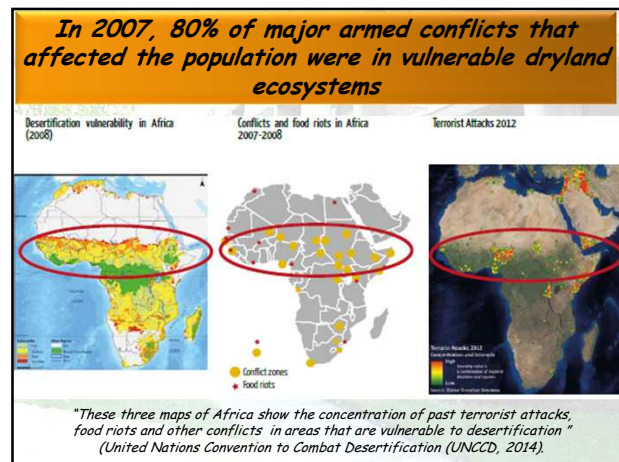
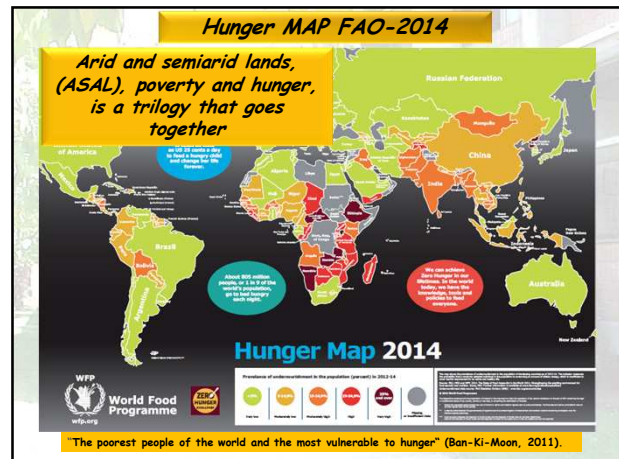


Facultad de Ciencias Agronómicas  
Universidad de Chile

**Recent advances in cactus agroindustries: ingredients and foods**

Prof. Dra. Carmen Sáenz  
e-mail: csaez@uchile.cl

International Cactus Pear Workshop  
Development of a cactus pear agro-industry for the sub-Sahara Africa Region  
27-28 January 2015, University of the Free State (UFS)  
Bloemfontein, South Africa



**Latin america**

*Arid and semiarid lands in Latin America and the Caribeann: about 450 million hectares, covering 22 countries from Mexico to Tierra del Fuego*

**Population:** about 100 million people

Sources: Centro del Agua para Zonas Áridas y Semiáridas de América Latina y el Caribe (CAZALAC) (2014); Morales y Parada (2005).



## Arid and semiarid lands in the sub-Saharan African Region

You know...



In this Workshop we can talk  
about the arid lands of  
South-Africa, Namibia,  
Zimbabwe, India, Zambia,...  
How many millions of  
hectares and how many  
people live there?.



We look for cactus pear and  
"nopalitos" processing  
as an alternative  
to reduce the undernourishment...



Cactus pear and  
"nopalitos" could  
help to cover  
partially the  
nutrients  
requirements of  
the people living in  
those areas

Cactus pear and nopalitos:  
perishable food, as many of  
fruits and vegetables

Challenge for the  
post-harvest  
experts and  
the food  
technologists

Food processing is the key to increase  
the shelf-life of fruits and vegetables  
highly perishable

and is considered the "drive force"\*  
for the agriculture development,  
included ASAL...

Many of the results of our researches  
are published in scientific papers and  
technical articles

\* Prof. José Garrido

We start our work on cactus pear  
processing in 1985, with a project  
supported by our University, later  
by the Ministry of Agriculture and  
currently by CONICYT



After 25 years researching on cactus pear I agree with a Sicilian journalist that has called cactus pear: "A treasure under the thorns"



In addition to the peculiarities of the plant ...

Fruits (cactus pear)

Cladodes or pads

Colored fruits

Nopalitos: part of the ordinary diet in some contries

Functional components with health benefits

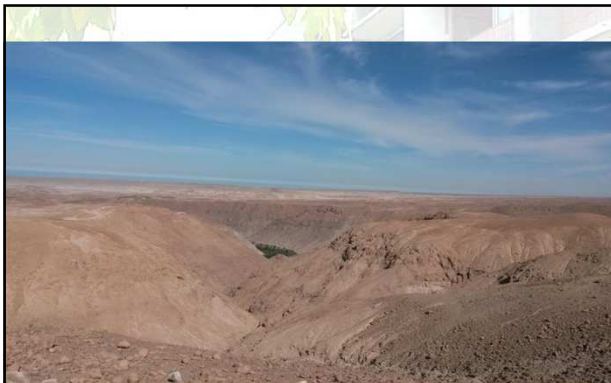


Contribution to a best cactus pear and cladodes utilization from R&D+i...+ training

Technical workshop for training little farmers in Chile, some years ago



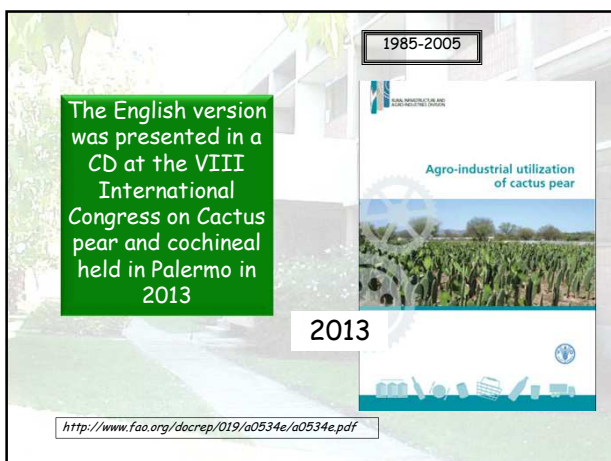
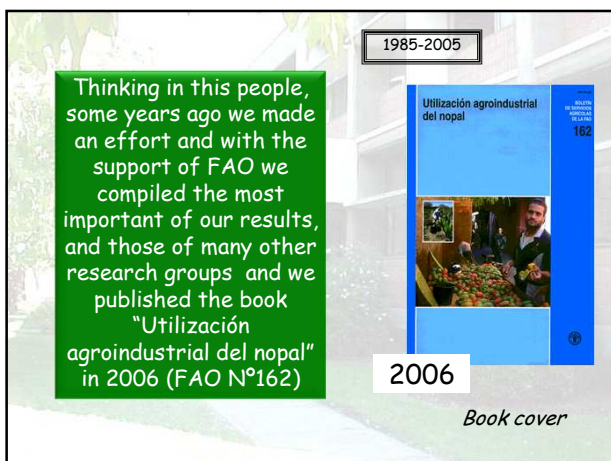
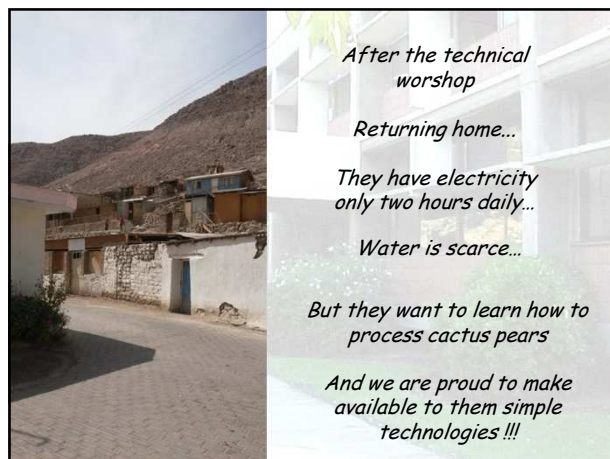
Training a group of little farmers from Codpa Valley (2.000 km north Santiago and 1.800 m.s.l.) (2015)



In the midle of the Tarapacá dessert is Codpa Valley



Figs, Mangos, Cactus pear,...

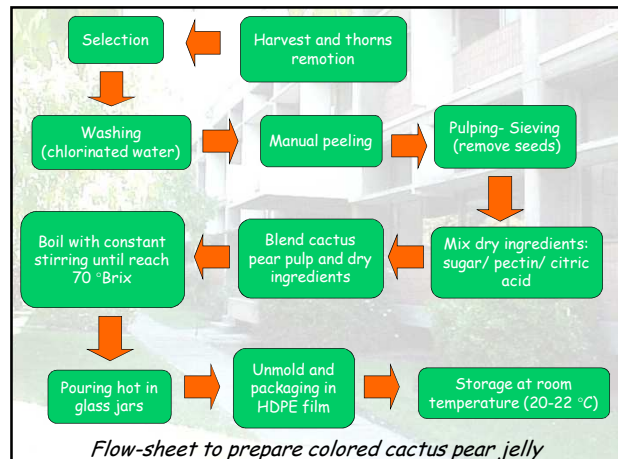




## Products for little farmers



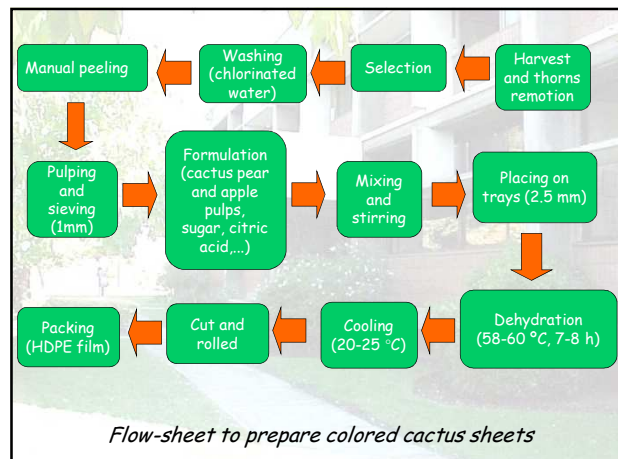
*Colored cactus pear jelly  
(eat with biscuits or bread as quince jelly)*



## Other products for little farmers



*Colored cactus pear sheets ("fruit leathers")  
(with apple pulp)*



## Nopalitos and colored cactus pear: great potential for foods and food ingredients



*Agriculture, foods, bioactive compounds, functional ingredients*

### Opuntia species

Fruit production:  
*Opuntia ficus-indica*,  
*Opuntia amyclae*,  
*Opuntia albicarpa*,  
*Opuntia xocanostle*, *Opuntia megacantha* y *Opuntia streptacantha*...



*O. nopalera*   *O. ficus-indica*   *O. amyclae*   *O. xocanostle*  
*O. matilde Scheinvar*   *O. albicarpa Scheinvar*

Nopalitos production: *Opuntia ficus-indica* y *Opuntia nopalera*

*The most cultivated in the world is Opuntia ficus-indica*

### Nopalitos or tender cladodes



Nopalitos production in a greenhouse (Hidalgo, Mexico)



Source: [www.siap.gob.mx](http://www.siap.gob.mx)

### Nopalitos Cleaning

*A small rural enterprises*



Hermosillo, Sonora, México




### Minimally processing technologies

**Fresh-cut fruits and vegetables**

Hygiene

Cold atmosphere

Package permeability

Consist in a minimum number of unit operations (wash, peel, cut...), packaging and storage at low temperatures

### Fresh-cut nopalitos






Scale to evaluate the darkening in nopalitos stored (4 °C) in clamshell and MA (Osorio-Cordoba et al., 2011)

Refrigerated (4-6 °C, 7-14 days)

### Fresh-cut nopalitos

Market in Mexico








Which attractive have the "nopalitos" to become so consumed? and under such different ways?



## BIOACTIVE COMPOUNDS



*Bioactive compounds or phytochemicals are compounds present in plants that have health benefits. Are named also functional compounds, but their effects depends on the intake doses. Not all the foods having functional compounds are functional foods.*



**Hippocrates** (460 b.c.)  
almost 2500 years ago

*"Let food be your  
medicine and your  
medicine be your food"*

## BIOACTIVE COMPOUNDS

- Pigments in fruit: **Betalains** and **Carotenoids** with antioxidant activity
  - Other antioxidants: Polyphenols, ascorbic acid
- **Dietary fiber**, mainly in cladodes, **mucilage** (hydrocolloids), **lignine**, **polyphenols**, ...



Results related with cladodes processing and uses

One of the most important component of the cladodes or *nopalitos* is the dietary fiber



## Dietary fiber

*The nopal dietary fiber can be used as a functional ingredient to formulate functional or healthy foods*

- Fiber addition in foods (generally low in the diet); recommended daily intake: 30 g/day
- Antioxidants: polyphenols, ascorbic acid, etc.

## Commercial products prepared with nopal powder

Mexican market



## Dietary fiber and total phenolics in nopalitos of different ages (g/100 g d.m.)

Parameter	250 g	500 g	1000 g
TDF	71,78 ± 6,9a	52,57 ± 5,8b	49,6 ± 3,9b
IF	45,5 ± 5,9a	41,1 ± 4,6a	43,1 ± 3,2a
SF	26,3 ± 4,3a	11,6 ± 1,7b	6,5 ± 1,3b
Total phenolics (mg GAE g <sup>-1</sup> )	29,4 ± 2,42b	15,3 ± 0,66a	16,6 ± 5,0a

Different letters mean significant differences among treatments (p<0,05).  
Source: Thesis P. Aguilera. 2012. Unpublished data.

More TDF, SF and total phenolics in more tender pads



The consumption of nopalitos cactus can help to increase the recommended daily intake of dietary fiber (25-30 g/day)

We can introduce a new vegetable..

## Mature cladodes drying



Nopal powder

Dietary fiber  
Polyphenols

This research was published on 2010

Is the base for the development of liquid and solid formulations for foods

## CHEMICAL AND PHYSICAL CHARACTERIZATION OF CACTUS CLADODE (OPUNTIA FICUS-INDICA) POWDER

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### ABSTRACT

Some physical and chemical characteristics of cactus cladode powder and the influence of concentration, temperature and pH on the viscosity of a water suspension were studied. The powder showed low water activity (0.5). The total dietary fiber content was 42.00%, and the ratio of insoluble fiber to soluble fiber was 2.1. The pH significantly influenced the viscosity of the powder suspension at low concentrations and temperatures. The concentration significantly affected the viscosity at all temperatures and pH values. The TDF/DFP ratio suggests that the main physiological effect would be to regulate intestinal functioning, depending on other factors such as daily intake.

\*Key words: cactus cladodes, cactus pads, cactus powder, dietary fiber, Opuntia ficus-indica, sensory panel.

416. Int. J. Food Sci. & Tech. 45, 2010

## Nopal powders problems??

Herbaceous aroma and mucilage content...

Powder purification

The results showed that it is possible to add more than 15% nopal fiber (blended with wheat flour) in biscuits

Results published in 2011

International Journal of Food Science and Nutrition, 2011, Early Online: 1-7

informa

Cactus pear cladodes powders as a source of dietary fiber: purification and properties

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\*Departamento de Alimentos y Nutrición, Facultad de Ciencias Agrarias, Universidad de Chile, Santiago, Chile, and \*Instituto de Ciencias Agrarias, Centro de Ciencia y Tecnología de Alimentos, Universidad Austral de Chile, Valdivia, Chile





## Phenolics Compounds and Dietary fiber in purified cactus cladodes powders

Phenolic compounds	NP	PF1	PF2	PF3	PF4
Total phenolics (mg GAE 100g <sup>-1</sup> )	1.431,6 <sup>a</sup>	709,3 <sup>b</sup>	613,7 <sup>c</sup>	684,1 <sup>b</sup>	657,0 <sup>c</sup>
Dietary Fibre	IF (g/100g)	SF (g/100g)	TDF (g/100g)	SF:IF	
FP3	60,6 <sup>b</sup>	20,7	81,3	0,34:1,00	

Source: Sáenz et al. (2011)

## Functional beverages formulation

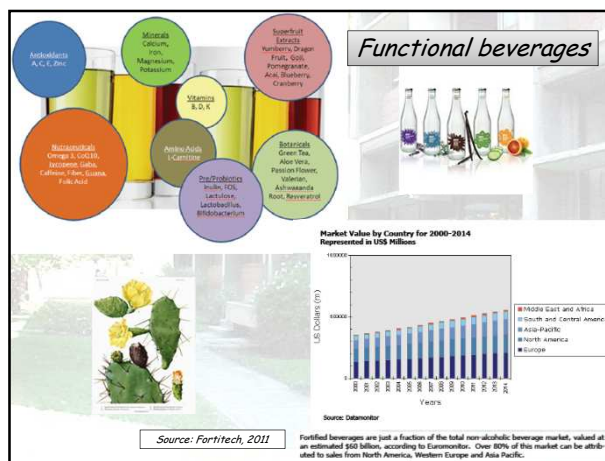
The addition of nopal powder is more easy in solids foods (cookies, flans, etc) but it is interesting in liquid foods as beverages.



**Challenge!!**

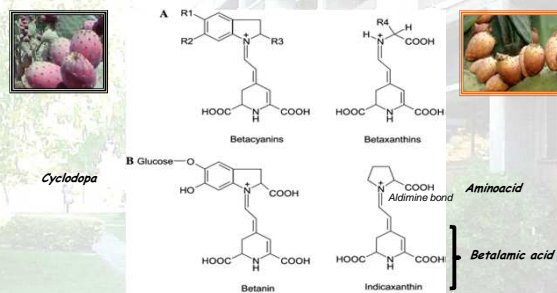
M.Sc. Thesis: Jery Jerez (in progress)

*Beverages that included fiber improve the perception of satiety and reduce the desire to eat (Lyly et al., 2009)*



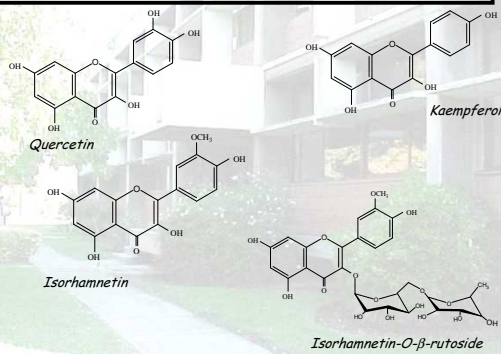
Results related with colored cactus pear

## Betalains in cactus pear



Affected by: pH, a<sub>w</sub>, O<sub>2</sub>, light, temperature

## Polyphenols in cactus pear fruit



Source: Kuti et al., 2004; Galati et al., 2003

## Concentrated juices



The concentrated juices was our first approach to the colorants... and to the development of new products, taking advantage of the attractive colors

Process Lab-University of Chile

## Toppings from colored cactus pear for desserts

**Bioactive Compounds in Toppings from Colored Cactus Pear Cultivated in Chile**

**Abstract**  
Cactus pear (*Opuntia ficinuda*) is a fruit cultivated in the coastal and semi-arid regions of Chile. It is a rich source of bioactive compounds, including polyphenols, carotenoids, and betalains. The aim of this study was to evaluate the bioactive compounds in cactus pear toppings. The results showed that the toppings contain high levels of polyphenols, carotenoids, and betalains. The study also evaluated the sensory attributes of the toppings, which were found to be acceptable.

**Keywords:** Cactus pear, toppings, bioactive compounds, sensory attributes.



## Bioactive Compounds in coloured cactus pear toppings

Bioactive Compounds	Purple cactus pear topping	Orange cactus pear topping
Carotenoids (µg/g)	0.186 ± 0.001	0.021 ± 0.001
Total phenolics totales (mg/L GAE)	350.50 ± 15.25	131.48 ± 5.72
Betalains	81.06 ± 1.83	63.80 ± 1.86
Betacyanines as betanin (mg/Kg)	66.09 ± 1.03	0.92 ± 0.00
Bethaxanthins as indicaxanthin (mg/Kg)	14.97 ± 1.53	62.88 ± 1.86

Source: Morales et al. (2009)

## Balsamic type vinegar from colored cactus pear

Vinegar from purple cactus pear: the best sensory evaluated

**Abstract**  
The aim of this study was to evaluate the sensory attributes of balsamic type vinegar made from cactus pear. The results showed that the vinegar made from purple cactus pear was the best sensory evaluated. The study also evaluated the bioactive compounds in the vinegar, which were found to be acceptable.



## Pigments as colorants for foods




The consumers prefer natural colorants instead artificial colorants





Red betalains can replace artificial colorants used in foods as: Ponceau 4 R (E-124); Eritrosine (E-127), Allura red (E-129), etc.

No new regulation is required: is the same pigment of beetroot-red, registered in U.S.A.(73.40 FDA) and in the E.U. (E-162), but without heart taste and free of nitrates



There are many "red" color in the fruits (peel and pulp) and the yield obtained is very important, thinking in colorants for foods.

In a collaborative project with Mexico, we are using ultrasound to improve the betalains yields, but the results until now is that we improve the polyphenols yield but not the betalains yield...



*Hielscher Sonicator UP200S (Universidad Autónoma de Aguascalientes, México).*

*We use the peel....*

**Total polyphenols and yield increase (%) using US in cactus pear peel**

*All treatments at 20% amplitude and frequency of 0.1 cycle*

Treatment*	Total polyphenols (mg/L GAE)**	Increase of the yield extraction (%)
Control	41,4±1,3 a	---
1	102,9±1,1 b	148,75
2	106,6±1,0 c	157,6
3	126,4±0,1 d	205,5

\*1 = 5' US y 10' pause; 2= 5' US, 5' pause, 5' US; 3= 10' US y 5' pause. \*\* GAE= Gallic acid equivalent

**Betalains**

Little molecules with great attractive: colorant power and antioxidant capacity

**Betalains**

Affected by:

- Oxygen
- Light
- Temperature
- aw

How stabilize them to use as additive -functional additive- in foods ?

➔ **Microencapsulation**

## Microencapsulation

Is a technology originally used in the pharmaceutical industry



**Encapsulation methods:**  
Spray drying is the most used technique in the food industry.

*In this technology bioactive compounds are introduced into a matrix or polymeric wall system in order to protect them from environment and interaction with other food components (Yañez et al., 2002).*

The first research of betalains encapsulation (colorant powder) from purple cactus pear was developed by our group led by Dr. Paz Robert from the Faculty of Pharmacy



Microparticles from purple cactus pear pulp

## Encapsulation by spray drying



Buchi equipment  
(Lab Dr. Paz Robert  
U. de Chile)

Encapsulated pigments from purple cactus pear

## Encapsulation agents

- Cactus pulp (CP)/Soy protein (SP)
- Cactus pulp/SP + Maltodextrin (MD)
- Cactus pulp (CP)/SP + Inulin (In)

### Encapsulation Efficiency:

Betacyanins and betaxanthins = 100% (97.9-99.9%)  
Poliphenols <100% (79.7-86.5%)



## Betalains Microencapsulation (%)



Microencapsulation by spray drying of bioactive compounds from cactus pear (*Opuntia ficus-indica*)

Carolina Salazar<sup>1</sup>, Sandra Tapia<sup>2</sup>, Jorge Chaves<sup>3</sup>, Paz Robert<sup>4</sup>

<sup>1</sup>Departamento de Alimentos, Facultad de Ingeniería, Universidad de Chile, Casilla 136 Correo Central, Santiago, Chile

<sup>2</sup>Departamento de Alimentos, Facultad de Ingeniería, Universidad de Chile, Casilla 136 Correo Central, Santiago, Chile

<sup>3</sup>Departamento de Alimentos, Facultad de Ingeniería, Universidad de Chile, Casilla 136 Correo Central, Santiago, Chile

<sup>4</sup>Departamento de Alimentos, Facultad de Ingeniería, Universidad de Chile, Casilla 136 Correo Central, Santiago, Chile



Our first work was published in 2009

We continue the studies about different encapsulating agents and different betalain extracts

## Betalains extracts

The ethanol extraction led us to consider other technologies without the use of organic solvents



## Betalains extracts using membrane technologies

The works related with membrane technologies are leaded in our group by Dr. Beatriz Cancino from UFS & INPROMEM E.I.R.L.

## Separation, concentration and microencapsulation of cactus pear betalains to be used as colorant foods

Grant FONDECYT-CHILE N° 1110126

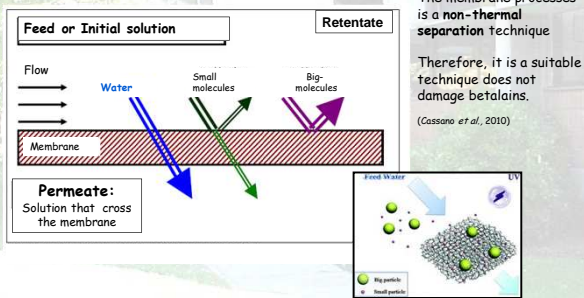


Betanin separation by membrane technologies

Encapsulation

## Membrane technologies

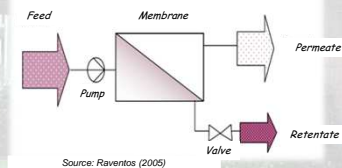
The membrane is a selective barrier. Allowing the cross of certain components of a mixture and retaining other (Cheryan, 1998).



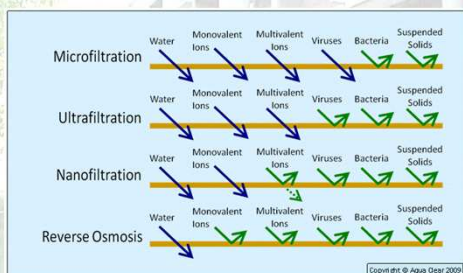
## Ultrafiltration and Nanofiltration

*Ultrafiltered extract (UF): feed MF permeate. Ceramic membrane. Flow: retentate or concentrate*

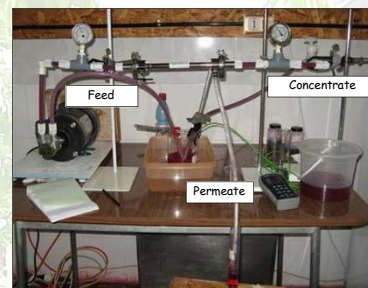
*Nanofiltered extract (NF): feed MF permeate. Polymeric membrane. Flow: retentate or concentrate.*



## Membrane process characteristics



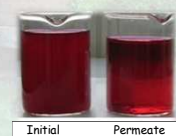
*All the cactus pear fiber is retained in the retentate of MF*

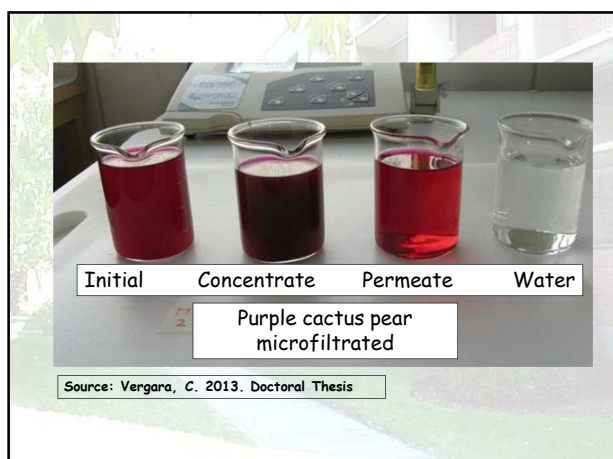


Microfiltration module

Membrane Laboratory  
Dr. Beatriz Cancino-Chile

Source: Vergara, C. 2013. Doctoral Thesis





### Cactus pear pulp microfiltration

Characterization of MF feed (diluted pulp) and permeate

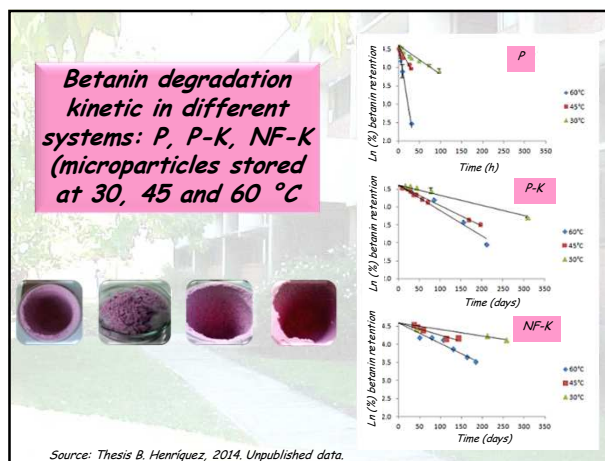
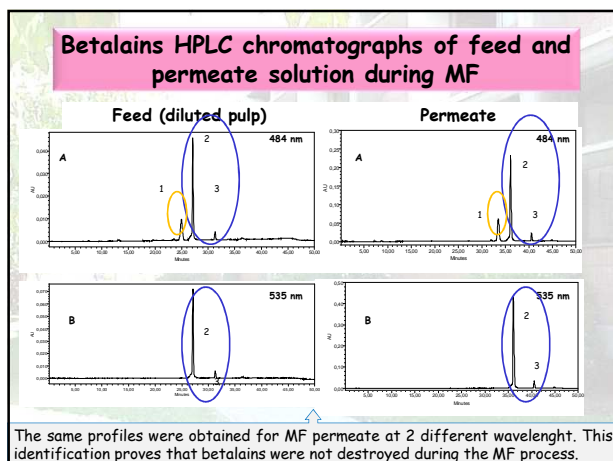
Parameters	Diluted Pulp	Permeate MF
Turbidity (NTU)	1226.7±64.2	0.0±0.0
Density (g/mL)	1.046± 0.03	1.006± 0.03
Soluble solid (°Brix)	7.1 ± 0.03	6.9 ± 0.03
pH	6.4±0.3	6.7± 0.2
Betacyanins (mg BE)	131.7±1.05	97.0±0.20
Betaxanthins (mg IE)	48.7±0.74	34.7±0.06
Total polyphenols (mg GAE/L)	196.7±0.02	245.3± 0.6

BE, betanin equivalent; IE, indicaxanthin equivalent; GAE, gallic acid equivalent;

Source: Vergara, C. (2013). Doctoral Thesis

The betalains content is lower in the permeate solution because some betalains are retained in the concentrate solution with the mucilages.

Feed Permeate



### Betanin degradation rate constant

System	60°C 10 <sup>3</sup> k <sub>obs</sub> ± DS (days <sup>-1</sup> )	R <sup>2</sup>
P	1739,2 ± 2,8 <sup>b</sup>	0,99
P-K	7,1 ± 0,0 <sup>a</sup>	0,96
NF	2567,2 ± 4,7 <sup>c</sup>	0,89
NF-K	5,8 ± 0,0 <sup>b</sup>	0,83

Source: Thesis B. Henríquez, 2014. Unpublished data.

