.2
4.919	2.25	*26*	6.224	2.25	*24.3*	4.7893	2.25	*24.5*	6.375	2.25	*27.8*	5.867	2.25	*30.7*	6.375	2.25	*25.6*
4.758	2.5	27.9	6.021	2.5	27.3	4.6576	2.5	26	6.17	2.5	31.6	5.645	2.5	33.8	6.1696	2.5	29.2
4.611	2.75	29.8	5.722	2.75	30.1	4.5469	2.75	27.3	5.959	2.75	35.5	5.409	2.75	37.3	5.9593	2.75	31.3
4.543	3	31.7	5.507	3	33.2	4.4347	3	28.8	5.736	3	39.7	5.192	3	41.4	5.736	3	35.1
4.35	3.25	34.1	5.306	3.25	37.3	4.3175	3.25	30.5	5.408	3.25	44	4.998	3.25	44.6	5.408	3.25	39
4.214	3.5	36.6	5.104	3.5	41.8	4.2606	3.5	32.3	5.203	3.5	48.6	4.795	3.5	50.2	5.203	3.5	42.8
4.085	3.75	39.7	4.924	3.75	47.1	4.1568	3.75	33.9	5.12	3.6	51.1				5.12	3.75	47
3.963	4	42.8	4.827	3.88333	50.1	4.055	4	36.3							4.4784	4.16667	50
3.841	4.25	46.1				3.9623	4.25	39.7									
3.728	4.45	50.1				3.8764	4.5	41.4									
						3.792	4.75	44.2									
						3.7056	4.98333	50.4									

Consent Form for Participation in Apple Cider and Apple Juice Sensory Evaluation

You are currently participating the sensory evaluation of apple cider and apple juice where you will be asked to taste and evaluate three (3) apple cider/juice samples and answer the questions that follow. Please respond to the questions with honesty. Please read this form carefully and ask any questions you may have before agreeing to take part in the study.

Compensation: Participants will be given $5.00 upon completion of the survey. Participants/volunteers acknowledge that they are being paid for their participation in this study and that the payment received is adequate

CONFIDENTIALITY

Sensory Evaluation Center's Responsibility: All the data collected in the Consumer Use Test will be treated with strict confidentiality. Your name will not be shared with the Sensory Evaluation Center's clients or associated with any presentation of data. We reserve the right to collect and record the data in any manner and to present such data in any forum we choose.

Your Responsibility: You agree not to disclose or discuss any aspect of the study with anyone other than the designated personnel of the Sensory Evaluation Center.

Non-Confidential Nature of Ideas: By agreeing to these terms and conditions as a participant, you acknowledge that you are fully aware that feedback, suggestions and/or ideas submitted to the Sensory Evaluation Center and its clients by you are submitted on a non-confidential basis and the Sensory Evaluation Center or its clients may use or disclose such feedback, suggestions and/or ideas. Neither Sensory Evaluation Center nor any third party has any obligation of any kind, equitable or contractual, express or implied, to compensate anyone submitting feedback, suggestions or ideas.

Risks and discomforts: There is no risk related to this study.

Voluntary participation: Your participation in this research study is voluntary. You may choose not to participate, and you may withdraw your consent to participate at any time.

Contact information: If you have any questions or concerns about this study or if any problems arise, please contact Junyi Chen at jc2792@cornell.edu.

STATEMENT OF CONSENT

I have read this consent form and have been given the opportunity to ask questions. I give my consent to participate in this study.

By clicking the "I Agree" button below, I accept the terms and conditions of this Agreement.

Sensory Test of Apple Cider

Before tasting this test sample please answer the following question...

1. How would you rate this test sample's OVERALL APPEARANCE? (please select one response)

Dislike it extremely - Dislike it very much - Dislike it moderately - Dislike it slightly - Neither like nor dislike it - Like it slightly - Like it moderately - Like it very much - Like it extremely

2. How would you rate this test sample's CLARITY/CLOUDINESS? (please select one response)

Dislike it extremely - Dislike it very much - Dislike it moderately - Dislike it slightly - Neither like nor dislike it - Like it slightly - Like it moderately - Like it very much - Like it extremely

3. How would you rate this test sample's COLOR? (please select one response)

Much too light - Somewhat too light - Just about right - somewhat too dark - much too dark

4. How would you rate this test sample's AROMA? (please select one response)

Dislike it extremely - Dislike it very much - Dislike it moderately - Dislike it slightly - Neither like nor dislike it - Like it slightly - Like it moderately - Like it very much - Like it extremely

Now please taste the sample and answer the following questions....

5. How would you rate this test sample's OVERALL FLAVOR? (please select one response)

Dislike it extremely - Dislike it very much - Dislike it moderately - Dislike it slightly - Neither like nor dislike it - Like it slightly - Like it moderately - Like it very much - Like it extremely

6. How would you rate the SWEETNESS of this sample? (please select one response)

Much too low - Somewhat too low - Just about right - somewhat too high - much too high

7. How would you rate the SOURNESS of this sample? (please select one response)

Much too low - Somewhat too low - Just about right - somewhat too high - much too high

8. How would you rate the APPLE FLAVOR INTENSITY of this sample? (please select one response)

Much too low - Somewhat too low - Just about right - somewhat too high - much too high

9. How would you rate the CONSISTENCY/BODY of this sample? (please select one response)

Much too low - Somewhat too low - Just about right - somewhat too high - much too high

10. How would you rate this test sample OVERALL LIKING? (please select one response)

Dislike it extremely - Dislike it very much - Dislike it moderately - Dislike it slightly - Neither like nor dislike it - Like it slightly - Like it moderately - Like it very much - Like it extremely

11. If this product were available to you in a store where you usually shop, at a price that you typically pay, and from the brand that you typically buy, would you say you would...? (Select one response)

Definitely would purchase - probably would purchase - may or may not purchase - probably would not purchase - definitely would not purchase

12. Please rank the products listed below, in the order that you prefer them from most to least.
    Start by clicking the product code which you like MOST, followed by clicking the product code which you like SECOND, continuing until the final product code you click is the one you like LEAST.
    After you make your selections the product codes will appear in the space below with the product you liked MOST on the left to the product you liked LEAST on right.
    If you'd like to change the order of your responses, click the "Reset" button in the lower right-hand corner.

    103 - 375 - 869

Table 4 pH measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Sample	Treatment	Measurements		
		1	2	3
1	FO-P	3.79	3.78	3.74
2		3.76	3.72	3.72
3		3.85	3.83	3.81
4	FO-NP	3.79	3.78	3.8
5		3.83	3.81	3.81
6		3.79	3.79	3.79
7	C	3.75	3.77	3.75
8		3.76	3.76	3.76
9		3.86	3.85	3.87

Table 5 Soluble solids content measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Sample	Treatment	Measurements		
		1	2	3
1	FO-P	11.01	11.03	11.01
2		11.05	11.03	11.01
3		11.00	10.97	10.97
4	FO-NP	11.04	11.01	11.00
5		11.05	11.01	11.03
6		10.94	10.92	10.95
7	C	11.03	11.09	11.02
8		10.97	11.01	11.00
9		11.07	11.08	11.09

Table 6 Titratable acidity measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Sample	Treatment	Measurements		
		1	2	3
1	FO-P	0.25%	0.25%	0.25%
2		0.32%	0.32%	0.32%
3		0.25%	0.25%	0.25%
4	FO-NP	0.30%	0.30%	0.30%
5		0.28%	0.28%	0.28%
6		0.29%	0.29%	0.29%
7	C	0.32%	0.31%	0.32%
8		0.32%	0.32%	0.32%
9		0.25%	0.25%	0.25%

Table 7 Water activity measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Sample	Treatment	Measurements		
		1	2	3
1	FO-P	0.9841	0.9889	0.9894
2		0.9900	0.9856	0.9839
3		0.9867	0.9939	0.9921
4	FO-NP	0.9908	0.9911	0.9881
5		0.9947	0.9925	0.9926
6		0.9888	0.9886	0.9904
7	C	0.9824	0.9910	0.9887
8		0.9865	0.9884	0.9889
9		0.9852	0.9885	0.9899

Table 8 Turbidity measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Sample	Treatment	Measurements		
		1	2	3
1	FO-P	331	333	335
2		287	290	290
3		307	307	304
4	FO-NP	495	499	493
5		306	312	311
6		422	421	419
7	C	519	524	516
8		394	395	393
9		469	465	473

Table 9 Color measurements of control (C), sample once concentrated with (FO-P) or without (FO-NP) pectinase. Measurements for each sample is triplicated.

Treatment	Sample	Test	L	a	b
FO-P	1	1	49.09	7.29	52.74
		2	49.11	7.29	52.65
		3	49.16	7.26	52.72
	2	1	51.63	4.83	53.02
		2	51.66	4.93	53.12
		3	51.59	4.88	52.65
	3	1	50.55	6.93	50.09
		2	50.24	6.71	50.18
		3	50.33	6.72	49.47
FO-NP	1	1	46.82	7.22	49.2
		2	47.18	7.2	48.03
		3	46.97	7.24	48.52
	2	1	51.13	5.7	49.37
		2	50.73	5.5	49.43
		3	51.04	5.43	48.24
	3	1	47.68	7.08	49.58
		2	47.96	7	48.66
		3	47.95	6.9	48.44
C	1	1	44.72	8.89	49.52
		2	44.77	8.89	49.57
		3	42.39	8.33	46.05
	2	1	45.96	6.12	47.98
		2	46.42	6	46.47
		3	46.01	5.92	46.72
	3	1	41.96	9.17	45.6
		2	42.93	9.52	47
		3	42.63	9.39	46.6