Creating microstructure of dehydrated fruits and vegetables with a multi-flash drying process

ESPCA/São Paulo School of Advanced Science
Advances in Molecular Structuring of Food Materials

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UFSC

What is the (old) problem?

Tropical fruits as bananas and mangoes are perishable products with significant economic importance in many countries.

↓

The development of solutions for their preservation and processing is necessary to reduce losses, obtain better products and add value to them

↓

Dehydration is one of the oldest techniques of preservation

How can we choose the drying process and process variables in order to control the microstructure of dehydrated fruits and vegetables?

Processes for fruits dehydration

Raw fruits

Selection

Wash, cut

Drying

Visual, color, texture
Soluble solids (°Brix)
Texture (penetration)

Solar drying | Convective drying | Vacuum drying | Freeze-drying

Creating microstructure

Convective-multiflash drying
Conductive-multiflash drying

- CMFD
- KMFD

Microwave vacuum drying

Solar drying: cheap and traditional, drying rate depends on weather conditions

Convective drying: allows controlling drying rates, thermal degradation (T, t) , fruits shrinkage leads to undesirable texture properties

Vacuum drying: Reduces problems of convective drying, heat sensitive foods, does not avoid shrinkage

Freeze-drying: Best dehydration process for het sensitive products, minimal shrinkage, time-consuming, energy-consuming, high cost

What is the Convective-multi-flash drying process (CMFD)?

CMFD is a dehydration process developed for fruits and vegetables dehydration and texturization

Patent application 017110000045 - Brazil

Selection and preparation of fruit samples on a stainless steel grid
→ Insertion of the grid+samples into a jacketed container

banana (*Musa sapientum* L.) : slices with thickness of 5 mm , 26 ºBrix
mango (*Mangifera indica* L.) : square slices (30 mm), 8 mm thick, 12.5 ºBrix

CMFD cycle

Heating the samples up to **60ºC**, at $\mathbf{P_{atm}}$, inside the container, **using hot air (70 ºC)** → convection, conduction, radiation

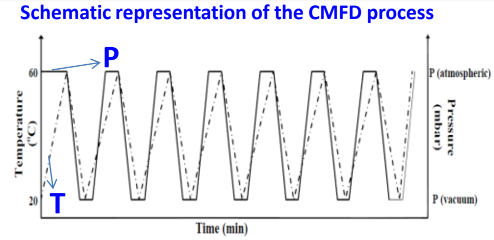
60ºC → Application of vacuum pulse (P_{abs} **=15 mbar**) for 3-5 min
→ flash drying-and-cooling

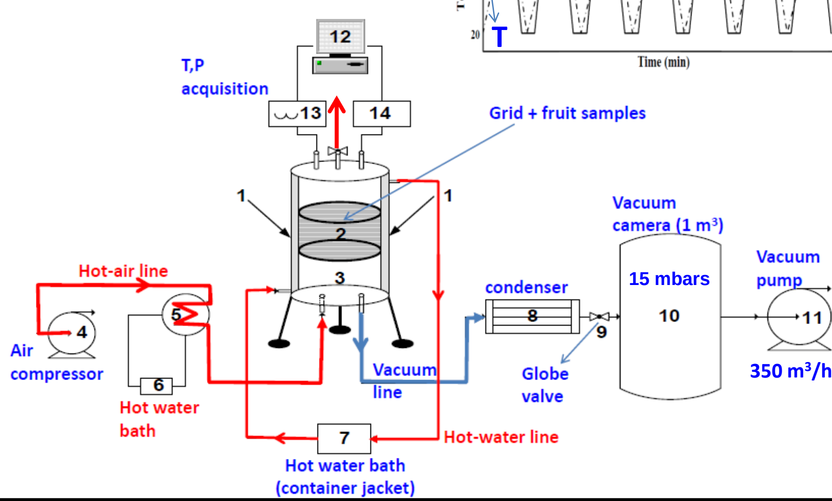
Recovery of the atmospheric pressure in the jacketed container

CMFD – Experimental device

The CMFD process doesn't use pressures higher than the atmospheric pressure

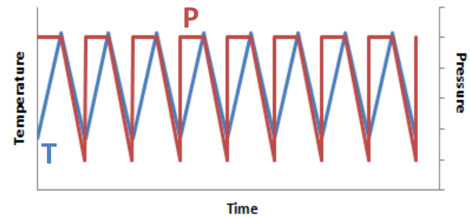
Schematic representation of the CMFD process

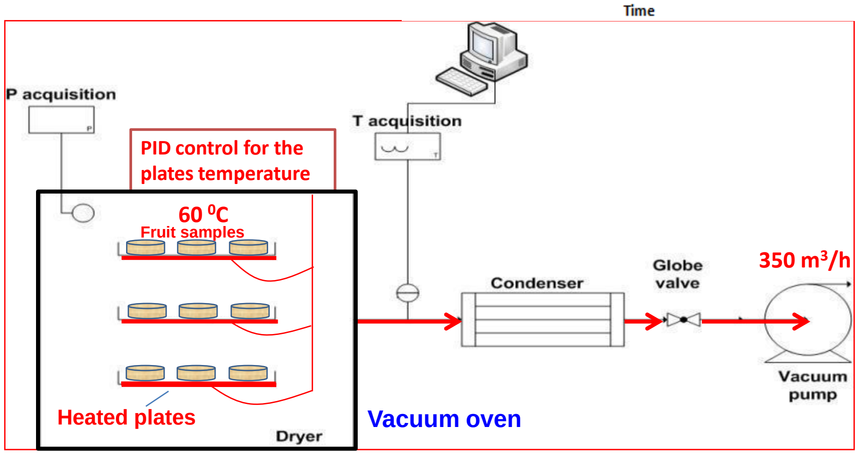




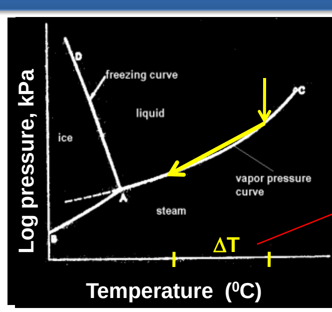
KMFD – Experimental device

The KMFD process doesn't use pressures higher than the atmospheric pressure



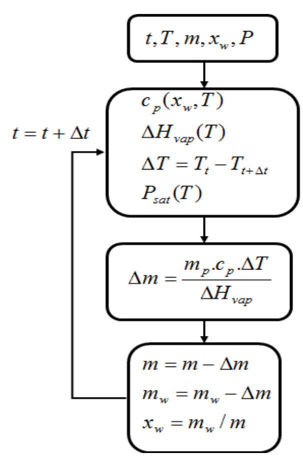


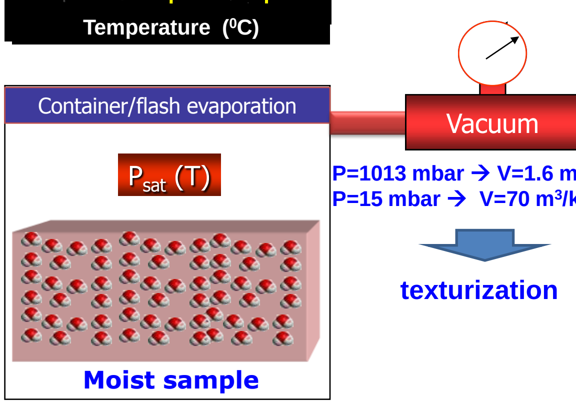
Heating + flash evaporation cycles



Water evaporation at each cycle, considering flash evaporation as an adiabatic process

$$\Delta m_w = \frac{c m_p \Delta T}{\Delta \hat{H}_v} \qquad \Delta H = 2250\,\text{kJ/kg} \ \text{at}\ P = 101.3\text{kPa}$$





P=1013 mbar → V=1.6 m³/kg
P=15 mbar → V=70 m³/kg

texturization

CMFD, KMFD X SIMILAR PROCESSES

Puff drying

➔The puff-drying is performed by submitting the product partially dehydrated to **pressures of 6-8 atm** and high temperatures, followed by a **sudden decompression to the atmospheric pressure**, which creates a product with an open structure

➔It was developed in order to dehydrate fruits and vegetables at large scale, which could be quickly reconstituted, with operating costs comparable to convective drying

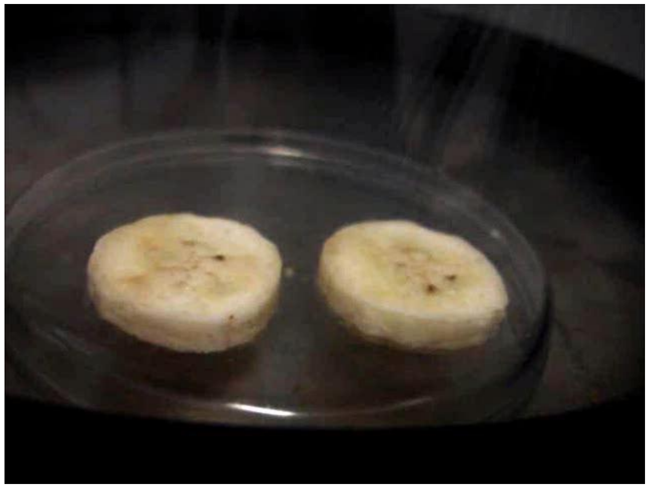
➔**Pre-dehydration of the product** to be submitted to the puff-drying is essential to **avoid product disintegration** during the sudden decompression, (THAKUR e THAKUR, 2000; LOUKA and ALLAF, 2002; IGUEDJTAL et al., 2007; MUJUMDAR, 2007).

➔It is used also for processes intensification (oil extraction)
LOUKA and ALLAF, 2002

SOME RESULTS OF BANANA AND MANGO DRYING USING THE CMFD

CONVECTIVE MULTIFLASH DRYING PROCESS

Convective-multi-flash drying process – CMFD
Movie banana – flash drying



Convective-multi-flash drying process – CMFD
Movie mango – flash drying + texturization

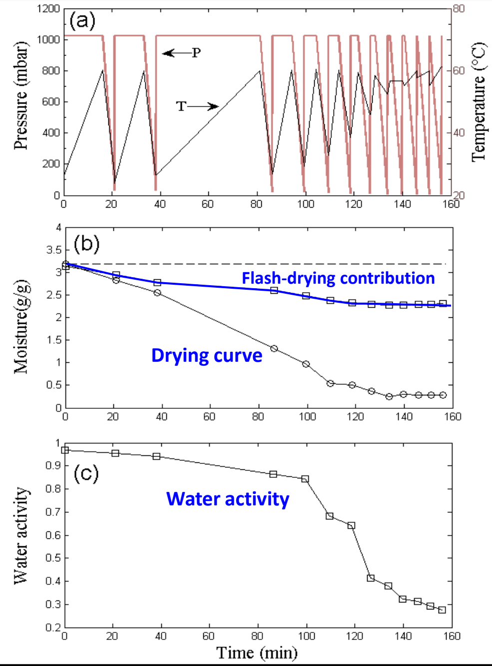
P=15-20 mbar →Water boiling at approximately 15 °C

Convective-multi-flash drying process – CMFD (banana)

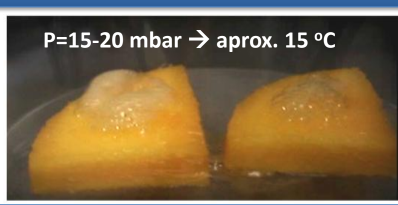
Evolution of the pressure in the jacketed container and fruit temperature during the CMFD process applied to banana samples

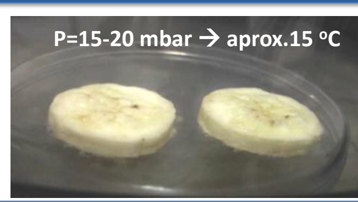
Evolution of experimental moisture content of banana during the CMFD process and the estimated contribution of flash-evaporation to the whole drying process

Evolution of banana samples water activity during the processing.



Convective-multi-flash drying process - CMFD

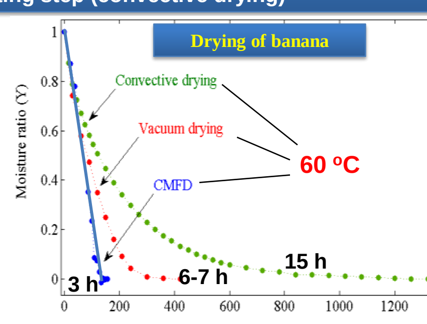




→ After flash evaporation (= flash cooling) → heat transfer from hot air (70 °C) to the fruits is improved by the high temperature difference between hot air and cooled fruits

→ During flash-evaporation part of the internal moisture is drained to the fruit surface and improve evaporation during the heating step (convective drying)

CMFD is a very efficient dehydration process



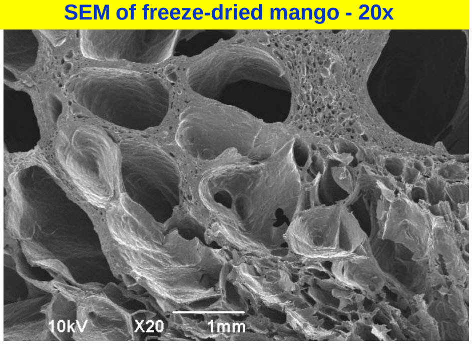
Some pictures of mango during dehydration by CMFD

Pictures of mango fruits after every heating-vacuum pulse cycle

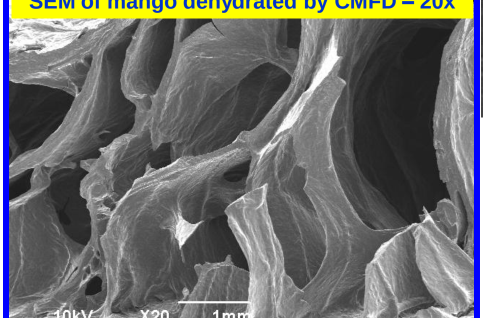
CMFD cycles

Pictures of mango fruits after 12 cycles of heating-vacuum pulses

SEM of freeze-dried mango - 20x

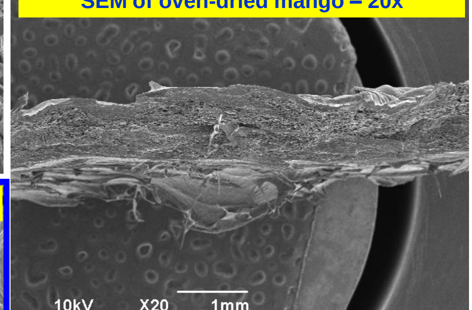


SEM of mango dehydrated by CMFD – 20x

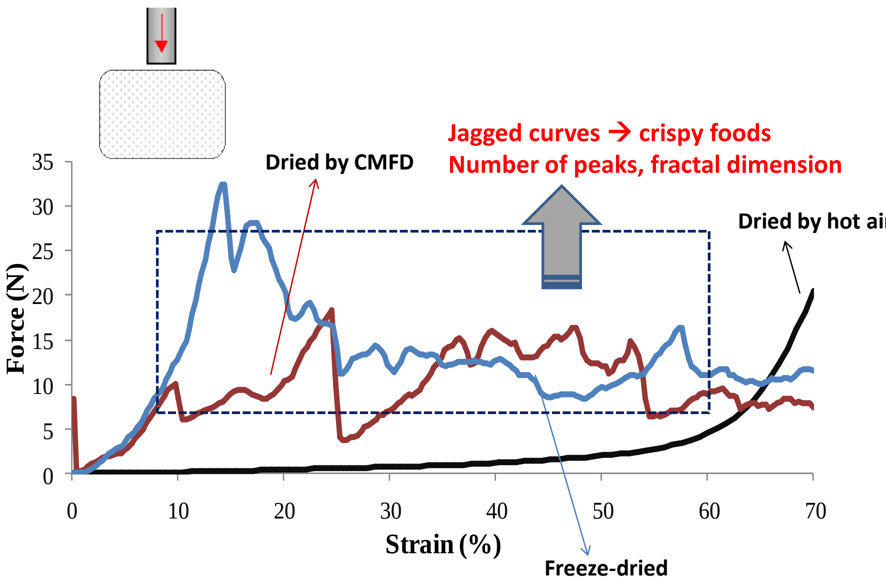


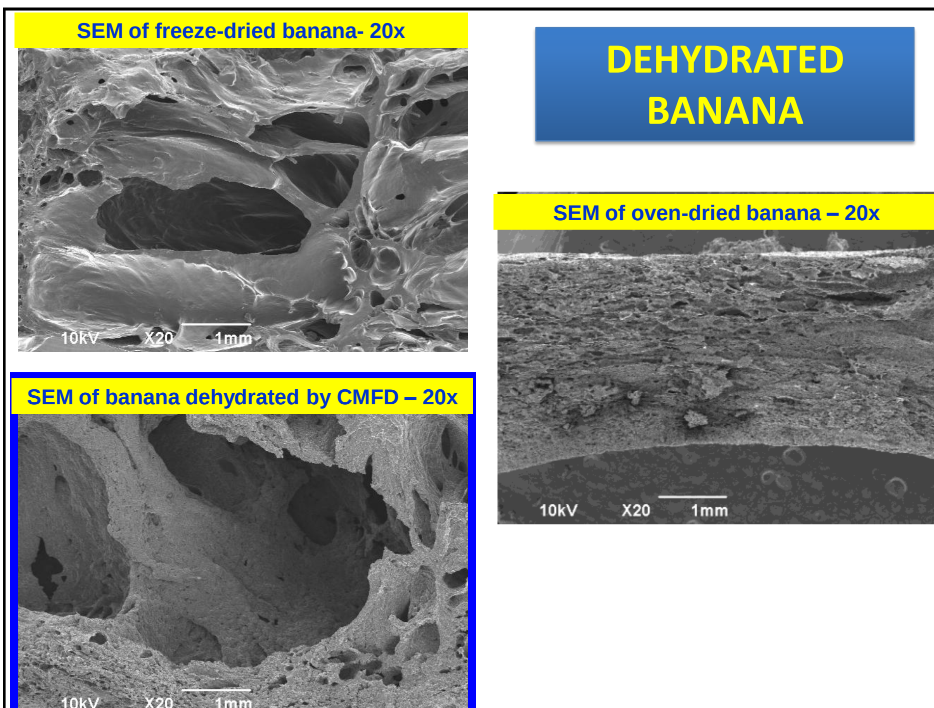
DEHYDRATED MANGO

SEM of oven-dried mango – 20x

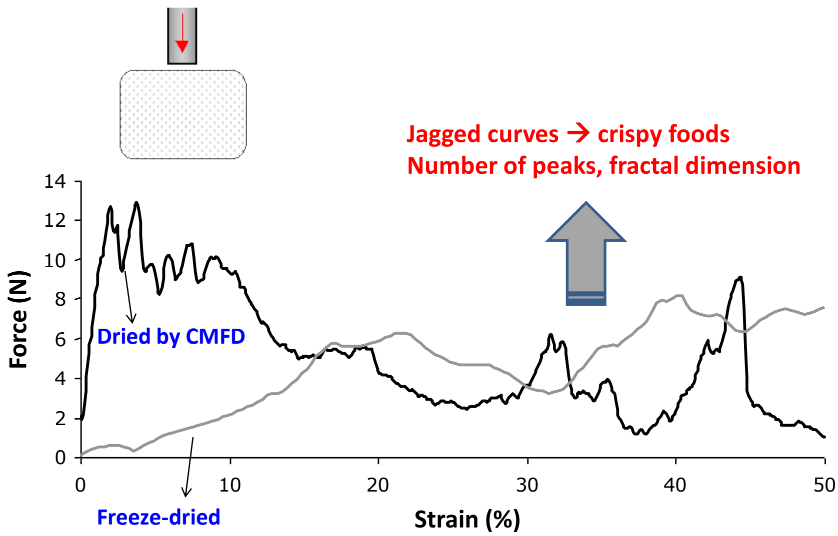


Puncture tests of dehydrated mango





Puncture tests of dehydrated banana



REMARKS

➔ It is possible to produce dried-and-crisp fruits using the convective-multi-flash drying process (CMFD) with texture properties that are similar to those obtained with freeze-drying

➔ Product color is preserved due to the use of moderate process temperatures (Do you want it?)

➔ Process time of CMFD and KMFD are shorter (about 2-3 hours at laboratory scale) than the characteristic times of freeze-drying

➔ Equipment and process are simple and use low pressures and temperatures ➔ smaller investment and energy requirements than freeze-drying

Can we control the microstructure of dehydrated fruits and vegetables?

YES, WE CAN!

How can we follow the microstructure evolution during drying?

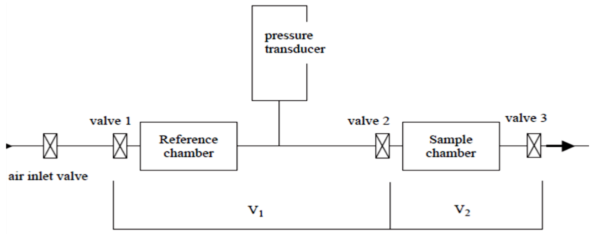
Bulk or apparent volume

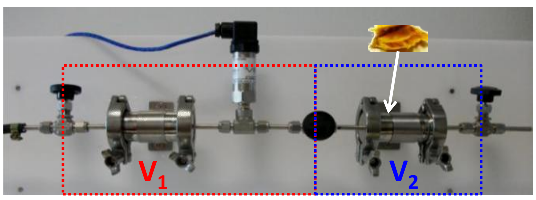
$$V_b = \frac{(m_b - m_a) - (m_{b1} - m_{a1})}{d_{solvent}}$$

V_b= apparent volume (cm^3)
m_b= sample weight in air (g)
m_a= support mass (g)
m_{b1}= "sample weight" immersed n-heptane (g)
m_{a1}= support weight immersed in n-heptane (g)

Becker with n-heptane

True volume of a porous material using a gas picnometer (Sereno et al., 2007)





$$V_t = \frac{V_1\left(\frac{P_1}{P_2}\frac{T_2}{T_1}-1\right)}{\left(\frac{P_{atm}}{P_2}\frac{T_2}{T_{atm}}-1\right)} + V_2$$

Volume of chamber 1 (V_1); Volume of chamber 2 (V_2); Pressure of system

V_p= true volume (cm³)

→ Moist material = volume of the solids forming the sample structure + volume of the liquid

→ Dry material = volume of the solids forming the fruit structure

FROM THE **BULK VOLUME** AND THE **TRUE VOLUME** WE CAN DETERMINE

Material porosity, ε

V_b= bulk volume (cm³)

V_p= true volume (cm³)

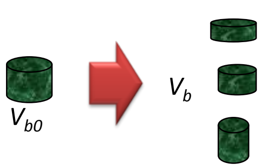
$$\varepsilon[\%] = \left[1 - \frac{V_p}{V_b}\right] \times 100$$

→ **Accessible porosity during drying**

Accessible porosity increases at each cycle of CMFD or KMFD during drying

Fruits shrinking during drying

$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$



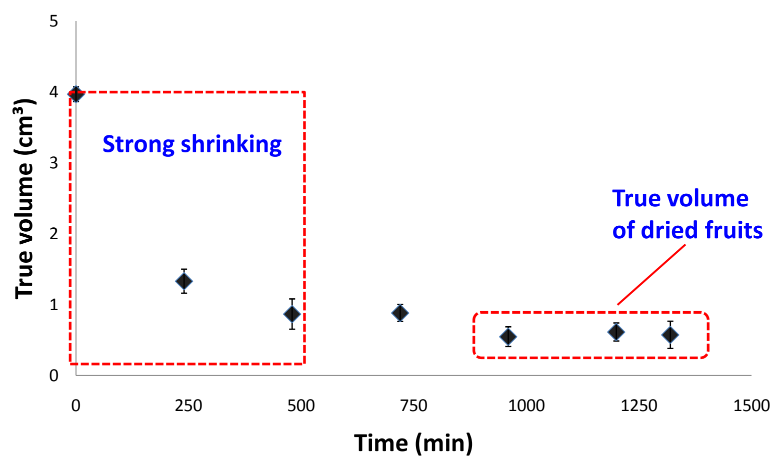
SEM- Scanning electronic microscopy

Samples preparation → fruit slices were removed from the dryer, frozen by liquid nitrogen and freeze-dried
(It was considered that ultra rapid freezing and freeze-drying did not change significantly the fruit structure)

Convective drying

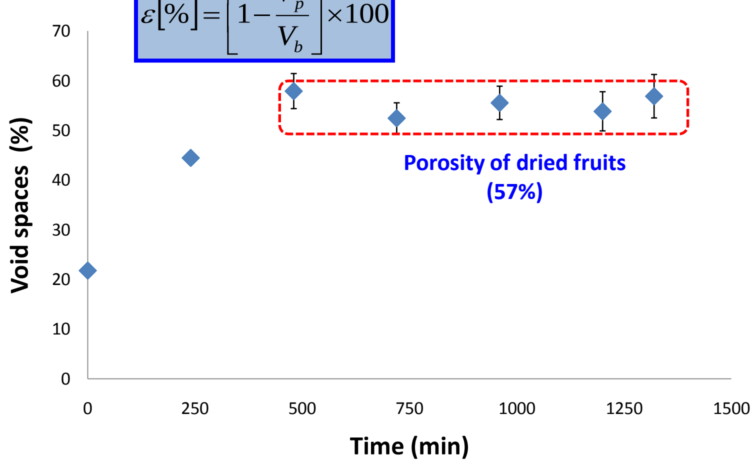
T = 60 °C

True volumes (solid + liquid) as determined with the gas porosimeter

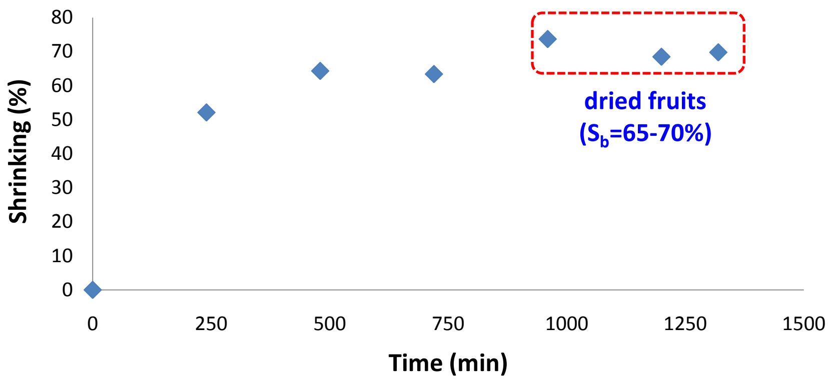


Evolution of the void spaces during drying using convective drying (moist samples)

$$\varepsilon[\%]=\left[1-\frac{V_p}{V_b}\right]\times 100$$



Shrinking (determined by immersion into heptane)

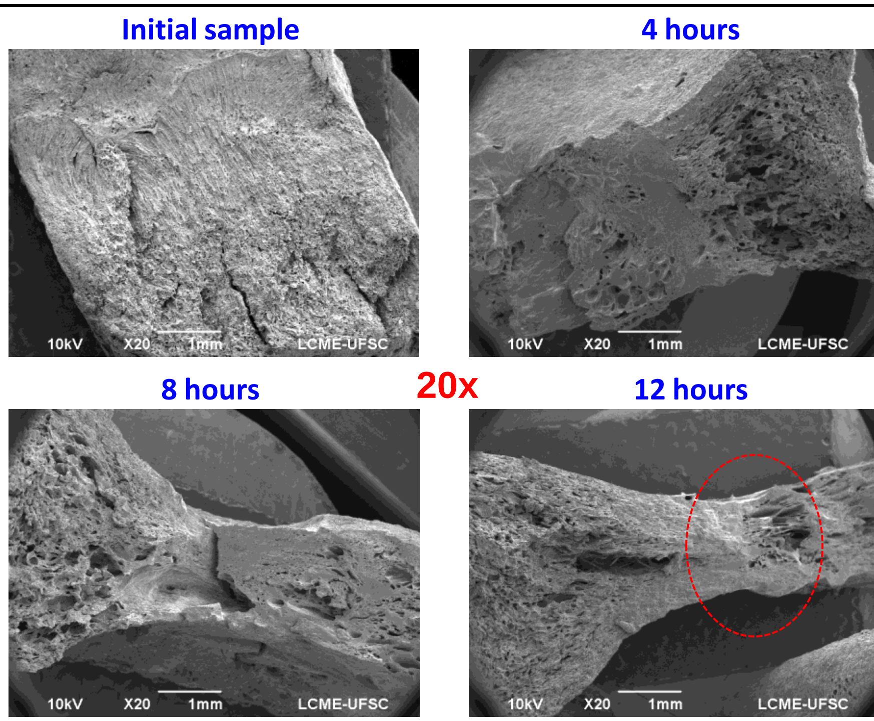


$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$

V_b = bulk volume at t (cm^3)

V_{b0}= bulk volume at t=0 (cm^3)

V_{b0}= average value= 5 cm^3



Vacuum drying

T = 60 °C and P = 15mbar

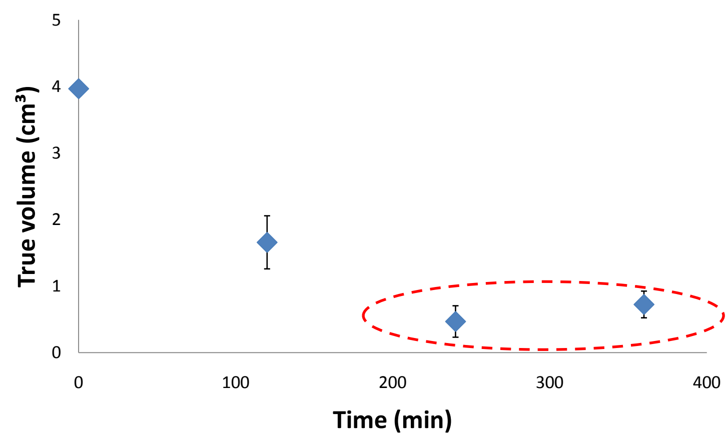
Vacuum Drying

➔Vacuum drying of bananas was performed using a vacuum oven (Ethick Technology, 440-DE model-SP, Brazil). Banana slices (5mm) were placed evenly in a thin single layer on the drying tray and placed inside the vacuum oven.

➔The vacuum pressure and the drying temperature were kept constant at 15mbar and 60^0C.

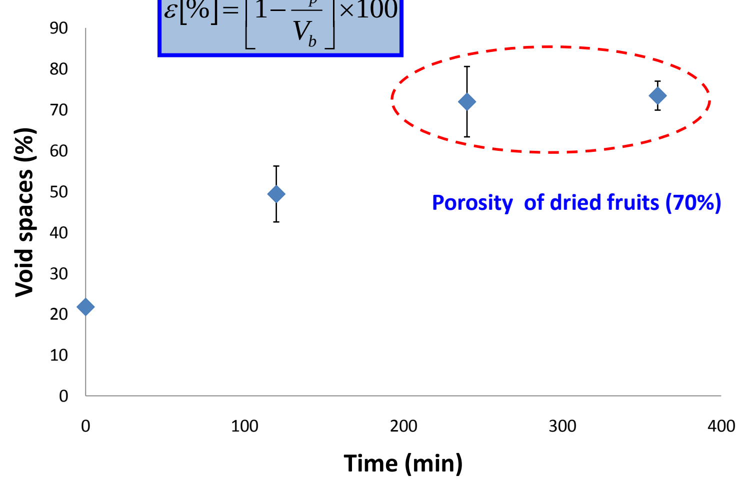
➔The fruits were dried for 6h to a final moisture content of 0,0760 g/g

True volumes (solid + liquid) as determined with the gas porosimeter Vacuum Drying

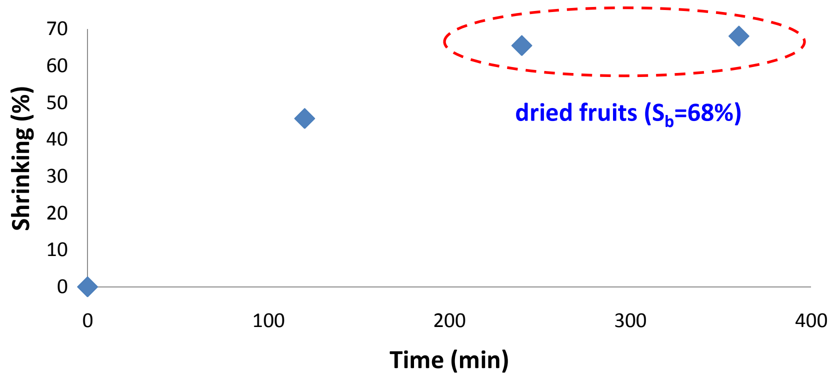


Evolution of the void spaces during drying using vacuum drying (moist samples)

$$\varepsilon[\%] = \left[1 - \frac{V_p}{V_b}\right] \times 100$$

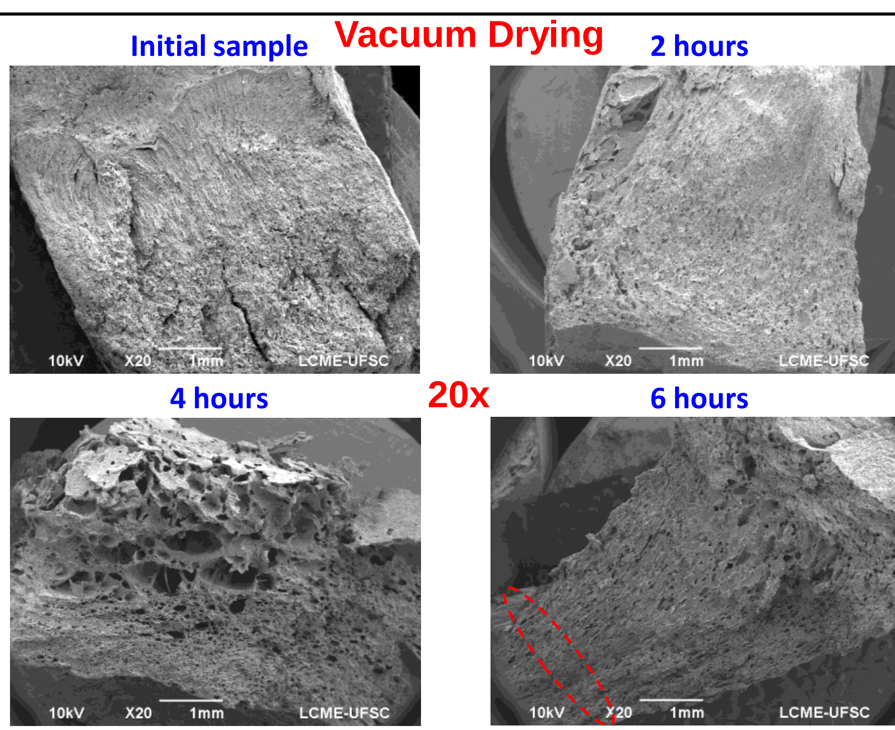


Shrinking - Vacuum Drying (determined by immersion into heptane)

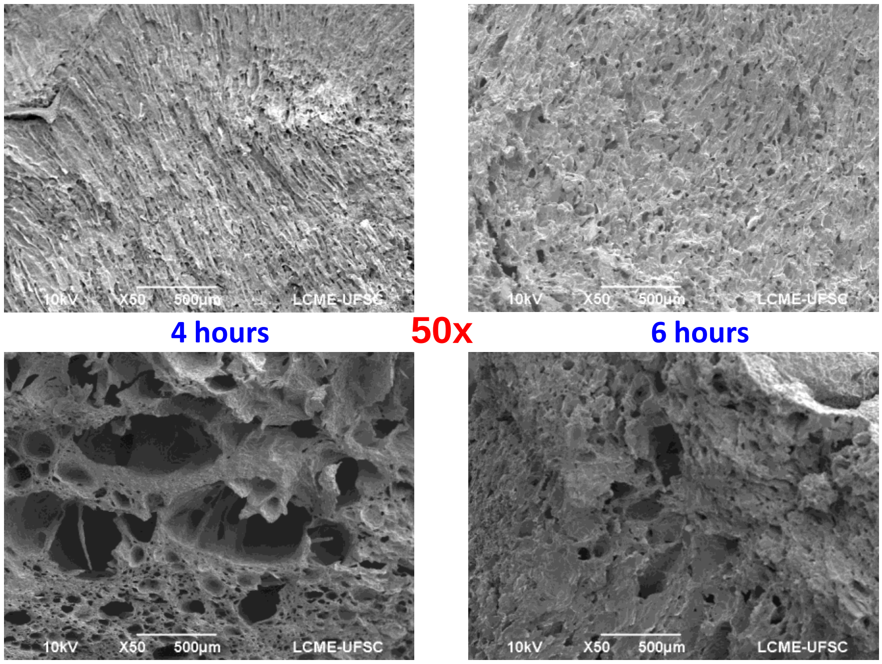


$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$

V_b = bulk volume at t (cm³)
V_{b0}= bulk volume at t=0 (cm³)
V_{b0}= average value= 5 cm^3



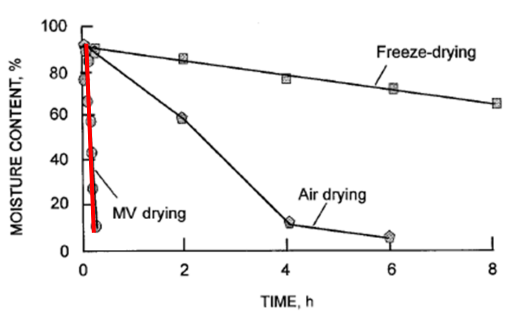
Vacuum Drying



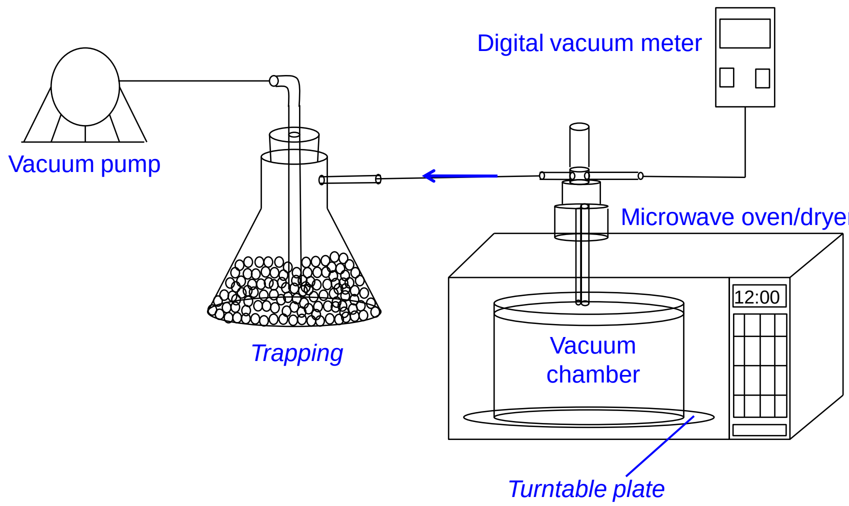
Microwave Vacuum Drying

Vacuum helps to reduce drying temperature by reducing the boiling point of water during microwave-vacuum drying.

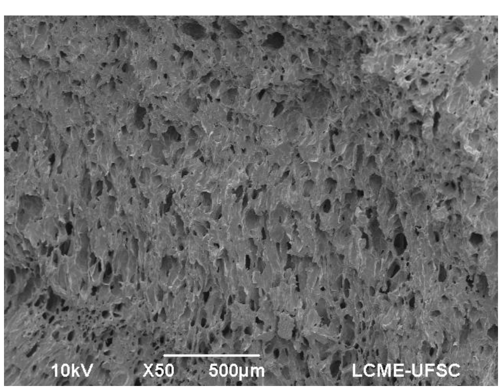
Drying rates of carrot slices (Durance, 1999)
- hot air at 70 C
- Freeze drying
- microwave-vacuum drying



Microwave vacuum drying
Experimental device



SEM - Microwave vacuum drying



Microwave vacuum drying	
Drying time	19 min
Moisture	0,03 g/g
Bulk volume	2,46 cm^3
Porosity	66%
Shrinking	51%

Structural changes in banana samples during drying by KMFD

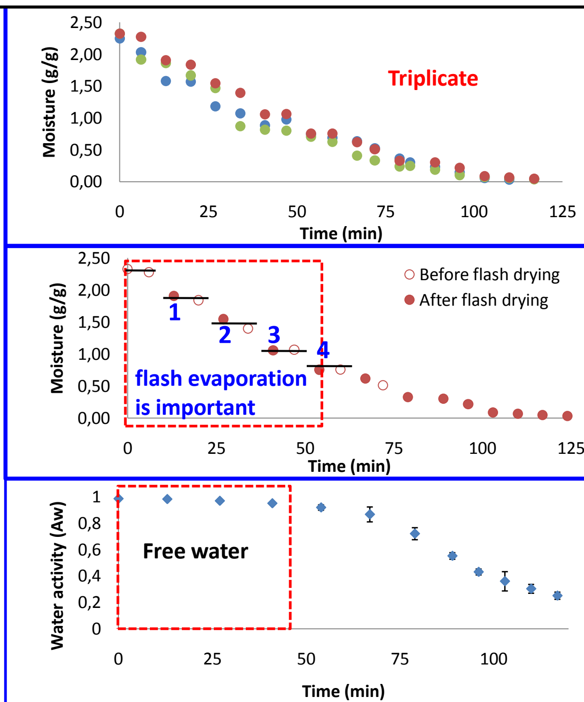
KMFD-*Conductive multi-flash drying,* T = 80°C

KMFD

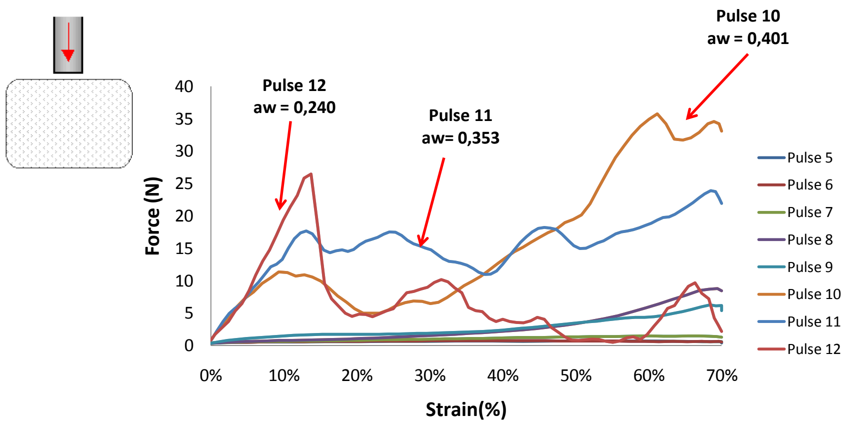
Drying curves reproducibility

Conductive and flash evaporation contributions

Water activity

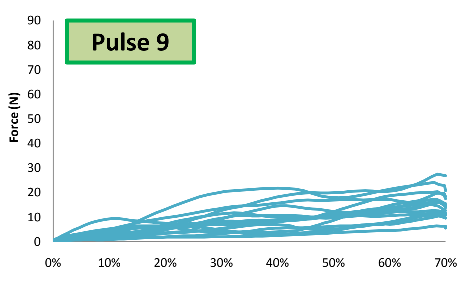


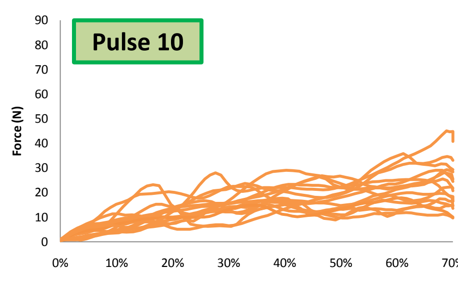
Puncture tests of fruits dried by KMFD

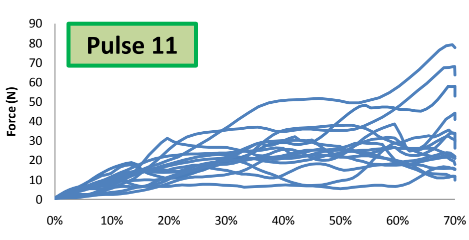


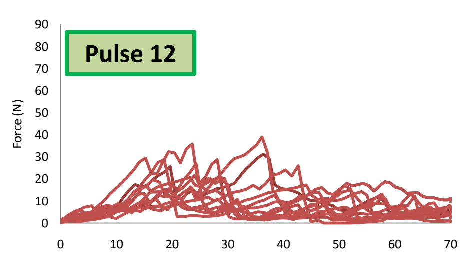
Pictures of banana slices after each KMFD cycle

Puncture tests of fruits during drying by KMFD

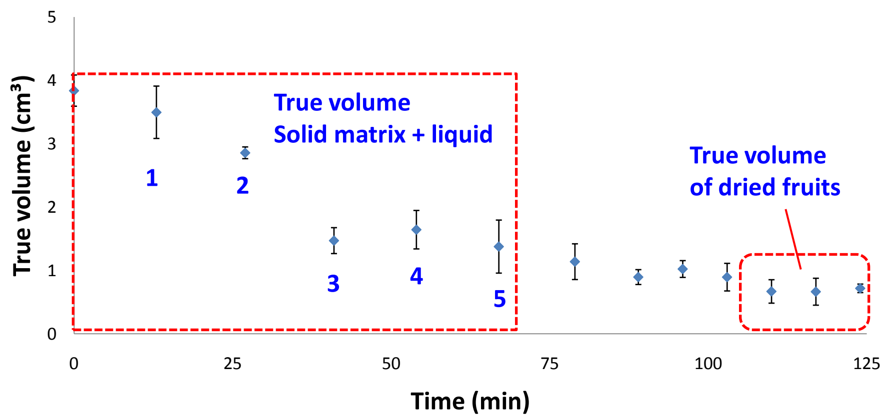






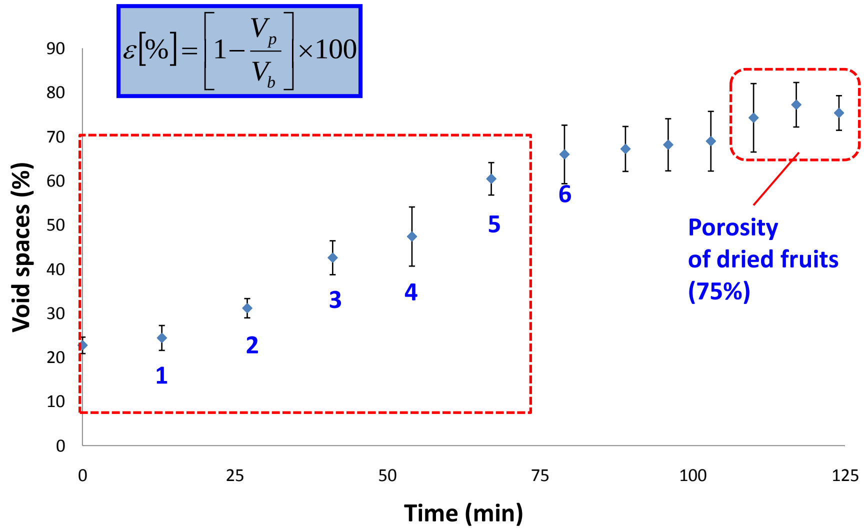


True volumes (solid + liquid) as determined with the gas porosimeter KMFD PROCESS

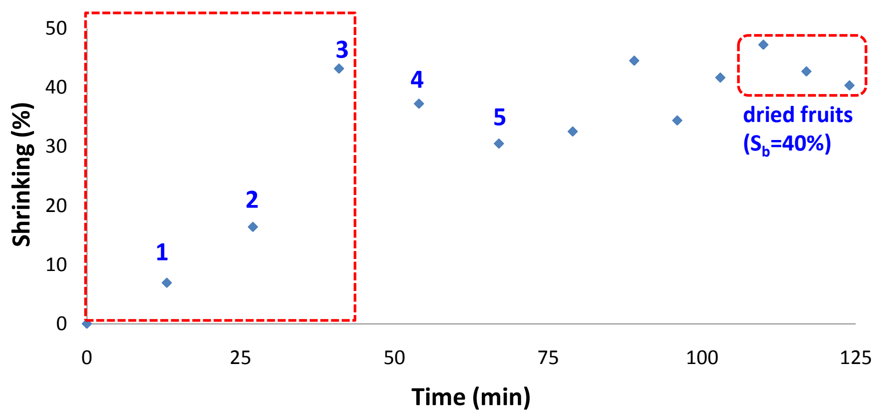


Evolution of the void spaces during drying using KMFD (moist samples)

$$\varepsilon[\%] = \left[1 - \frac{V_p}{V_b}\right] \times 100$$



Shrinking - KMFD PROCESS (determined by immersion into heptane)



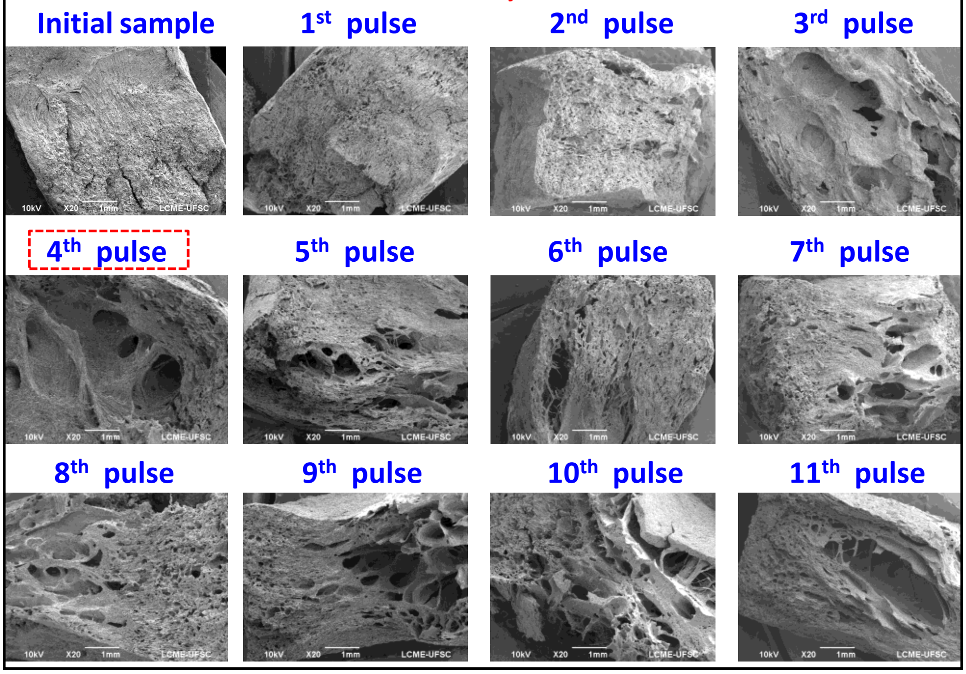
$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$

V_b = bulk volume at t (cm^3)
V_{b0}= bulk volume at t=0 (cm^3)
V_{b0}= average value= 5 cm^3

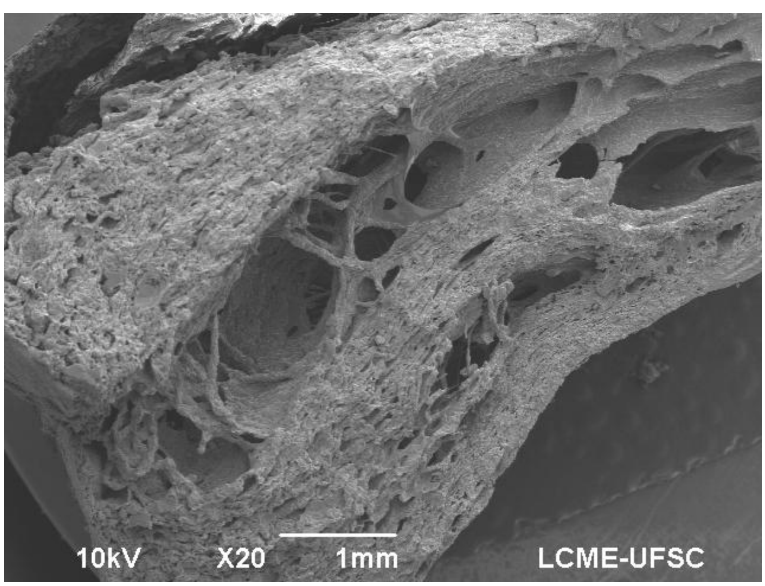
Structural changes in banana samples during drying – KMFD

Optical microscopies and SEM

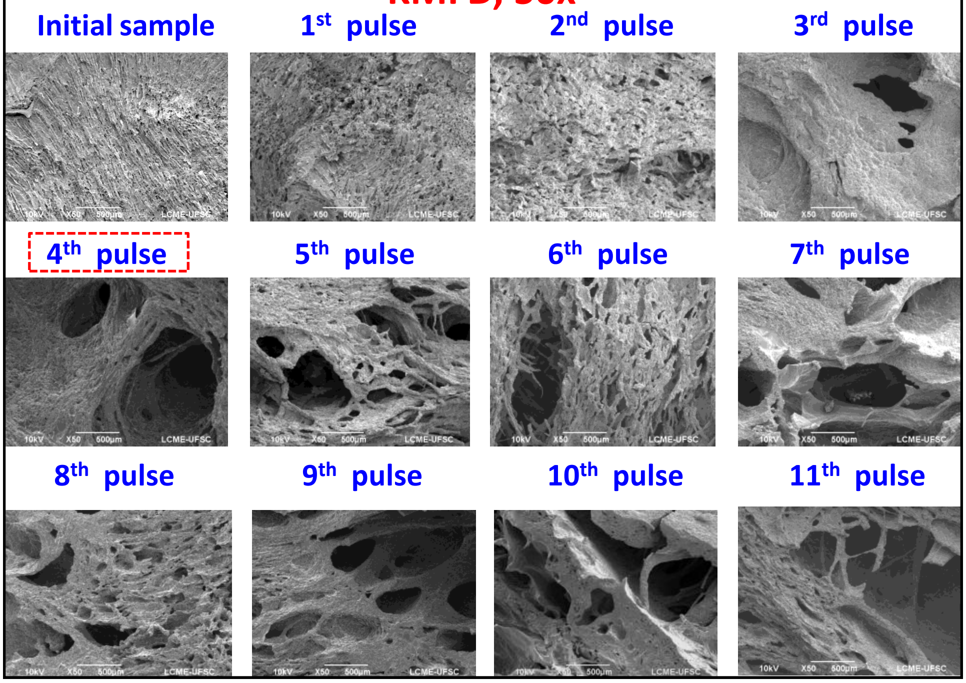
KMFD, 20x



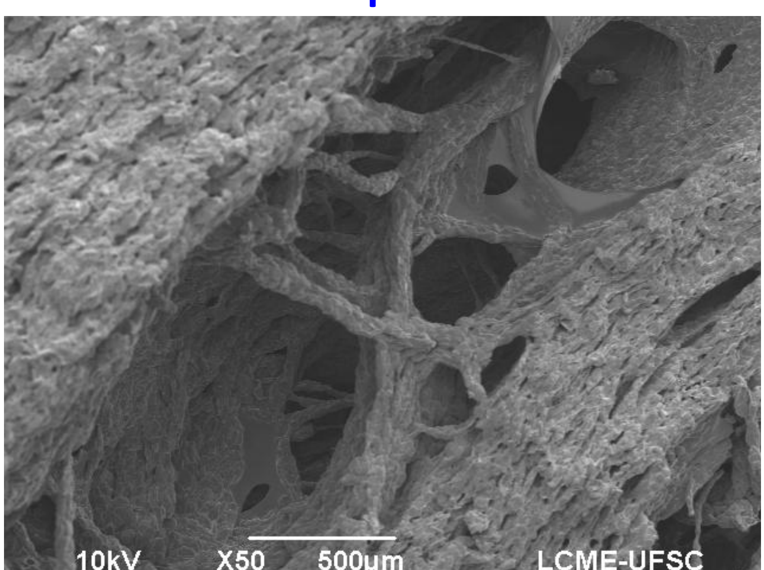
12th pulse



KMFD, 50x



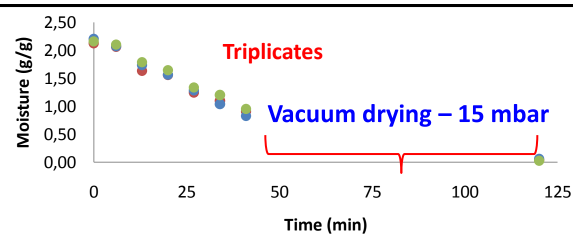
12th pulse



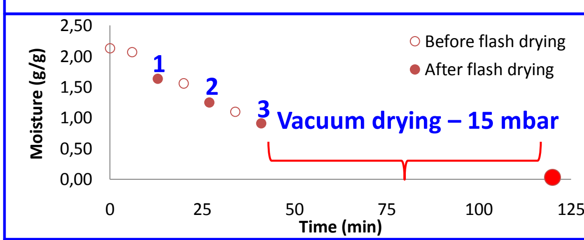
KMFD (4 vacuum pulses) + VD

Conductive multi-flash drying + vacuum drying
T = 80°C

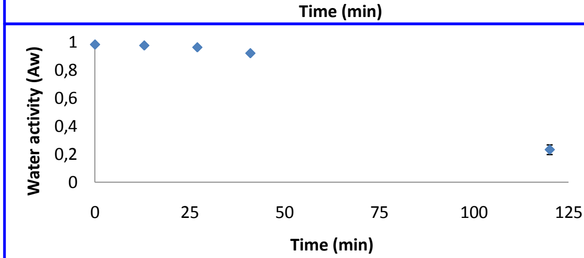
Drying curves reproducibility



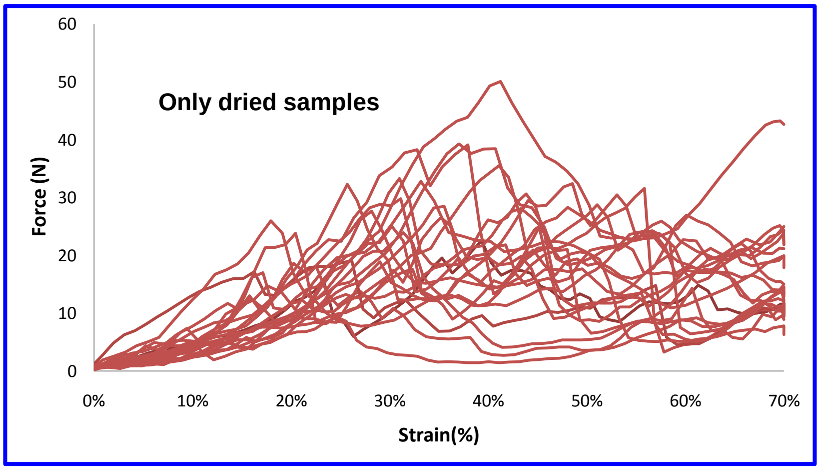
Conductive and flash evaporation contributions



Water activity

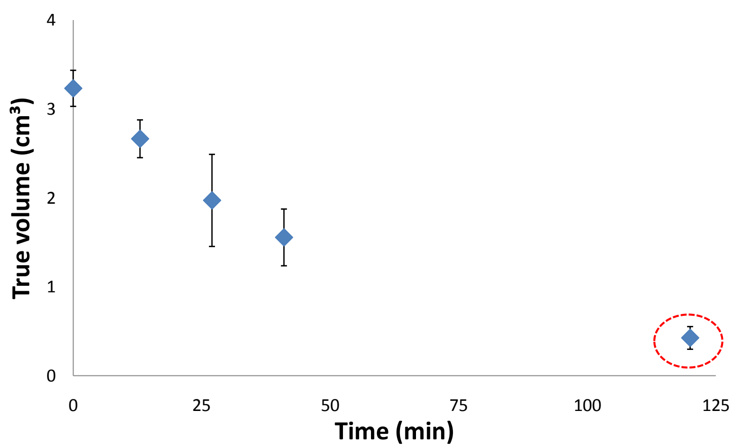


Puncture tests of dried samples KMFD (4 vacuum pulses) + VD



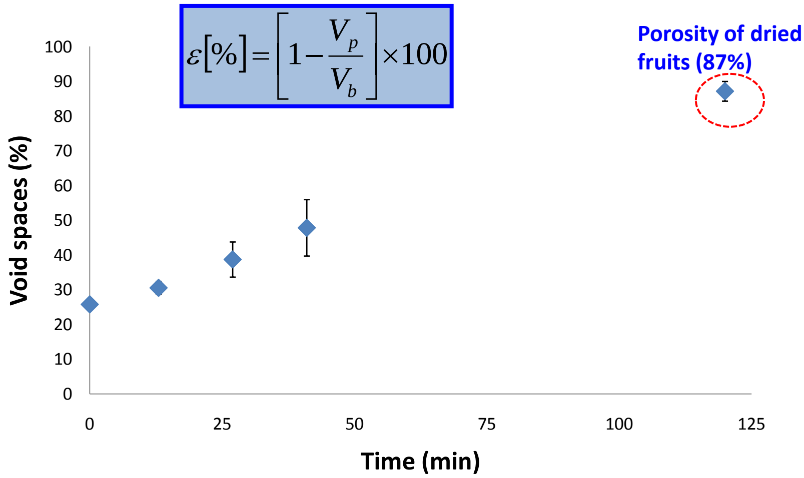
Structural changes in banana samples during KMFD + vacuum drying

True volumes (solid + liquid) as determined with the gas porosimeter (KMFD + vacuum drying)

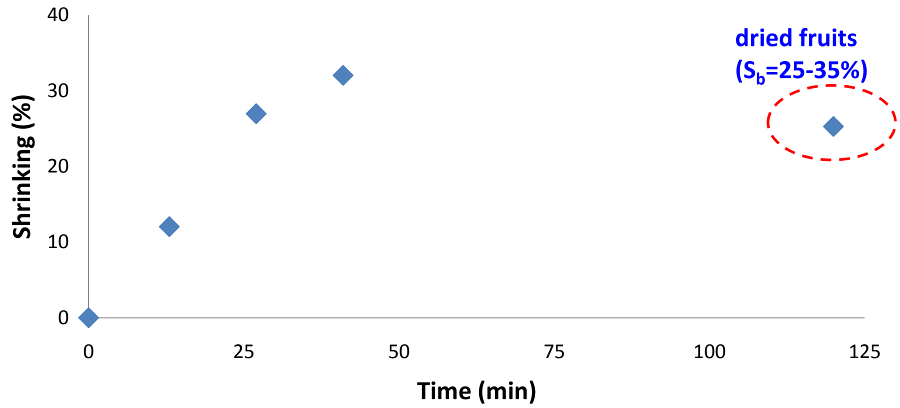


Evolution of the void spaces during drying using KMFD + vacuum drying (moist samples)

$$\varepsilon[\%] = \left[1 - \frac{V_p}{V_b}\right] \times 100$$



Shrinking (determined by immersion into heptane)
KMFD + vacuum drying



$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$

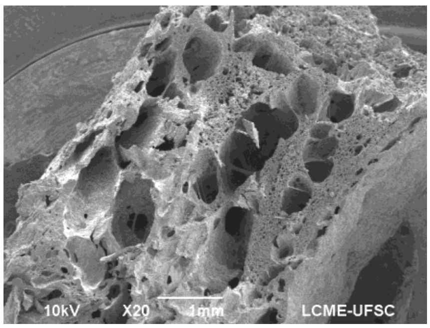
V_b = bulk volume at t (cm³)
V_{b0}= bulk volume at t=0 (cm³)
V_{b0}= average value= 5 cm^3

KMFD + vacuum drying
SEM –20x, after Freeze drying of samples frozen by liquid nitrogen

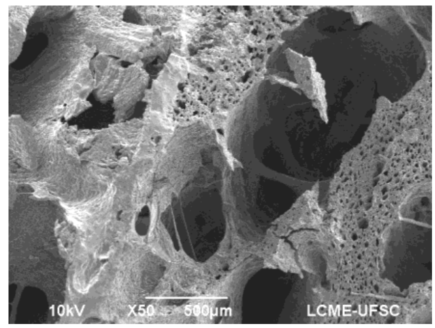
KMFD + vacuum drying (dehydrated sample)

After 4 pulses + 65 min of vacuum drying

20x



50x



SEM of banana samples dehydrated by different methods

COMPARISON OF GENERAL PATTERNS

Some pictures of dehydrated banana

US$10/kg

Air drying

US$70/kg

Freeze-drying (retail-store)

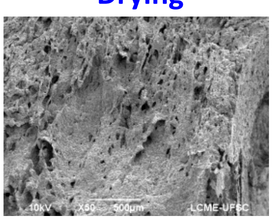
Freeze-drying (Laboratory)

KMFD
Conductive multi-flash drying

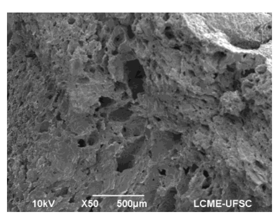
Microwave
Vacuum-drying

CMFD
Convective multi-flash drying

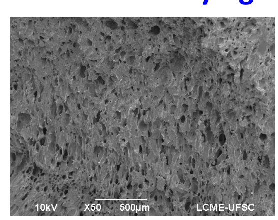
Convective Drying



Vacuum drying

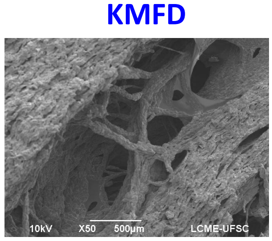


Microwave drying

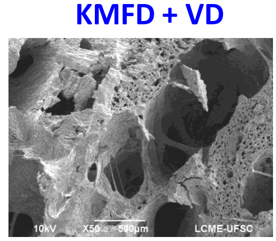


50x

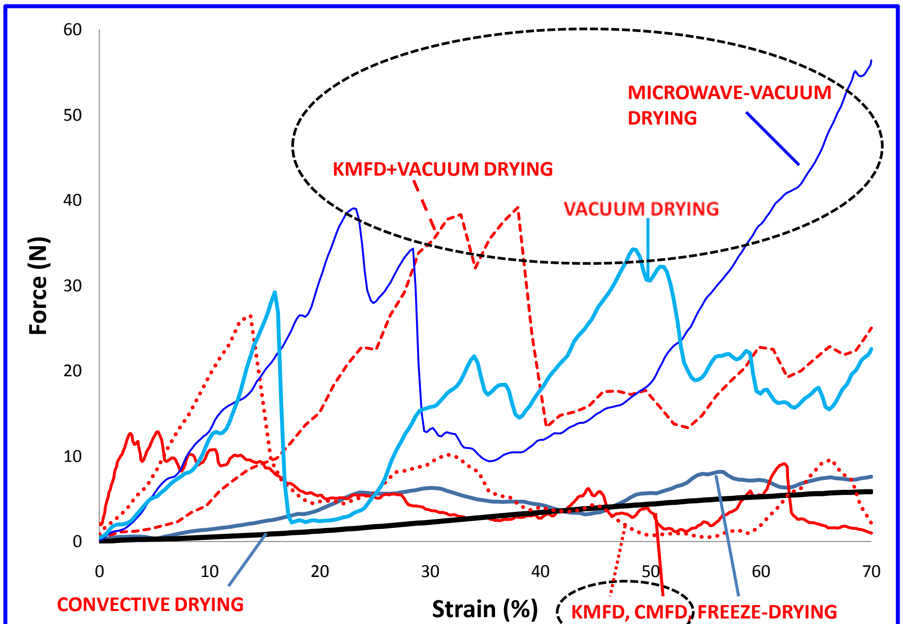
KMFD



KMFD + VD



Puncture test results for different drying processes



Global microstructure parameters of dehydrated banana for the different drying processes

	Convective drying	Vacuum drying	MW	KMFD	KMFD + VD
Drying time	20 h	6 h	20 min	2 h	2 h
Moisture (g/g)	0.12	0.08	0.03	0.03	0.03
Bulk volume (cm^3)	**1.53**	**1.61**	2.46	2.95	3.25
Porosity (%)	57	71	66	75	**87**
Shrinkage (%)	**70**	68	51	40	**25-35**

$$S_b = \left(1 - \frac{V_b}{V_{b0}}\right) \times 100$$

$V_{b0} \cong 5\ cm^3$

CONCLUDING REMARKS

➔ It is possible to control the whole pattern of dehydrated fruits (e.g., banana, mango) in order to produce dried-and-crisp fruits. CMFD and KMFD and their combination with vacuum drying are appropriate processes to reach this goal

➔ Texture properties can be similar to those obtained with freeze-drying (depending on the operation conditions). Shorter drying times

➔ Product color is preserved due to the use of moderate process temperatures. Vitamins retention and sensorial properties need to be investigated for each fruit

➔ Equipment and process are simple and use low pressures and temperatures ➔ smaller investment and energy requirements than freeze-drying

Future studies

i) What the influence of fruits ripening on the microstructure formation?

ii) How the steepness of pressure drop (vacuum pulses) influences the texture formation during drying of a given fruit?

iii) How to correlate sensorial texture and puncture tests of dehydrated fruits?

iv) How can we combine microwave vacuum drying and vacuum pulse to produce texture during dehydration? How the microwave power (per kg of fruit mass) influences the fruit texture?

v) What are the more appropriate fruits and vegetables to be dehydrated by these techniques?

vi) Energy consumption, costs, scale-up.

THANK YOU FOR YOUR ATENTION!

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