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"Food Process Engineering in a Changing World"
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Dynamic approach for assessing food quality and safety

the case of processed foods

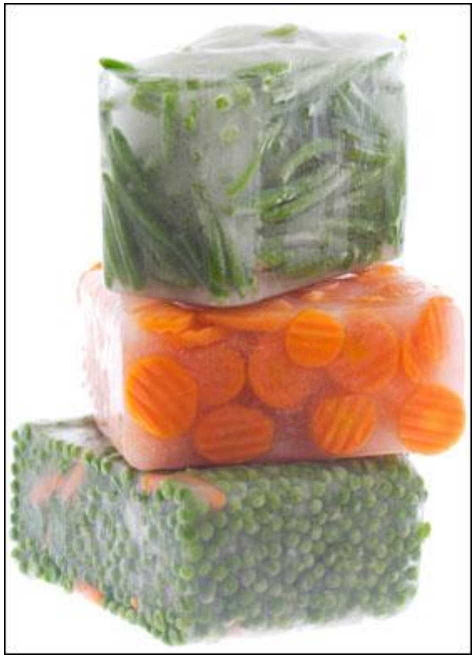
CBQF – Centro de Biotecnologia e Química Fina
School of Biotechnology
Catholic University of Portugal

Teresa R.S. Brandão, **Cristina L.M. Silva**

Why are foods processed ?

to be safe

to be preserved



to be in more convenient forms

to be appelative

Food processing

Laboratory research

Industrial scale

Food processing

Laboratory research

lts is c

Industrial scale

Modelling

The use of mathematical models that describe/predict changes of processed foods characteristics with **accuracy** and **precision** in such realistic dynamic conditions is an important tool

in developing new products

to control systems

$$\eta_i(t) \approx \sum_{j=1}^{m} \gamma_{ij}(t)\xi_j(t) + \sum_{j,k=1}^{m} \beta_{ijk}(t;t-\lambda)\xi_j(t)\xi_k(t-\lambda) + \sum_{j=1}^{m} \int_{t-\lambda}^{t} \gamma'_{ij}(\tau)\xi_j(\tau)d\tau +$$

Modelling

- The greatest modeller's effort has been given to data obtained under constant (or static) environmental conditions

- From a realistic point of view this is somehow restrictive, since the majority of thermal processes occur under time-varying environmental conditions, and kinetic parameters obtained under such circumstances may differ from the ones estimated at static conditions, which compromises safety control and quality prediction

This presentation will focus on …

- Study of food products in terms of **quality** and **safety** characteristics, when they are submitted to processes with **time-varying temperature** conditions

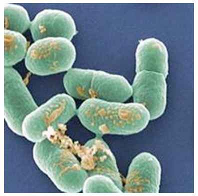
- Assessment of **mathematical models** that adequately describe the observed responses

Several combinations of **food/characteristics** were used as case studies

3 cases will be presented

Case 1

Thermal inactivation of *Listeria* in culture media and foods

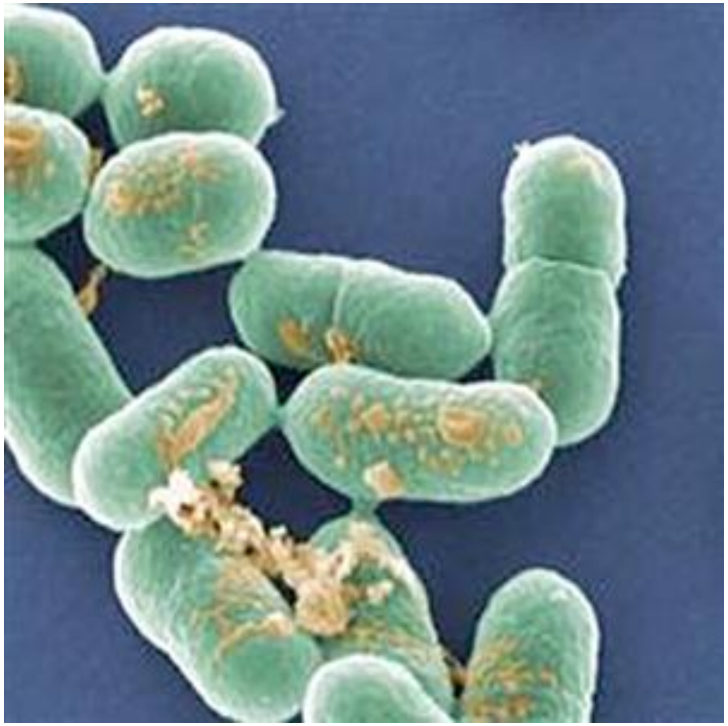


Case 2

Frozen storage of vegetables

Case 3

Solar drying of grapes



Case 1

Miller F.A.

Thermal inactivation of *Listeria* in culture media and foods

Listeria innocua as non-pathogenic surrogate of *Listeria monocytogenes*

Listeria monocytogenes

Listeria innocua

- pathogenicity
- similar characteristics
- found in the same food products
- found in the same environments
- use validated in numerous studies






Experimental design

Isothermal conditions

52.5 C

55.0 C

57.5 C

60.0 C

62.5 C

65.0 C

L. innocua **NCTC 10528**

L. innocua **2030c**

culture media

TSBYE

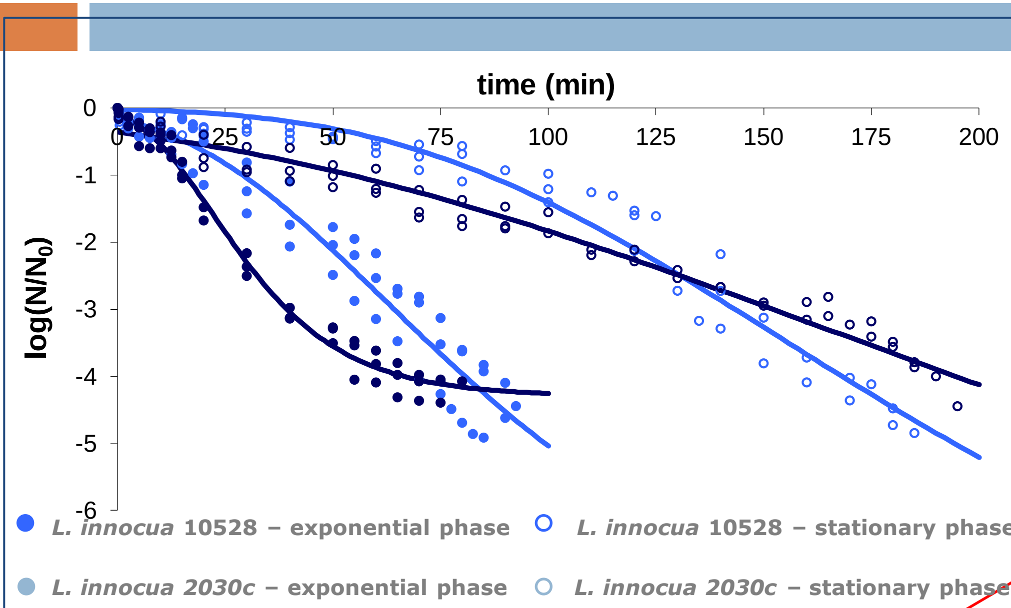
30 ºC/9h

30 ºC/20h

Exponential phase

Stationary phase

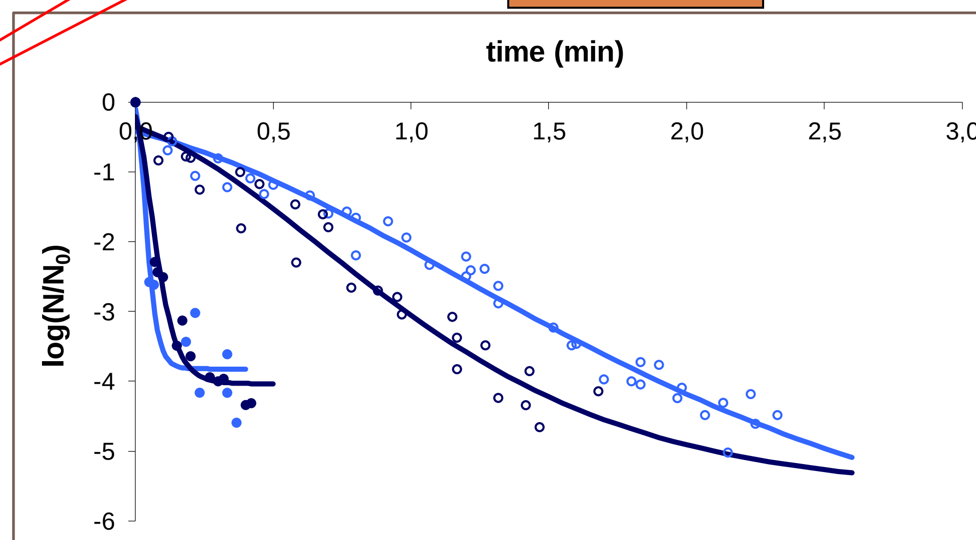
Some results …



52.5 °C

$$\log\left(\frac{N}{N_0}\right) = \log\left(\frac{N_{res}}{N_0}\right) \exp\left(-\exp\left(\frac{-k_{max}\, e\,(\lambda - t)}{\log\left(\frac{N_{res}}{N_0}\right)} + 1\right)\right)$$

65.0 °C



Significant temperature effects

$N_0 \cong 10^7$ cfu/mL

Some results …

$$\log\left(\frac{N}{N_0}\right) = \log\left(\frac{N_{res}}{N_0}\right) \exp\left(-\exp\left(\frac{-k_{max}\, e}{\log\left(\frac{N_{res}}{N_0}\right)}(L - t) + 1\right)\right)$$

Significant temperature effects

Shoulder parameter

$$L = c\,(T - d)^2$$

c and d are model parameters

Maximum inactivation rate

$$k_{max} = k_{ref} \exp\left(-\frac{Ea}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)$$

k_{ref} is inactivation rate at temperature T_{ref}
Ea is the inactivation energy
R is the gas constant

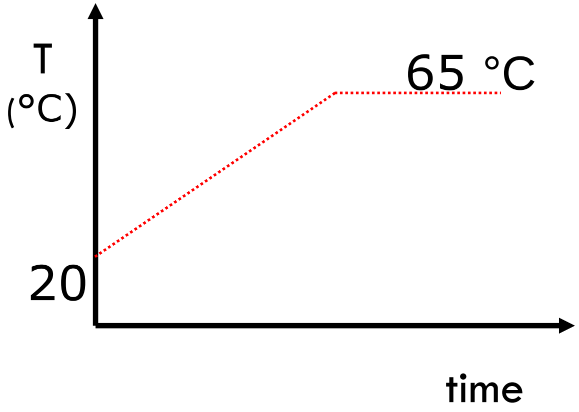
Experimental design

Non-isothermal conditions

(P1) 1.5 C / min

(P2) 1.8 C / min

(P3) 2.6 C / min



culture media

TSBYE

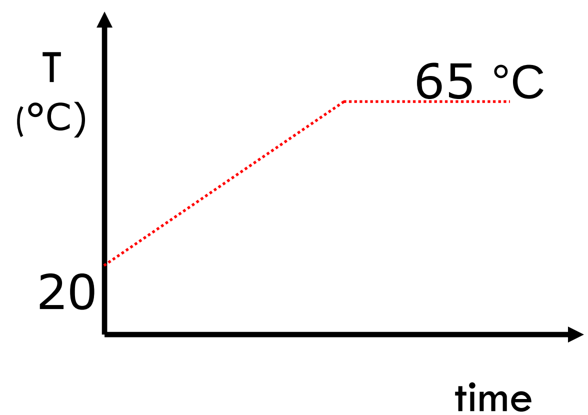
Experimental design

Non-isothermal conditions

(P1) 1.5 C / min

(P2) 1.8 C / min

(P3) 2.6 C / min

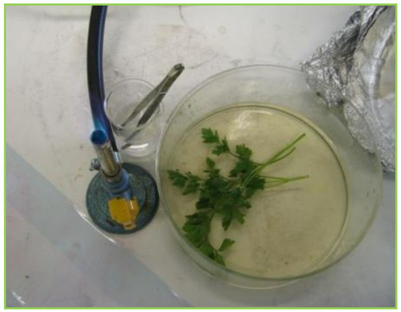


parsley

Petroselinum crispum

Experimental procedure

parsley **artificially inoculated**



TSBYE bacterial suspension
~ 10^7 cfu/mL of *L. innocua*

samples vacuum sealed

thermal treatment

sampling

stomaker

Palcam agar

30 °C / 5 days

The model

Gompertz model encompassing the time-temperature effect

T=f(t)

$$\log\left(\frac{N}{N_0}\right)_{non-isothermal} = \int_0^t \frac{d\left(\log\left(\frac{N}{N_0}\right)_{isothermal}\right)}{dt}\,dt'$$

$$k_{max} = k_{ref}\exp\left(-\frac{Ea}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right)$$

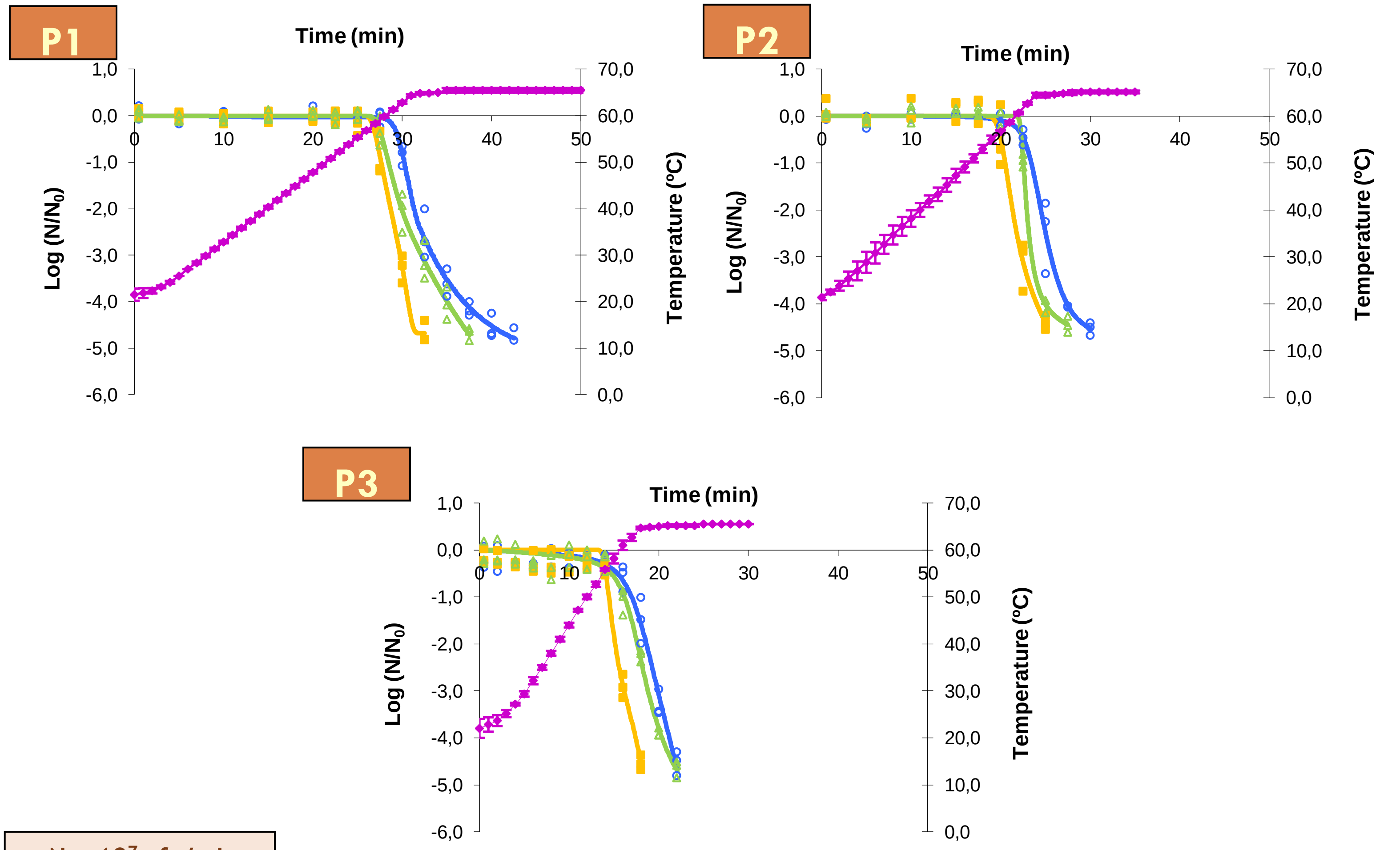
$$L = c\left(T-d\right)^2$$

$$\log\left(\frac{N}{N_0}\right)_{non-isothermal} = \int_0^t \left[-k_{max}\left(t'\right)e\,\exp\left(-\frac{k_{max}\left(t'\right)e}{\log\left(\frac{N_{res}}{N_0}\right)}\left(\left(t'\right)-t'\right)+1\right)\exp\left(-\exp\left(-\frac{k_{max}\left(t'\right)e}{\log\left(\frac{N_{res}}{N_0}\right)}\left(\left(t'\right)-t'\right)+1\right)\right)\right]dt'$$

Results

culture media

TSBYE



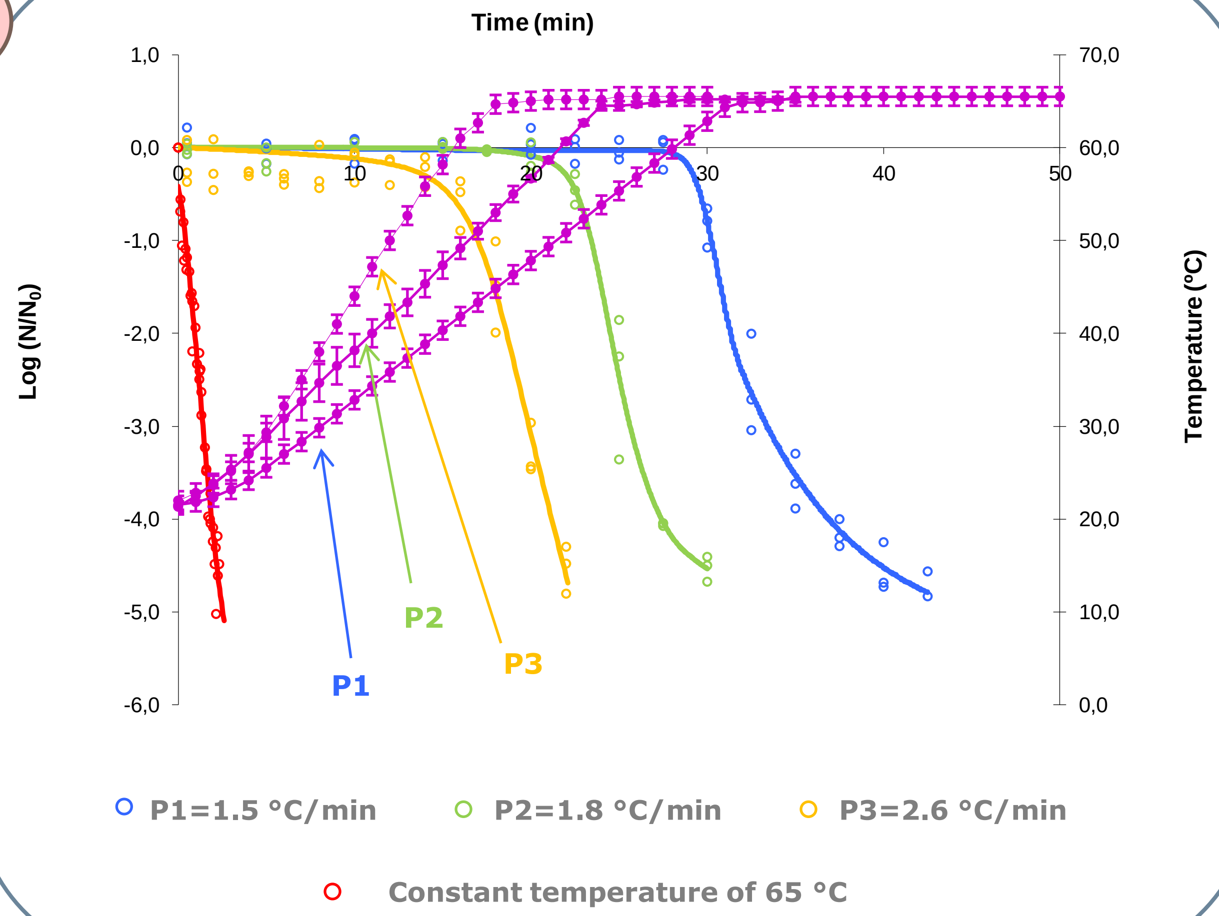
$N_0 \cong 10^7$ cfu/mL

Results

culture media

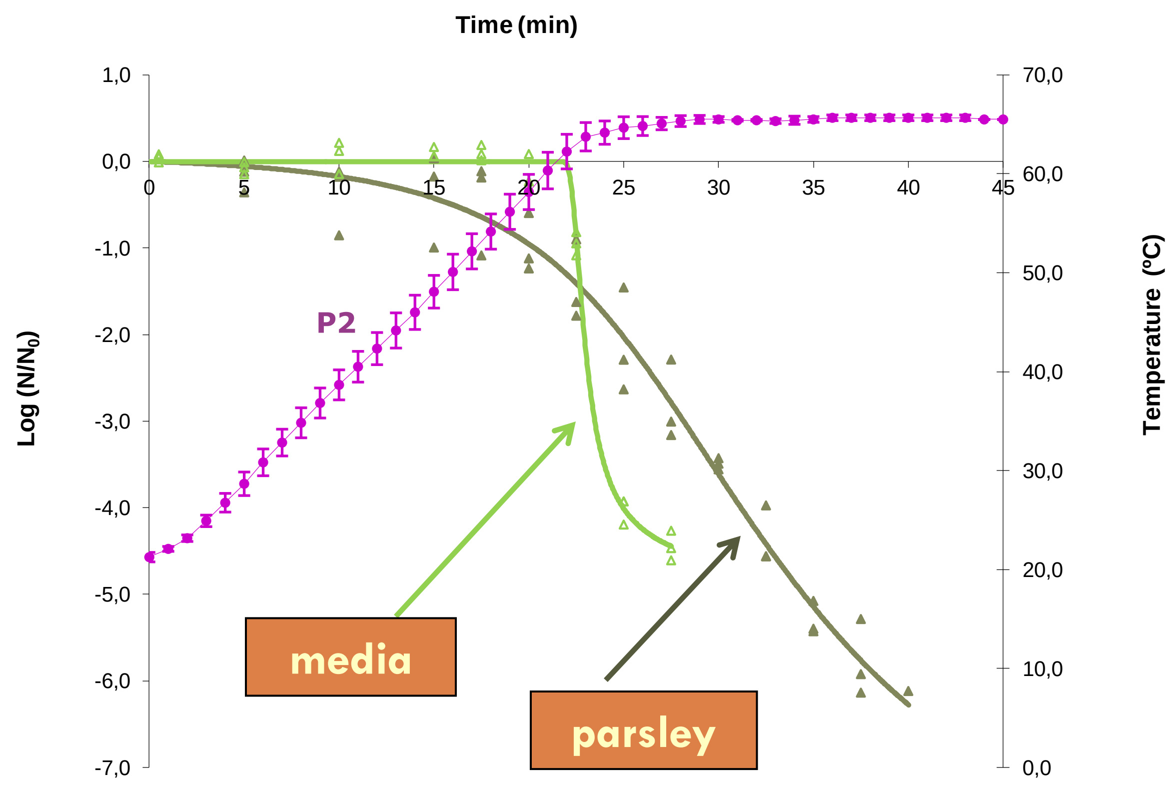
TSBYE

TSAYE



Results

Palcam Agar



$N_0 \cong 10^7$ cfu/mL

Conclusions

Can results obtained in broth be applied in predicting microbial responses in solid foods ?

Attention !

Results corroborate that microbial kinetic behaviour in "real" food surfaces differs to the one observed in broth. Consequently, caution should be taken when using the latter ones in food processing predictions

Conclusions

- **Broth-based experiments highlights the importance of studying the influence of dynamic conditions on the thermal resistance of microorganisms, since the heating up phases can contribute to an increase in cells thermotolerance.**
- **Results obtained in parsley demonstrated that the product greatly affects bacteria thermal resistance; although the heat resistance of *Listeria* increased (when compared to liquid medium), the inactivation began earlier.**

Conclusions

- Overall it can be said that the model assumed has the ability of dealing with time-varying temperature conditions, which is a key value to predict microbial loads of foods that suffer a thermal process.

Case 2

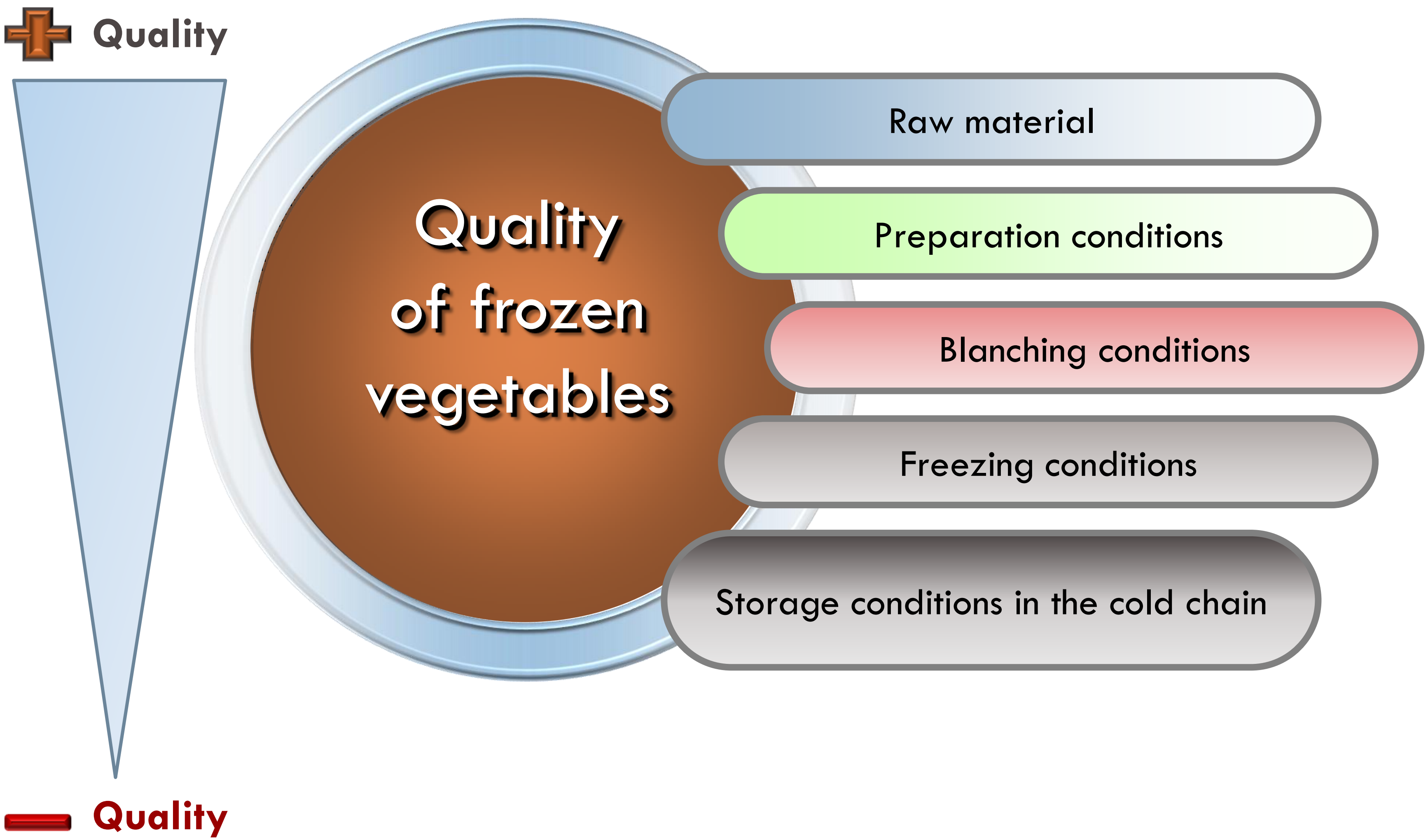
Gonçalves E.M.

Frozen storage of vegetables

Why choose fozen products?

Available all year

Frozen vegetables



Pre - blanching

however…

adversely affects the quality factors …

Objective

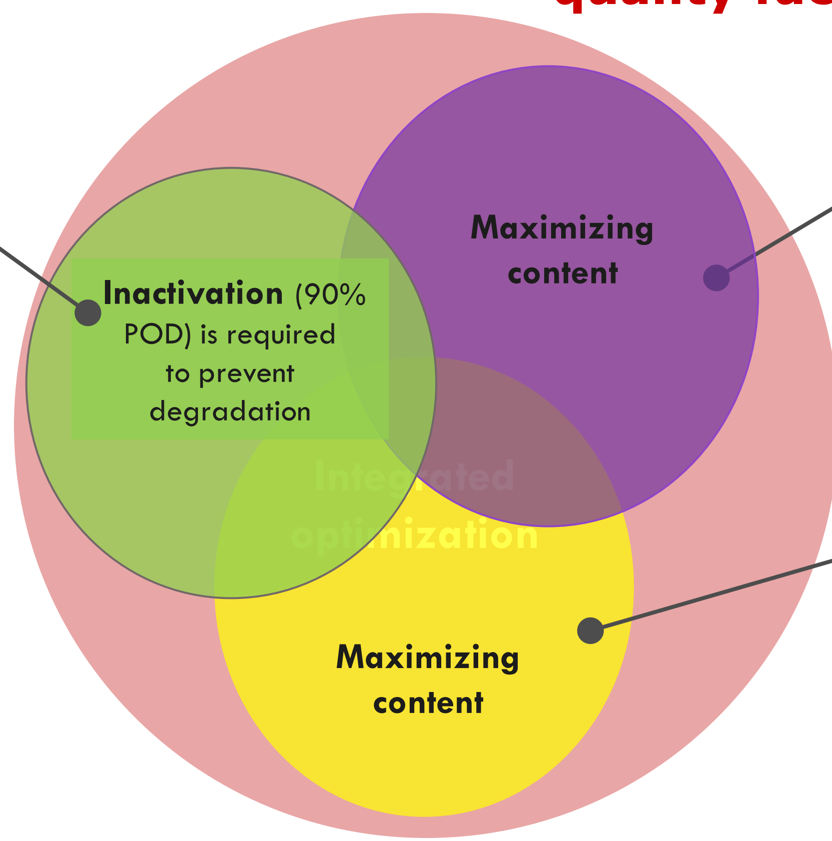
Inactivate degradative enzymes

Reference: Peroxidase (POD)

and

Eliminate bacteria and chemical contaminants

…



Physical and organoleptic

- Texture
- Colour

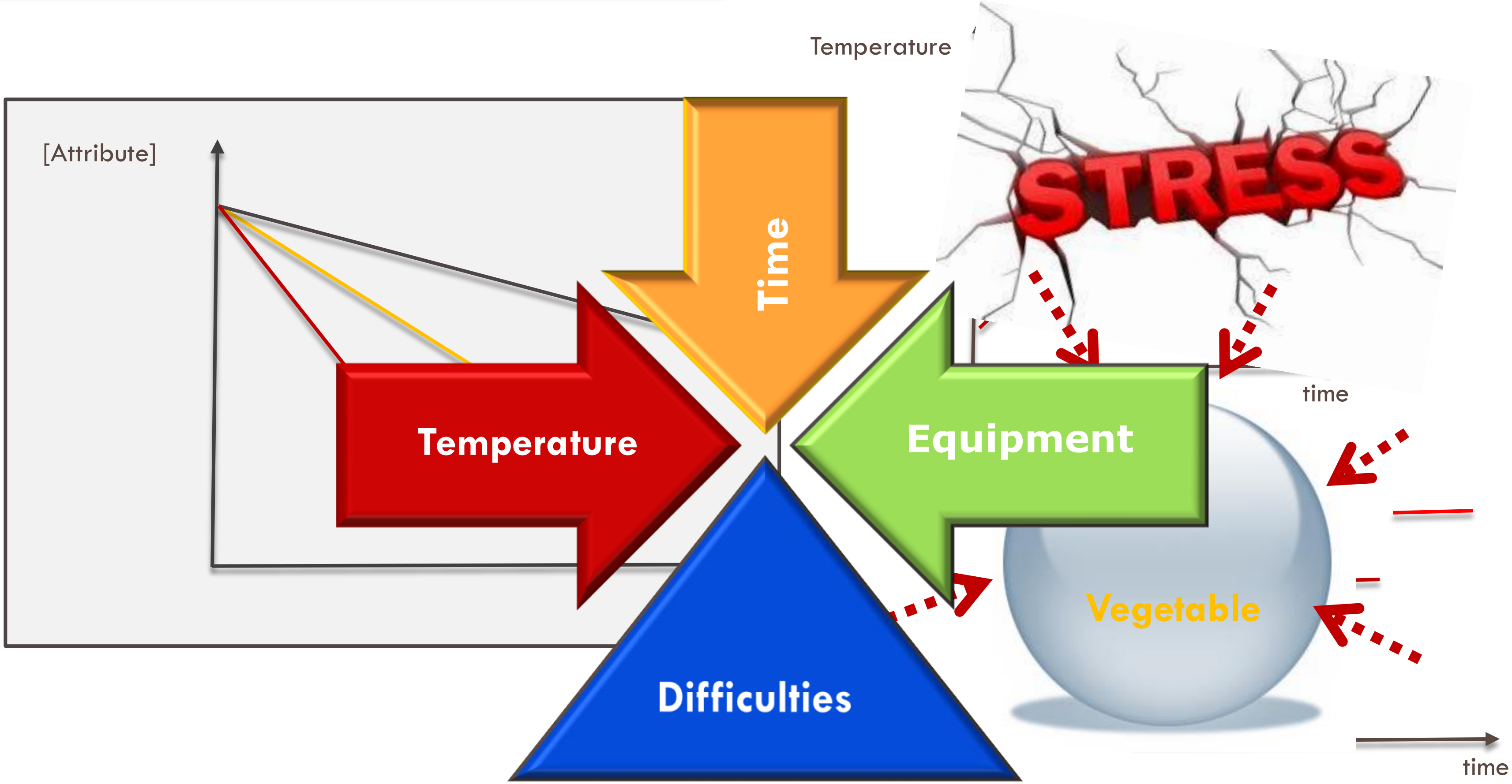
Nutritional

- Vitamins
- Minerals
- Pigments

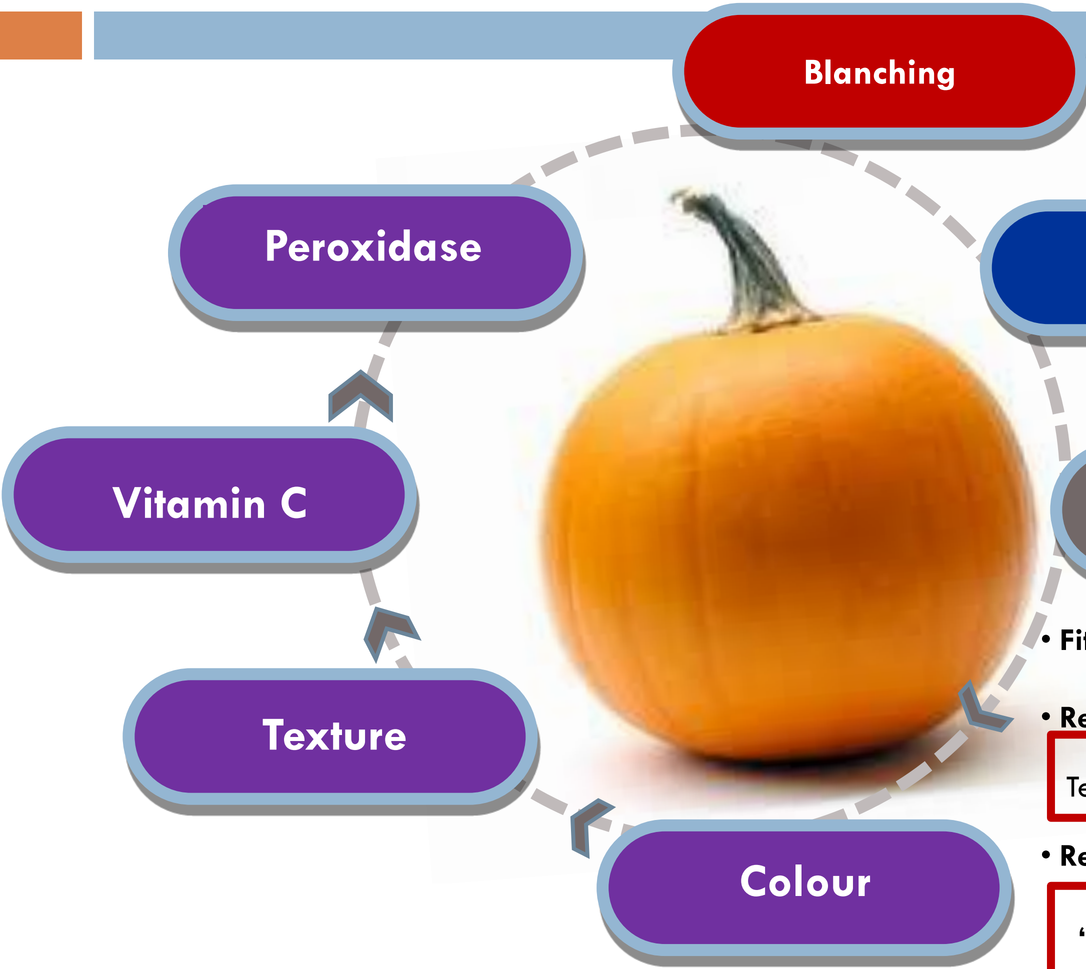
Storage conditions

Studies of Time-Temperature-Tolerance (TTT)

Studies with accelerated life tests



Experimental procedures



- **Fitotherm chambers**
- **Regime I:** **Isothermal conditions**

Temperature (°C): -7, -15 , -25 time (days):140

- **Regime II:** **Non-isothermal conditions**

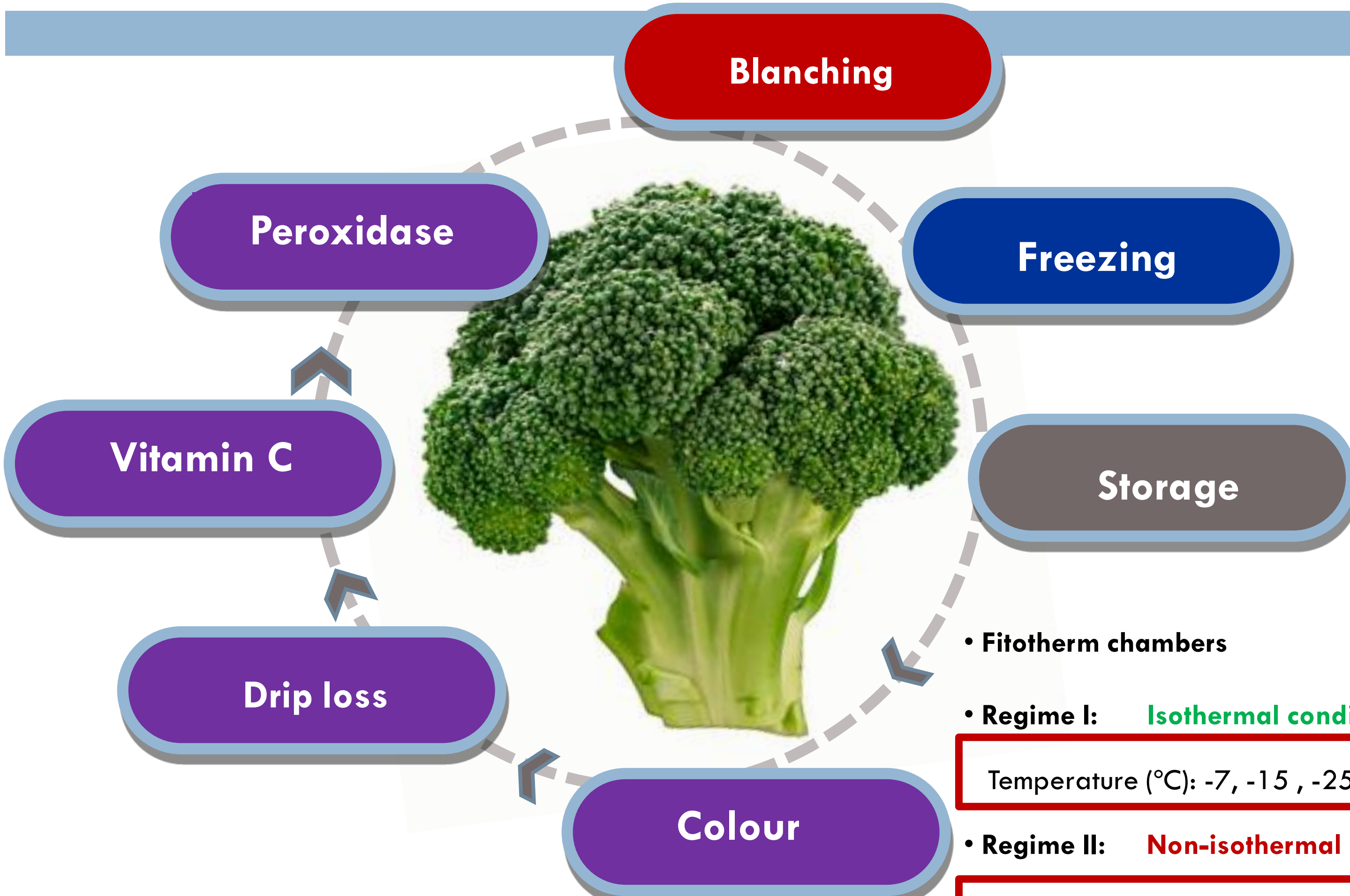
"step-stress"

Temperature(°C)/time(days): -30 /21; -20 /16; -10 /11 and -5/9

total: 57 days

Pumpkin *(Cucurbita maxima L.)*

Experimental procedures



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"step-stress"

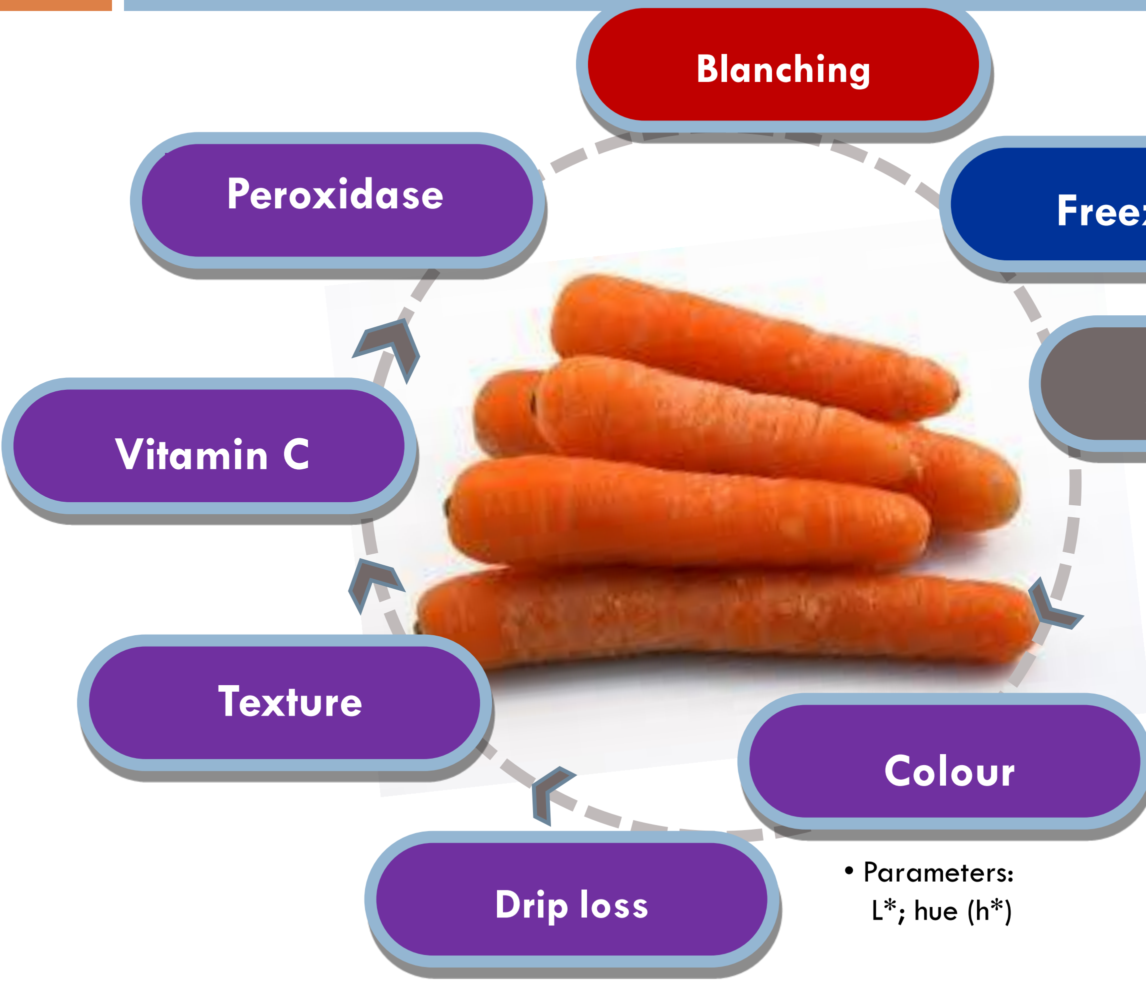
Temperature(°C)/time(days): -30 /21; -20 /16; -10 /11

total: 57 days and -5/9

- Parameters: a^*/a_0^*; hue ($\tan^{-1} b^*/a^*$)

Broccoli (*Brassica oleracea L. ssp.*)

Experimental procedures



- Parameters: L*; hue (h*)

- **Fitotherm chambers**
- **Regime I:** **Isothermal conditions**

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"step-stress"	
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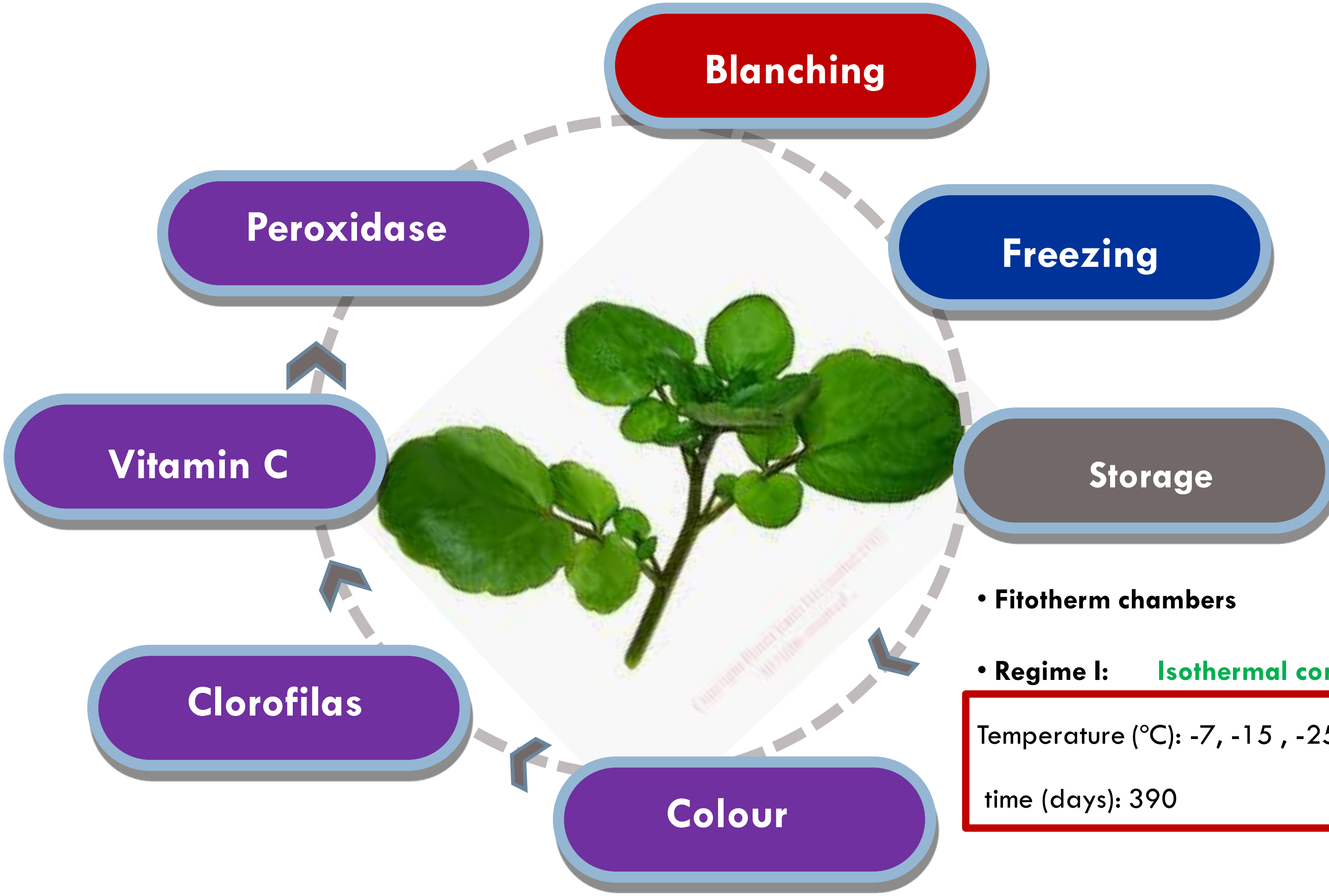
total: 57 days	and -5/9

Carrot *(Daucus carota L.)*

Experimental procedures



- **Fitotherm chambers**
- **Regime I:** Isothermal conditions

Temperature (°C): -7, -15 , -25
time (days): 390

Watercress *(Nasturtium officinale R. Br.)*

The models

Kinetic models

Assessment of the time-temperature efects on degradation rates of quality attributes

Isothermal conditions

$$C = C_0 - \left(k_{ref} \exp\left(-\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)t\right)$$

zero-order

$$C = C_0 \exp\left(-k_{ref} \exp\left(-\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)t\right)$$

first order

$$C = C_{eq} + (C_0 - C_{eq}) \exp\left(-k_{ref} \exp\left(-\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)t\right)$$

fractional conversion model

Non-isothermal conditions

$$C = C_0 - \left[k_{ref} \int_0^t \exp\left[-\frac{E_a}{R}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right]dt\right]$$

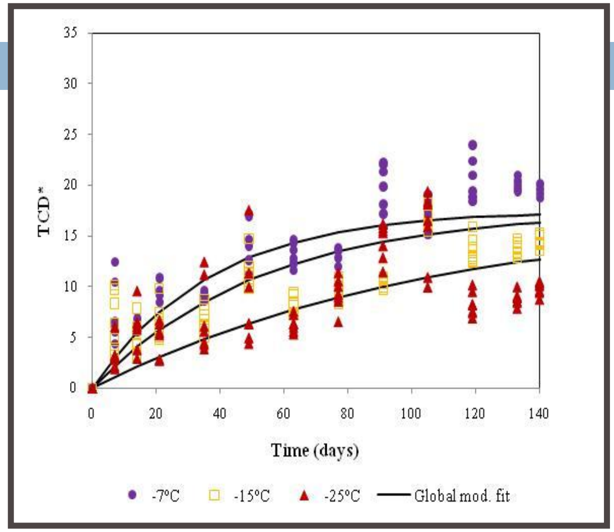
$$C = C_0 \exp\left[-k_{ref} \int_0^t \exp\left[-\frac{E_a}{R}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right]dt\right]$$

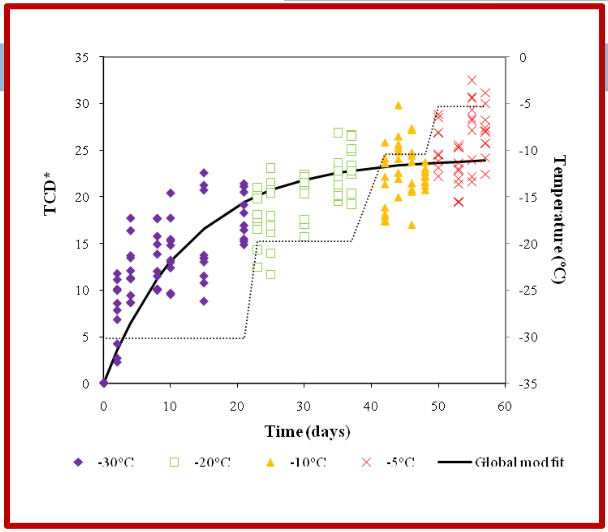
$$C = C_{eq} + (C_0 - C_{eq}) \exp\left[-k_{ref} \int_0^t \exp\left[-\frac{E_a}{R}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right]dt\right]$$

Integration of time effects

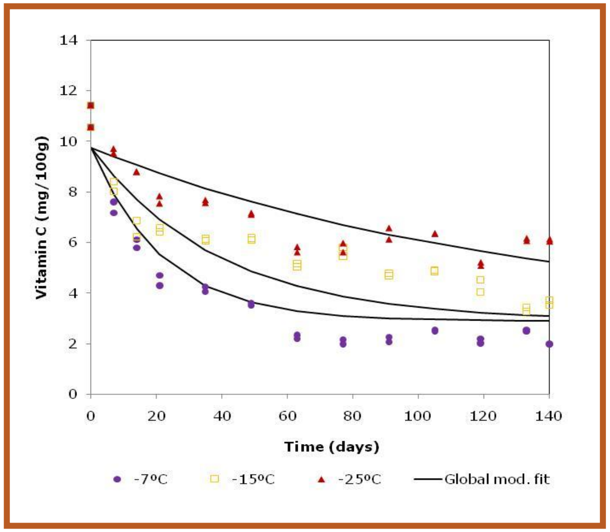
Results

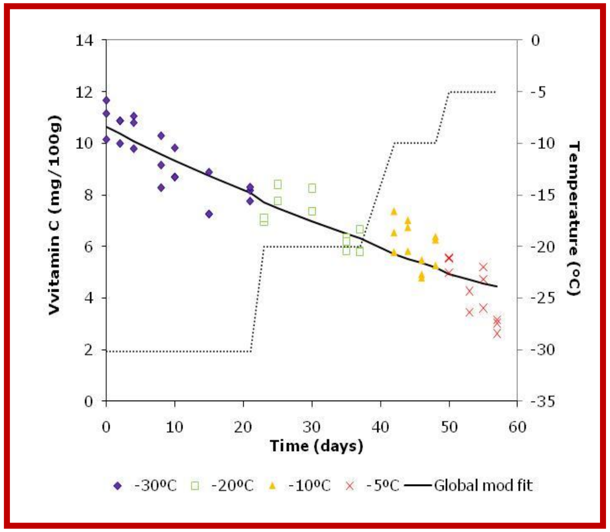
Colour _TCD





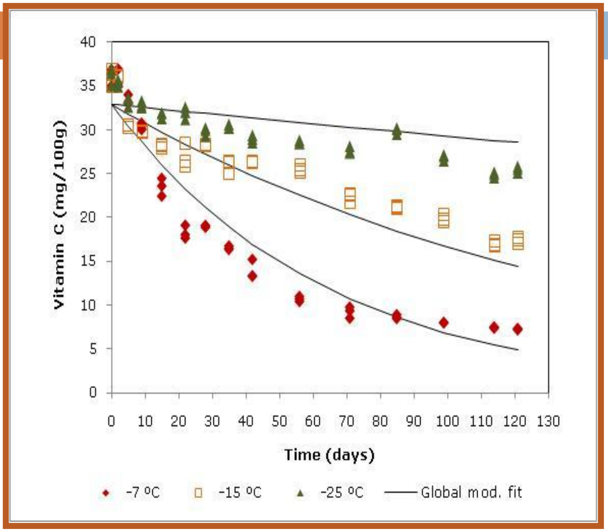
Vitamin C

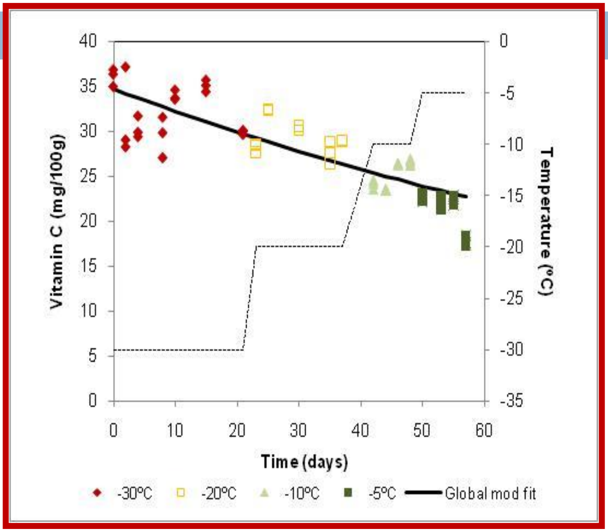




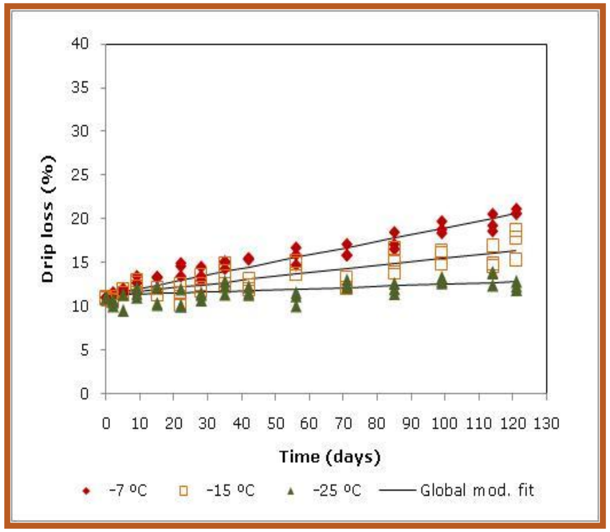
Pumpkin (*Cucurbita maxima L.*)

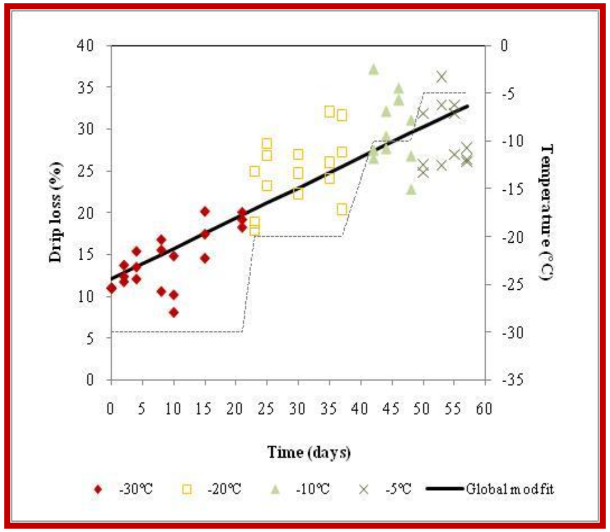
Results





Vitamin C

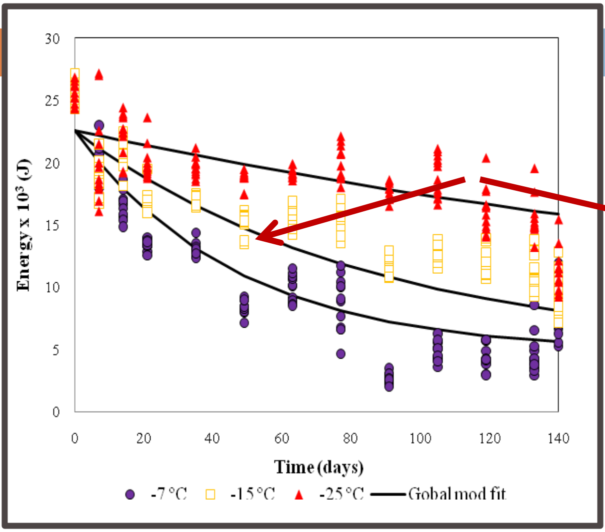


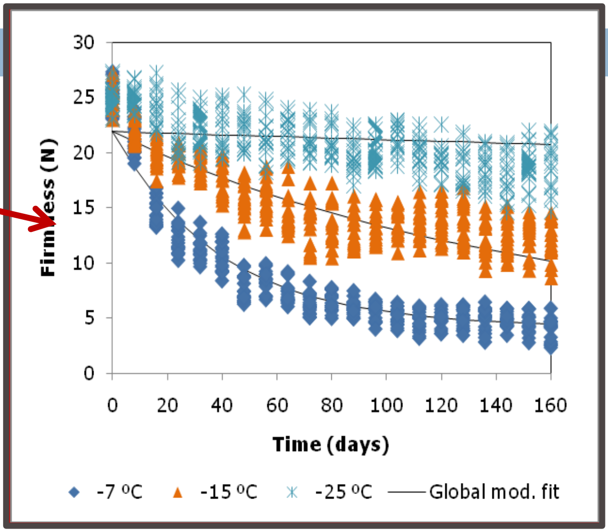


Drip loss

Broccoli (*Brassica oleracea L. ssp.*)

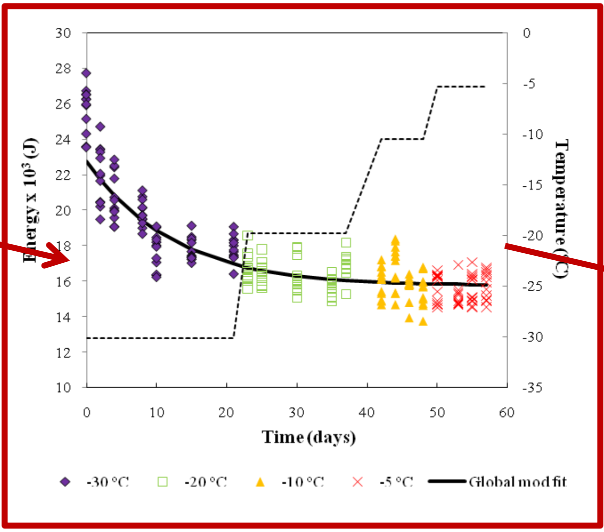
Results

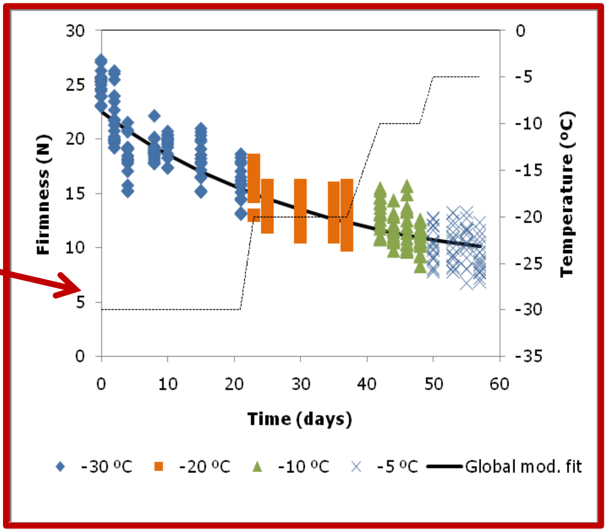




texture

pumpkin

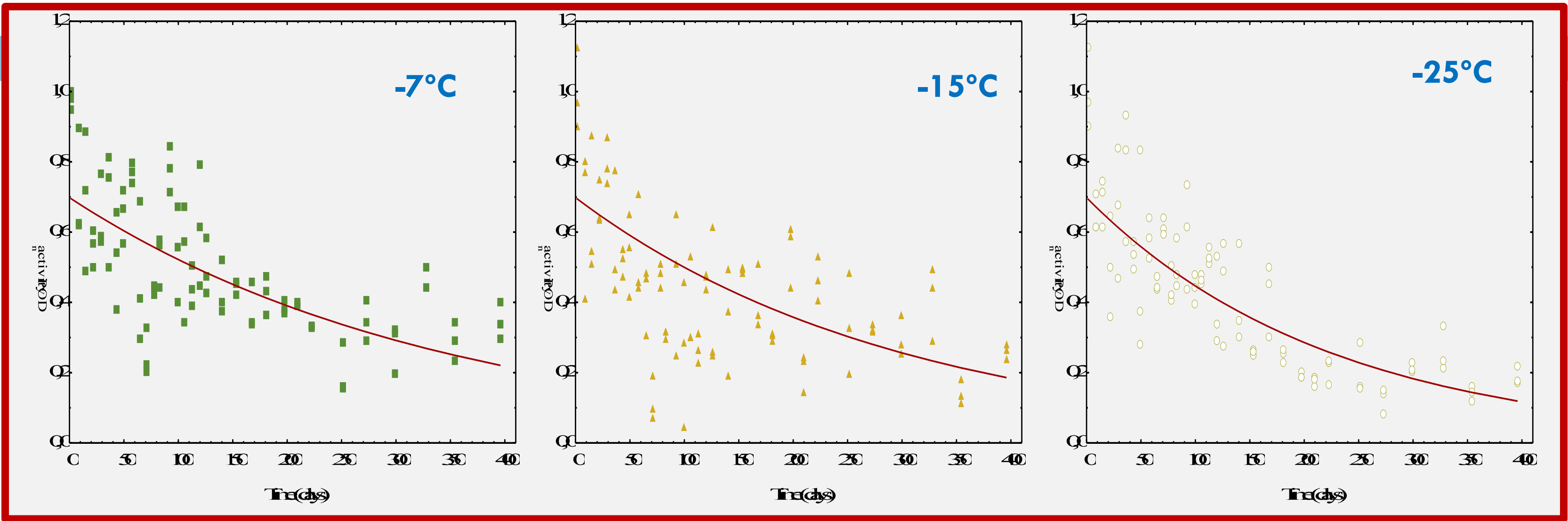




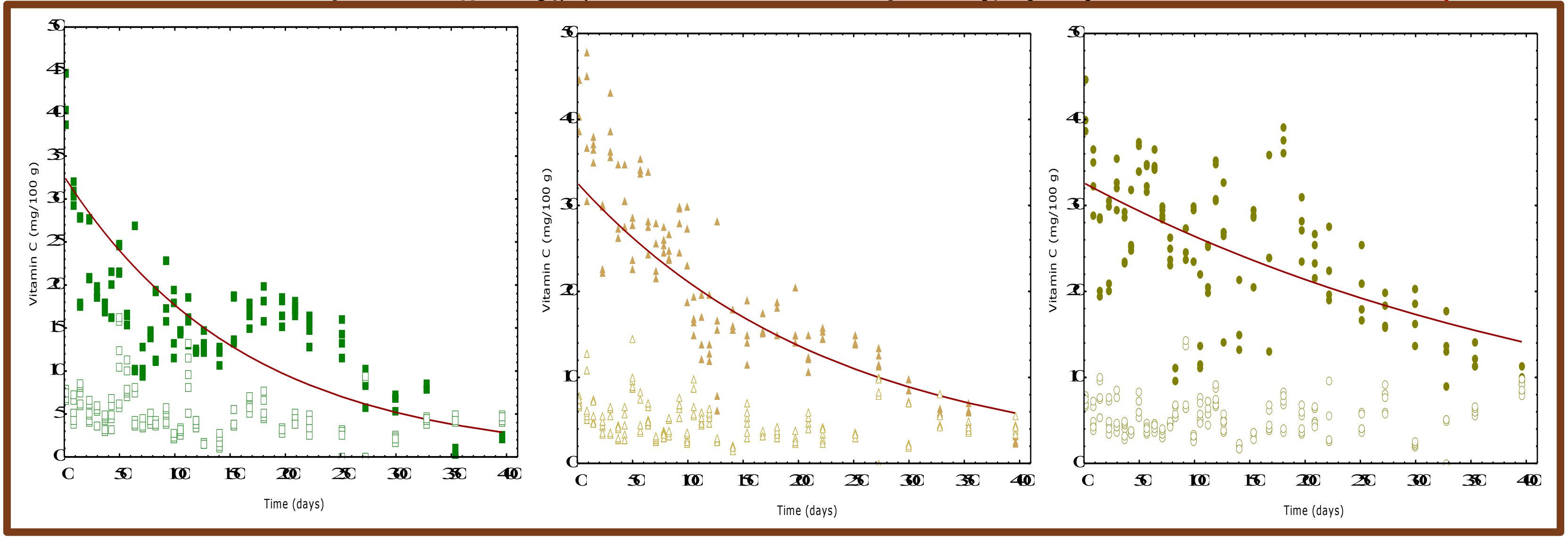
texture

carrot

Results



Vitamin C
AA+DHAA



POD

Watercress (*Nasturtium officinale R. Br.*)

Results

Shelf life = Kinetic model + 50% of vitamin C reduction + -18°C

Prediction

61 days

125 days

118 days

6 months

Conclusions

- Accelerated life tests applied to all vegetables were a satisfactory methodology for studying kinetics of quality changes during frozen storage

- Activation energies are considerable lower when compared to the ones estimated under isothermal conditions

Case 3

Ramos I.N.

Solar drying of grapes

Solar drying of grapes

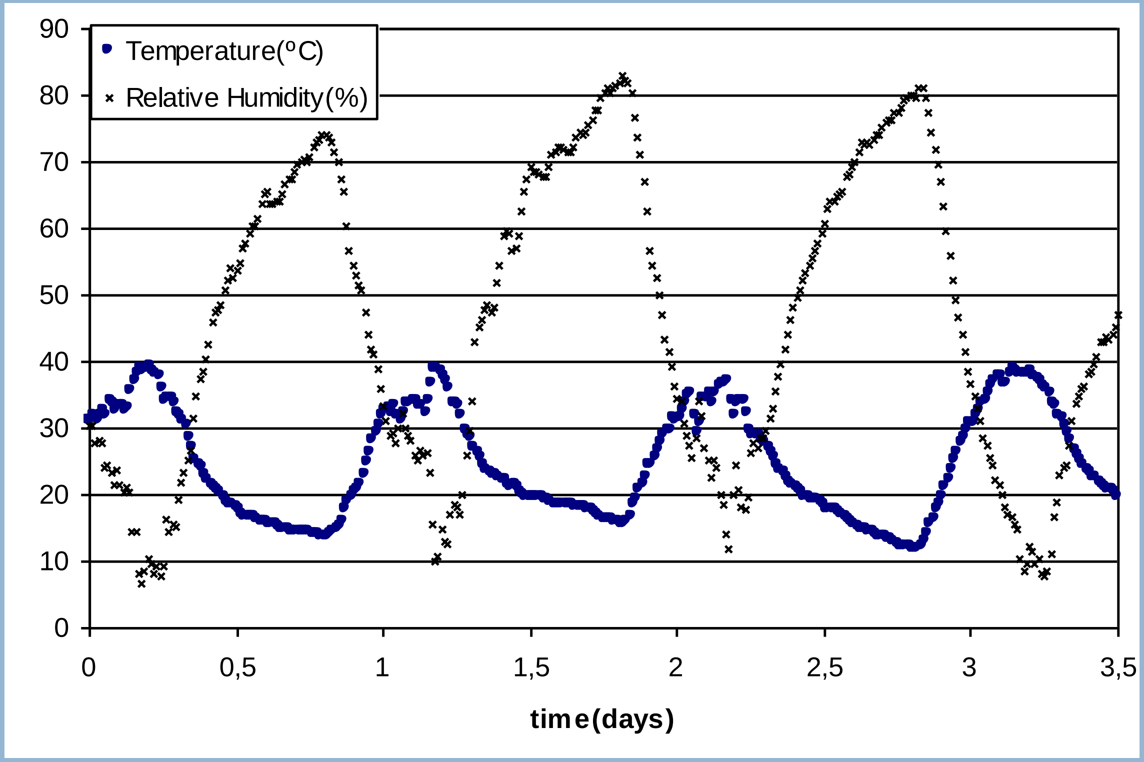
Solar Dryer in Mirandela – Portugal

Solar drying of grapes

The objective was to simulate solar drying of grapes by integrating heat and mass transfer

Solar drying of grapes

Air conditions inside solar dryer



Heat and mass transfer model

Global energy balance

$$\frac{d(m\,Cp\,T_p)}{dt} = \alpha\,A_p\,I(t) - Qc - Qe - Qr$$

$$\frac{d\,(m\,Cp\,T_p)}{dt} = \alpha\,A_p\,I(t) - \bar{h}\,A_s(T_p - T) - \frac{d\,(\lambda\,m_w)}{dt} - A_s\,\varepsilon\,\sigma\,(T_p^{\,4} - T^4)\,F$$

Energy increment

Radiant energy absorbed

heat loss by convection

heat loss by evaporation

heat loss by radiation

Tp – temperature of the product

Meteorogical model

Charles-Edwards e Acock model

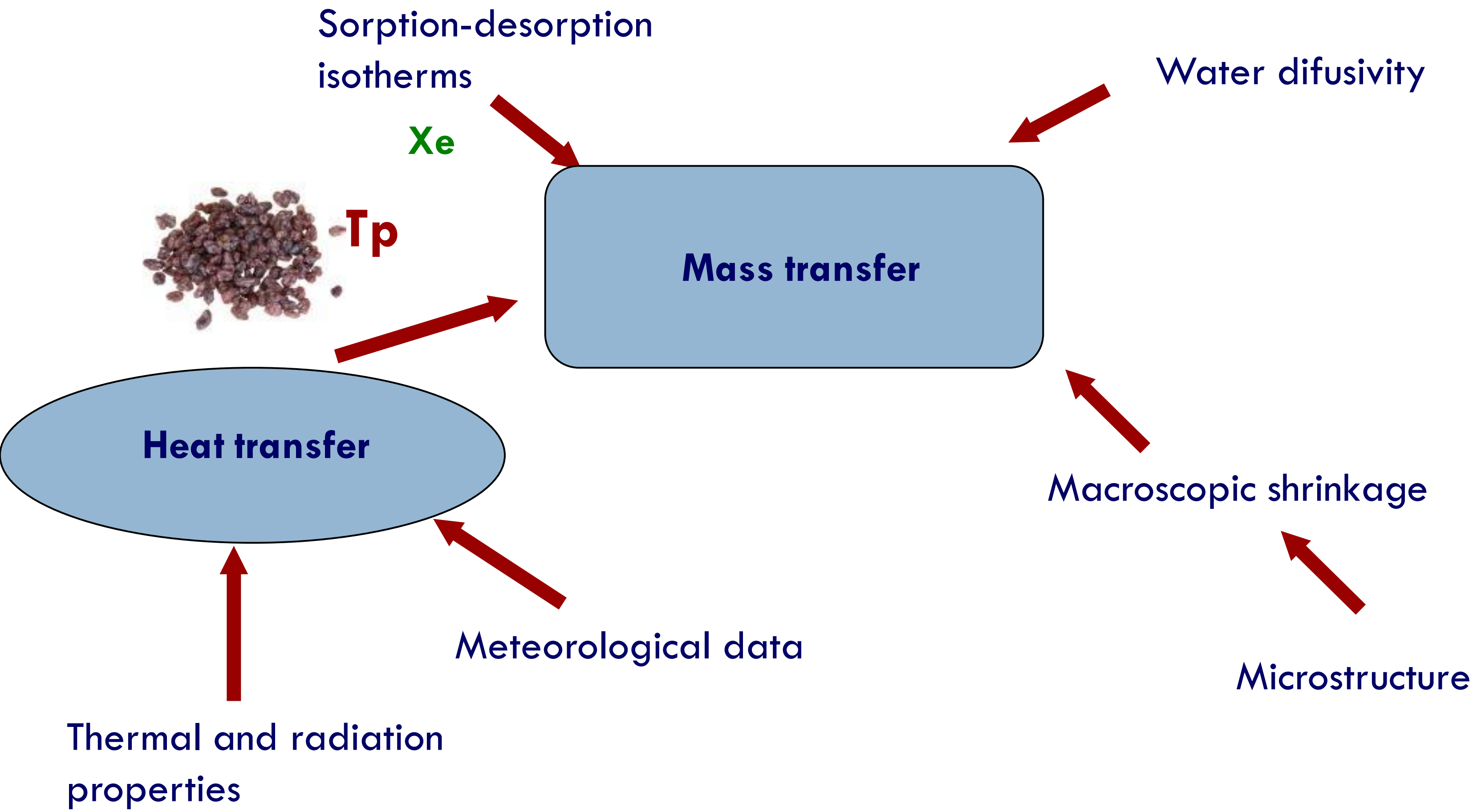
Radiation flux

$$I(t_d) = \frac{J_N}{g_N}\left\{1 + \cos\left[(t_d - 0.5) \times \frac{2\pi}{g_N}\right]\right\}$$

$$0.5 - \frac{1}{2} g_N \leq t_d \leq 0.5 + \frac{1}{2} g_N$$

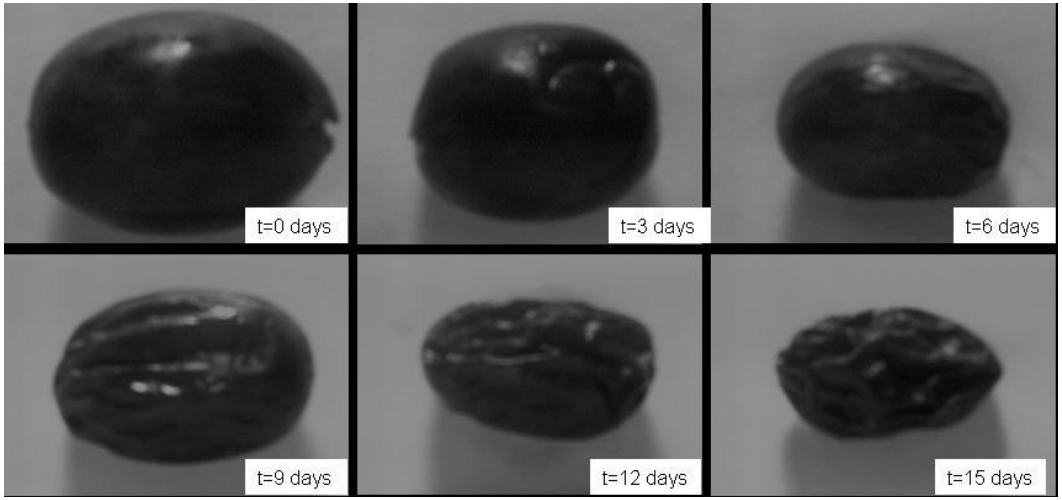
$$g_N = \frac{2 \arccos(-\tan\phi \tan\delta)}{2\pi}$$

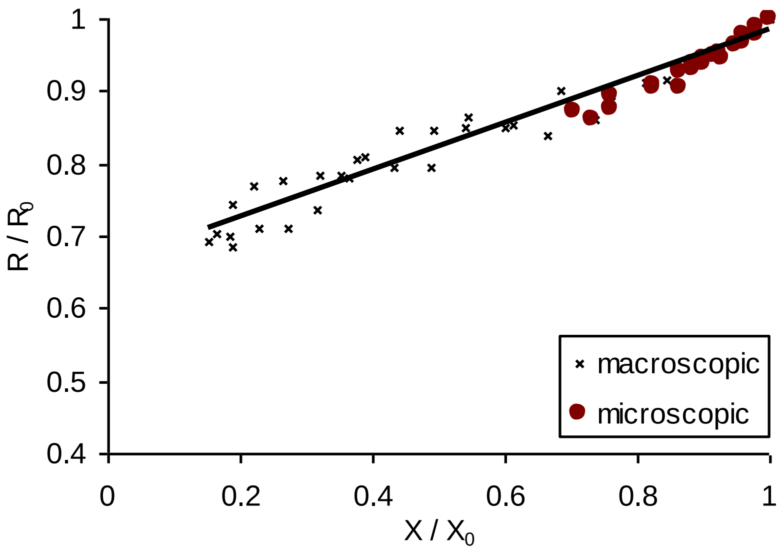
Heat and mass transfer model



- Finite differences resolution

Macroscopic shrinkage





Grape radius

$$R = R_0 \left(0.3654 \frac{\bar{X}}{Xexp_0} + 0.6288 \right)$$

Diffusivity

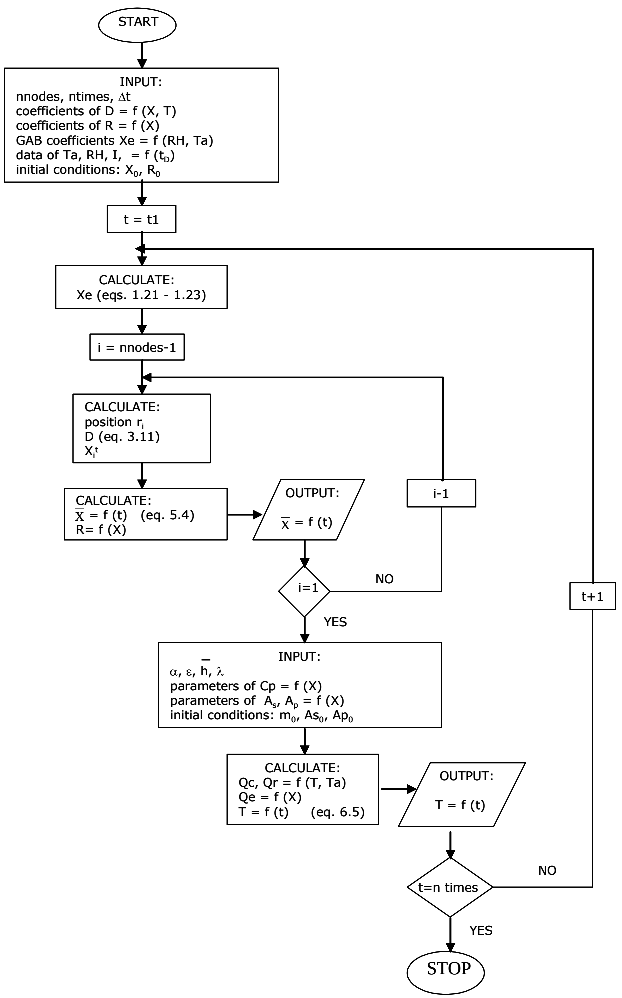
$$D_{eff} = D_0 \exp\left[a'\frac{X}{X_0} - b'\left(\frac{X}{X_0}\right)^2 - c'\left(\frac{1}{T} - \frac{1}{T_{av}}\right)\right]$$

Parameter	Estimate: Experiment 1	Estimate: Experiment 2
D_0 x10^{12} ($m^2\ s^{-1}$)	1.75	2.93
a′ (g dm / g H_2O)	18.3	14.5
b′ (g dm / g H_2O)^2	32.7	27.1
c′ (K)	687x10	629x10
R^2	0.9833	0.9921
s	0.1054	0.0869

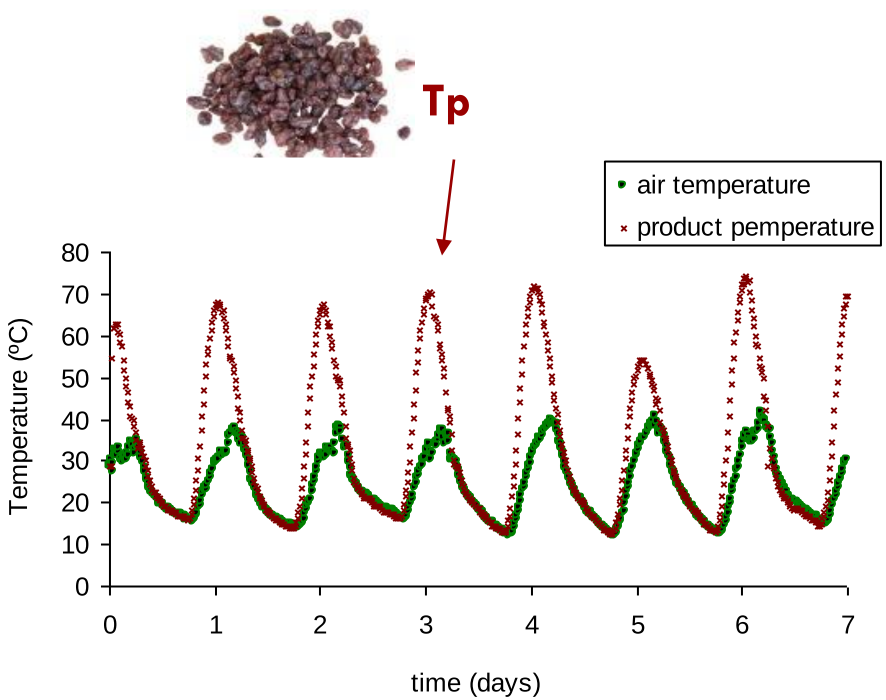
Ea = 57.1 and 52.3 kJ/mol ← (c′)

$1\times10^{-16} < D < 1\times10^{-10}$ m^2/s

Heat and mass transfer model



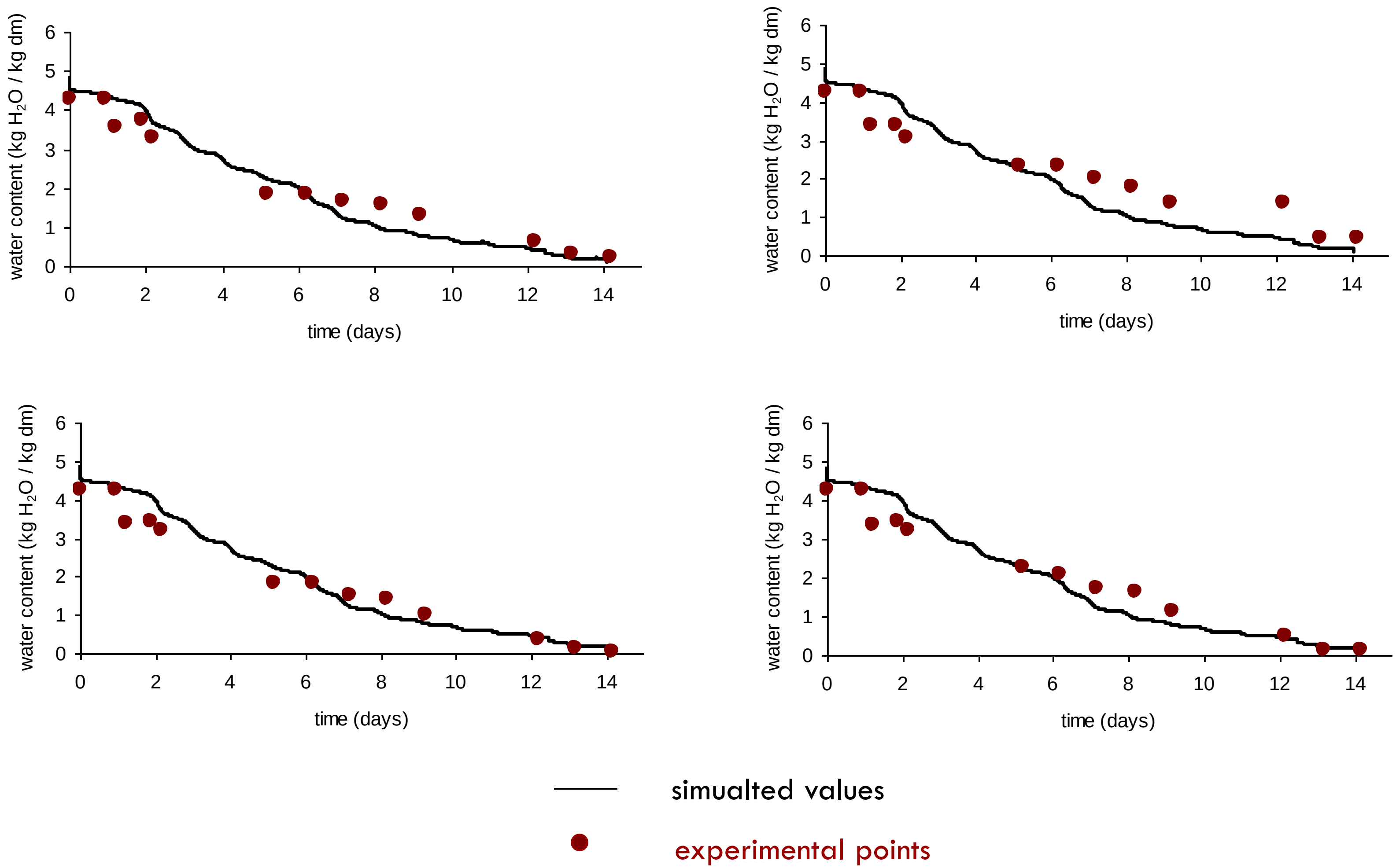
Simulation of temperature histories



Algorithm of the developed program

Heat and mass transfer model

Simulation of solar drying of grapes



Conclusions

- **Simulation of solar drying achieved by the integrated model can help in:**
  - prediction of drying times, and consequently the design of dried fruit production
  - optimization of the initial amount of product

- **This integrated model can be easily applied to simulate the solar drying of different fruits**

Conclusions

- Modeling and simulation of drying in dynamic conditions, using gradients of water content and shrinkage of the product simultaneously, were innovative and represent a contribution to Food Engineering

The cases presented clearly illustrate the application of …

Dynamic approach for assessing food quality and safety …

successfully!

Thank you !

CBQF – Centro de Biotecnologia e Química Fina
School of Biotechnology
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