CALIFORNIA
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## ENERGY RESEARCH AND DEVELOPMENT DIVISION

## FINAL PROJECT REPORT

# Energy Savings Through Osmotic Concentration for the Food Industry

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Partnerships created through the EPIC program provide small companies with the chance to collaborate with industry to explore research concepts. This collaboration enables discovery of practical solutions for industry and lends brand-name credibility to the innovations of small businesses.

Porifera is thankful to partners, each of whom demonstrated professionalism and persistence throughout the project:

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United States Department of Agriculture, Agricultural Research Service (USDA-ARS), Albany, California — Rebecca Milczarek, and Tara McHugh.

Porifera is grateful for the opportunities provided by the CEC to further the development of osmotic concentration technology for wide-ranging commercial use. This project provided the engineering team the chance to define and solve processing challenges and discover solutions applicable across industries.

# PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov

# ABSTRACT

The Porifera Forward Osmosis (PFO) Concentrator, a non-thermal, membrane-based system can create a high-quality, high-concentration concentrate without degradation and without high power requirements.

The purpose of this project was to install a commercial-scale PFO Concentrator, produce a sellable product, and demonstrate the benefits of this technology in producing non-thermal juice concentrates and freeze-dried powder products. The demonstration took place over three years at Van Groningen & Sons' commercial watermelon juicing facility in Manteca, California.

The project demonstrated continuous 24-hour cycle concentration of watermelon juice from 8 to 30, 50, and 65 degrees Brix with superior nutritional quality compared to thermally processed juice. Sensory analysis confirmed that the flavor and the aroma of the juice concentrate were well preserved during and after processing. The PFO Concentrator was demonstrated to have 24-94 percent lower greenhouse gas (GHG) emissions than the competing technologies, depending on the operational parameters.

Implementation of Porifera's technology within the food and beverage industry will significantly reduce seasonal electrical and natural gas demand during the harvest and processing season. The energy savings occur in reduced energy needed for processing and for refrigeration. Substantial reduction of GHG emissions can be achieved by transporting concentrates instead of single strength juice.

**Keywords:** Porifera Forward Osmosis Concentrator, osmotic concentration, non-thermal concentration, juice concentrates, freeze-dried powder products, food and beverage industry, energy savings, California

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# Executive Summary

## Background

Currently, food and beverage products are concentrated using thermal processes. Thermal processing severely degrades product quality and consumes enormous amounts of energy. Porifera's forward-osmosis system can create a high-quality concentrated product without product degradation and without high power requirements. The Porifera Forward Osmosis (PFO) Concentrator lacks the disadvantage of product degradation during concentration, and this is its innovation. The PFO Concentrator uses a nonthermal process that can achieve significantly higher concentration than other nonthermal processes.

The commercial demonstration of the PFO Concentrator and the benefits quantification of its nonthermal capabilities will result in faster implementation and adoption of this technology by food and beverage processors. This will accelerate energy savings and greenhouse gas (GHG) emissions reductions in California and will place California companies at the forefront of food and beverage concentrate production. This benefits California's food and beverage industry, ratepayers, and economy.

The PFO Concentrator removes water from food and beverage products and concentrate products up to 10 times by volume while retaining a fresh, natural taste. This has extraordinary ramifications for the food and beverage industry. For example, with orange juice concentration, imagine a fresh-squeezed taste compared to the metallic and additive-laden taste we experience today at one-tenth of the existing transportation, packaging and storage, and refrigeration costs. The resultant GHG savings associated with these reductions is another benefit of using the PFO Concentrator, whether it be with oranges, other fruits and vegetables, dairy products, cold-brewed coffee, or other energy-intensive food and beverage products.

## Project Purpose and Approach

This project sought to install a commercial-scale PFO Concentrator for California food and beverage processors that is able to produce a sellable product as well as demonstrate the benefits of Porifera's technology in producing nonthermal juice concentrates and freeze-dried powder products. The demonstration took place over three years at a watermelon processing facility where three different demonstration attempts were made during each year's watermelon processing seasons (typically July–October). In between the watermelon processing seasons, the process was evaluated, and the systems were reconfigured for the next demonstration.

The objectives of this project were to: a) design, build, and install a sanitary PFO Concentrator at Van Groningen & Sons' commercial watermelon juicing facility in Manteca, California to produce nonthermally processed watermelon concentrates and freeze-dried powders for technology benefits demonstration, and b) demonstrate the system's energy savings. The system required:

- Optimization of the watermelon juice concentration process, including watermelon handling methods (that is, steaming to pre-clean; with or without pasteurization).
- Optimization of the PFO Concentrator operating conditions.
- Development of a standard procedure to meet customer requirements and specifications of the watermelon juice concentrate product.

Porifera collaborated with the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) in Albany, California to develop optimal conditions for freeze-dried processing of watermelon juice concentrate and create powder samples. These samples were analyzed by certified third-party laboratories to validate food safety.

The project advanced scientific knowledge through establishing an optimal energy-saving system for concentrating and freeze-drying watermelon juice. The system is also applicable to many other products. Porifera defines an optimal system as one which allows processors to:

- Meet food safety standards.
- Measure and verify energy savings and GHG reductions.
- Create concentrates and powders with verifiable and quantifiable improvements in flavor, color, and nutrition not possible with current state-of-the-art thermal processing.

The demonstration system allowed customers to view the equipment, taste samples generated from the system, and perform economic analysis of energy and cost savings. To demonstrate Porifera's technology and produce market-ready product, Porifera built a fully sanitary, commercial-scale PFO Concentrator and installed it at a commercial customer's site. The system was fully instrumented to demonstrate the energy savings and other benefits to the customer.

Several outstanding features allow the PFO Concentrator to achieve high concentrations:

- The PFO Concentrator uses forward osmosis and reverse osmosis differently than conventional membrane systems. This minimizes membrane fouling and maximizes energy savings.
- The PFO Concentrator can produce juice concentrates, and those concentrates can be freeze-dried into powders of higher quality than competing technologies.

- Porifera’s process uses considerably less energy than competing technologies.

In addition to delivering the system, Porifera verified concentrate product quality. Samples of both the initial juice and concentrates were analyzed to quantify the flavor, color, and nutrient content as well as compared to thermally processed concentrates. Samples generated under different processing conditions were analyzed at Porifera’s facilities and at USDA-ARS. The microbiological quality of the produced concentrates was evaluated to verify their safety for consumption. The samples were sent to a certified third-party laboratory for independent measurement and verification of food safety.

Samples of produced watermelon concentrate were collected for freeze-drying studies at USDA-ARS. Freeze drying of high sugar content products is challenging, and freeze drying of produced watermelon concentrate could not be accomplished. Porifera’s team tried a common approach, which is adding some carrier to help the drying process. Adding different amounts of maltodextrin did not result in any significant improvement in freeze drying of the concentrate.

## In response to the feedback received Key Results

Porifera demonstrated the concentration of watermelon juice from 8 to 30, 50, and 65 degrees Brix. The common industry standard for fruit juice concentrate is 65 degrees Brix, but different lower target concentrations may result in a better tradeoff between transportation and refrigeration savings and energy use in processing. Quality of Porifera’s produced watermelon concentrate was superior in comparison to thermally processed concentrate. Nutritional analysis performed on both the fresh juice and the concentrate diluted back to the original strength (reconstituted) indicated that forward osmosis concentration can maintain the original nutritional content of the source material. Furthermore, sensory analysis confirmed that the flavor and aroma of the juice concentrate were well preserved during and after processing.

Porifera’s system proved successful in processing the watermelon juice at the juice processing facility for three seasons. Porifera demonstrated its PFO Concentrator to have 24 percent to 94 percent lower GHG emissions than the competing technologies, depending on the operational parameters.

Implementing Porifera’s technology within the food and beverage industry can significantly reduce seasonal electrical and natural gas demand during the harvest and processing season and can lower overall peak demand. This reducing of peak energy demand could improve reliability and reduce costs associated with energy production and transmission, which could improve California’s grid reliability. The energy savings occur primarily in reduced energy needed for processing (that is, steam generation, evaporator use, etc.) and for refrigeration but also come indirectly at the site from reduced well and process water pumping requirements, less energy for wastewater treatment, or reduced reheating in boilers. The PFO Concentrator can directly replace or improve energy savings for multiple energy loads within a facility including:

- Evaporators. Membranes are energetically more efficient than thermal processes.
- Refrigeration. The energy needed to store diluted juice at low temperature is significantly higher than the energy needed to store a 3–10 times smaller volume of a more shelf stable, concentrated product at a higher temperature.
- Boilers, cooling towers, scrubbers, etc. High quality, soft water extracted from products can be reused to improve the operation and efficiency of key mechanical equipment.

## Knowledge Transfer and Next Steps

The intended use of the project results was to demonstrate, through sample product and data, the relatively new concentrator technology to food processors. Porifera produced sample concentrates with trials and shared the samples with customers at tradeshows as part of Porifera's show booth or mailed them directly to relevant customers.

Porifera performed both passive and active information sharing activities. Passive sharing activities included the preparation and publication of multiple manuscripts, a business case study, and additional relevant materials. Active sharing activities included hosting booths at tradeshows and exhibitions, in addition to oral presentations given both in person and virtually.

Porifera plans to continue sharing the benefits of its concentrator technology through both general marketing collateral as well as targeted information for food and beverage processors. Porifera maintains its presence at and contribute to food and beverage expos and conferences. Porifera's website will be continuously updated with new case studies and products obtained with the PFO Concentrator technology.

Target markets for this technology are companies producing concentrates of coffee and fruit and vegetable juices.

# CHAPTER 1: Introduction

## Porifera Company Overview

Porifera Inc. is a California-based company, which manufactures proprietary forward osmosis (FO) membranes and provides process solutions to a variety of industries. Porifera's innovative FO solutions enable industries to efficiently remove water and retain only the most valuable components of their products. This unique technology facilitates the minimization of water waste, improvements to water reuse, and more efficient processing solutions to create better products using less energy.

Porifera operates a 25,000 square-foot facility at its San Leandro, California headquarters. The facility contains administrative offices, engineering workspace, loading docks, a membrane characterization laboratory, and a food and beverage laboratory. The facility is equipped with several chemical hoods and other chemistry instrumentation.

Porifera operates another 12,500 square-foot manufacturing facility, also in San Leandro, California. This facility contains semi-automated equipment for assembly of PFO elements and modules as well as quality assurance testing equipment.

## Porifera Technology Overview

### Introduction to Forward Osmosis

Forward osmosis has unique advantages for food and beverage applications because it can operate reliably when processing challenging liquids that quickly clog or foul other types of membrane processes, such as reverse osmosis (RO). It competes with thermal evaporators to produce a superior product at a lower cost and with less energy. In some cases, it can replace thermal evaporators, and in other cases it may replace combinations of concentration technologies including RO, centrifuges, and thermal processes.

Porifera's forward osmosis (PFO) innovations are unique in that PFO can:

- Operate reliably on challenging liquids with high solids, pulps, sugars, fiber, etc. Porifera is the only FO provider of spacerless elements suited to these applications. Spacerless membrane elements are key to addressing these applications because they do not have a spacer inside of the flow channel and the liquid is free to move through the channel without having fibers and particulates get caught on the spacer.
- Achieve higher membrane flux, rejection, and efficiencies than competing FO technologies using the same draw solution chemistry.
- Operate at high rejection and high efficiencies using a "draw solution" that is easily recyclable using RO. Competing FO technologies either require toxic draw solutions or allow too much leakage of the draw salt into the product.

Operate at temperatures up to 80 °C. Standard FO and RO membranes cannot exceed 45 °C, which negates a significant amount of potential energy savings in food and beverage applications when some heating is needed for sterilization or finishing.

Operate at a wide range of pH (2-11), expanding the applicability of FO-based solutions, which in the past could not operate at low pH. This is important as many fruit juices are acidic (that is, low pH).

### Porifera Forward Osmosis Concentrator

Porifera's concentrator combines its proprietary FO and modified reverse osmosis (ROX-maxG2) draw regeneration technology to achieve greater product concentrations than conventional RO technologies can achieve on their own. While the PFO can also be used without the draw regeneration or with other draw regeneration systems, such as traditional RO, Porifera's standard ROX or various thermal processes, when combined with ROX-maxG2 achieve the highest concentrations and best energy savings. The ROX technology is comprised of multiple flexible ROX steps. While traditional RO operates in a single step at pressures of up to 800 psi, ROX-maxG2 utilized in this project is a two-stage process with special membranes optimized for concentration of glycerol draw solute.

## Project Goals and Objectives

This project aimed to demonstrate the PFO Concentrator at commercial scale. Objectives included the following:

Demonstrate the PFO Concentrator's benefits for food and beverage product concentration (for example, aroma, flavor, color, nutritional content, and energy savings).

Advance the PFO Concentrator's abilities between multiple watermelon processing seasons.

Demonstrate market readiness by validating the concentration of other food and beverage products.

Demonstrate the freeze-drying of PFO Concentrator products.

Source: CSE

# CHAPTER 2:
# Project Approach

## General

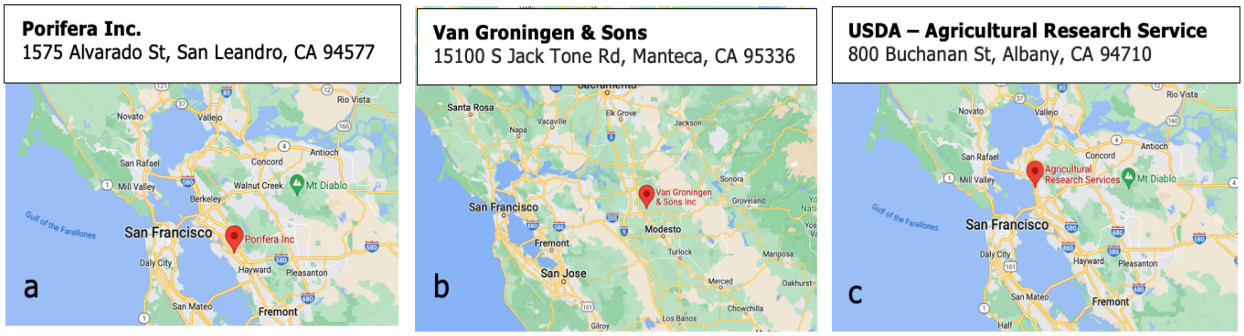
Over a three-year period, Porifera installed a commercial-scale PFO Concentrator for a California food and beverage processor and demonstrated its benefits in producing nonthermal juice concentrates and products. The demonstration took place over three years at a watermelon processing facility, Van Groningen & Sons in Manteca, California. Three demonstration attempts occurred during each year's watermelon processing seasons, typically July through October. In between the watermelon processing seasons, Porifera evaluated the results of the previous year and prepare for the next year with improvements. The project was separated into three phases, each phase was happening during the California watermelon season. Watermelon concentrate evaluation and additional product research was completed in partnership with the U.S. Department of Agriculture (USDA) in Albany, California.

In addition to watermelon juice concentration, Porifera demonstrated its technology in other applications, such as lemon juice, at Porifera's headquarters.

### Locations

The project was executed at Porifera Inc. in San Leandro and two other locations. The Van Groningen & Sons' facility in Manteca, California was the site for FO concentration, and the USDA-Agricultural Research Service (USDA-ARS) in Albany, California was the site for physical, chemical, and sensory analysis of produced samples. All three locations are shown in Figure 1.

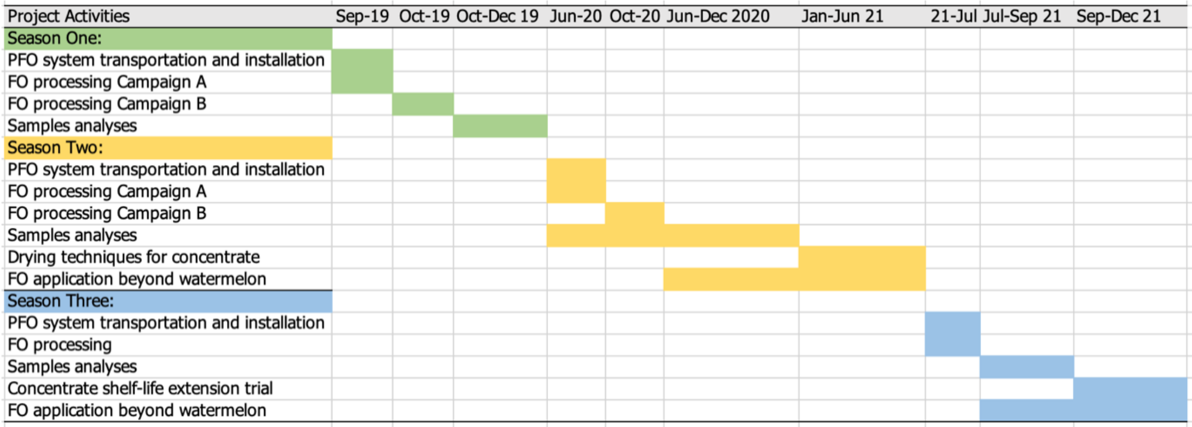
**Figure 1: Project Locations: Porifera Inc. (a), Van Groningen & Sons (b), and USDA-ARS (c)**



Source: Google Maps

The Project activities over three-year period were listed in the project timeline shown in Figure 2.

### Figure 2: Project Timeline



| Project Activities | Sep-19 | Oct-19 | Oct-Dec 19 | Jun-20 | Oct-20 | Jun-Dec 2020 | Jan-Jun 21 | 21-Jul | Jul-Sep 21 | Sep-Dec 21 |
|---|---|---|---|---|---|---|---|---|---|---|
| Season One: | | | | | | | | | | |
| PFO system transportation and installation | 🟩 | | | | | | | | | |
| FO processing Campaign A | 🟩 | | | | | | | | | |
| FO processing Campaign B | | 🟩 | | | | | | | | |
| Samples analyses | | | 🟩 | | | | | | | |
| Season Two: | | | | | | | | | | |
| PFO system transportation and installation | | | | 🟨 | | | | | | |
| FO processing Campaign A | | | | 🟨 | | | | | | |
| FO processing Campaign B | | | | | 🟨 | | | | | |
| Samples analyses | | | | 🟨 | 🟨 | 🟨 | | | | |
| Drying techniques for concentrate | | | | | | | 🟨 | | | |
| FO application beyond watermelon | | | | | | 🟨 | 🟨 | | | |
| Season Three: | | | | | | | | | | |
| PFO system transportation and installation | | | | | | | | 🟦 | | |
| FO processing | | | | | | | | 🟦 | | |
| Samples analyses | | | | | | | | | 🟦 | |
| Concentrate shelf-life extension trial | | | | | | | | | | 🟦 |
| FO application beyond watermelon | | | | | | | | | 🟦 | 🟦 |

Source: Porifera

### Equipment and Materials

The main components for project execution included the following:

- Commercial-scale PFO Concentrator
- Feed solution (freshly produced watermelon juice)
- Draw solution (75 percent glycerol solution)
- Miscellaneous disinfection and cleaning chemicals
- Sample containers suitable for storage and quality testing
- Lab testing system (one proprietary FO element, feed and draw tanks, scales, and two peristaltic pumps)
- Continuous RC3 system (proprietary PFO-100 elements, feed and draw tanks, pumps, and instrumentation).

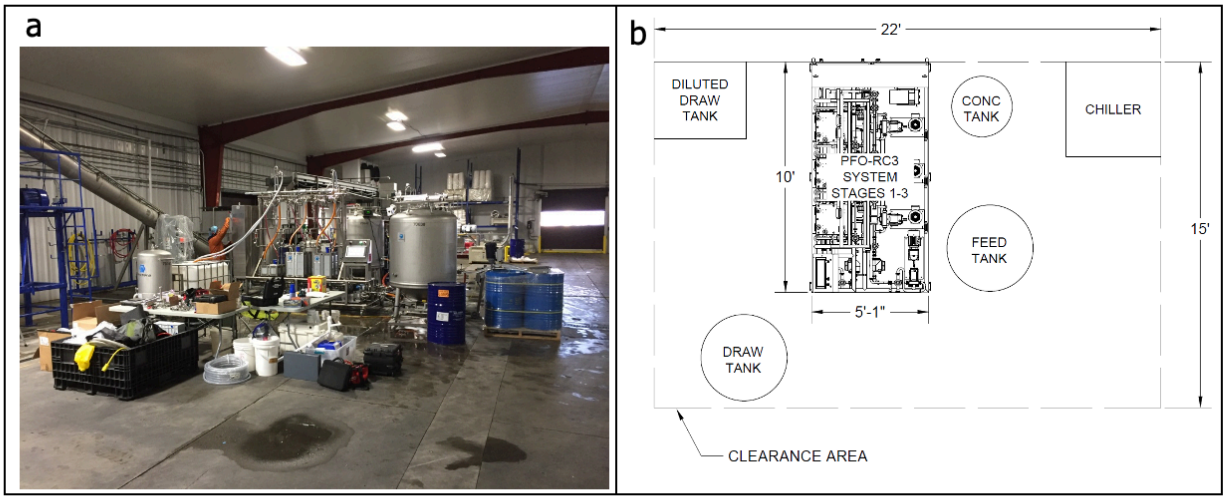
Porifera designed, fabricated, and operated the test equipment. Van Groningen & Sons provided the feed solution, watermelon juice, and Porifera provided the draw solution and cleaning chemicals. The equipment and materials used for testing varied for each phase of the project and is summarized in the following subsections.

## Watermelon Juice Concentration

### Season One – 2019

For the first season Porifera planned a trial concentration run with pilot partner Van Groningen & Sons to be around peak watermelon ripeness in September and October. Porifera then prepared and transported Porifera's multi-stage forward osmosis concentrator (RC3 system) to Van Groningen and Sons' facility in Manteca, California on September 9th-10th, 2019. The RC3 system was installed in the refrigerated juice processing facility, adjacent to watermelon processing machines. The location of the RC3 system in the facility and its areal schematic diagram are shown in Figure 3.

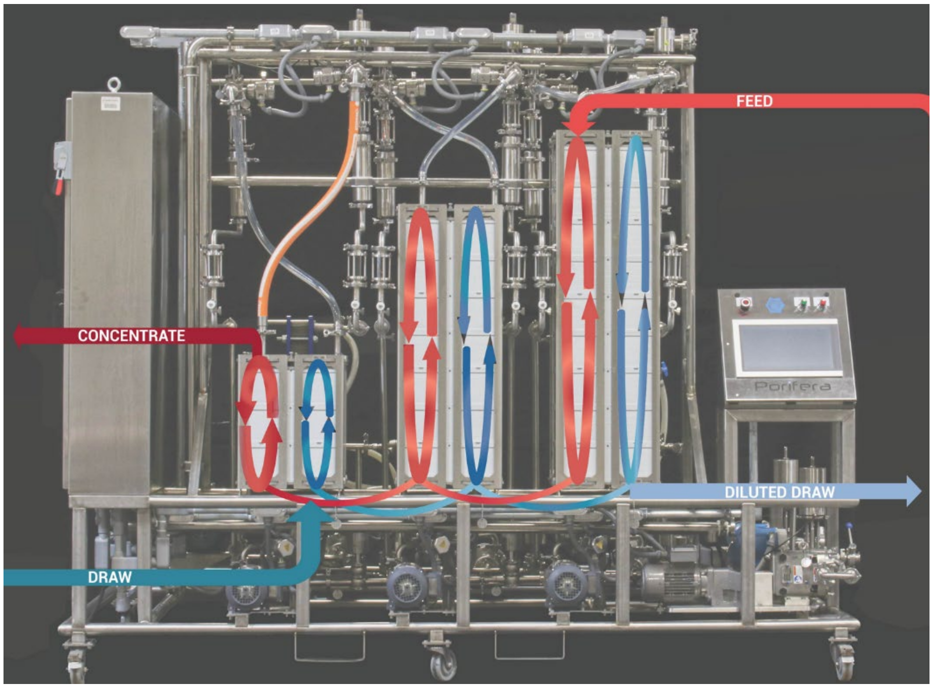
**Figure 3: Location of the RC3 System in the Production Warehouse (a) and its Areal Schematic Diagram (b)**



Credit: Porifera Inc.

For the Season One trial, Porifera's team planned to perform multiple watermelon concentration campaigns. Each campaign consisted of three runs with a 24-hour cycle, to accommodate daily cleanings and system checks. In the first campaign (Campaign A), the element configuration in the continuous three-stage system included seven PFO-100 elements (7 $m^2$ each) for a total membrane area of 49 $m^2$. In the second campaign (Campaign B), Porifera's team tripled capacity and increased the membrane area to 133 $m^2$ with nineteen PFO-100 elements. A schematic flow diagram of the RC3 system and its running mode is shown in Figure 4. The feed was freshly produced watermelon juice, and the draw solution was 70-75 percent glycerol. In both campaigns watermelon juice was concentrated from 8 °Brix to 65 °Brix. Porifera's team continuously monitored the feed, product (concentrate), and draw streams during the campaign to collect data on flow rates, °Brix, and pressures. Through all runs, flux and target Brix remained constant. Porifera processed more than 10,000 kg of juice and produced more than 1,250 kg of concentrate.

**Figure 4: RC3 System and its Running Mode**



**Picture of the RC3 system with schematic flows of feed, draw, concentrate, and diluted draw**

Credit: Porifera Inc.

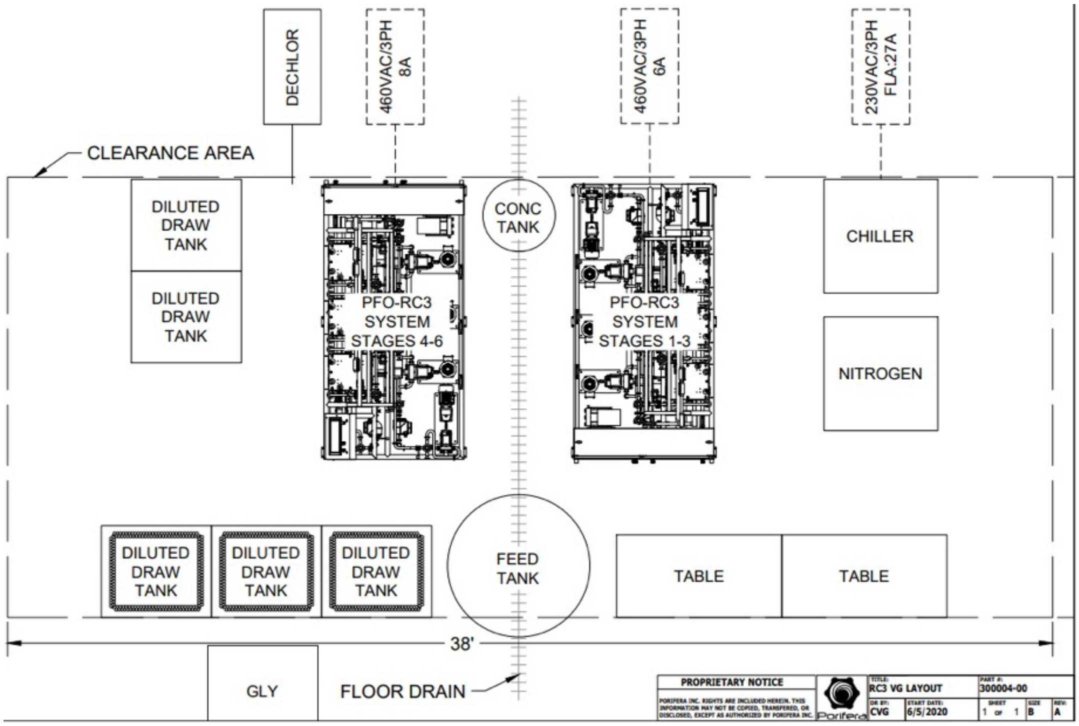
## Season Two – 2020

During the second season of operation, the project goals were to: 1) incorporate lessons learned from the Season One, 2) study operational conditions, and 3) produce concentrate for customers to increase market demand. Porifera planned two watermelon juice concentration campaigns with the pilot partner Van Groningen & Sons. Campaign A was planned for the beginning of California watermelon season in June, and Campaign B was planned towards the end of the season in October. The objective of Campaign A was to make sample concentrate for Van Groningen & Sons to provide to their customer, to increase sales. Campaign B was planned as a continuation and improvement of the Season One trial. In both campaigns Porifera concentrated the juice with a multi-stage PFO Concentrator RC6 system. The RC6 system is a significant increase in concentration capacity compared to the Season One, when RC3 system was used.

### *Campaign A*

In June 2020, Porifera prepared and transported Porifera’s RC6 system to Van Groningen and Sons’ facility in Manteca, California. The concentration run was performed continuously from June 22 to June 26, 2020. The RC6 system was installed in the refrigerated juice processing facility (13 °C), adjacent to the watermelon juice processing machines. The location of the RC6 system in the facility and its areal schematic diagram are shown in Figure 5.

### Figure 5: The Areal Schematic Diagram of the RC6 System for Campaign A



Credit: Porifera Inc.

The element configuration in the continuous six-stage system included forty-four PFO-100 elements (7 $m^2$ each) for a total membrane area of 308 $m^2$. Watermelon juice was concentrated from 8.4 °Brix to 65 °Brix. The draw solution was 70 percent glycerol in water. Initially, the runs were planned for four days (June 22-26), but the run planned on June 23rd was cancelled due to lack of fresh juice available from an interruption in the supply chain. A run on the first day lasted 10 hours and runs on the third and the fourth day were sequentially for 20 hours each. In this campaign, Porifera's team processed 15,140 L of juice and produced 1,135 L of watermelon concentrate (Figure 6).

### Figure 6: Processing with the PFO Concentrator RC6 (a) and Watermelon Concentrate Produced at Van Groningen & Sons During Campaign A (b)

**Pictures of the RC6 system in the warehouse and glycerol tanks, and watermelon concentrate filled in buckets**

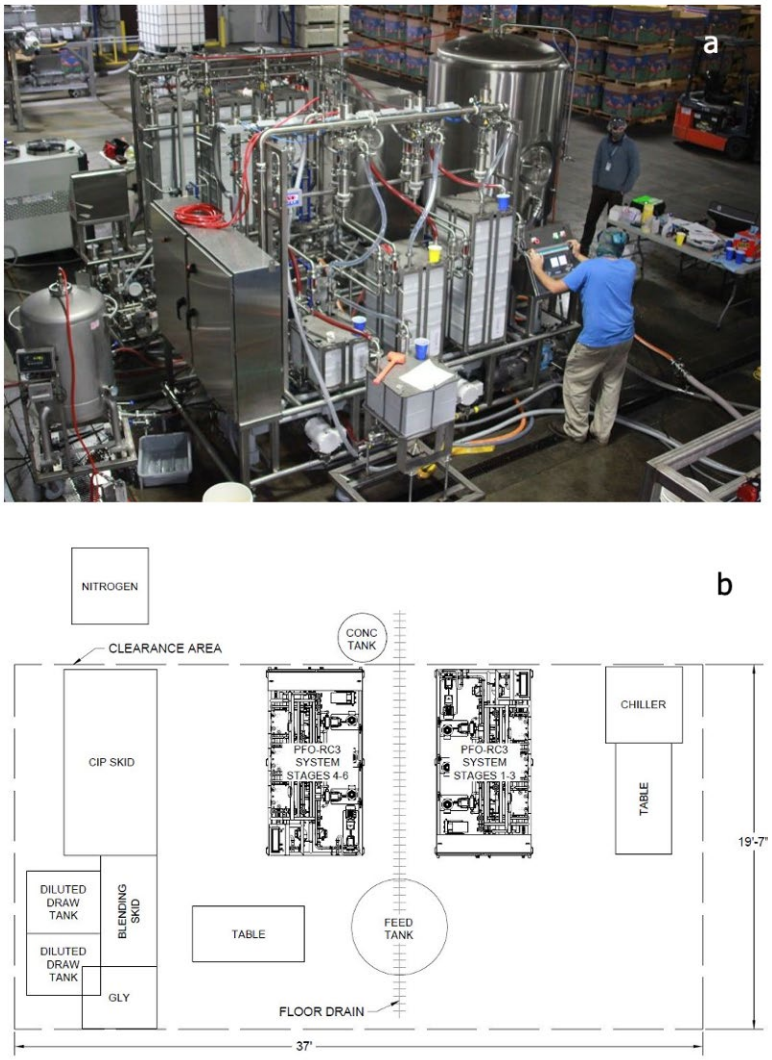
Credit: Porifera Inc.

In conclusion, the Campaign A goals to increase the system capacity and by operating a pair of RC3 systems as an RC6 system for the first time and to produce 150 pails of concentrate were successfully met.

### *Campaign B*

For Campaign B, Porifera prepared and transported Porifera's PFO Concentrator (RC6 system), in addition to new ancillary equipment, to Van Groningen and Sons' facility in Manteca, California in October 2020. The RC6 system was again installed in the refrigerated juice processing facility (7.2 °C), adjacent to watermelon processing machines. The location of the RC6 system in the facility and its areal schematic diagram are shown in Figure 7.

**Figure 7: Porifera's RC6 System in the Production Warehouse (a) and its Areal Schematic Diagram (b) for Campaign B**

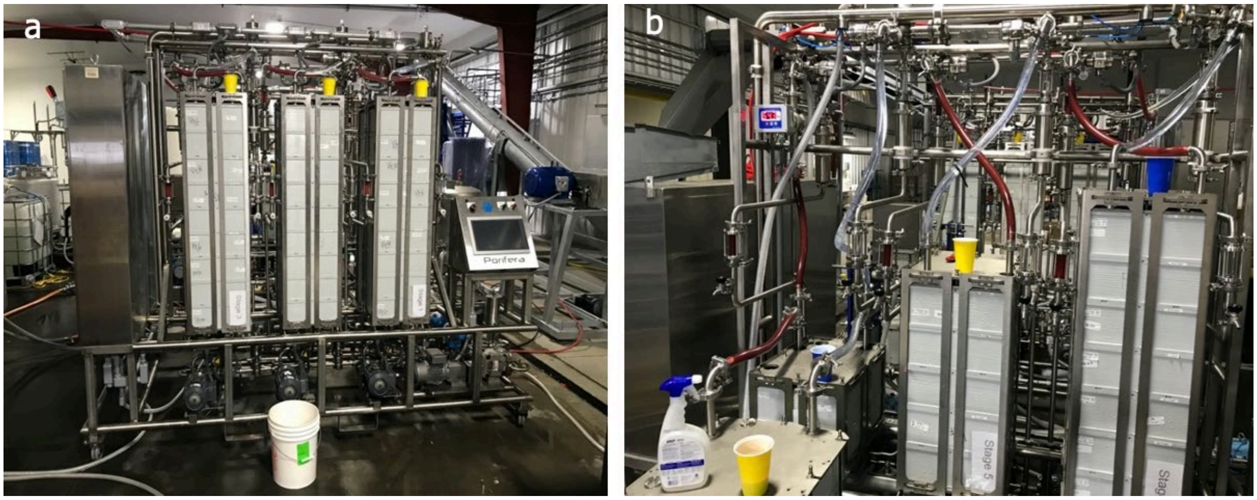


**Picture of the RC6 system in the warehouse during Campaign B, and its areal schematic diagram**

Credit: Porifera Inc.

For Campaign B, Porifera’s team planned to perform a run continuously for 3 days without daily cleanings and system checks. In this campaign, two RC3 systems were coupled and the element configuration in the continuous six-stage system included forty-three PFO-100 elements (7 $m^2$ each) for a total membrane area of 301 $m^2$ (Figure 8).

**Figure 8: The RC6 System Processing Watermelon Juice**

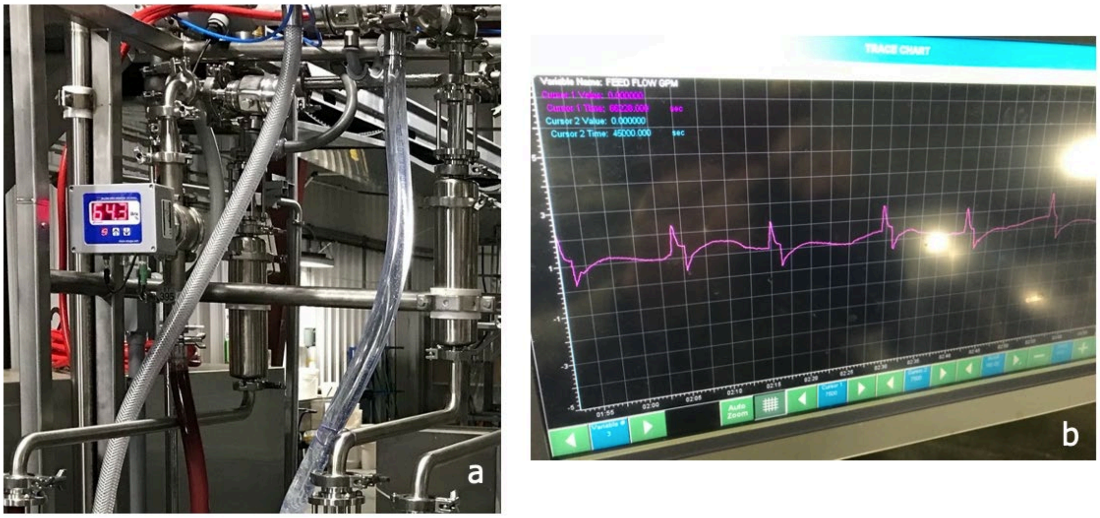


**Pictures showing RC6 system concentrating watermelon juice**

Credit: Porifera Inc.

Compared to the previous season, in addition to increasing the concentrator capacity, the system and processing were improved by addressing the lessons learned from Season One. Namely, automation of the process was improved by utilizing the clean-in-place (CIP) and sanitization-in-place (SIP) blending skid. An in-line refractometer was installed to measure °Brix and control the concentration pump as shown in Figure 9. This feature significantly decreased labor and time required to operate the system.

**Figure 9: In-Line Refractometer (a) and Concentration Pump Control (b)**

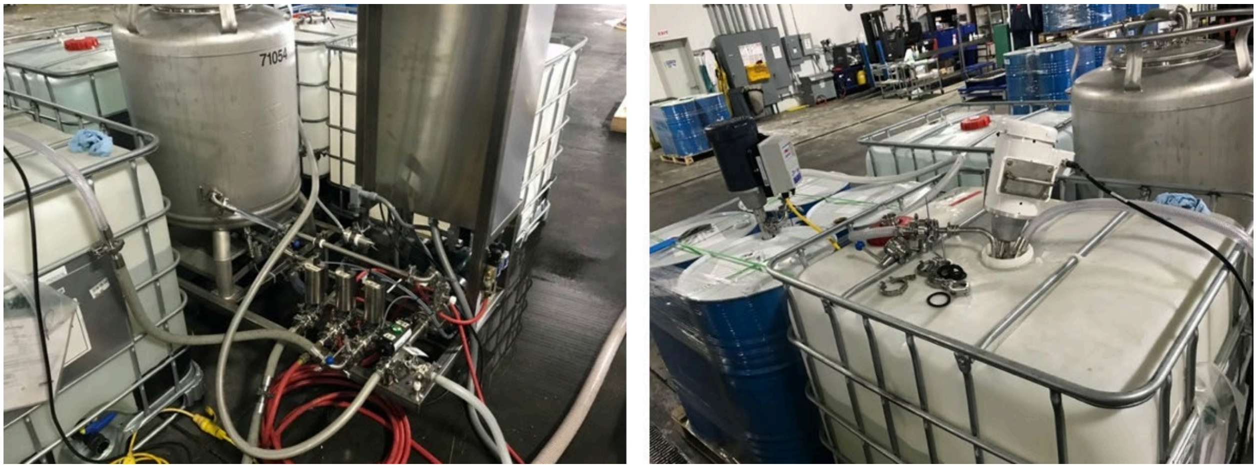


**Pictures of the in-line refractometer and the chart showing concentration pump activity**

Credit: Porifera Inc.

Furthermore, as making up additional draw while the system was running caused the introduction of a slug of glycerol into the system during the Season One run, Porifera built a draw solution blending skid (Figure 10). The blending skid also improved the efficiency of draw solution management during the concentration process.

**Figure 10: Blending Skid for Draw Solution**



**Pictures showing components for the blending skid that makes draw solution**

Credit: Porifera Inc.

The feed was freshly produced watermelon juice, and the draw solution was 70 percent glycerol in water. Watermelon juice was concentrated from 8.6 °Brix to 65 °Brix. The feed, product (concentrate) and draw streams were monitored continuously during the campaign to collect data on flow rates, brix, pressures. Through the run, flux and target brix remained constant. During the 55-hour run, we processed 17,035 L of juice and produced greater than 1,583 L of concentrate. A portion of produced concentrate is shown in Figure 11.

**Figure 11: Watermelon Concentrate Produced During Campaign B**

**Bottles of produced watermelon concentrate**

Credit: Porifera Inc.

In conclusion, the Campaign B goals were successfully met:  to run 2 RC3 systems paired together (RC6 system) and double the production capacity from Season One; to improve the production efficiency and lower manual labor by installing CIP and SIP blending skid, to install a draw solution blending skid; and to produce 75 pails of concentrate.

### Season Three – 2021

During the third season of operation, the project's goals were to:

- Operate the system with the draw solution of 40 percent glycerol in water by weight (GBW) targeting different concentrations before changing to 70 percent GBW
- Improve microbiological results as Van Groningen & Sons changed their cleaning practices (pre-cleaning rinds before the fruit is juiced)
- Accurately measure energy consumption with power meter
- Produce concentrate using elements that were in use since 2019
- Use recovered draw that was evaporated to 75 percent GBW.

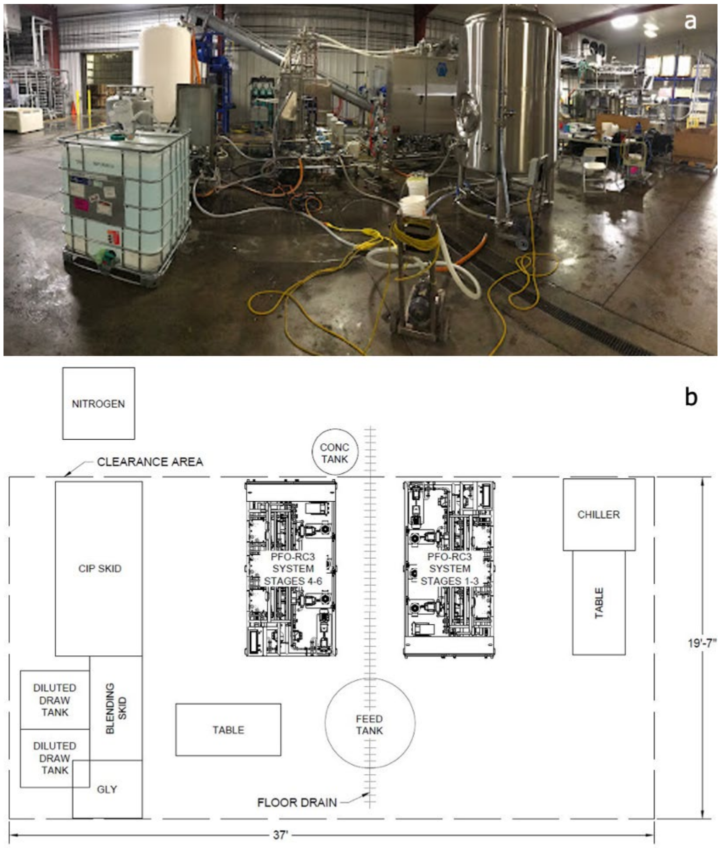
Porifera planned one watermelon juice concentration campaign with the pilot partner Van Groningen & Sons. The campaign was planned for the middle of California's watermelon season in July. The objective of the campaign was to make sample concentrate for Van Groningen & Sons to provide to their customer, to increase sales. In the campaign, watermelon juice was concentrated with our multi-stage PFO Concentrator RC6 system. In July 2021, Porifera prepared and transported Porifera's RC6 system to Van Groningen and Sons' facility in Manteca, California (Figure 12). The concentration runs were performed on July 20th and 21st.

**Figure 12: Transporting Porifera's RC6 System to Van Groningen and Sons Facility in Manteca, California**

Credit: Porifera Inc.

The RC6 system was installed in the refrigerated juice processing facility (13 °C), adjacent to the watermelon juice processing machines. The location of the RC6 system in the facility and its areal schematic diagram are shown in Figure 13.

**Figure 13: Location of the RC6 System in the Production Warehouse (a) and its Areal Schematic Diagram (b)**



Credit: Porifera Inc.

The element configuration in the continuous six-stage system included forty-three PFO-100 elements (7 m$^2$ each) for a total membrane area of 301 m$^2$ (Figure 14).

**Figure 14: Stacks of PFO-100 Elements Within RC6 System**

Credit: Porifera Inc.

Fresh watermelon juice was produced on each day prior to the concentration run. In this campaign, Porifera’s team processed 8,705 L of juice and produced 1,250 kg of watermelon concentrate (Figure 15).

**Figure 15: Watermelon Concentrate Produced at Van Groningen & Sons Facility in Manteca, California During 2021**

**Pictures of watermelon concentrate coming out of the system and stored in buckets**

Credit: Porifera Inc.

The feed was freshly produced watermelon juice, and the draw solution was 70 percent glycerol in water. Watermelon juice was concentrated from 9.2 °Brix to 65 °Brix. Porifera’s team continuously monitored the feed, product (concentrate), and draw streams during the campaign to collect data on flow rates, °Brix, and pressures. Flux and target °Brix remained constant throughout the run. The run lasted for 33 hours.

### Draw Regeneration Studies

Porifera's team performed thermal processing of draw generated during Season Three and validated that thermal toll processing is a valid solution for the customer. Also, Porifera's team worked on membrane draw regeneration studies using ROX-maxG and tested membranes and measured rejection and energy. The draw regeneration system is shown in Figure 16. Diluted draw was regenerated, and resulting streams were a permeate and a concentrate (permeate being the clean water stream that goes through the membrane and the concentrate being the concentrated stream created by the removal of permeate).

**Figure 16: ROX-maxG System**

Credit: Porifera Inc.

# CHAPTER 3: Results

The project's results are described in three sections to present each season's achievements.

## Season One – 2019

### Quality of the Produced Forward-Osmosis Concentrate

For the Season One trial, Porifera's team planned to collect samples of the initial juice and final FO concentrate and to then analyze the samples for microbiological, chemical, nutritional, and sensory quality. Samples were collected before, during, and after each run according to the sampling plan shown below in Table 1. All sample containers were pre-labeled with sample name, purpose, and date. Once collected, samples were immediately refrigerated or frozen until further use.

**Table 1: Sampling Plan**

| When | Sample | Amount of sample | Storage |
|---|---|---|---|
| Before the run starts | Fresh watermelon juice | 6 x 1L sample bottle | Freeze immediately |
| | | 2 x 1.25-gallon pail | Freeze immediately |
| | | 1 x 50 mL sample vial | Refrigerate and ship cold for micro analyses |
| | | 1 x 50 mL sample vial | Refrigerate for glycerol analysis |
| At steady state | Concentrate stage 3 | 1 x 50 mL sample vial | Refrigerate and ship cold for micro analyses |
| | Concentrate final product tank | 4 x 1L sample bottle | Freeze immediately |
| | | 2 x 1.25-gallon pail | Freeze immediately |
| Steady state middle run | Concentrate stage 3 | 1 x 50 mL sample vial | Refrigerate and ship cold for micro analyses |
| At the end of the run | Concentrate final product tank | 1 x 50 mL sample vial | Refrigerate and ship cold for micro analyses |
| | | 1 x 50 mL sample vial | Refrigerate for glycerol analysis |

Source: Porifera Inc.

Both the fresh juice and the concentrate diluted back to the original strength (reconstituted) were analyzed for nutritional content. As shown below in Table 2, the data indicates that compared to the fresh juice the reconstituted FO watermelon concentrate had very similar levels of all the nutrients of interest. This result supports the notion that FO concentration is a milder process than thermal concentration and that FO concentration is able to maintain the original nutritional content of the source material.

## Table 2: Nutritional Data for Watermelon Juice and PFO Reconstituted Concentrate

| **ANALYTE** | **WATERMELON JUICE** | **WATERMELON PFO CONCENTRATE RECONSTIT.** | **UNIT*** |
|---|---|---|---|
| TOTAL ASH | 0.26 | 0.31 | % |
| **BRIX @ 20°C** | **8.0** | **8.5** | **deg.** |
| CALORIES | 31 | 32 | cal/100g |
| CARBOHYDRATE | 6.92 | 7.29 | % |
| FAT | 0.14 | 0.07 | % |
| MOISTURE | 92.09 | 91.78 | % |
| PROTEIN | 0.58 | 0.55 | % |
| TOTAL DIETARY FIBER | 0.5 | 0.6 | % |
| **LYCOPENE** | **14.6** | **16.3** | **ppm** |
| **CITRULLINE** | **0.123** | **0.134** | **%** |
| **BETA-CAROTENE** | **1.8** | **1.1** | **ppm** |
| CALCIUM | 4.18 | 6.73 | mg/100g |
| SODIUM | 1.6 | 3.89 | mg/100g |
| FRUCTOSE | 3.2 | 3.2 | % |
| GLUCOSE | 1.6 | 1.4 | % |
| SUCROSE | 1.3 | 1.3 | % |
| MALTOSE | <0.2 | <0.2 | % |
| LACTOSE | <0.2 | <0.2 | % |
| TOTAL SUGARS | 6.1 | 5.9 | % |
| **VITAMIN C** | **1.95** | **0.87** | **mg/100g** |

* % per weight, ppm (mg/kg)

Source: Porifera Inc.

In addition to nutritional, sensory analysis was conducted at the USDA Western Regional Research Center located in Albany, California. During sensory analysis (hedonic sensory rating), 41 panelists performed a rank-rating evaluation on the samples using a structured 15-point hedonic scale, which ranged from "Dislike" to "Like", with an anchor of "Neither Dislike Nor Like" at the center of the scale. A higher score indicated greater liking of a sample. The reconstituted FO concentrate was statistically indistinguishable from the fresh juice, in terms of consumer liking of the product (Figure 17). This was a confirmation that the flavor and the aroma of the juice concentrate were well preserved during and after processing.

**Figure 17: Sensory Hedonic Scores for Watermelon Juices**

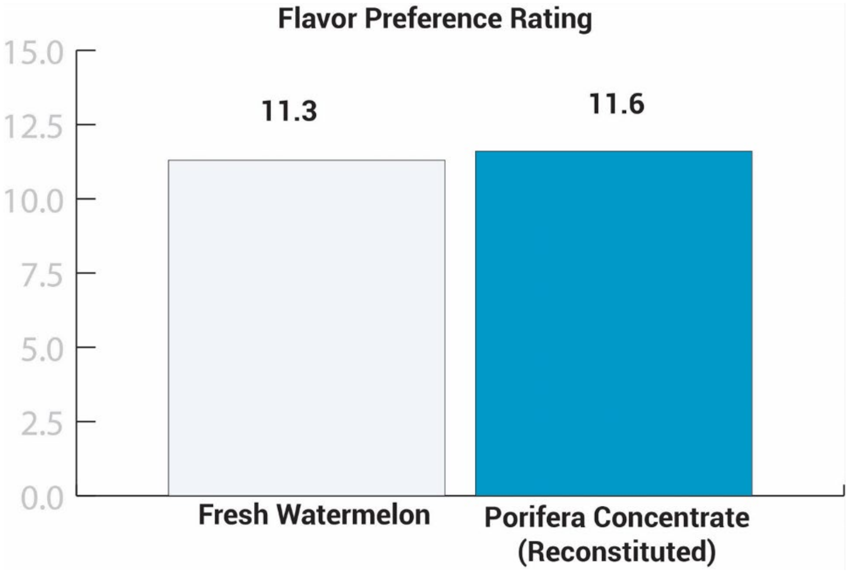


**Chart showing sensory hedonic scores for fresh watermelon juice and FO watermelon concentrate**

Credit: Porifera Inc.

### Energy Use Measurements

The focus of the first season was primarily to achieve the customer's target Brix and demonstrate excellent product quality in terms of flavor, aroma, and nutritional content. Energy use was not optimized. The system removed 89.7 liters per hour on average with a measured energy use of 2.5 kW (3.1 ampere and 460-volt 3, phase power). This yielded a unit energy use of approximately 27.6 kWh/m$^3$ of water removed or 17 kWh/ton of watermelon product processed. Compared to the target metric of 8 kWh/ton, this is about 2 fold higher. Opportunities for optimization of energy use exist in optimizing processing parameters (that is, optimizing concentration done by each of the concentration stages) and by optimizing utilization of the pumps to operating at high efficiency points of their efficiency curves.

## Season Two – 2020

### Campaign A

The produced watermelon concentrate in Campaign A was analyzed for its nutritional quality. For the analysis, the concentrate was diluted back to the original strength (reconstituted) and compared to the original juice. The data showed that compared to the fresh juice the reconstituted FO watermelon concentrates had almost same levels of all the nutrients of interest (Table 3). This result confirms the notion that FO concentration is a milder process than thermal concentration and that FO concentration is able to maintain the original nutritional content of the source material.

## Table 3: Nutritional Data for Watermelon Juice and PFO Reconstituted Concentrate in Campaign A

| ANALYTE | WATERMELON JUICE | WATERMELON PFO CONCENTRATE RECONSTIT. | UNIT* |
|---|---|---|---|
| BRIX @ 20°C | 8.4 | 8.4 | deg. |
| LYCOPENE | 14.3 | 17.1 | ppm |
| CITRULLINE | 2,000 | 1,970 | ppm |
| BETA-CAROTENE | 1.1 | 1.3 | ppm |
| VITAMIN C | 1.06 | 0.74 | mg/100g |

* % per weight, ppm (mg/kg)

Source: Porifera Inc.

In addition to the nutritional analyses, the concentrate was tested for microbial contamination. The results for both fresh watermelon juice and concentrate are shown in Table 4.

## Table 4: Microbiological Data for Watermelon Juice and PFO Concentrates in Campaign A

| | Aerobic Plate Count | Yeast | Mold |
|---|---|---|---|
| **Run Date: 6/22/2020** | | **(CFU/mL)** | |
| Watermelon juice 1 (before the run starts) | 440,000 | 490 | 90 |
| Watermelon conc 2 (at steady state) | 650,000 | 860 | 2,000 |
| Watermelon conc 3 (steady state middle run) | 430,000 | 1,000 | 1,000 |
| Watermelon conc 4 (at the end of the run) | 440,000 | 1,000 | 4,000 |
| **Run Date: 6/24/2020** | | | |
| Watermelon conc 2 (at steady state) | 150,000 | 130 | 30 |
| Watermelon conc 3 (steady state middle run) | 110,000 | 1,000 | 400 |
| Watermelon conc 4 (at the end of the run) | 60,000 | 2,000 | 1,100 |
| Watermelon conc 4 (at the end of the run) | 130,000 | 1,000 | 850 |

Source: Porifera Inc.

Even though the initial aerobic plate count was relatively high for fresh watermelon juice, the process of FO concentration did not cause any increase to the aerobic plate count. That is a very good result given that no heat treatment was involved during the concentration process. Also, running the system in a refrigerated facility prevented potential microbial growth.

**Campaign B**

To estimate a potential of concentrating watermelon juice to lower °Brix than the final concentrate of 65 °Brix, concentrate sample was collected at 40 °Brix. The fresh juice and both concentrates diluted back to the original strength (reconstituted) were tested for nutritional quality. The data (Table 5) shows that compared to the fresh juice the reconstituted FO watermelon concentrates had almost identical levels of all the nutrients of interest. This result demonstrates the possibility to produce a high-quality watermelon juice concentrate by FO. Also, there was no difference in amounts of tested compounds between 40 °Brix concentrate and 65 °Brix concentrate.

**Table 5: Nutritional Data for Watermelon Juice and PFO Reconstituted Concentrates in Campaign B**

| ANALYTE | WATERMELON JUICE | WATERMELON PFO 40 °Brix CONCENTRATE RECONSTIT. | WATERMELON PFO 65 °Brix CONCENTRATE RECONSTIT. | UNIT* |
|---|---|---|---|---|
| BRIX @ 20°C | 8.2 | 8.2 | 8.2 | deg. |
| LYCOPENE | 29.7 | 39.2 | 37.3 | ppm |
| CITRULLINE | 0.20 | 0.21 | 0.21 | % |
| BETA-CAROTENE | 370 | 410 | 410 | ppm |
| VITAMIN C | 1.02 | 1.17 | 1.07 | mg/100g |

* % per weight, ppm (mg/kg)

Source: Porifera Inc.

In Season two, sensory analysis of the fresh watermelon juice and reconstituted concentrate at the USDA Western Regional Research Center was not possible due to COVID-19 safety procedures. The concentrates were tested for microbial contamination. The results for both fresh watermelon juice and concentrates are shown in Table 6.

## Table 6: Microbiological Data for Watermelon Juice and PFO Concentrates in Campaign B

| | Aerobic Plate Count | Yeast | Mold |
|---|---|---|---|
| **Run Date: 10/13/2020** | | **(CFU/mL)** | |
| Watermelon juice, feed tank (before the run starts) | 480,000 | 220 | 150 |
| Concentrate, stage 6 (at steady state) | 370,000 | 110 | 420 |
| Concentrate, stage 6 (steady state middle run) | 400,000 | 300 | 260 |
| Concentrate 40 °Brix | 410,000 | 290 | 440 |
| Watermelon juice, feed tank (towards the end of the run) | 380,000 | 190 | 210 |
| Concentrate, final product tank (at the end of the run) | 320,000 | 250 | 520 |
| **Run Date: 10/14/2020** | | | |
| Watermelon juice, feed tank (before the run starts) | 370,000 | 570 | 80 |
| Concentrate, stage 6 (at steady state) | 430,000 | 210 | 320 |
| Concentrate, stage 6 (steady state middle run) | 480,000 | 230 | 330 |
| Concentrate 40 °Brix | 430,000 | 600 | 540 |
| Watermelon juice, feed tank (towards the end of the run) | 390,000 | 370 | 120 |
| Concentrate, final product tank (at the end of the run) | 440,000 | 130 | 200 |
| **Run Date: 10/15/2020** | | | |
| Watermelon juice, feed tank (before the run starts) | 310,000 | 290 | 60 |
| Concentrate, stage 6 (at steady state) | 380,000 | 390 | 290 |
| Concentrate, stage 6 (steady state middle run) | 420,000 | 440 | 230 |
| Concentrate 40 °Brix | 410,000 | 360 | 470 |
| Watermelon juice, feed tank (towards the end of the run) | 490,000 | 370 | 210 |
| Concentrate, final product tank (at the end of the run) | 430,000 | 270 | 280 |

Source: Porifera Inc.

Even though the initial aerobic plate count was relatively high for fresh watermelon juice on each day of the campaign, the process of FO concentration did not cause significant increase to the aerobic plate count. The amount of yeast decreased in the final concentrate on the second and third day of the run, with insignificant increase on the first day. Amount of mold was a slightly increased for all three days, but that was not a concern as the numbers are below the maximum allowed amount. These are very good results given that no heat treatment was involved during the concentration process.

## Energy Use Measurements

The focus of the second season was primarily to scale-up the system capacity; however, some initial energy use optimization was performed based on lessons learned from the previous season. Table 7 summarizes the energy use results for the different runs in 2020 and compares it with the energy use from the 2019 season and indicated that the unit energy use per $m^3$ of water dewatered was reduced from approximately 44.6 kWh/$m^3$ to 17.7 kWh/$m^3$ by running faster and improving the recirculation pump efficiency. This energy use data was measured without draw regeneration, that would have further improved energy savings.

### Table 7: Energy Use Results for the Runs in 2020 and 2019

| | **June 2020**<br>**Run – 2X draw dilution** | **October 2020**<br>**Run 1 -**<br>**high flow, 2X draw dilution** | **October 2020**<br>**Run 2 -**<br>**low flow, 5X draw dilution** | **2019 Run** | **Energy equivalents for competing**<br>**small evaporator** |
|---|---|---|---|---|---|
| **No. of stages** | 6 | 6 | 6 | 3 | 1-effect with vacuum to reduce max heat* |
| **Water removal (lph)** | 244.4 | 285.2 | 81.5 | 89.7 | 500 |
| **Process electricity (kW)** | 4.2 | 5.1 | 4.9 | 4 | 15 |
| **Chilling electricity (kW) to maintain 10 °C** | 0.54 | 0.54 | 0.15 | (cooling not measured) | N/A |
| **Total power**** | | | | | |
| **Process only unit energy Use**<br>**(kW/$m^3$ water removed)** | 4.7 kW/$m^3$ incl. 6.9 MJ/h cooling load | 5.6 kW/$m^3$ incl. 7.8 MJ/h cooling load | 5.1 kW/$m^3$ incl. 2.2 MJ/h cooling load | 4 kW/$m^3$ + cooling load | 15 kW/$m^3$ + 11.3 therms/h + 126 MJ/h cooling load |
| **Process only performance**<br>**(kWh equivalent /ton of single strength juice sold)** | 17.0 kWh/m3 | 17.7 kWh/m3 | 61.2 kWh/m3 | 44.6 kWh/m3 | 30 kWh/m3 + 22.6 therms/m3 |
| **Emissions from kWh and Therms used [lbs.$CO_2$e/ton juice]** | 9.7 | 10.1 | 35.0 | 25.5 | 223.8 |

* Estimate using API Heat Transfer's smallest sanitary evaporator to the same concentration factor
** Note: 29.3 kWh equivalents per US therm and 0.28 kW equivalent per MJ/h

Source: Porifera Inc.

The most representative energy use for Season Two occurred during the first run of October 2020 (middle column in the Table 7, highlighted in gray), during which all systems were being operated at adjusted conditions for stable target concentration factor. The system removed 285.2 liters per hour on average with an energy use of 5.1 kW. This yielded a unit energy use of approximately 17.7 kWh/m$^3$ of water removed or 13.9 kWh/ton of single-strength watermelon juice product. Opportunities for further energy optimization exist both in terms of process design as well as pump operation / selection. Note that the energy use of the PFO Concentrator system is highly dependent on the efficiency of the recirculation pumps and that larger pumps will be significantly more efficient. For example, replacing the current centrifugal pumps with positive displacement pumps would decrease unit energy use by 67 percent for this size of system and by 80 percent for a commercial system that would be 10 times larger in terms of dewatering capacity for the same concentration factor. It should be also noted that the energy use of the ROX draw recovery system was not measured in 2020 and the system was operated with the draw as partially reused consumable. Energy use of PFO Concentrator operated in this mode was compared to a sanitary evaporator by API Heat Transfer (https://www.apiheattransfer.com/), which uses both electrical energy and steam. The PFO Concentrator's operation generates 95 percent lower greenhouse gas (GHG) emissions than the competing evaporator.

### Juice Processing into Powder

Watermelon juice concentrate produced in the 2019 campaign with the pilot partner Van Groningen & Sons was stored in a freezer for additional testing beyond nutritional, microbiological, and sensory analyses. To further extend the shelf life of concentrated watermelon juice and possibly find different applications, watermelon concentrate was tested for two drying techniques, freeze drying and spray drying. Details on work performed on this are provided in Appendix A.

## Season Three – 2021

As the main goals of the Season Three run focused on operational conditions and energy measurements, the produced watermelon concentrate was tested only for microbial contamination. The results for both fresh watermelon juice and concentrate are shown in Table 8.

## Table 8: Microbiological Data for Watermelon Juice and PFO Concentrates

| | Aerobic Plate Count | Yeast | Mold |
|---|---|---|---|
| **Run Date: 7/20/2021** | | (CFU/mL) | |
| Watermelon juice, feed tank (before the run starts) | 100,000 | 470 | 170 |
| Concentrate, 40 °Brix (stage 6) | 120,000 | 990 | 720 |
| Concentrate, 65 °Brix (stage 6) | 100,000 | 400 | 380 |
| Watermelon juice, feed tank (towards the end of the run) | 83,000 | 750 | 230 |
| Concentrate, final product tank (at the end of the run) | 83,000 | 1,000 | 650 |
| **Run Date: 7/21/2021** | | | |
| Watermelon juice, feed tank (before the run starts) | 170,000 | 60,000 | 16 |
| Concentrate, 65 °Brix (stage 6) | 120,000 | 8,000 | 240 |
| Watermelon juice, feed tank (towards the end of the run) | 190,000 | 85,000 | 29 |
| Concentrate, final product tank (at the end of the run) | 130,000 | 48,000 | 270 |

Source: Porifera Inc.

Even though the initial aerobic plate count was relatively high for fresh watermelon juice, the process of FO concentration did not cause any increase to the aerobic plate count. That is a very good result given that no heat treatment was involved during the concentration process. Also, running the system in a refrigerated facility prevented potential microbial growth. Watermelon juice and concentrate were submitted for analyses to an external lab. The requested analyses included microbiological screening for common pathogens and basic physicochemical properties of juices and concentrates (Table 9). The process of FO concentration did not cause any pathogen growth, and FO watermelon concentrate tested negative for the common pathogens. °Brix measurement confirmed our lab and in-line refractometers values, whereas lower than initial pH values were expected for the concentrate.

## Table 9: Physicochemical and Microbiological Properties of Watermelon Juices and PFO Concentrate

| Sample | E. Coli | E. Coli O157:H7 | Listeria Monocytogenes | Salmonella | °Brix at 20°C | pH | Titratable acidity % |
|---|---|---|---|---|---|---|---|
| Watermelon juice | - | - | - | - | 8.8 | 5.61 | 0.08 |
| Watermelon conc. | <10 CFU/g | negative/25g | negative/25g | negative/25g | 65.4 | 5.32 | 0.47 |

Source: Porifera Inc.

This season, sensory analysis of the fresh watermelon juice and reconstituted concentrate at the USDA Western Regional Research Center was not possible due to COVID-19 safety procedures. Energy use measurements were tracked during third season. Prior to this season only apparent power was measured, and therefore in order to measure real power, three power meters were installed. They measured RC6 and Draw Blending Skid (DBS), CIP machine, and chiller (connected to feed tank and RC heat exchangers). The results are shown in Table 10.

## Table 10: Energy Use Measurements

| Machine | Average Power | Energy per Cleaning |
|---|---|---|
| RC6 + DBS | 4.5 | n/a |
| CIP | n/a | 23.9 |
| Chiller | 0.8 | n/a |

Source: Porifera Inc.

The power factor was lower than expected. Calculated energy use per kg of concentrate was 0.18 kWh. Based on price of $0.12 per kWh, calculate energy cost per kg of concentrate was $0.022.

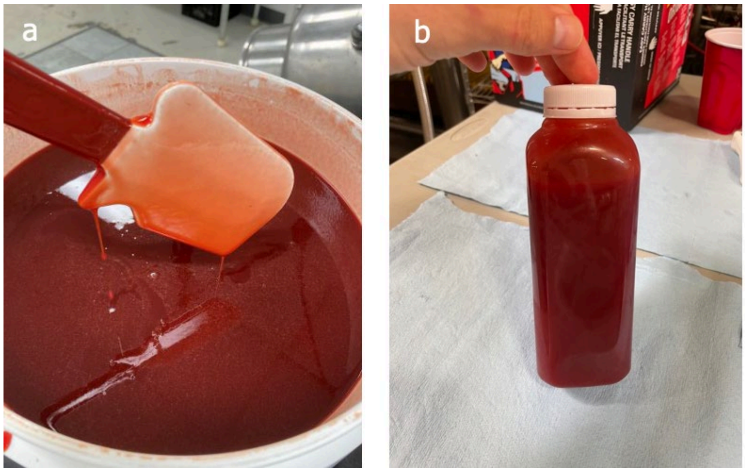
### *Juice Processing into Powder*

During Season Three, Porifera's team continued to explore techniques beyond freeze drying and spray drying to extend the shelf life of concentrated watermelon juice, details of which are provided in Appendix A. The freeze drying results showed that watermelon concentrate at 65 °Brix cannot be successfully freeze dried regardless the type and amount of carriers added. Furthermore, it can be concluded that watermelon concentrate can be freeze dried only when it is diluted greatly, that negate the initial purpose of concentrating watermelon juice. In spray drying studies of watermelon concentrate, the use of freeze-dried powder of watermelon rind and pomace as carriers was explored. In the carrier materials for the spray drying of watermelon concentrate, watermelon co-products can be substituted for up to 25 percent of maltodextrin. This substitution enhances the quality and nutrition of the resulting powder, especially for lycopene and citrulline.

### Microwave Treatment of FO Watermelon Concentrate

With the intention of lowering microbial load and extending shelf-life of the produced watermelon concentrate, Porifera's team explored a possibility to apply microwave treatment to FO concentrate. The Season Three concentrate was processed at a third-party facility. The concentrate was processed at 73 °C for 13 seconds, using STK Nomatic Pilot Line. Microwave processing conditions were as following: inlet to line ~25 °C, flow rate: ~1.2 lpm, temp end of final microwave processing: ~69.3 °C, end hold: ~75.6 °C, hold time: ~13 sec, cooling: ~30 °C, line pressure: ~45 psi reflection: ~500-600 W. The microwaved concentrate was packed in 16-oz bottles and frozen before shipping back to Porifera. The microwaved FO concentrate prior and after microwave processing is shown in Figure 18.

**Figure 18: FO Watermelon Concentrate Prior (a) and After (b) Microwave Processing**



Credit: Porifera Inc.

Porifera's team has conducted taste tasting of the microwaved concentrate by rehydrating the concentrate back to original strength. Rehydrated FO concentrate was prepared as well for comparison. The appearance of rehydrated concentrates can be seen in Figure 19.

## Figure 19: Rehydrated FO Concentrate (Left) and Microwave Processed FO Concentrate (Right)

Credit: Porifera Inc.

Several Porifera employees tasted the samples and half of them did taste a difference between the two watermelon juices. All of them who tasted a difference between the concentrates, favored the one without microwave heating over the heated one.

Color analysis of the concentrates and rehydrated juices was accomplished at the USDA Western Regional Research Center. CIELAB (L*, a*, b*) color values were measured using a portable spectrophotometer (Model CM-508c, Konica Minolta). Color L*/a*/b* values of the watermelon juice concentrates, and watermelon juices are given in Figure 20.

## Figure 20: CIELAB Color Values of Watermelon Concentrates and Rehydrated Juices

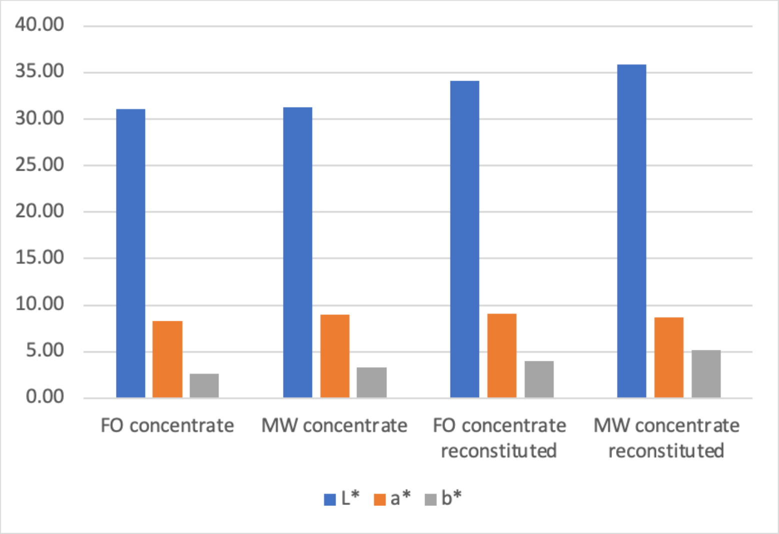


**Chart showing results of CIELAB color values of watermelon FO and MW concentrates and their rehydrated counterparts.**

Credit: Porifera Inc.

Reconstituted watermelon juices notably differed in terms of L* (lightness), a* (red/green), and b* (blue/yellow) color values. Although the difference in color values was much less pronounced between the concentrates, slight difference was still noticed. The color results suggest that microwave treatment affects the color of watermelon concentrates and consequently the rehydrated watermelon juice.

Based on taste testing and color analysis, microwave processing did change FO watermelon sensory attributes. Therefore, the quality of the produced FO concentrate deteriorated during microwave treatment.

Microbiological analysis revealed that there was significant decrease in coliform bacteria count in after microwave processing (Table 11). Also, there was a decrease in number of yeast and mold in microwave treated concentrate. Aerobic plate count was increased in comparison to FO concentrate, but there is an assumption that that there was some post-process contamination.

**Table 11: Microbiological Data for Watermelon Concentrates Pre and Post MW Processing**

| Watermelon conc. | Aerobic Plate Count | Yeast | Mold | Coliform bacteria |
|---|---|---|---|---|
| Pre-processing | 3,500 | 800 | 2200 | 25,800 |
| Post-processing | 6,300* | 200 | 400 | 3,900 |

** Likely due to post-process contamination*

Credit: Porifera Inc.

Results for microbial reduction indicated that applied heat-time treatment was not sufficient in achieving 5 log reduction of microbial load. Since processing at 73 °C for 13 seconds already changed the sensory properties of the concentrate, there was no point in testing processing at higher temperature or longer time. Applying high pressure processing could be another potential treatment for FO watermelon concentrate worth exploring.

## Energy Use Measurements – Season 3

Porifera measured energy use under different operating parameters as described in Table 12 to probe various tradeoffs in system operation. Membrane-based ROX-maxG2 recovery could not reach 70 weight percent draw, so Porifera's team reduced the target concentrate concentration to 50 °Brix, and 30 °Brix and measured performance for two different sets of parameters for each of the target concentrations. Case 3 and Case 4 were operated in different modes with the different ratios of draw to feed. In Case 3 (where draw flow was equal to feed flow) energy of FO was higher than the energy of ROX-maxG2 draw recovery. In Case 4 (where draw flow was equal to half of the feed flow) energy of FO was lower than the energy of ROX-maxG2 draw recovery. Overall Case 4 was more energy efficient but that came with a reduction of processing capacity and increase of CAPEX required per unit juice processed. Systems with 6 stages are more expensive because they contain more pumps and instruments and use more power than systems with 3 stages because of higher recirculation demand. In some cases, 6 stage systems can result in higher water removal rate for the same starting draw concentration, which can then compensate for the higher recirculation energy used. Also, replacing the centrifugal recirculation pumps with more efficient positive displacement pumps may make a 6-stage system more efficient than a 3-stage system.

**Table 12: PFO Concentrator Energy Use Under Different Operating Parameters**

| | Start °Brix | End °Brix | Draw IN % GBW | D/F (volumetric) | FO power measured (kW) | Feed processed (kg/h) | FO energy use | ROX-maxG2 energy use | Total energy use (FO+ROX) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (kWh/ton juice processed) | | |
| Case 2 (as 6-stage) | 8.5 | 65 | 70 | 0.5 | 4.5 | 290 | 16 | N/A | |
| Case 2 (as 3-stage) | 8.5 | 65 | 70 | 0.5 | 2.7 | 232 | 12 | N/A | |
| Case 3 (as 6-stage) | 8.5 | 50 | 40 | 1 | 4.5 | 387 | 12 | 40 | 52 |
| Case 3 (as 3-stage) | 8.5 | 50 | 40 | 1 | 2.7 | 310 | 9 | 40 | 49 |
| Case 4 (as 6-stage) | 8.5 | 50 | 40 | 0.5 | 4.5 | 258 | 17 | 24 | 41 |
| Case 4 (as 3-stage) | 8.5 | 50 | 40 | 0.5 | 2.7 | 206 | 13 | 24 | 37 |
| Case 5 (as 6-stage) | 8.5 | 30 | 40 | 0.5 | 4.5 | 552 | 8 | 12 | 20 |
| Case 5 (as 3-stage) | 8.5 | 30 | 40 | 0.5 | 2.7 | 442 | 6 | 12 | 18 |

Source: Porifera Inc.

# Applications Beyond Watermelon Juice

## Goals and Objectives

The goal of this part of the project was to explore a possibility to concentrate various beverages and liquids by FO. The products that were concentrated with FO are listed in Table 13. The final °Brix in the table is not the highest achievable for the products, but the one targeted in the specific trials.

**Table 13: List of Products Concentrated with FO**

| Product | Initial °Brix | Final °Brix |
|---|---|---|
| Orange juice-unpasteurized | 13.6 | 60 |
| Orange juice-pasteurized | 11 | 53 |
| Peach juice | 10.8 | 46.3 |
| Coconut water | 5.2 | 48.6 |
| Milk | 13 | 48 |
| Half and half | 18 | 36.5 |
| Lime juice | 4.3 | 49.5 |
| Lemon juice | 8.7 | 57 |

| Product | Initial °Brix | Final °Brix |
|---|---|---|
| Coffee | 5.1 | 40 |

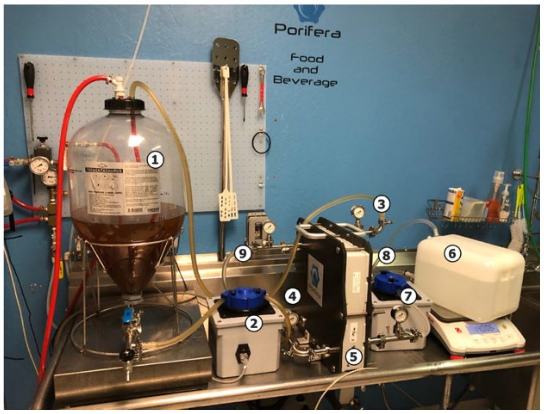
Source: Porifera Inc.

### Lab Trials

Application studies were performed at Porifera's Food & Beverage Lab in San Leandro, California. The testing set up includes one proprietary FO element (PFO), feed and draw tanks, scales, and two peristaltic pumps. The typical set up is shown in Figure 21.

**Figure 21: Lab Testing System**

1. Feed Tank
2. Feed Pump
3. Feed Inlet to PFO element
4. Feed Outlet from PFO element [tank return]
5. PFO Membrane [PFO-50 Element, 3.5 m$^2$]
6. Draw Tank
7. Draw Pump
8. Draw Inlet to PFO element
9. Draw Outlet from PFO element [tank return]



**Picture of the lab system with marked and listed components**

Credit: Porifera Inc.

Typical draw solution used for FO concentration of beverages is glycerol solution. The amount of glycerol is determined based on initial °Brix of the feed.

#### *Orange Juice*

Two types of orange juice, unpasteurized and pasteurized, were concentrated using the testing system shown in Figure 21. Unpasteurized orange juice was sourced from a local farmer's market, for the freshest flavor. Initial volume of the unpasteurized orange juice in the feed tank was 27 kg, and initial °Brix was 13.6. Starting draw solution was 30 percent glycerol, that was adjusted to pH 3.6. During 3.5 h of FO concentration, draw solution was changed two times, first to 50 percent glycerol and then to 65 percent of glycerol, with maintained pH of 3.6. Average flux throughout the run was 1.68 liter/m$^2$/h (LMH). The feed was concentrated to 60 Brix. That means that achieved concentration by °Brix was 4.4 fold. The amount of produced orange juice concentrate was 1.8 L. Pulp that was present in the initial juice was not an obstacle during concentration process and no prior filtration was needed. The unpasteurized orange juice had nice color and consistency as it can be seen in Figure 22.

**Figure 22: Unpasteurized Orange Juice Concentrate**

**Picture of orange concentrate in the feed tank at the end of FO concentration**

Credit: Porifera Inc.

The concentrate was reconstituted to the original °Brix, and when it was tasted among Porifera stuff, no one could tell the difference between initial juice and reconstituted concentrate. The samples were stored frozen (Figure 23).

**Figure 23: Frozen Samples of Unpasteurized Orange Juice and Its Concentrate**

Credit: Porifera Inc.

The similar run was conducted for pasteurized juice – Tropicana. All parameters of the run resembled the previously described concentration process. Initial °Brix of the orange juice was slightly lower (11 °Brix) then for the unpasteurized juice. The final concentrate reached 53 °Brix. The FO orange juice concentrate is shown in Figure 24.

**Figure 24: Pasteurized Orange Juice Concentrate**

Credit: Porifera Inc.

After sending the samples to interested parties, Porifera's team is expecting to receive commercial requests for producing FO orange juice concentrate at larger scale.

### *Peach Juice*

Peach juice is particularly sensitive to heat treatments and therefore possibility to concentrate it without applying heat, would be a way to preserve peach juice characteristics. Peach juice was obtained from a small producer, and Porifera's team conducted a trial to concentrating it using FO. The feed, 18 L of peach juice, was processed for 2 hours with 3.5 $m^2$ of membrane area. The feed was concentrated by 4.3 fold, from 10.8 Brix to 46.3 °Brix (Figure 25). Three batches of draw solution were used (25, 35, and 50 percent glycerol). The product was concentrated at room temperature, with maximum feed pressure of 5 psi. The final concentration of juice was limited by the amount of feed available.

**Figure 25: Concentrated Peach Juice**

Credit: Porifera Inc.

After completing this trial, Porifera's team hasn't explored potential market for peach juice FO concentrate.

### *Coconut Water*

Concentrating coconut water was explored in an attempt to expand Porifera's concentrate sample collection. 40 kg of coconut water was purchased from a local grocery store. Coconut water was concentrated from 5.2 °Brix to 48.6 °Brix using FO. Starting draw solution was 25 percent glycerol. During 6 hours of run, average flux was 1.2 LMH, and inlet pressure was constant (4-5 psi). The coconut water concentrate was a good product by visual and taste observation. Potential market was this product is now being explored.

### *Milk*

Porifera's team tried to concentrate whole milk over a course of several runs. Challenges that Porifera's team run into during milk concentration trial were a low flux throughout a run and a need to lower the running temperature to 5 °C. Most of the previous application studies were done at ambient temperature. During the first run, 13 L of milk was concentrated at ambient temperature from 13 °Brix to 48 °Brix (Figure 26). The average flux was 0.8 LMH, and the run lasted for 6 hours. The goal of this run was to see if FO membrane could be suitable for dairy applications. Whole milk was concentrated 3.7 fold and that was a good achievement, given a more complex structure of milk molecules.

**Figure 26: FO Concentration of Whole Milk**

Credit: Porifera Inc.

For the second run, Porifera's team installed a chiller in the system and kept the temperature during the run at 5 °C. That ensured no microbiological growth during the concentration process. This time 14 L of whole milk was concentrated to 42 °Brix for 5 hours. The average flux was the same as in the previous run (0.8 LMH). Initial draw solution was also the same for both runs, and it was 25 percent glycerol, followed by increase to 45 percent and 60 percent of glycerol.

### *Half and Half*

After successful concentration of whole milk, half and half was tested using the same running conditions. 14 L of half and half was concentrated from 18 °Brix to 36.5 °Brix. The average flux was 0.6 LMH, that was lower than the flux for whole milk concentration. Consequently, the run lasted over 6 hours. Also, the feed pressure increased from 5 to 11 psi. Even though half and half FO concentrate was produced, additional work is necessary mostly to overcome the low flux.

FO dairy concentrates need further exploration in their possible applications, and that could include freeze drying of the produced concentrates, as well as mixing dairy products with other beverages prior to FO process.

### *Lime Juice*

After successful concentration of two types of orange juice, and the increasing market demand in high quality citrus concentrates, lime juice was tested in the Food & Beverage Lab. Clear lime juice was previously obtained from a producer from Mexico, and Porifera's team conducted a trial to concentrate it using PFO-50. The feed, 35 L of peach juice, was processed for 6 hours with 3.2 m$^2$ of membrane area. The feed was concentrated by 11.5 fold, from 4.3 °Brix to 49.5 °Brix (Figure 27). Six batches of draw solution were used (30-70 percent glycerol). Average flux was 1.87 LMH. The product was concentrated at 10 °C, with maximum feed pressure of 7 psi. The final concentration of juice was limited by the amount of feed available.

**Figure 27: Concentrated Lime Juice**

Credit: Porifera Inc.

Figure 28 shows samples of initial lime juice, concentrated lime juice and rehydrated lime juice.

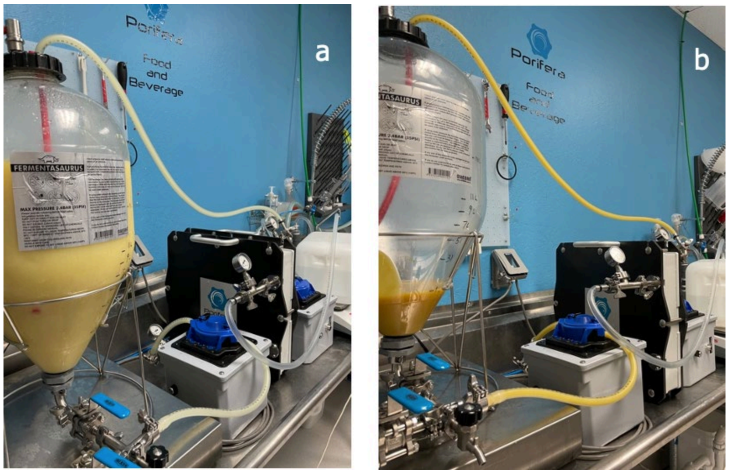
**Figure 28: Initial, Concentrated, and Rehydrated Lime Juice (From Left to Right)**

Credit: Porifera Inc.

### *Lemon Juice*

FO concentration of lemon juice followed the successful lime juice concentration. Porifera's team purchased lemon juice from a southern California producer. The same laboratory set up as for lime juice was used for lemon juice processing. The feed, 42 L of lemon juice, was processed for 8.5 hours with 3.2 $m^2$ of membrane area. The feed was concentrated by 6.5 fold, from 8.7 °Brix to 57 °Brix (Figures 29 and 30). Eight batches of draw solution were used (30-75 percent glycerol). Average flux was 1.4 LMH. The product was concentrated at 10 °C, with maximum feed pressure of 11.5 psi.

**Figure 29: Lemon Juice at the Beginning of the Run (a) and Towards the End of the Run (b)**



Credit: Porifera Inc.

**Figure 30: Initial Lemon Juice (left) and Final Concentrate (right)**

Credit: Porifera Inc.

## RC1 Trial

Porifera’s team wanted to produce FO pomegranate juice concentrate at larger scale. To scale up the lab trial, Porifera’s team used Porifera’s RC1 system (Figure 31).

**Figure 31: RC1 System**

**RC1 system with one PFO-100 element**

Credit: Porifera Inc.

The batch RC1 system was equipped with one proprietary PFO-100 element (7 $m^2$), feed and draw tanks, and circumferential pumps. The system was operated at ambient temperature.

### *Pomegranate Juice Concentration Using RC1 System*

Pomegranate juice was supplied in the amount needed to run larger than a lab system. Initial volume of pomegranate juice in the feed tank was 92 kg, and initial °Brix was 13.7.
The targeted concentration of pomegranate juice was 65 °Brix. Draw solution was 40 percent glycerol by weight. Pomegranate juice was concentrated for 6 hours. Average flux throughout the run was 1.9 LMH at ambient temperature. Feed inlet pressure was between 7 and 13 psi throughout the run.

The final concentrate reached 65 °Brix, and the sample of 50 °Brix was taken as well (Figure 32). That means that achieved concentration by °Brix was 4.7 fold. The amount of produced pomegranate juice concentrate was approximately 8 kg.

**Figure 32: Pomegranate Juice, 50 °Brix Concentrate and 65 °Brix Concentrate (From Left to Right)**

Credit: Porifera Inc.

Pomegranate juice concentrate was successfully freeze dried in a small freeze dryer (Harvest Right HR 3000) at Porifera. Freeze-dried coffee was ground, and fine powdered freeze-dried pomegranate concentrate was produced (Figure 33).

**Figure 33: Freeze-Dried Pomegranate Concentrate**

Credit: Porifera Inc.

The process of freeze drying was accomplished in 24 hours, where freezing was done for 12 hours, and vacuum for 12 hours. This demonstrates a potential to economically create high quality, nonthermally processed pomegranate concentrate. FO reduces the water content in the concentrate, thus reducing the overall energy use associated with freeze drying while maintaining the quality of the product. The freeze-drying application results in further expansion of application of pomegranate concentrate, while preserving its attributes such as aroma and flavor.

## RC3 Trials

After receiving positive feedback from several potential customers regarding the quality of the produced FO orange juice concentrate, Porifera's team wanted to produce FO orange juice concentrate at larger scale. To scale up the trial, Porifera's team used Porifera's RC3 system (Figure 34).

**Figure 34: RC3 System**

**RC3 system with PFO-100 elements in the 7-5-3 configuration**

Credit: Porifera Inc.

The continuous RC3 system was equipped with proprietary PFO-100 elements plumbed in series, feed and draw tanks, and circumferential and centrifugal pumps. The three-stage system included fifteen PFO-100 elements (7 $m^2$ each) for a total membrane area of 105 $m^2$. The system was operated at 10 °C temperature, controlled using a chiller.

### *Orange Juice Concentration Using RC3 System*

Orange juice was supplied in amount needed to run the large system. Initial volume of orange juice in the feed tank was 720 kg, and initial °Brix was 10.7. The targeted concentration of orange juice was 65 °Brix, and it was measured with a digital in-line refractometer (Figure 35). Draw solution was 70 percent glycerol by weight. Orange juice was concentrated for 8.5 hours. Average flux throughout the run was 0.66 LMH at 10 °C. Feed inlet pressure was between 16 and 24 psi throughout the run. The feed-to-draw transmembrane pressure was maintained at 2-5 psi.

**Figure 35: In-Line Refractometer Measuring Orange Juice °Brix**

Credit: Porifera Inc.

The final concentrate reached 65 °Brix. That means that achieved concentration by °Brix was 6 fold. The amount of produced orange juice concentrate was approximately 40 kg. Orange juice concentrate sample was filled in sample bottles (Figure 36) and bags. The concentrate was immediately frozen and stored in a freezer.

**Figure 36: Collecting Orange Juice Concentrate at 65 °Brix**

**A Porifera team member is collecting OJ concentrate from the third stage of the RC3 system**

Credit: Porifera Inc.

The FO orange juice concentrate and initial orange juice are shown in Figure 37. To evaluate the sensory properties of the produced orange juice concentrate Porifera's team did the same test as for the concentrate produced on the small FO system (Season Two). The concentrate was reconstituted to the original Brix, and when it was tasted among Porifera stuff, no one could tell the difference between initial juice and reconstituted concentrate. The smell and taste of the FO concentrate was indistinguishable from fresh orange juice.

**Figure 37: Orange Juice (Left) and Orange Juice Concentrate (Right)**

Credit: Porifera Inc.

Concentrating orange juice using the RC3 system showed that it was possible to produce a high-quality concentrate using FO. The membrane performance was as expected. It was confirmed that RC3 system has commercial system performance.

### *Lemon Juice Concentration Using RC3 System*

For the lemon juice concentration, a different number of elements and its configuration was used than for orange juice trial. The continuous RC3 system included nine PFO-100 elements (7 $m^2$ each) for a total membrane area of 63 $m^2$ (Figure 38). The system was operated at 10 °C temperature, controlled using a chiller. Lemon juice was purchased in amount needed to run the large system. Initial volume of lemon juice in the feed tank was 416 kg, and initial °Brix was 8.8.

**Figure 38: RC3 System with 9 PFO-100 Elements**

**RC3 system with PFO-100 elements in the 3-3-3 configuration**

Credit: Porifera Inc.

The targeted concentration of lemon juice was 55 °Brix, and it was measured with a digital in-line refractometer. Draw solution was 40 percent glycerol by weight at the beginning of the run and increased to 70 percent glycerol by weight after the feed reached 45 °Brix. Lemon juice was concentrated for 4 hours. Average flux throughout the run was 1.40 LMH at 10 °C. Feed inlet pressure was approximately 15 psi throughout the run. The feed-to-draw transmembrane pressure was maintained at 2-5 psi.

The final concentrate reached 55 °Brix (Figure 39). That means that achieved concentration by °Brix was 6 fold. The amount of produced orange juice concentrate was approximately 20 kg. Lemon juice concentrate was filled in bags. The concentrate was immediately frozen and stored in a freezer.

**Figure 39: Lemon Juice Concentrate**

**Glycerol solution (draw, left) and concentrated lemon juice (feed, right) lines of the RC3 system**

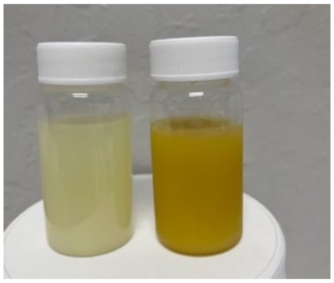
Credit: Porifera Inc.

### *Lime Juice Concentration Using RC3 System*

The same continuous RC3 system with nine PFO-100 elements (Figure 38) was used to concentrate 424 kg of lime juice. The initial °Brix was 8.3, and the targeted final °Brix was 55. The run lasted for 5 hours. Draw solution was 40 percent glycerol by weight at the beginning of the run and increased to 70 percent glycerol by weight after the feed reached 45 °Brix. Average flux throughout the run was 1.09 LMH at 10 °C. Feed inlet pressure was between 11 and 15 psi throughout the run. The feed-to-draw transmembrane pressure was maintained at 2-5 psi.

The final concentrate reached 55 °Brix. That means that achieved concentration by °Brix was 6.6 fold. The amount of produced lime juice concentrate was approximately 18 kg. Lime juice and concentrate are shown in Figure 40. Lime juice concentrate was filled in bags. The concentrate was immediately frozen and stored in a freezer.

## Figure 40: Lime Juice (Left) and Lime Juice Concentrate (Right)



Credit: Porifera Inc.

### *Energy Calculations for Lemon and Lime Runs*

Energy consumption for the lemon and lime runs were calculated and the results are shown in Table 14.

**Table 14: Energy Consumption for the Lemon and Lime Runs**

| Run | Run Hours (h) | Power (kW) | Energy (kWh) | Conc. Produced (kg) | Energy /unit Conc (kWh/kg) | Energy Cost/unit Conc. ($/kg conc) |
|---|---|---|---|---|---|---|
| Lemon | 4.1 | 4.4 | 18.0 | 21 | 0.86 | $0.10 |
| Lime | 4.9 | 4.4 | 21.6 | 19 | 1.13 | $0.14 |

Source: Porifera Inc.

Power consumed during the run was estimated based on the RC3 system and draw blender usage, and chiller usage (2.8 kW and 1.6 kW). For 21 kg of produced lemon juice concentrate 18 kWh energy was used, and for 19 kg of lime juice concentrate 21.6 kWh. Based on the price of $0.12 kWh, costs calculated for the runs were $0.10/kg conc. for lemon juice concentrate and $0.14/kg conc. for lime juice.

### *Lab Analyses*

Lemon and lime juices and concentrates were submitted for analyses to an external lab. The requested analyses included microbiological screening and basic physicochemical properties of juices and concentrates (Table 15). The process of FO concentration did not cause any increase to the aerobic plate count, and both concentrates tested negative for the common pathogens. Brix measurement confirmed our lab and in-line refractometers values, whereas lower than initial pH values were expected for the concentrates.

## Table 15: Physicochemical and Microbiological Properties of Lemon and Lime Juices and FO Concentrates

| Sample | Aerobic plate count | E. Coli | E. Coli O157:H7 | Listeria Monocytogenes | Salmonella | °Brix at 20°C | pH | Titratable acidity % |
|---|---|---|---|---|---|---|---|---|
| Lemon juice | <10 CFU/g | - | - | - | - | 8.4 | 2.44 | 6.32 |
| Lemon conc. | <10 CFU/g | <10 CFU/g | negative/25g | negative/25g | negative/25g | 54.6 | 1.89 | 40.54 |
| Lime juice | <10 CFU/g | - | - | - | - | 8.2 | 2.49 | 5.77 |
| Lime conc. | <10 CFU/g | <10 CFU/g | negative/25g | negative/25g | negative/25g | 54.8 | 1.83 | 36.22 |

Source: Porifera Inc.

In conclusion, using Porifera's continuous RC3 system for lemon and lime juice large-scale FO concentration resulted in high quality lemon and lime concentrates.

### *Coffee Concentration Using RC3 System*

Results from the initial coffee concentration study that was performed on the lab testing system (data not shown) indicated that coffee can be successfully concentrated via FO. After that testing, coffee was supplied in the amount needed to run the large system. Initial volume of coffee in the feed tank was 567 kg, and initial °Brix was 5.1.

The targeted concentration of coffee was 40 °Brix, and it was measured with a digital in-line refractometer. Draw solution was 28 percent glycerol by weight (Figure 41). Coffee was concentrated for 5.5 hours. Average flux throughout the run was 3.16 LMH at ambient temperature. Feed inlet pressure was 16 psi throughout the run. The feed-to-draw transmembrane pressure was between 2 and 4 psi.

**Figure 41: Feed and Draw Lines: Coffee (Right) and Glycerol Solution (Left)**

Credit: Porifera Inc.

The final concentrate reached 40 °Brix. That means that achieved concentration by °Brix was 8 fold. Coffee concentrate (Figure 42) was filled in sample bottles, and it was immediately stored in a freezer.

**Figure 42: Coffee (Left) and Coffee Concentrate (Right)**

Credit: Porifera Inc.

Concentrating coffee using the RC3 system showed that it was possible to produce a high-quality concentrate using FO. The membrane performance was as expected. It was confirmed that the RC3 system has commercial system performance. Furthermore, concentrated coffee was successfully freeze dried in a small freeze dryer (Harvest Right HR 3000) at Porifera. Freeze-dried coffee was ground, and fine powdered freeze-dried coffee concentrate was produced (Figure 43).

**Figure 43: Freeze-Dried Coffee Concentrate**

Credit: Porifera Inc.

The process of freeze drying was accomplished in 24 hours, where freezing was done for 12 hours, and vacuum for 12 hours. This demonstrates a potential to economically create high quality, nonthermally processed coffee concentrate. FO reduces the water content in the concentrate, thus reducing the overall energy use associated with freeze drying while maintaining the quality of the product. In some customers' trials higher °Brix (60 °Brix) was achieved using PFO concentrator, and in such cases energy use for freeze drying of coffee concentrate would be significantly lower. The freeze-drying application results in further reduction of transportation and storage cost of coffee, while preserving its attributes such as aroma and smell.

## Energy Savings

Energy savings provided by using Porifera’s technology are showcased in watermelon juice concentration and coffee concertation studies. Porifera’s technology is compared with similar or competing technologies in terms of both energy savings and GHG emissions reductions.

### Energy Savings in Watermelon Juice Processing

Comparison of energy use and GHG emissions of PFO concentrator during watermelon production and competing technologies is shown in Table 16. In concentrating watermelon juice to 65 °Brix, Porifera’s technology achieved 96 percent less GHG emissions comparing to API evaporator. In this case draw was not regenerated, so this is not fully representative of PFO concentrator. When concentrating watermelon juice to 50 °Brix using Porifera’s technology, results for two different cases are presented and compared to freeze concentration, Centritherm evaporator and API evaporator. In the first case (Case 3), PFO concentrator produced 58 percent less GHG than freeze concentration, 23 percent less than Centritherm evaporator, and 84 percent less than API evaporator. Slightly lower electrical energy consumption and consequently less GHG produced were recorded in the second case (Case 4) PFO concentration in comparison to the other technologies. As expected, the least energy consumption was registered when watermelon juice was concentrated to 30 °Brix. In this case, the differences in GHG production between Porifera’s technology and competing ones were the highest, in favor of Porifera’s technology.

**Table 16: Comparison of Energy Use and GHG Emissions of PFO Concentrator and Competing Technologies**

| | PFO End Concentration | Total PFO Concentrator FO+ROX | Total PFO Concentrator GHG | Freeze Concentrator (10 to 40 Brix) | **% GHG less than Freeze** | Centritherm Evaporator (7 to 38 Brix) | **% GHG less than Centritherm** | API evaporator 8 to 65 Brix | **% GHG less than API** |
|---|---|---|---|---|---|---|---|---|---|
| Units | °Brix | kWh/ton juice | kg $CO_2$/ton juice | kWh/ton juice | | kg $CO_2$/ton juice** | | kg $CO_2$/ton juice** | |
| Case 2 (as 3-stage) | 65 | 12* | 4 | | | | | | **96%*** |
| Case 3 (as 3-stage) | 50 | 49 | 16 | 116.5 | **58%** | 21 | **23%** | 102 | **84%** |
| Case 4 (as 3-stage) | 50 | 37 | 12 | 116.5 | **68%** | 21 | **42%** | 102 | **88%** |
| Case 5 (as 3-stage) | 30 | 18 | 6 | 116.5 | **84%** | 21 | **71%** | 102 | **94%** |

***Note that draw was not regenerated in this case, so it should only be considered if draw is treated as a consumable.**

**** Conversion used: 5.3 kg CO2e/therm, 0.331kg CO2e/kWh**

Source: Porifera Inc.

### Energy Savings in Coffee Processing

In Table 17, energy use and GHG emissions in coffee concentration were compared for the PFO Concentrator and three competing technologies: 1) freeze concentration, technology that damages the product the least, 2) Centritherm evaporator, one of the most “gentle processing” evaporators, which still damages the product somewhat and 3) a standard evaporator (make and model not available due to customer confidentiality) that significantly changes the product during concentration. Since the customer data was available for different starting and ending concentrations, PFO Concentrator energy use was calculated based on pilot measurements using customer's extracts for different starting and ending concentrations available (that is 10 to 40 Brix for Freeze Concentration, 7 to 38 Brix for Centritherm and 9 to 60 Brix for a standard evaporator).

Freeze concentration requires high electrical energy consumption of 0.1165 kWh/kg coffee processed whereas PFO Concentrator uses only 0.031 kWh/kg coffee processed. This means that energy savings and emission reduction for the PFO Concentrator is 74 percent. Electrical energy consumption for the Centritherm evaporator and PFO Concentrator are 0.0123 and 0.0176 kWh/kg coffee processed, respectively, while the evaporator also used an additional 0.0031 therm/kg of initial coffee, resulting in 72 percent emissions reduction with the PFO Concentrator (Table 17).

Electrical energy consumption for the standard evaporator and the PFO Concentrator when going from 9 Brix to 60 Brix are 0.0029 and 0.0221 kWh/kg coffee processed, respectively, while the evaporator also used an additional 0.0024 therm/kg of initial coffee, resulting in 46 percent emissions reduction with PFO Concentrator (Table 17). Note that the gentler evaporator (Centritherm) uses a similar amount of electrical energy as the PFO Concentrator while the standard evaporator uses less electrical energy than the PFO Concentrator. Most of the emissions generated by the evaporators are due to the steam power used.

**Table 17: Comparison of Porifera's and Competing Technologies for Coffee Processing**

| | | | Start °Brix | End °Brix | Alternative tech concentration steam energy | Electrical Energy Use | | Total emissions | |
|---|---|---|---|---|---|---|---|---|---|
| Coffee | | | | | therm/kg initial | kWh/kg coffee processed | % Energy savings over freeze concentration | kg $CO_2$/kg coffee processed | % Reduction of emissions |
| The most gentle | Freeze concentration | Freeze Conc. | 10 | 40 | | 0.1165 | | 0.039 | |
| | | PFO Concentrator | 10 | 40 | | 0.031 | 74% | 0.010 | 74% |
| Lowest impact | Centritherm Evaporator | Evaporator | 7 | 38 | 0.0031 | 0.0123 | | 0.021 | |
| | | PFO Concentrator | 7 | 38 | | 0.0176 | | 0.006 | 72% |
| Higher impact | Evaporator | Evaporator | 9 | 60 | 0.0024 | 0.0029 | | 0.014 | |
| | | PFO Concentrator | 9 | 60 | | 0.0221 | | 0.007 | 46% |

Source: Porifera Inc.

Cost and feature comparisons of Porifera’s technology and three competing technologies are shown in Table 18. Unlike Porifera’s technology, reverse osmosis has a concentration limitation, freeze concentration is limited by high viscosities at low temperatures, and Centritherm evaporator degrade flavor and aroma of the final product. Preservation of flavor and aroma of concentrated products and its yield are the highest when Porifera’s technology was used. Furthermore, OPEX for coffee concentration from 10 °Brix to 40 °Brix using freeze concentration and Centritherm evaporator are twice as high as for using Porifera’s technology. When energy consumption and GHG emissions are compared among technologies, only Porifera’s technology and reverse osmosis are competing with low energy consumption and low GHG emissions.

**Table 18: Cost and Feature Comparisons with Competing Technologies**

| | PFO Concentrator | Reverse Osmosis | Freeze Concentration | Centritherm Evaporator |
|---|---|---|---|---|
| | | Concentration limited by osmotic pressure | Limited by high viscosities at low temperatures | Flavor and aroma degradation |
| Preserves flavor & aroma profile | Best | Medium | High | Medium |
| Reaches high concentrations | ✓ | — | — | ✓ |
| Yield | 99 % | 90 % | 70 % - 90 % | 85 – 97 % |
| Uptime | High | Medium | Low | Medium |
| Steady state operation | ✓ | — | — | ✓ |
| CAPEX (coffee 10 to 40 °Brix) | less than 1 year payback period | N/A (cannot not reach 40 °Brix) | 2x Porifera | similar |
| OPEX (coffee 10 to 40 °Brix) | | N/A (cannot not reach 40 °Brix) | 2x Porifera | 2x Porifera |
| Energy | Low | Low | High (4-9x Porifera!) | High |
| Water for Reuse | ✓ | ✓ | — | — |
| GHG Emissions | Low | Low | Very High (4-9x Porifera) | High (>2x Porifera) |

Source: Porifera Inc.

### GHG Emissions Reduction from Reduced Transportation Volumes: Reducing the Carbon Footprint of Orange Juice

In addition to energy savings during processing of concentrates, implementation of Porifera’s technology will result in large reductions of GHG emissions by reducing transported volumes. The Orange juice case study bellow illustrates the potential for GHG emissions reduction from transportation.

Ninety percent of orange juice in the world is produced by four large companies. One of those companies (Company A) is the largest global producer of orange juice concentrate. The company processes about 45-50 percent of the orange juice in Brazil and about 20 percent of the orange juice in the world. The company’s juice extractors process 100,000 oranges per minute. That’s enough to make about two thousand tons of orange juice each and every working day.

The orange juice is processed into a “Not from Concentrate” (NFC) product or into a 65 °Brix concentrate, referred to as frozen concentrated orange juice (FCOJ). The NFC and FCOJ are shipped to consumers all around the world. Though the FCOJ's carbon footprint demands only half of the carbon footprint of NFC, is easier to handle, and less expensive to deliver, NFC has retained a dominant share of the market. NFC is preferred by most consumers due to its superior flavor, aroma and nutritional value. While the state-of-the-art TASTE evaporators were specifically designed to minimize the impact to the quality of the concentrate, elevated processing temperatures degrade the concentrate quality.

Porifera's concentration process results in a new product in which the flavor, aroma and nutritional value are comparable to NFC but with the low carbon footprint and all the logistical advantages of the concentrate.

### CO2 Emissions Reduction for the Planet: Potential to Reduce CO2 Emissions by >2 Million Metric Ton (MT) per Year

Pilot tests at Porifera's facilities demonstrated that the natural concentrate produced by Porifera's technology creates a superior orange juice concentrate, which when diluted compares favorably to fresh orange juice NFC. Company A is also considering converting a large amount of juice that is currently sold as NFC into Porifera's Natural Concentrate. Implementation of Porifera's technology in creation of a new product that competes with NFC would not only provide cost and energy savings in the juice processing, but also reduce transported juice volume by 74 percent. Implementation of Porifera's technology for 95 percent of all the juice Company A processes would result in potential reduction of $CO_2$ emission of approximately 592,000 MT of $CO_2$ (Table 19). If implemented in 95 percent of all the orange juice production facilities in the world, the $CO_2$ reductions would be approximately 2,860,000 MT/year.

**Table 19: Potential Benefits of Porifera's Technology Implementation**

| Source of savings | Full implementation at Company A [Thousands of MT $CO_2$/year] | Full implementation in global orange juice industry [Millions of MT $CO_2$/year] |
|---|---|---|
| Maritime transport | 302 | 1.46 |
| Trucking | 281 | 1.36 |
| On-land cold storage | 9 | 0.04 |
| **TOTAL** | **592** | **2.86** |

Source: Porifera Inc.

### Additional Reduction of Air Pollution: Potential to Remove the Equivalent of >30 Percent World's Cars

In addition, implementation of Porifera's technology would also significantly reduce air pollution due to the reduced requirements of storage and shipment. Shipping is by far the biggest transport polluter in the world because due to the use of dirtier, higher polluting fuels. The world's 90,000 maritime shipping vessels burn approximately 370 million tons of fuel per year, emitting 20 million tons of sulphur oxides ($SO_x$). A single large ship can generate approximately 5,200 tons of $SO_x$ pollution in a year. There are 760 million cars in the world today emitting approximately 78,600 tons of $SO_x$ annually. That equates to the global shipping fleet emitting 260 times more $SO_x$ than the world's automotive fleet.

If implemented for 95 percent of juice that Company A processes, the air pollution reduction would be equivalent to removing 49 million cars from the roads. If Porifera's technology were implemented across the entire orange juice industry, the potential pollution reduction would be equivalent to eliminating 31 percent of the total cars in the world (>200 million cars).

### Tradeoffs and Optimization of Benefits

Certain tradeoffs need to be considered to fully optimize benefits for each of the considered applications and industry standards may eventually need to be redefined to maximize benefits of the new technology approaches. For example, while the PFO Concentrator uses less energy than competing thermal processes, concentrating to higher concentration with the PFO Concentrator requires more energy than to lower concentration with the same equipment (Table 17, Case 4 vs Case 5 or Case 4 vs concentrating to 65 Brix). The question "Is the 65 Brix juice concentrate really needed?" should be considered. While 65 Brix juice concentrate has been a standard, the difference in transportation volume saving between 50 Brix and 65 Brix concentrate is less than 6 percent, so the overall $CO_2$ emissions are lower if a customer concentrates with an energy-efficient PFO Concentrator to 50 Brix instead of going to 65 Brix with a thermal draw regeneration back-end that uses more than 2x the energy.

Another optimization consideration has to do with the energy use/capital expenditures tradeoff. PFO Concentrator Systems designed to use less energy generally require more capital (See comparison of Cases 3 & 4 in Table 17). Depending on their particular circumstances, customers may consider total cost of ownership to understand the value of reduced OPEX at the expense of increased CAPEX.

# CHAPTER 4: Conclusion

## Ratepayer Benefits

This agreement has resulted in developments that promise significant savings for California's food and beverage processors. Food and Beverage processors are amongst the largest industrial consumers of energy in California. Replacement of energy-intensive thermal evaporators with the PFO Concentrator is estimated to provide an average of 40-80 percent energy savings for each facility that utilizes this technology. Assuming 25 percent replacement of food and beverage evaporators, the estimated energy savings would be equivalent to a reduction of 781,000 metric tons of $CO_2$ emissions per year. In addition, reduced energy demand will improve reliability of the state's electrical grid and reduce costs associated with energy production and transmission. The PFO Concentrator also has contributed to improved development of more nutritious and better tasting food and beverage products, giving California processors a competitive advantage in the growing consumer market for healthy, natural products. Lastly, increased water reuse onsite improved groundwater and surface water availability.

## Technological Advancement and Breakthroughs

This Agreement has led to technological advancement and breakthroughs that overcome barriers to the achievement of the State of California's statutory energy goals by demonstrating advantages of Porifera's breakthrough technology and accelerating its adoption. The PFO Concentrator can concentrate food and beverage products to very high concentrations that conventional membrane systems cannot achieve alone. In addition, PFO technology requires significantly less energy than evaporators, the only competing systems that can achieve the same sugar concentration targets and does not degrade or alter the food and beverage product. The PFO Concentrator can create concentrates of higher quality than competing technologies. In many cases, as demonstrated, the reconstituted products are as good as fresh. This creates an opportunity for great reduction in shipping weight by shipping concentrates instead of fresh products. If broadly implemented, the technology demonstrated in this project will result in large reductions of $CO_2$ emissions and pollution reduction. Reductions of $CO_2$ emissions are estimated to be 2.86 million MT/year $CO_2$ reduction for orange juice alone and almost 30 million MT/year for world's juice industry. If Porifera's PFO Concentrator technology were implemented across the entire orange juice industry, the potential pollution reduction would be equivalent to eliminating 31 percent of the total cars in the world (>200 million cars).

## Remaining Challenges and Recommendations

Despite its great benefits towards decarbonization of industry, the adoption of new technology takes a long time due to slow implementation of capital projects and general industry's risk aversion towards new technologies. Projects like this one greatly help with overcoming such barriers.

To help implementation of new technologies in industry programs designed to increase the value proposition, business cases for industrial decarbonization are needed. Further technology demonstrations and technology transfer efforts are needed to promote adoption by increasing awareness of decarbonization opportunities, highlighting successful approaches, and overcoming risk aversion.

# GLOSSARY

| Term | Definition |
|---|---|
| °Brix | Measure of the dissolved solids in a liquid |
| Ampere | Unit of electrical current |
| CAPEX | Capital expenditures |
| CEC | California Energy Commission CEC |
| CIELAB | Color space defined by the International Commission on Illumination |
| CIP | Clean-in-place |
| $CO_2$ | Carbon dioxide |
| EPIC | Electric Program Investment Charge |
| F&B | Food and beverage |
| FO | Forward osmosis |
| FPSA | Food Processing Suppliers Association |
| GBW | Glycerol in water by weight |
| GHG | Greenhouse gas |
| IFT | Institute of Food Technologists |
| LMH | Liter/$m^2$/h |
| lpm | Litre per minute, a volumetric flow rate |
| MD | Maltodextrin |
| mTorr | Millitorr, a unit of pressure based on an absolute scale |
| OPEX | Operational expenditure |
| PFO | Porifera Forward Osmosis |
| ppm | Parts per million, mg/kg |
| psi | Pounds per square inch |
| RC3 system | Porifera's multi-stage forward osmosis concentrator |
| RC6 system | Porifera's multi-stage forward osmosis concentrator |
| RO | Reverse osmosis |
| ROX-maxG2 | Modified reverse osmosis |
| SIP | Sanitization-in-place |
| TAC | Technical advisory committee |
| UHPRO | Ultra-high pressure reverse osmosis |
| USDA-ARS | United States Department of Agriculture-Agricultural Research Service |
| Volt | Unit of electric potential |
| W | Watt, unit of power |

# PROJECT DELIVERABLES

- Season 1 Summary Report
- Season 2 Summary Report
- Season 3 Summary Report
- Installation Guidelines
- Operation and Clean-in-Place Manual
- CPR Report #1
- Juice Processing Report
- Applications Beyond Watermelon Processing Memo
- Technology/Knowledge Transfer Report

# APPENDIX A:
# Research on Watermelon Powder Production via Freeze and Spray Drying

For drying liquid materials that have high sugar content, addition of some type of carrier is needed. Common carriers used to reduce stickiness and improve product stability are maltodextrin (MD), starch, modified starch, and gum arabic.

## Freeze Drying

Freeze drying is a technique that is used for drying of material without applying heat. Therefore, it was the first choice in drying watermelon juice that was concentrated by FO where no heat was employed.

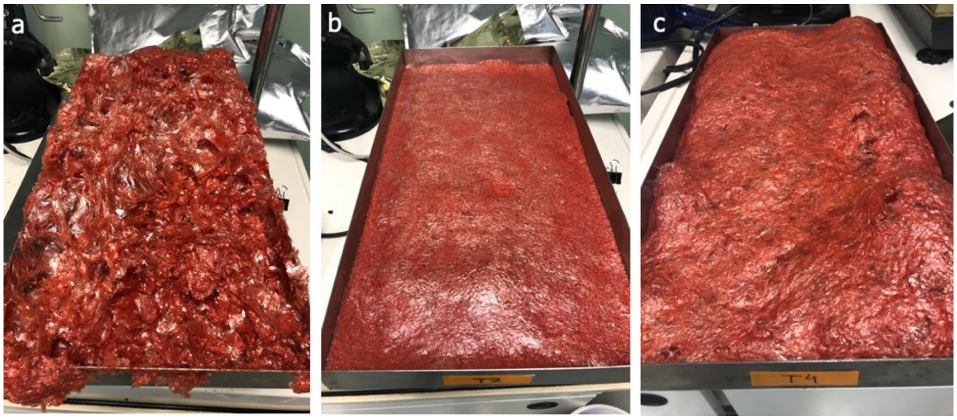
Different samples were prepared for freeze drying run. As previously mentioned, to aid drying process and improve dried product properties, different carriers were added to watermelon concentrate. Porifera's team wanted to explore more natural carriers such as fresh watermelon pulp and pectin. Watermelon concentrate, mixture of watermelon concentrate with watermelon pulp, and watermelon concentrate with 2 percent pectin were pre-frozen and placed in a pilot scale freeze drier (VirTis Ultra 25EL-85, SP Industries, Gardiner, N.Y., USA). The freeze dryer (Figure A-1) was operated in shelf driven mode, which was controlled based on shelf temperature, and run with a programmed procedure. The programmed procedure lasted for 72 h, and included six drying steps (temperature from -20 °C to +20 °C, and vacuum from 500 to 200 mTorr).

**Figure A-1: Pilot Scale Freeze Drier at the USDA, Albany, California**

Credit: Porifera Inc.

After completion of freeze-drying process, the samples were not fully dried. Watermelon concentrate foamed a lot, and it was sticky; watermelon concentrate with watermelon pulp was sticky; watermelon concentrate with 2 percent pectin foamed and it was sticky. Freeze-dried samples are shown in Figure A-2.

**Figure A-2: Freeze-Dried Samples: Watermelon Concentrate (a), Watermelon Concentrate with Watermelon Pulp (b), Watermelon Concentrate With 2% Pectin (c)**



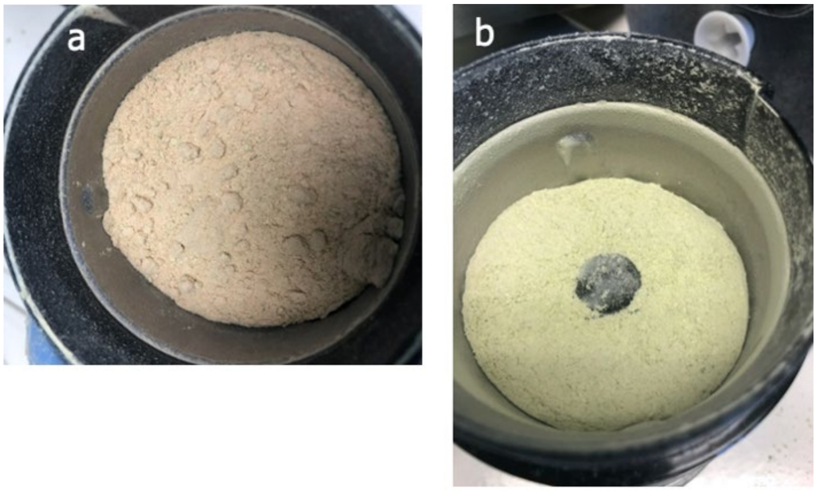
**Pictures of plates with freeze-dried watermelon concentrate, watermelon concentrate with pulp and watermelon concentrate with pectin**

Credit: Porifera Inc.

In the second attempt to get samples fully dried, the temperature for pre-freezing was lowered from -20 °C to -40 °C. The watermelon concentrate sample could not freeze completely even at -40 °C. That was the most likely cause for foaming during the drying steps in the freezer. An additional sample was prepared, and it was watermelon concentrate with 2 percent MD. After the same programmed spray drying procedure, the samples dried without foaming, but all of them were sticky, which made their removal from sample trays unsuccessful.

The next trial included watermelon concentrate with higher amount of MD, concentrate with previously prepared watermelon pomace and rind powders (freeze dried and finely ground, Figure A-3), as well as diluted watermelon concentrate to 40 °Brix and 16 °Brix with addition of different carriers.

## Figure A-3: Freeze-Dried and Finely Ground Pomace (a) and Rind (b)



Credit: Porifera Inc.

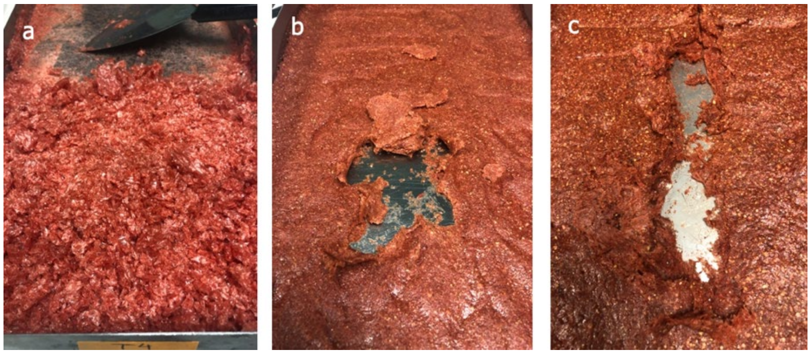
The samples prepared for freeze drying were according to formulations presented in Table A-1. Percentage of carrier added was expressed in weight/weight (w/w).

## Table A-1: Freeze-Drying Formulations

| | Carrier | % w/w |
|---|---|---|
| **Watermelon concentrate** | MD | 17 |
| | MD | 33 |
| | Pulp powder | 9 |
| | Rind powder | 5 |
| **Watermelon conc. diluted to 40 °Brix** | MD | 18 |
| | Pulp powder | 9 |
| | Pulp powder | 4.5 |
| **Watermelon conc. diluted to 16 °Brix** | Pulp powder | 8 |

Watermelon concentrates samples with different amounts of MD foamed after drying, and watermelon concentrate with pulp and rind powder have not dried well, as the samples were sticky and gummy. Watermelon concentrate diluted to 40 °Brix with addition of pulp and rind powder have not dried well – they were sticky, and the one with addition of MD has absorbed ambient moisture quickly (Figure A-4).

**Figure A-4: Freeze-Dried Samples of Watermelon Concentrate Diluted to 40 °Brix with Different Carriers: 18 % MD (a), 9 % pulp powder (b), 4.5 % pulp powder (c)**



Credit: Porifera Inc.

The only sample that dried well was watermelon concentrate diluted to 16 °Brix with pulp powder as a carrier (Figure A-5).

**Figure A-5: Freeze-Dried Watermelon Concentrate Diluted to 16 °Brix with 8 % pulp**

Credit: Porifera Inc.

These results confirmed that watermelon concentrate at 65 °Brix cannot be successfully freeze dried regardless the type and number of carriers added. Furthermore, it can be concluded that watermelon concentrate can be freeze dried only when it is diluted greatly, that negate the initial purpose of concentrating watermelon juice.

## Spray Drying

Spray drying is a common technique employed for the dehydration of fruit juices. This process usually occurs with the temperature of the product much lower than 100 °C, and therefore it may be suitable for the drying of heat-sensitive materials. Traditional carriers used to reduce stickiness and improve product stability, such as MD, add few health benefits to the product. Watermelon pomace, the co-product of juice, and watermelon rind, the co-product of fresh-cut melon, have promise to both increase the quality and nutrition of spray-dried watermelon juice and provide a value-added use for watermelon co-products, increasing the sustainability of the powder production process.

Preliminary spray drying trials showed that drying of watermelon FO concentrate without previous dilution and addition of a carrier (such as MD) is not possible due to high sugar content of watermelon FO concentrate. Different dilutions of watermelon FO concentrate and amounts of a carrier added were evaluated, and dilution to 16 °Brix and addition of 25 percent MD were the conditions necessary to obtain the dried powder. The possibility to replace some amount of MD with freeze dried pomace or rind was explored in subsequent trials. Watermelon FO concentrate was diluted to 16 °Brix and mixed with 25 percent maltodextrin (MD) weight/weight (w/w) or blends of MD and freeze-dried pomace or rind. The compositions of the carrier blends were as follows:

- 100 percent MD (control)
- 11 percent pomace / 89 percent MD
- 25 percent pomace / 75 percent MD
- 11 percent rind / 89 percent MD
- 25 percent rind / 75 percent MD

The feed mixture was spray-dried in a pilot plant scale spray dryer (FT80 Tall Form Spray Dryer Armfield Inc., Jackson, NJ) (Figure A-6). The spray drying conditions were as follows: inlet temperature 190 °C, exhaust temperature 69 to 85 °C, relative humidity of the cyclone separator exhaust air 4.5 to 8.7 percent, chamber pressure −1.66 mbar, cyclone differential pressure 5.8 mbar, air pressure 1.24 bar, feed pressure 0.21 bar, feed flow 2.67 mL/min, inlet fan (blower) 32 Hz, exhaust fan (ventilator) 36 Hz, feed pump 4 Hz.

**Figure A-6: Pilot Scale Spray Drier at the USDA, Albany, California**

Credit: Porifera Inc.

To date, there is no literature reporting on the use of freeze-dried powder of watermelon rind and pomace as carriers in spray drying of juices. Thus, the objectives of this study were to explore the possibility to replace different amounts of MD with the freeze-dried powder of watermelon rind and pomace and to characterize the physico-chemical properties of the concentrated watermelon juice powder.

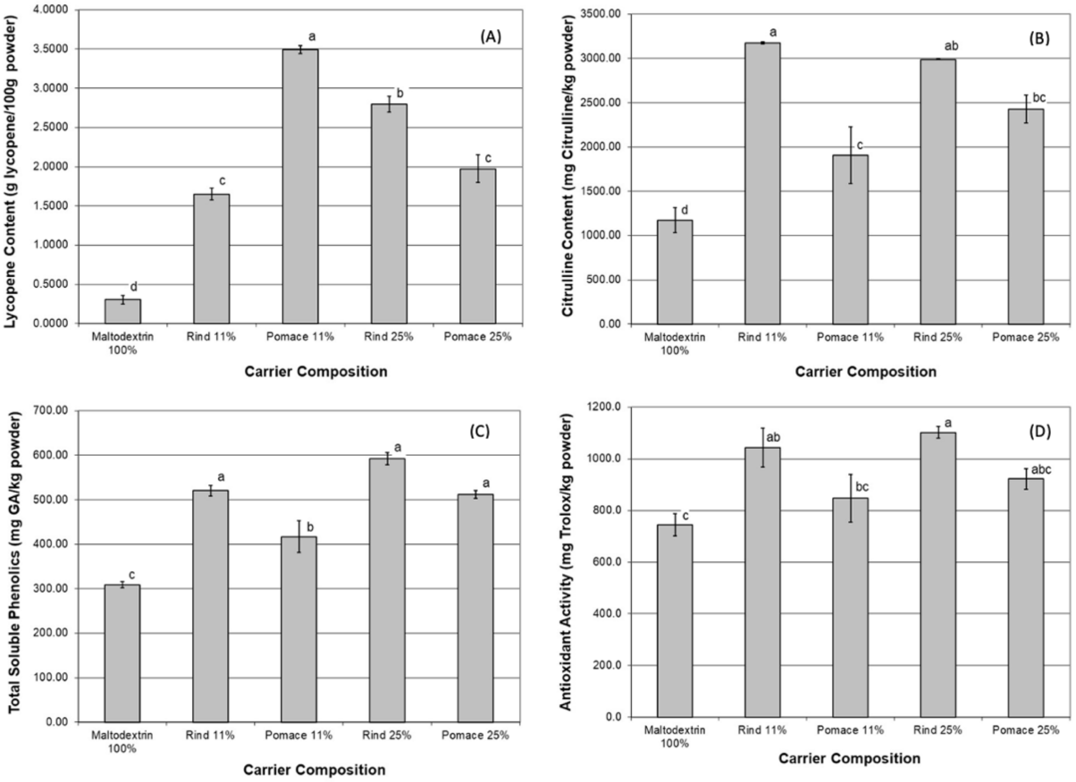
Approximately 500 g of liquid feed mixture was placed in the spray dryer for each trial. The resulting dried material was packed in small bags (made of laminated foil and polyethylene films) with desiccant pouches and sealed. The samples were stored at ambient temperature until needed for analyses. Produced spray-dried samples are shown in Figure A-7.

**Figure A-7: Watermelon spray-dried samples with different carrier composition: maltodextrin 100 % (1), rind 11% (2), pomace 11% (3), rind 25% (4), and pomace 25% (5)**

Credit: Porifera Inc.

The solids content of the powders ranged from 95.1 to 97.4 percent, and the water activity of the powders ranged from 0.20 to 0.24 – all acceptable values for this type of product. ANOVA results indicated that carrier composition had a significant ($p < 0.05$) effect on all the measured quality metrics. Powders with any amount of co-product carrier had higher a* color value (characteristic red color of watermelon) than the 100 percent MD control. All the co-product carrier blends conferred an increase of at least 5 fold lycopene, 1.5 fold citrulline, and 1.3 fold total soluble phenolics, compared to the all-MD carrier. Co-product carrier blends that contained only rind conferred an increase of at least 1.4 fold antioxidant activity. Rind contributed more citrulline than did pomace at the 11 percent substitution level; this is expected because citrulline is produced primarily in the rind of the fruit (Figure A-8).

**Figure A-8: Effect of Carrier Composition on Lycopene content (A), Citrulline Content (B), Total Soluble Phenolics (TSP) Content (C), and Antioxidant Activity (D) of Watermelon Powders**



*Error bars indicate +/- 1 standard error of the mean. GAE = gallic acid equivalents, TE = Trolox equivalents.*

**Charts showing results for lycopene content, citrulline content, total soluble phenolics (TSP) content, and antioxidant activity of watermelon powders.**

Credit: Porifera Inc.

In the carrier materials for the spray drying of watermelon concentrate, watermelon co-products can be substituted for up to 25 percent of maltodextrin. This substitution enhances the quality and nutrition of the resulting powder, especially for lycopene and citrulline. This information will help the development of new sustainable processing strategies for watermelon juice powder. Future studies will examine additional powder quality metrics (flowability, dissolvability, etc.) and the sustainability of the powder-making process as a whole (including both concentration and drying operations).

# APPENDIX B:
# Technical Advisory Committee

The Technical Advisory Committee (TAC) was formed during Season Two. Porifera prepared and presented the project objectives and progress and requested input from the committee members. The committee members included: Tatiana Koutchma, Jaime Reeves, Noel E. Anderson, Phil Tong, Jimmy Yu, and Kevin Mori (See Table B-1).

**Table B-1: Expertise and Organization of TAC members**

| Name | Area of Expertise | Organization |
|---|---|---|
| **Tatiana Koutchma** | Internationally recognized expert in innovative food processing technologies with emphasis on microbiological and chemical safety of new processes and novel foods, improved quality, creating added product values, new processes research and development, new process validation | • Chair of IFT Nonthermal Processing Division<br>• Research Scientist at Agriculture and Agri-Food Canada<br>• Editor of several industry publications |
| **Jaime Reeves** | Director, R&D for Broth, Fruit, Innovation & Thermal Process at Del Monte Foods | Del Monte |
| **Noel E. Anderson** | Senior R&D executive with an outstanding record of business and technical achievements across the global food and beverage industry. | • Chair Elect of IFT<br>• Managing Partner and Co-Founder at Mosaic Food Advisors |
| **Phil Tong** | 29 years at Cal Poly, Dr. Tong has instructed undergraduate and graduate courses on dairy foods processing, and he has organized numerous symposia and short courses including the annual Dairy Ingredients Symposium | Professor Emeritus, Dairy Science, Cal Poly State Univ. |
| **Jimmy Yu** | Expert from one of the largest food and beverage manufacturers | PepsiCo R&D |
| **Kevin Mori** | CEC Program Manager for Porifera's previous projects | CEC Program Manager |

Source: Porifera Inc.

The feedback received was summarized below:

- Provide estimates for an overall cost of ownership and to focus less on the exact details that will be different for each food and beverage producer.
- Provide more detail on the cleaning frequency, the exact methods used for cleaning, and the methods used to preserve the membrane between runs.
- Provide a detailed energy evaluation and comparison with competing technologies.
- More information on the actual membranes used including - cleaning and fouling rates and the ability to sanitize effectively.
- Suggestion to combine high temperature, short duration thermal kill steps, which would minimize degradation of the flavors that the technology preserves.

In response to the TAC feedback, Porifera has done the following:

- Created more detailed standard operating procedures for cleaning and preserving elements.
- Investigated different thermal kill steps to minimize product degradation, such as microwave processing and ultra-high-pressure pasteurization.
- Developed detailed CAPEX/OPEX model for our customer.