Modelling Food Quality Changes Kinetics During Thermal Processing

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Thermal processing conference, *Campden BRI, Chipping Campden, Gloucestershire – UK, 12-13 June, 2014*

Outline

- Objectives of thermal processing
- Importance of thermal processes
- Factors affecting quality changes
- Modelling approaches
- Quality changes kinetics
- Predictive quality
- Combining with other technologies
- Post-harvest treatment
- Challenges

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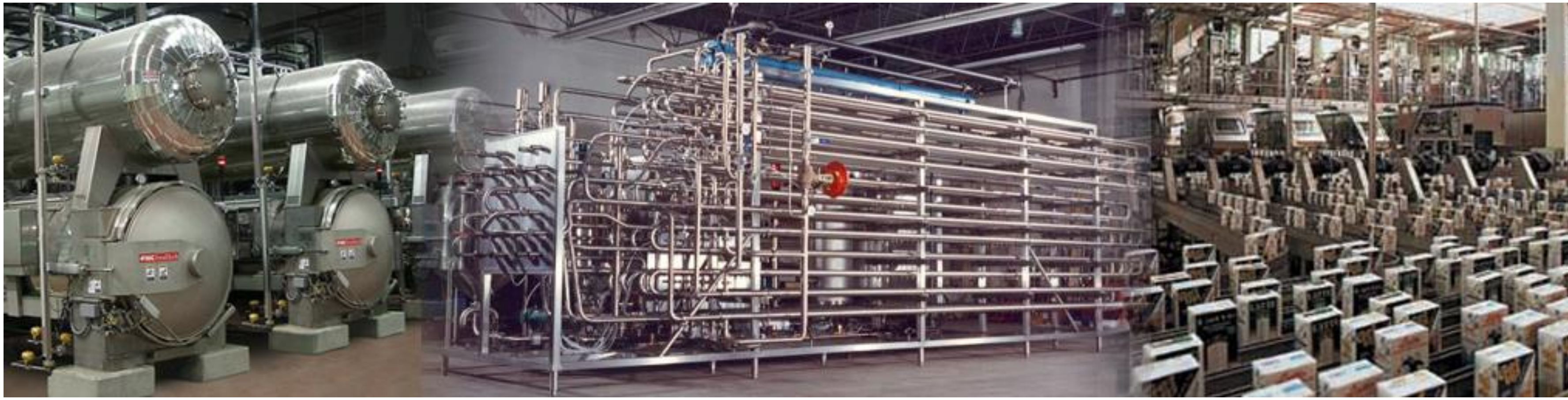
Objectives of thermal processing



… Originally designed to inactivate

<u>**spoiling and pathogenic microorganisms**</u>

bacteria
yeasts
molds

safety

and <u>**enzymes**</u>

Objectives of thermal processing

… consumers request

- ✓ Fresh like, appealing, convenient, healthy

- ✓ Environmental care

Objectives of thermal processing

Thermal Processes

↓ **Should**

prevent the degradation of the original **organoleptic** and **nutritive** food characteristics

quality

Objectives of thermal processing

thermal processes affect negatively quality factors

process design

safety

quality

Pathogenic bacteria
Chemical contaminants
…

Texture
Microstructure
Colour
Vitamin C
…

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Importance of thermal processes

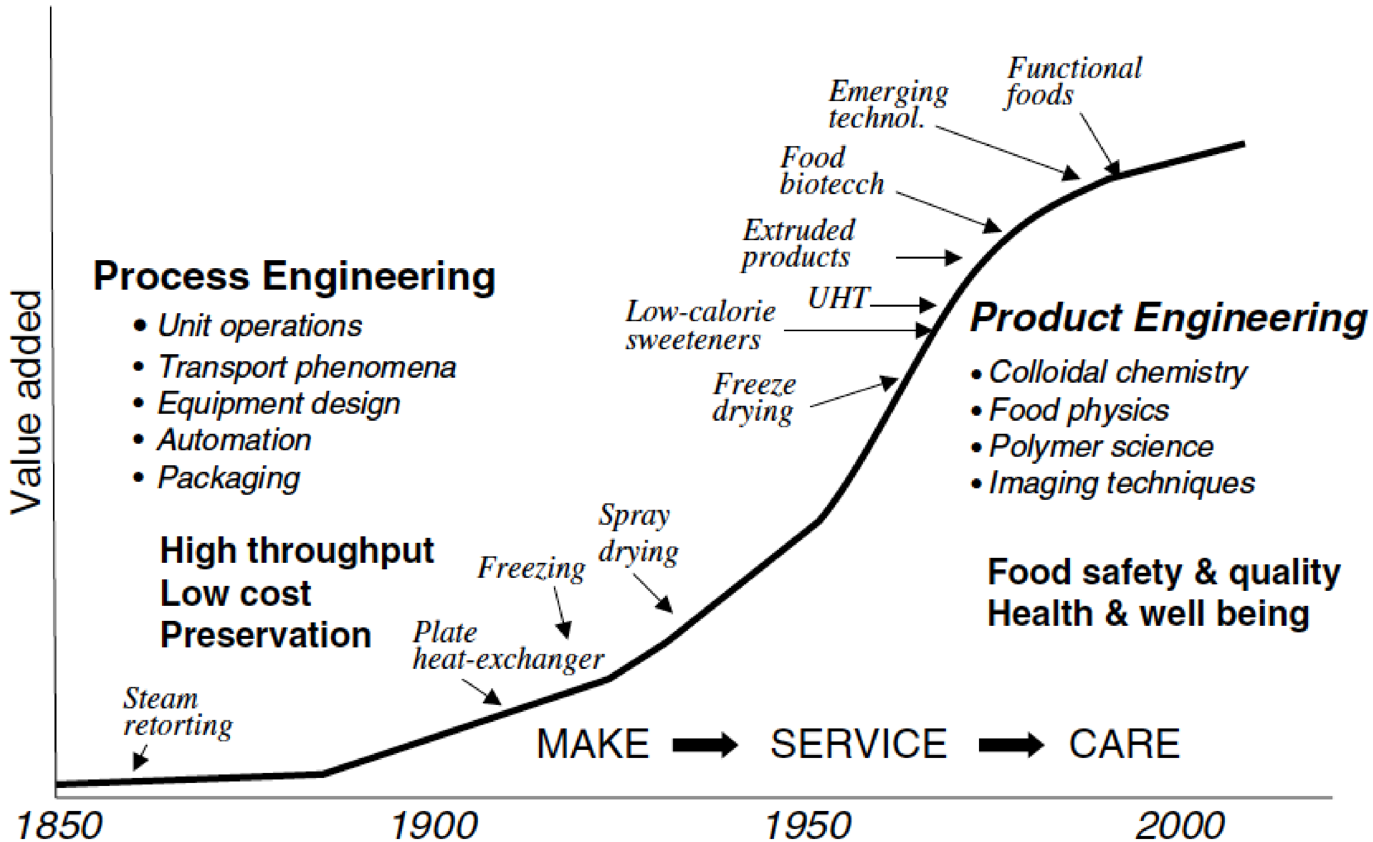


Figure 1. Evolution of the food industry in terms of value added to products and shift in emphasis from process engineering to product engineering. This transition has implied a change in concepts and techniques that support each approach.

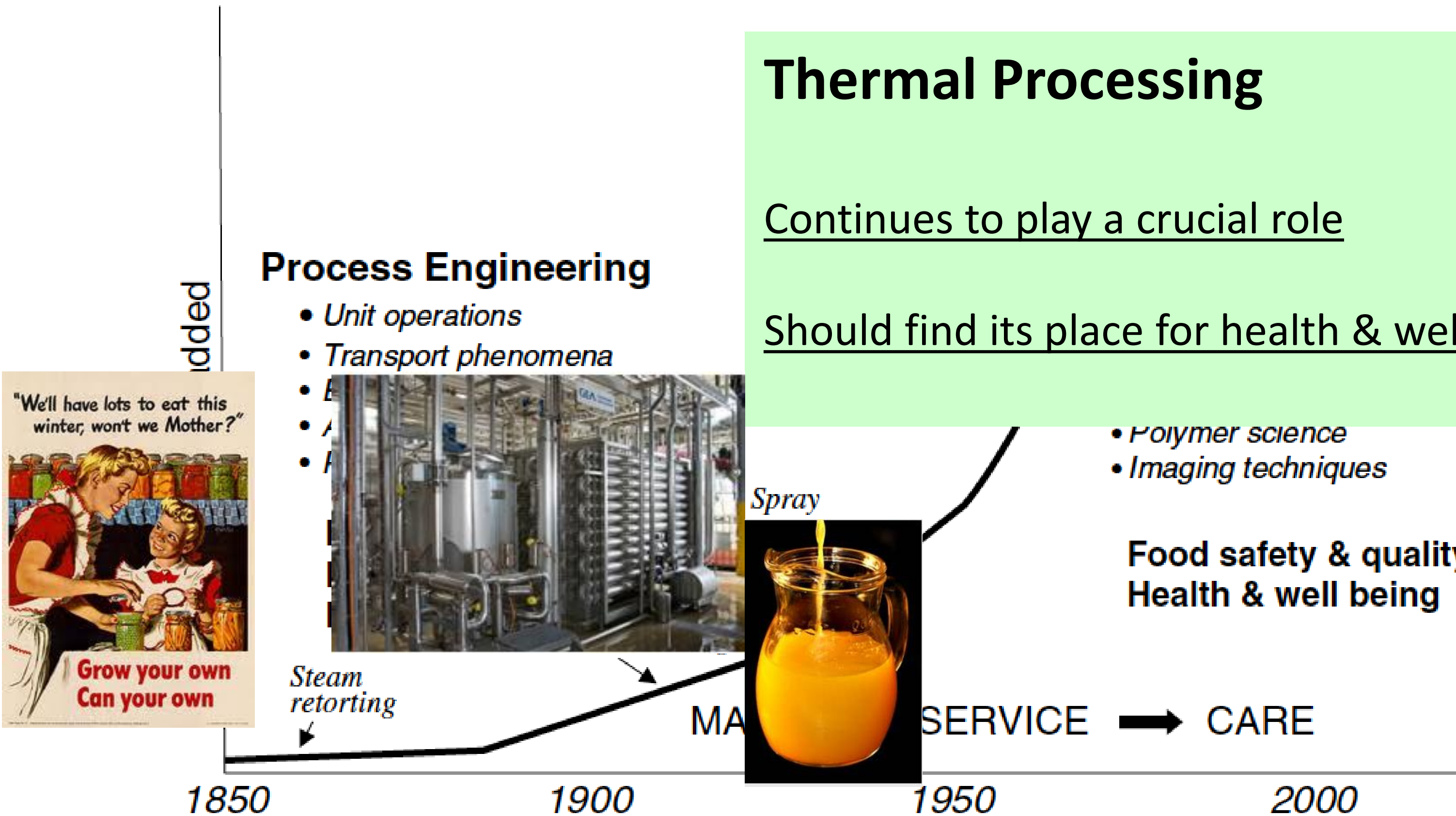
[1]Aguilera J. (2006). J. Sci. Food & Agric. 86(8): 1147-55.

Importance of thermal processes

Thermal Processing

<u>Continues to play a crucial role</u>

<u>Should find its place for health & well being</u>



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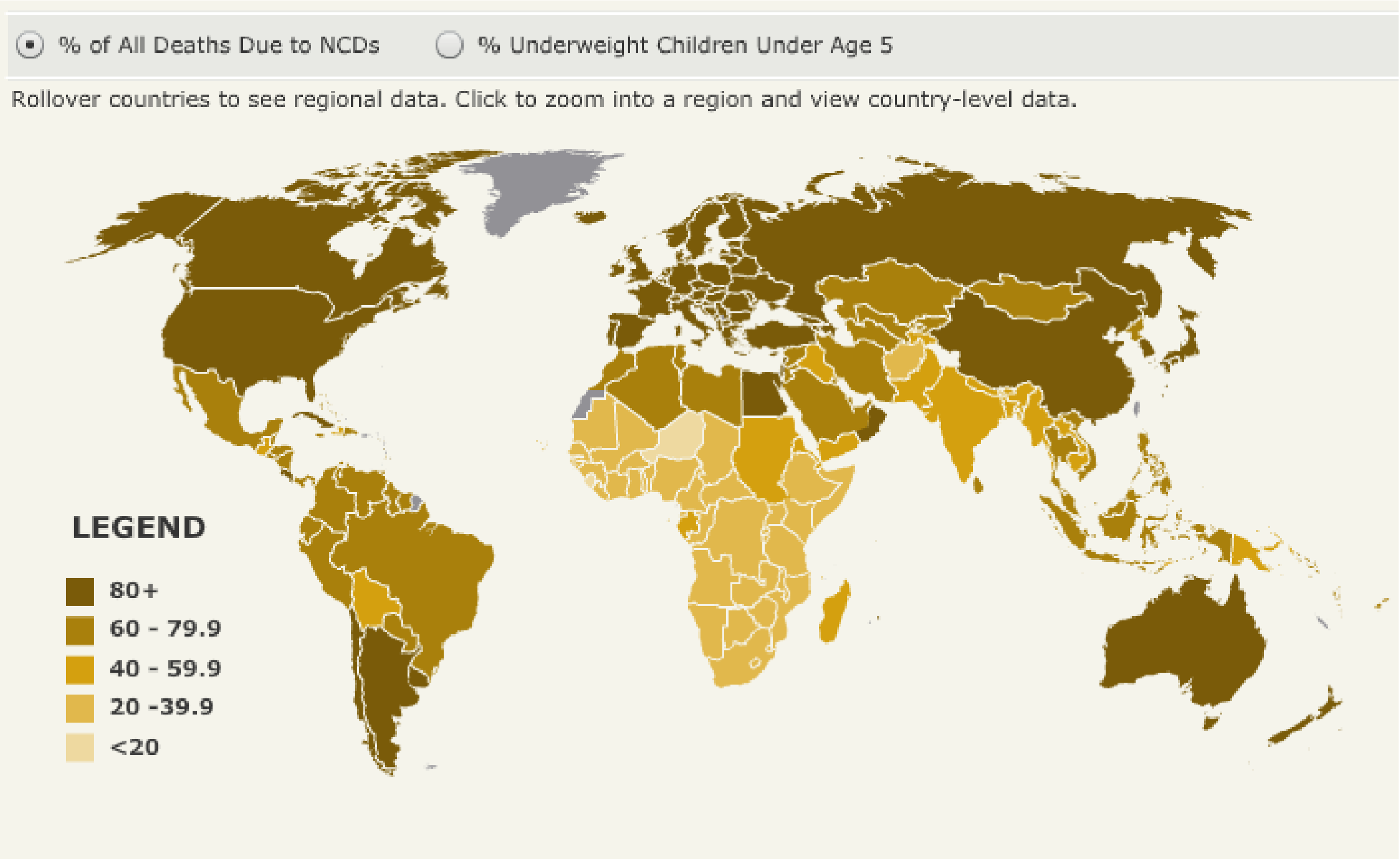
Importance of thermal processes

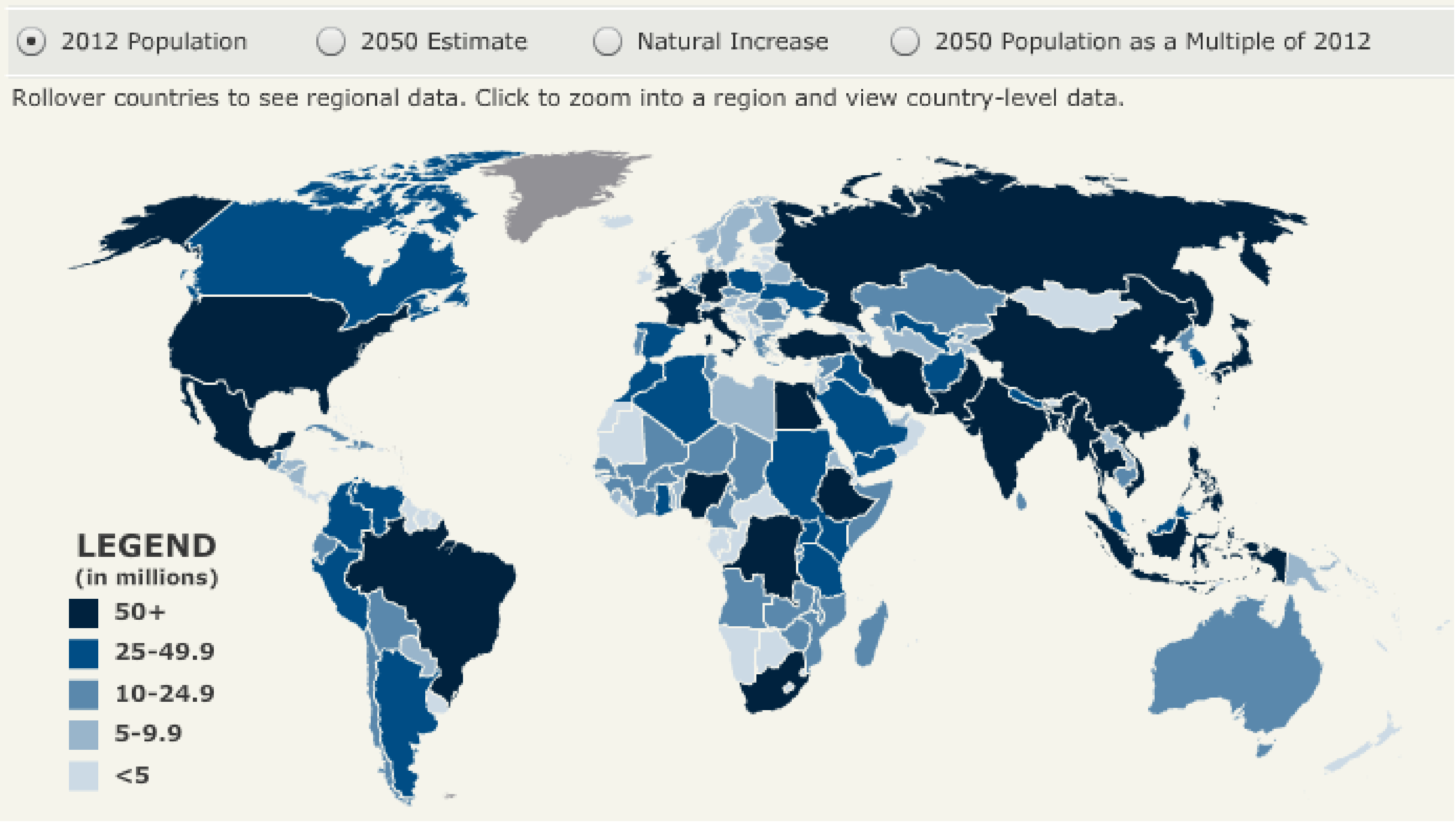


population ageing

Importance of thermal processes

population ageing

Importance of thermal processes

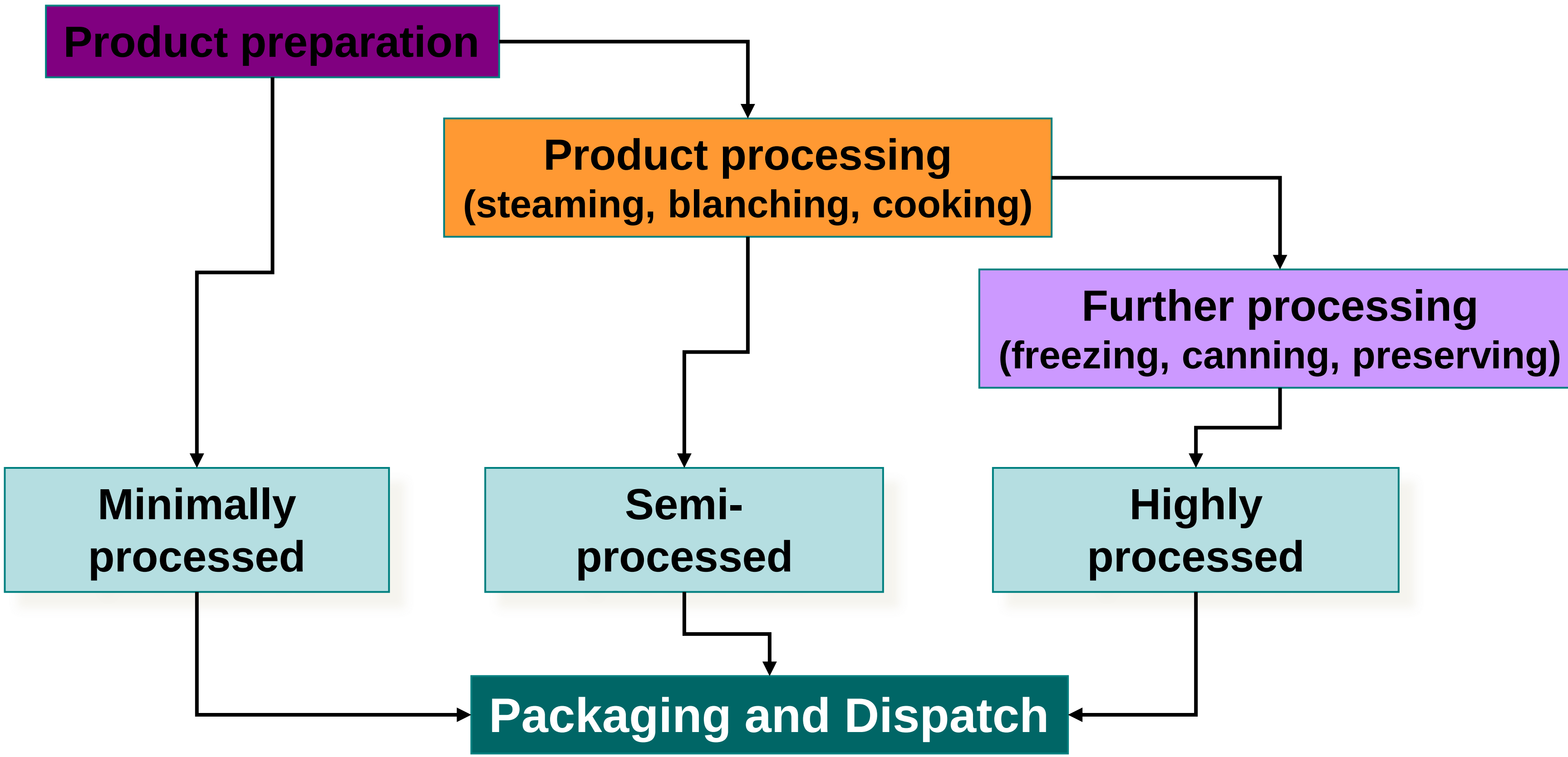


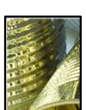
population growth

Importance of thermal processes

population growth

Importance of thermal processes





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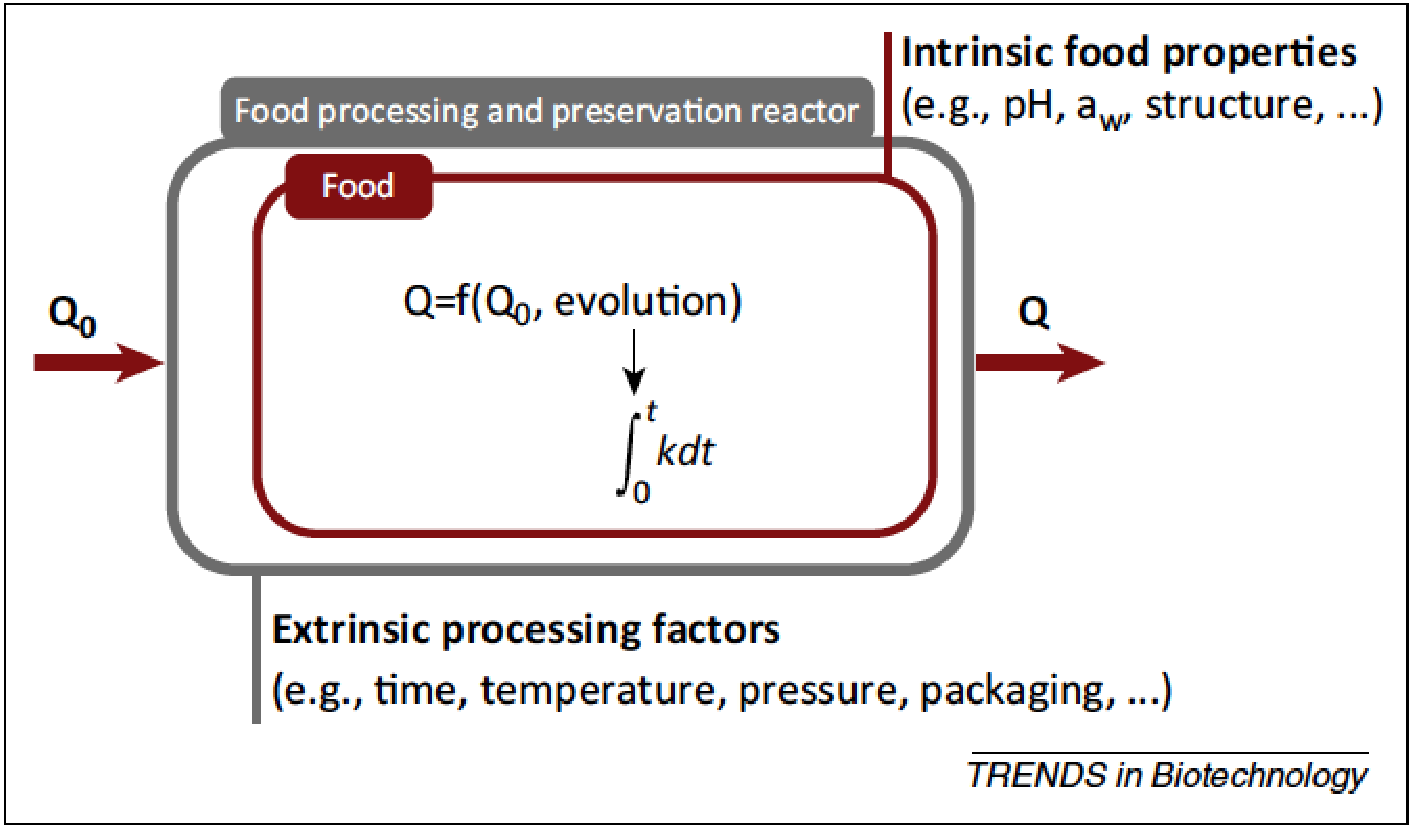
Factors affecting quality changes

Quality attributes response depends on:

- **Intrinsic** factors
  - pH
  - a_w
  - others
- **Extrinsic** factors
  - time
  - T
  - pH
  - Pressure
  - Other hurdles
- **System dynamics**

Factors affecting quality changes



Grauwet et al, 2014

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Modelling approaches

Model → mathematical expression

$$y_i = f(x_{ij}, \theta_k) + \varepsilon_i$$

i=1,2,...,n (number of experimental runs/observations)

j=1,2,...,v

k=1,2,...,p

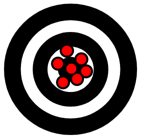
Minimize differences

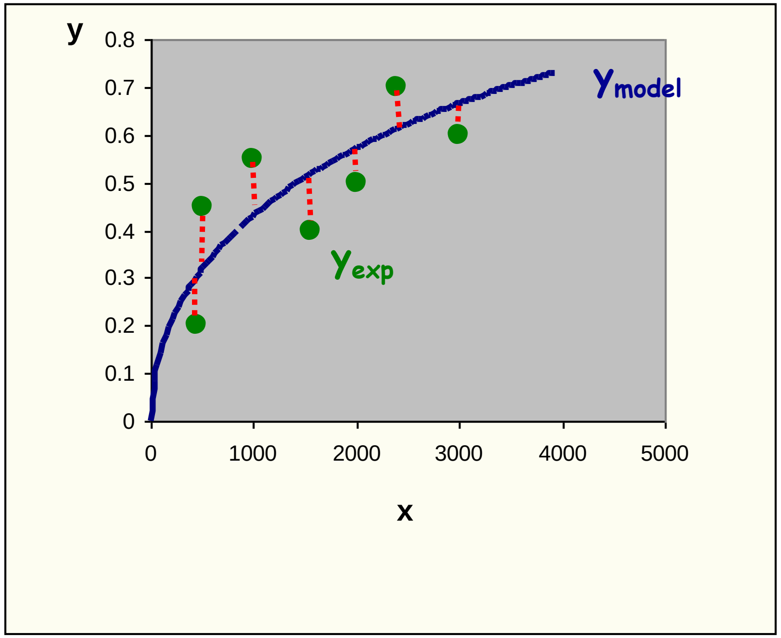
↓

θ^*

Precise ?

Accurate ?





Modelling approaches

objective

precise and accurate description of observations

model adequacy

quality of model parameters

Modelling approaches

Sampling:

- **Heuristic sampling**
- **Experimental design**

Minimize variance of:

- ***predicted response***
- ***parameter estimates***

Modelling approaches

Data analysis:

- **Regression schemes**

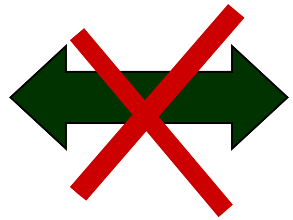
$$SSR = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left[y_i - f\left(x_{ij}, \theta_k \right) \right]^2$$

Least-squares method

- **Analysis of residuals**

Modelling approaches

Mathematical complexity



Adequate description

quality

model

parameters

Modelling approaches

advantages

- **knowledge of the process**
- **process effects on product**
- **control of process variables**

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Quality changes kinetics

Historically: → single-response studies

→ static conditions

Quality changes kinetics

Single-response → empirical

Kinetic Models

Atribute at time t

Initial value

Time

Activation energy

Zero order

$$C = C_0 - k_{(T)} t$$

1st order

$$C = C_0 \, e^{-k_{(T)} t}$$

Fractionary

$$\frac{C - C_{eq}}{C_0 - C_{eq}} = e^{-kt}$$

Equilibrium value

Reaction rate

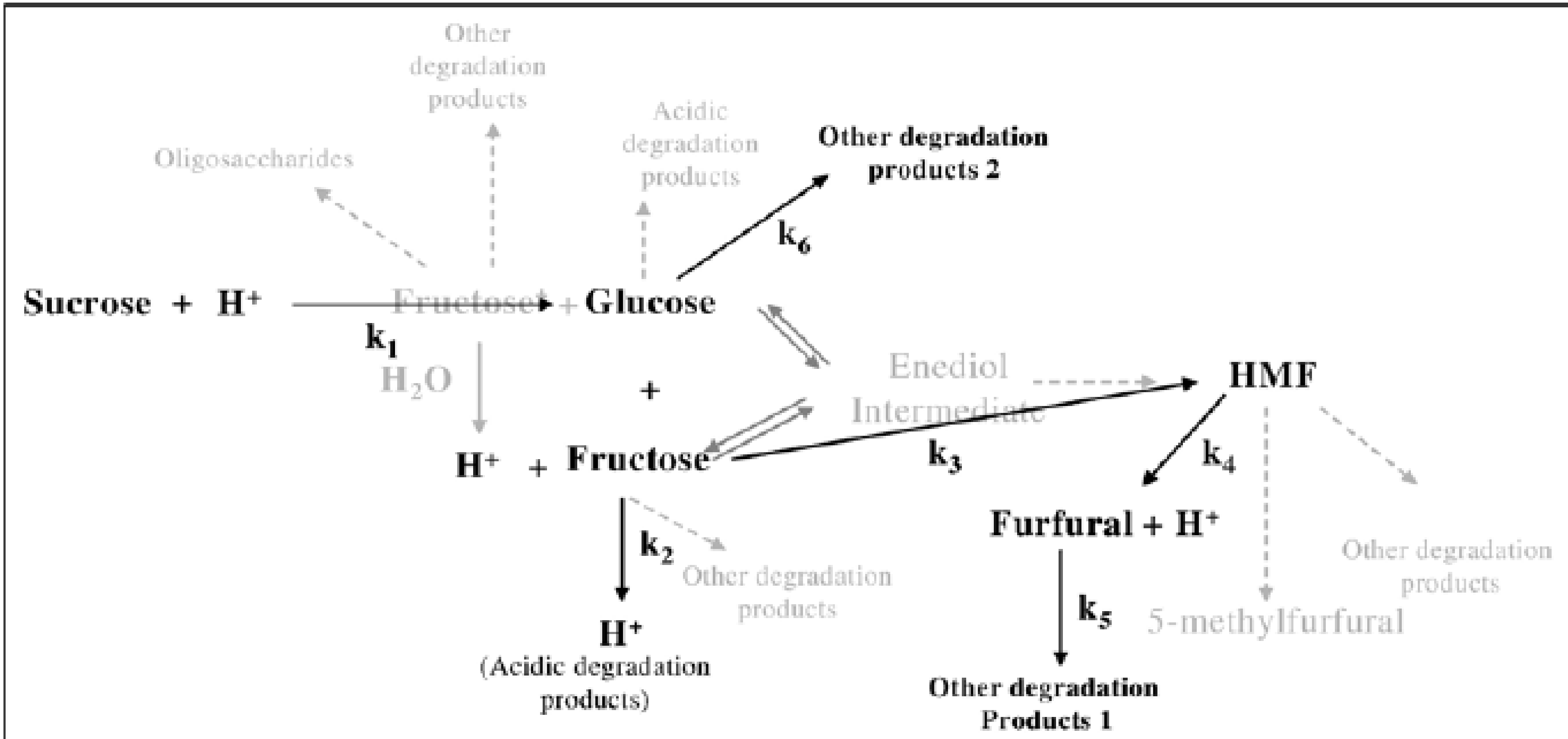
$$k_{(T)} = k_{ref} \exp\left[-\frac{Ea}{R} \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right]$$

T effect on k

Arrhenius law

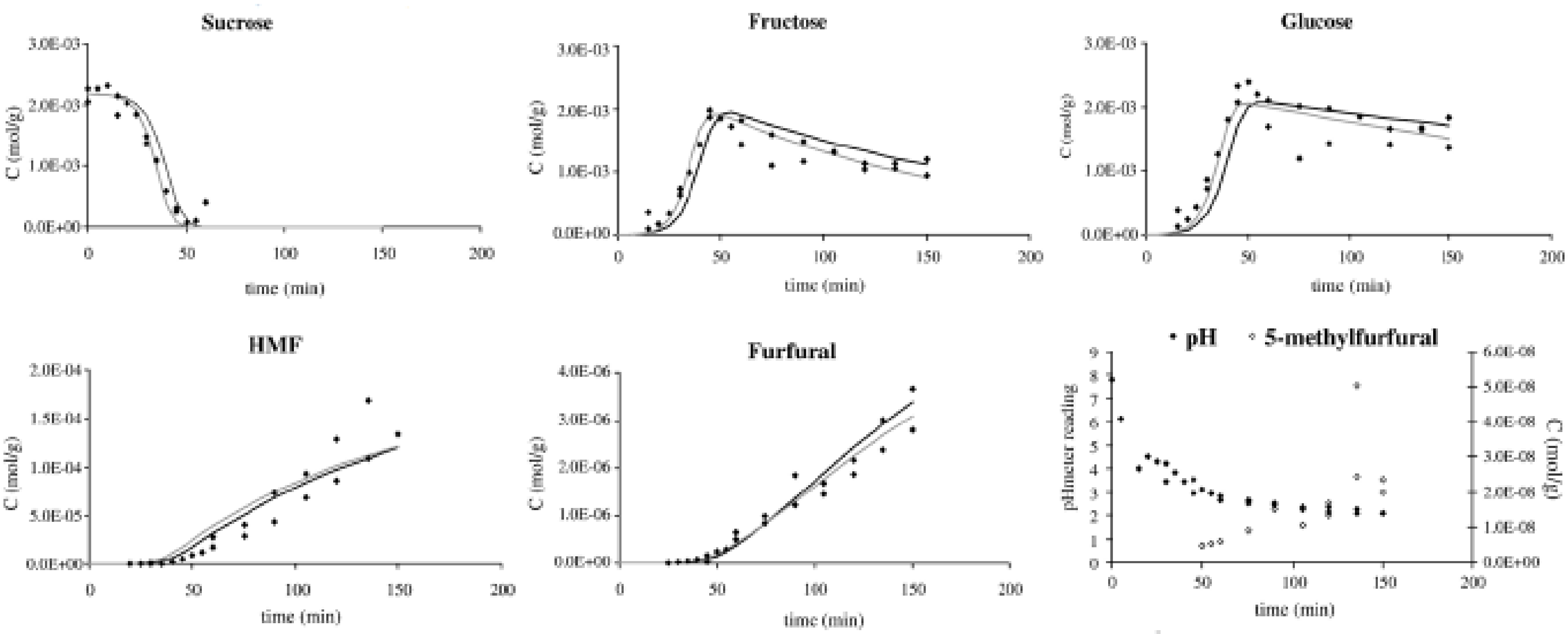
Quality changes kinetics

Multiresponse Modelling → mechanistic



Quintas et al, 2007

Quality changes kinetics



Quintas et al, 2007

Quality changes kinetics

Laboratory research

Industrial scale

Quality changes kinetics

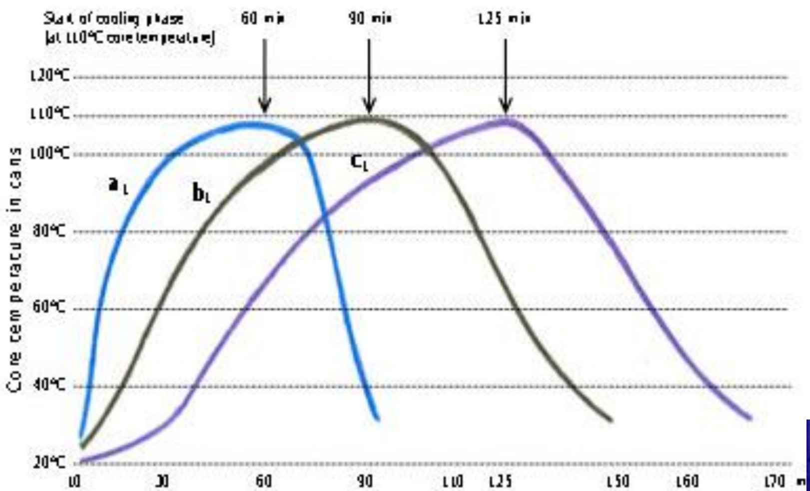
The complexity of dynamic conditions

Laboratory research	Industrial scale
Studies are often carried out at constant temperatures	Time-varying temperature conditions are common

transfer of results is compromised →

isothermal	non-isothermal

Quality changes kinetics



→ **Need to have temperature histories and distributions**

Quality changes kinetics

→ **Need to have temperature histories and distributions**

→ Hot - filling

Quality changes kinetics

Isothermal conditions

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

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

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

Non-Isothermal conditions

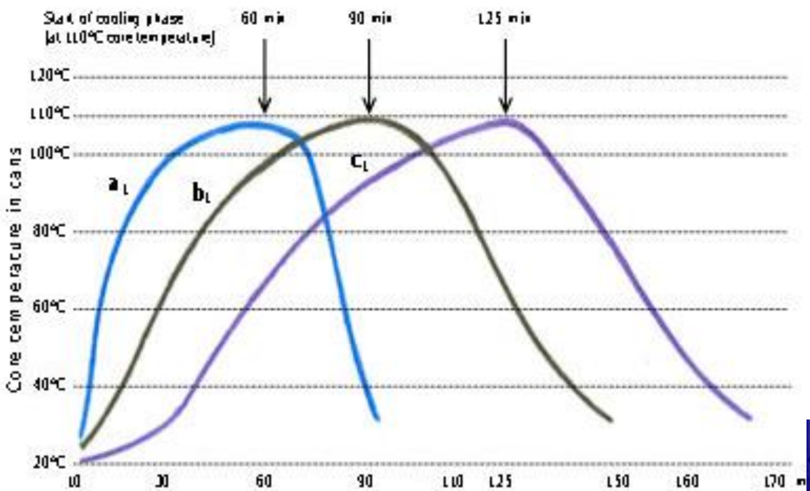
$$C = C_0 - \left[k_{ref} \int_0^t \exp\left[-\frac{E_a}{R}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right]dt\right]$$

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

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

Integration

Quality changes kinetics



→**Reverse Engineering**
can be an excellent tool

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Predictive quality

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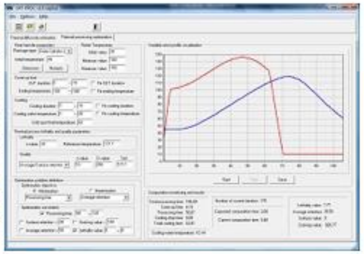
25/10/2010
OPT-PROx 1.0 alpha-version is released.

12/01/2012
OPT-PROx 1.5 alpha-version is released.

REVIEWS

manufacture of shelf stable canned foods, and has been the cornerstone of the food processing industry for more than a century" (A. Teixeira)



"OPT-PROx" is a software specially developed for thermal food processing numerical optimization. The diversity of thermal food processing optimization problems with different objectives and required constraints are solvable by OPT-PROx software. The adaptive random search algorithm coupled with penalty functions approach, and the finite difference method with cubic spline approximation are utilized by OPT-PROx for simulation and optimization of thermal food processes. The possibility of numerical estimating the thermal diffusivity coefficient based on the mean squared error function minimization is included.
"OPT-PROx" software was successfully tested on the real thermal food processing problems.

The following objective functions and constraints are supported by "OPT-PROx" software.

Objective functions:

- Minimization of total processing time.
- Minimization of cooking value.
- Maximization of Surface quality retention.
- Maximization of Average quality retention.

Constraints:

- Surface quality retention.
- Average quality retention.
- Cooking value.
- Thermal lethality value.
- Total thermal processing time.

Predictive quality

Predictive microbiology

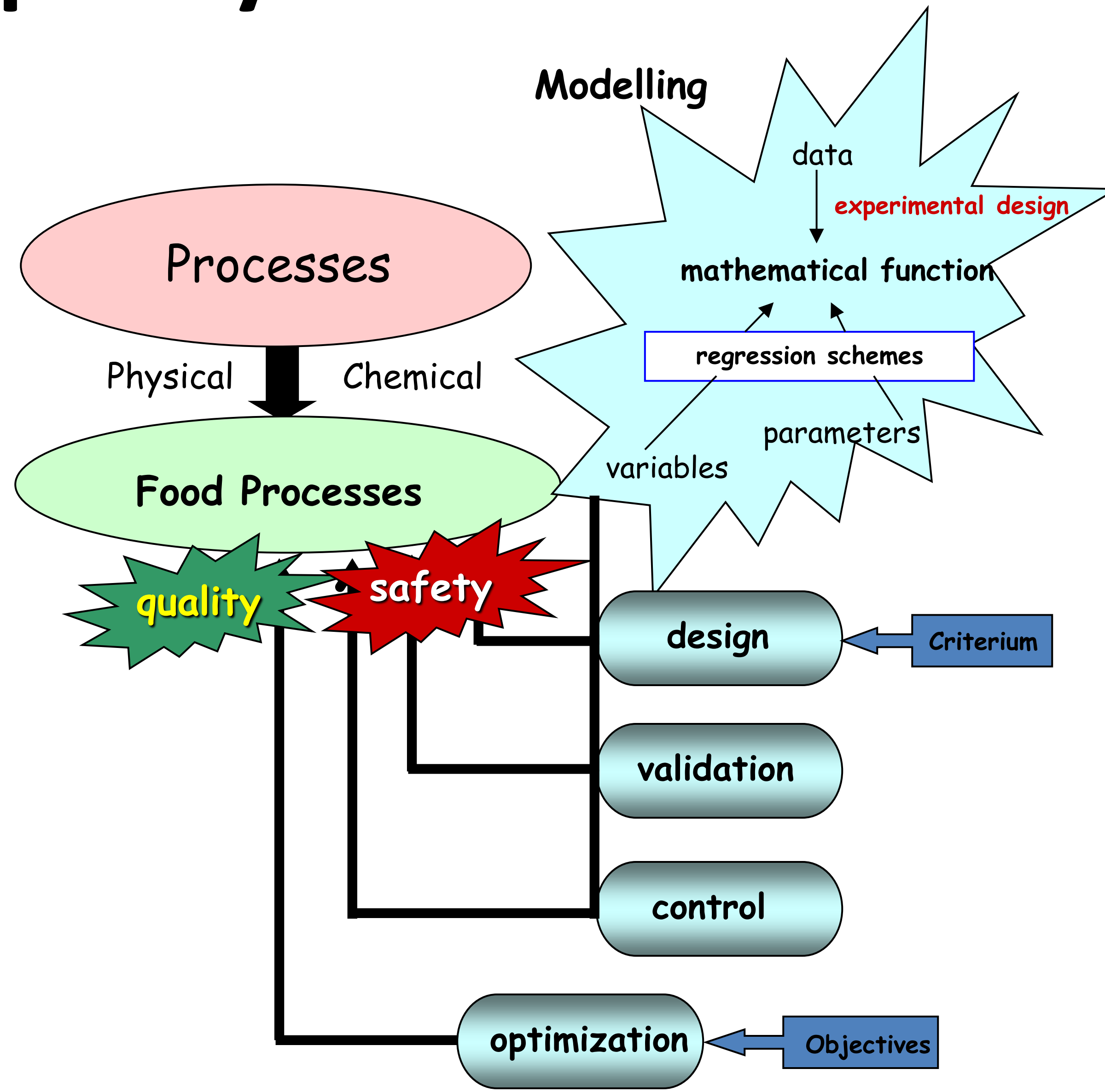
The use of **mathematical models** in the description of **microbial responses** to environmental stressing factors

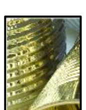
Predictive quality

Transport Phenomena
- heat
- mass
- *momentum*

Reaction kinetics

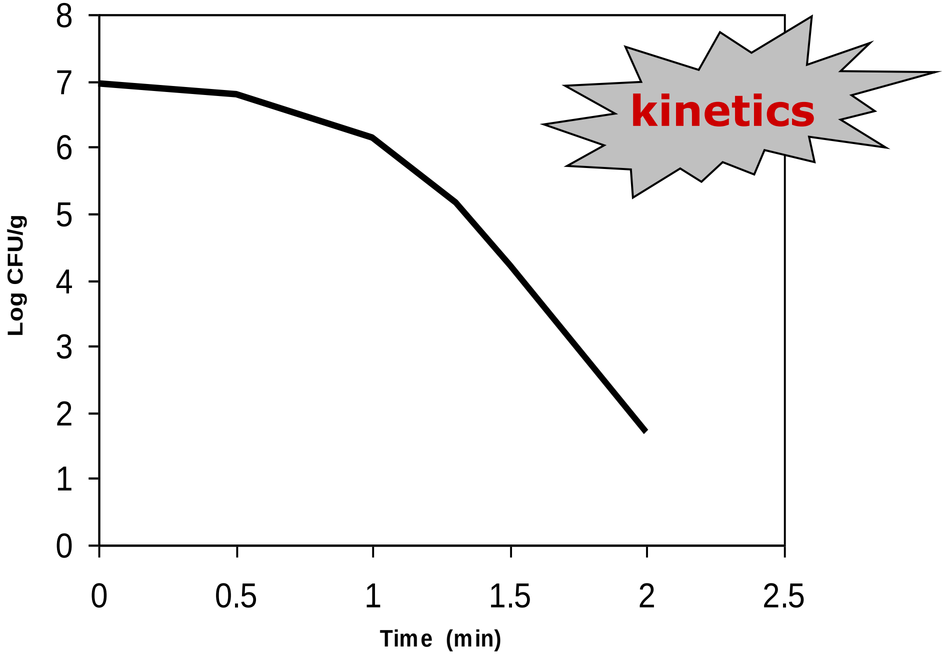
Properties





Predictive quality

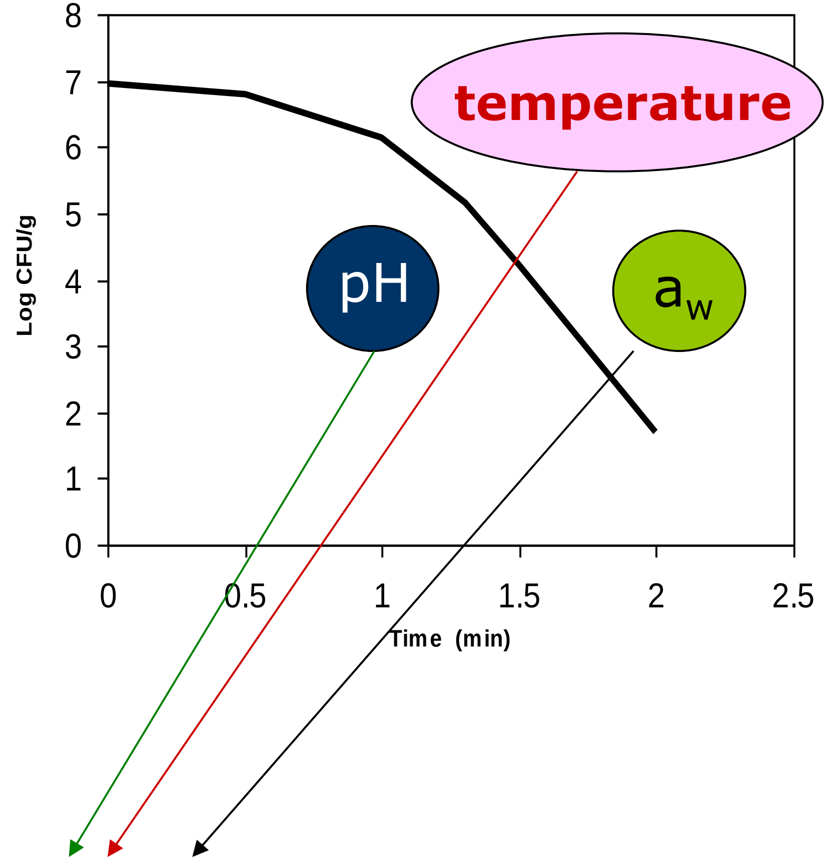
- primary model



parameters

Predictive quality

- primary model

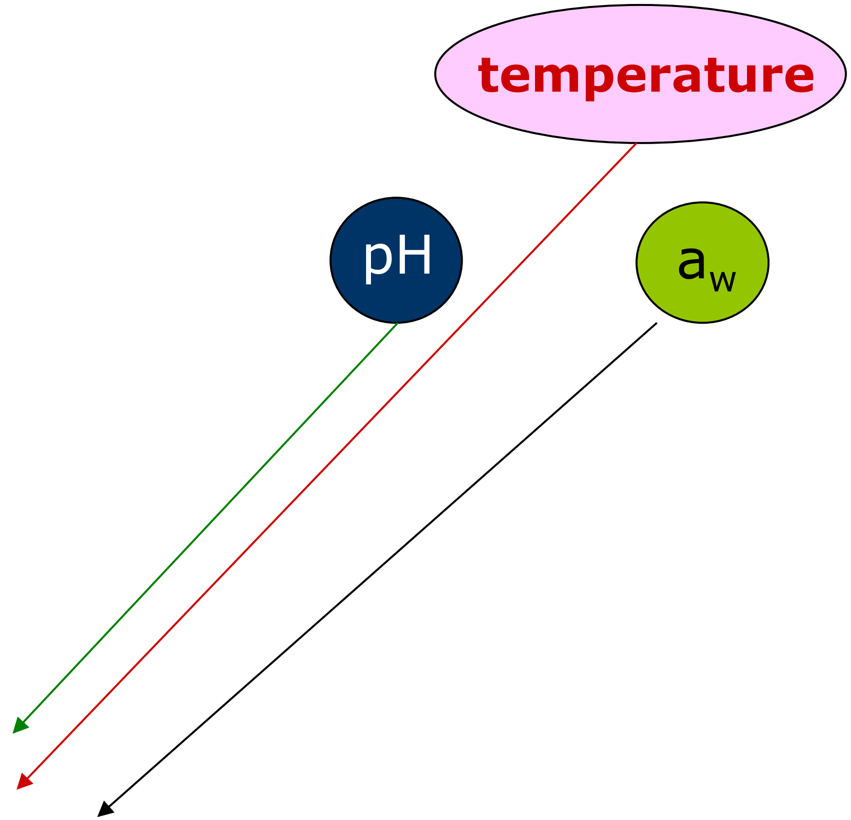


- secondary model

parameters

Predictive quality

- **primary**



- **secondary**

parameters

- **terciary -** integration of the previous models - **software**

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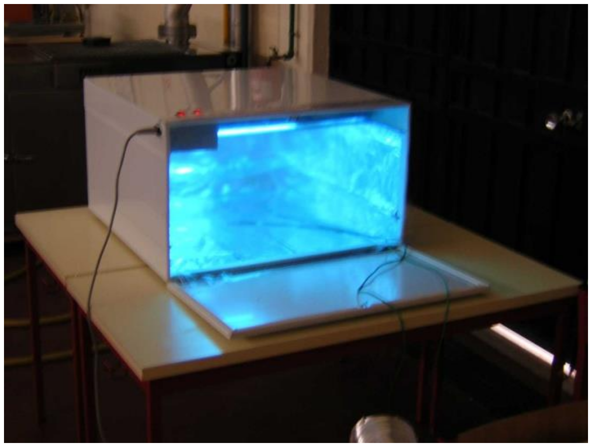
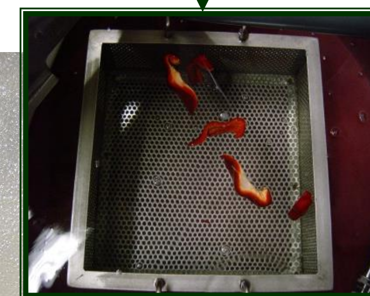
Combining with other technologies

UV-C radiation

UV-C chamber (University of Algarve), 4 germicidal UV lamps (TUV G30T8, 16 W, Philips, peak emission at 254 nm), average intensity 12.36 W/m^2



Ozone



ozone generator, concentration measured by potential difference, 0.3 ppm

Ultrasonication / Thermosonication

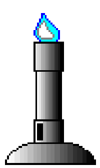
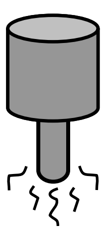
ultrasound equipment (Bandelin Sonorex RK 100H) operating at 32 kHz

Combining with other technologies

watercress

Nasturtium officinale

Types of combined treatments with ultrasound

 +  **Heat + Ultrasound** **Thermosonication**

Combining with other technologies

watercress

Nasturtium officinale

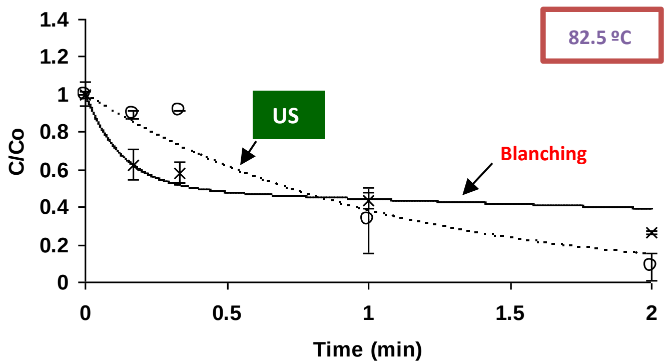
Quality

Colour changes

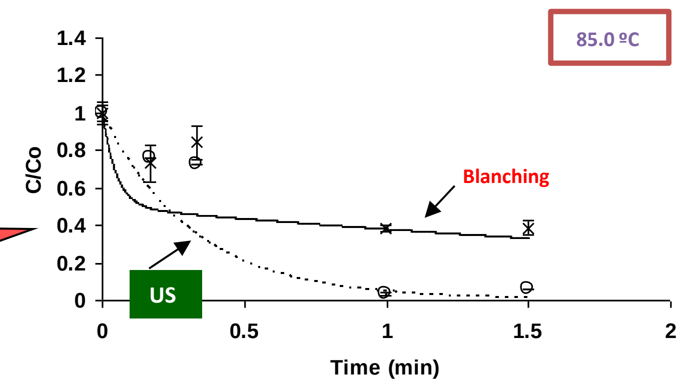
Peroxidase

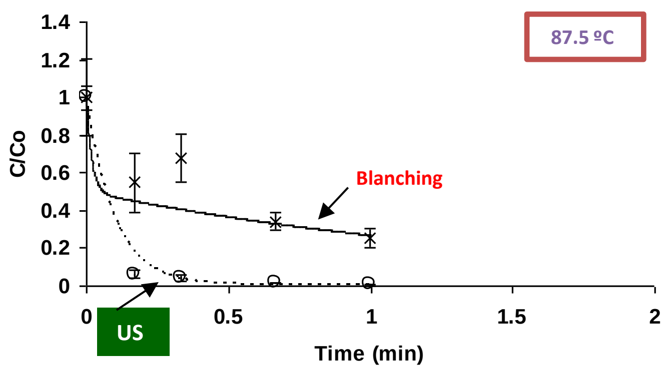
Vitamin C

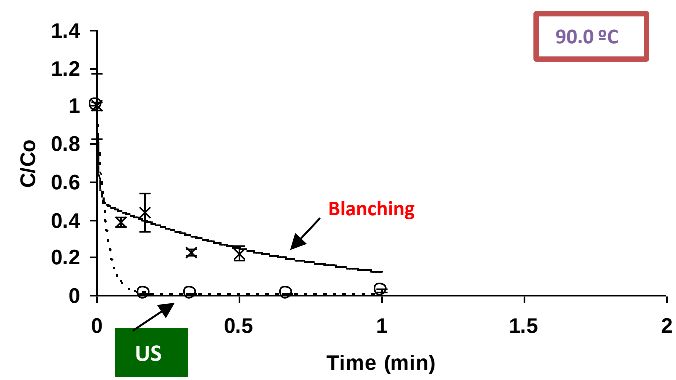
Combining with other technologies



Peroxidase







Cruz et al, 2014

Combining with other technologies



The application of thermosonication

- **temperatures above 85 ºC and for the same blanching times**

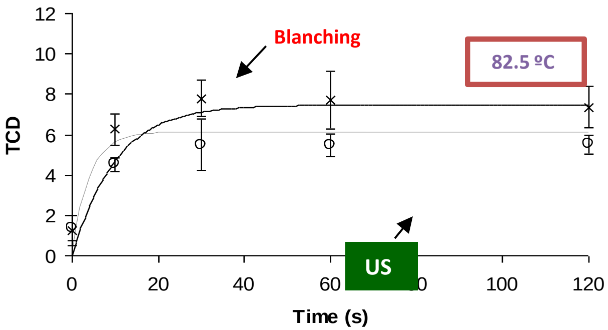
led to higher enzyme inactivation when compared to heat blanching cesses

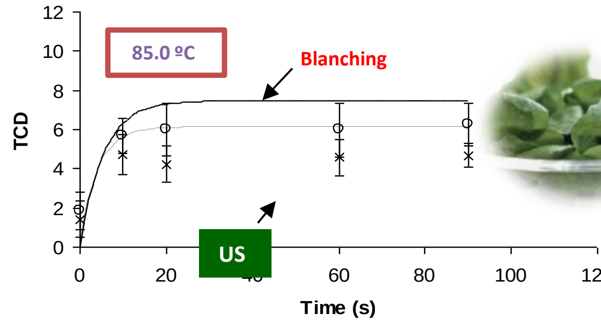
Peroxidase

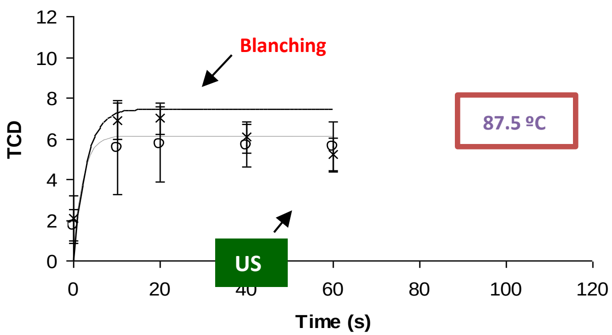
These results allow the application of shorter blanching times at this range of temperatures, leading to a product with a higher quality, or minimized processing

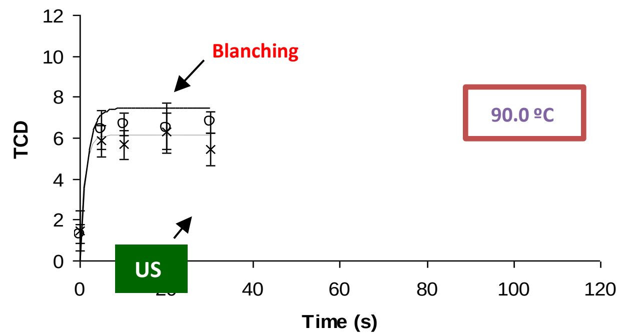
Combining with other technologies

85 ºC

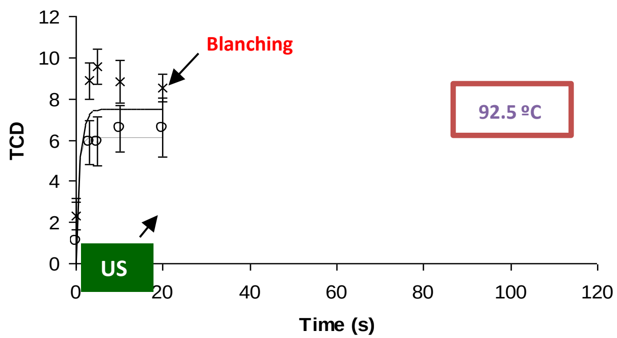








Colour



Cruz et al, 2014

Combining with other technologies

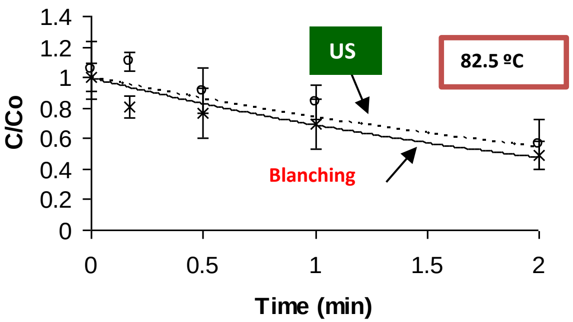
The application of thermosonication

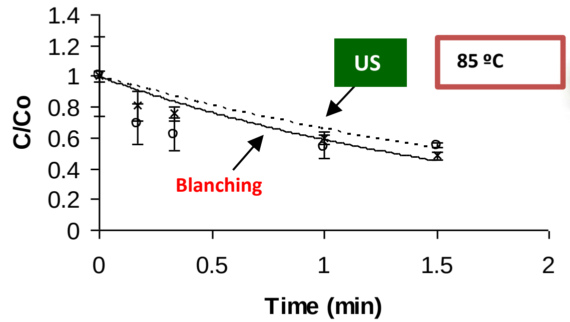


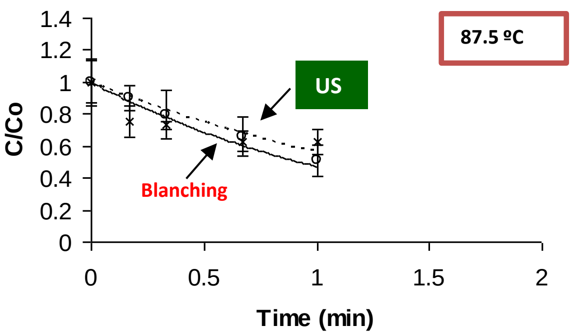
Colour

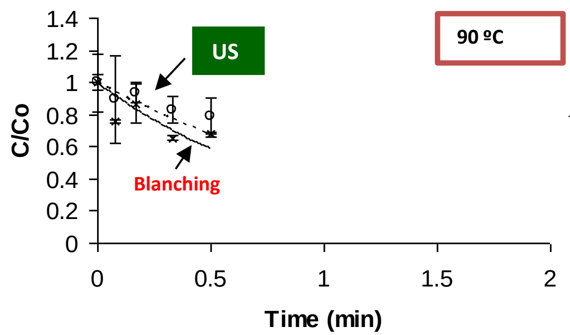
Reaction rates of watercress colour changes due to heat and thermosonication blanchings were not significantly different

Combining with other technologies

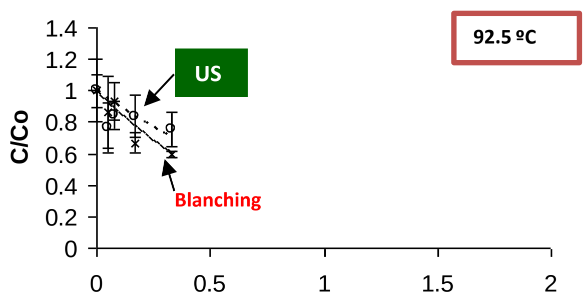








Vitamin C



Cruz et al, 2014

Combining with other technologies

The application of thermosonication

Vitamin C

Results showed no significant differences between heat and thermosonication treatments

The treatment will allow good vitamin C retention

Combining with other technologies

The application of thermosonication

Quality

The thermosonication treatments can be a good alternative to the traditional heat blanching processes, since higher quality products are attained

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Postharvest treatment

Postharvest treatment

Turning maturity stage (TM)

Tomato
(cv. Zinac)

Pink maturity stage (PM)

Industrial decontamination
(**HIPO:** 150 ppm chlorine, 5 ºC, pH 6.5, 2 min)

Rising
(water)

Water heat treatment
(**WHT**: 40 ºC / 30 min)

Cooling
(5 min, water / ice)

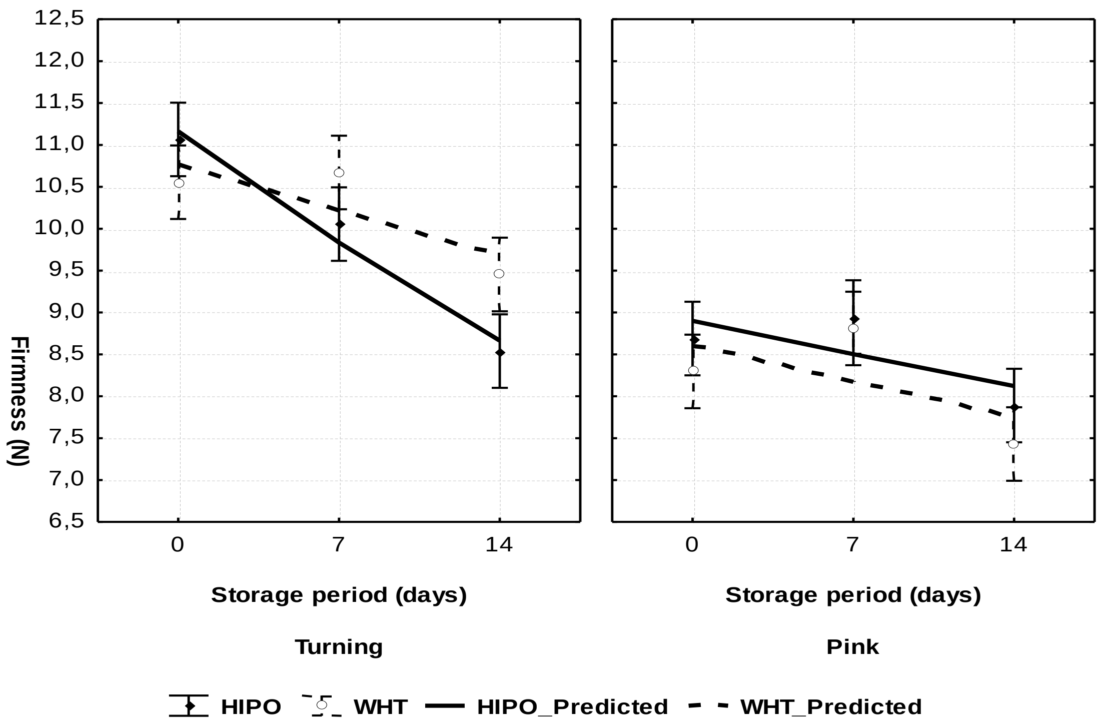
Drying
(Absorbent paper)

Storage
(10 ºC / 14 days)

Pinheiro et al, 2014

Postharvest treatment

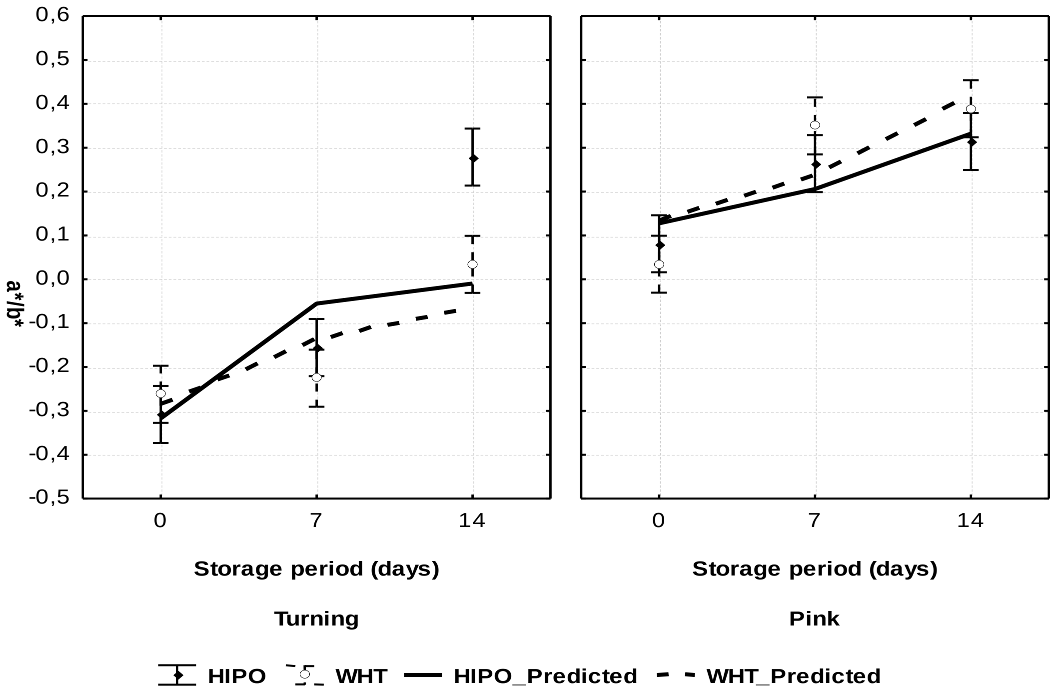
Firmness



Pinheiro et al, 2014

Postharvest treatment

Colour



Pinheiro et al, 2014

Postharvest treatment

$$C = C_0 \, e^{-k_{(T)} t}$$

Maturity stages	Treatment	*a*/b**	Firmness (N)
Turning	**HIPO**	$C_0 = -0.32 \pm 0.12$ $k_{10ºC}$ (day $^{-1}$) $= 0.25 \pm 0.32$	$C_0 = 11.16 \pm 0.52$ $k_{10ºC}$ (day $^{-1}$) $= 0.02 \pm 0.006$
	WHT	$C_0 = -0.28 \pm 0.11$ $k_{10ºC}$ (day $^{-1}$) $= 0.11 \pm 0.10$	$C_0 = 10.77 \pm 0.69$ $k_{10ºC}$ (day $^{-1}$) $= 0.01 \pm 0.01$
Pink	**HIPO**	$C_0 = 0.13 \pm 0.07$ $k_{10ºC}$ (day $^{-1}$) $= -0.07 \pm 0.05$	$C_0 = 8.90 \pm 0.43$ $k_{10ºC}$ (day $^{-1}$) $= 0.01 \pm 0.01$
	WHT	$C_0 = 0.13 \pm 0.07$ $k_{10ºC}$ (day $^{-1}$) $= -0.08 \pm 0.04$	$C_0 = 8.60 \pm 0.72$ $k_{10ºC}$ (day $^{-1}$) $= 0.01 \pm 0.01$

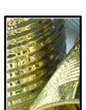
→ Results provide strong evidence that postharvest water **heat treatment (40 ºC - 30 min)** for tomato fruits (cv. 'Zinac') at turning maturity stage guarantees the overall quality at 10 ºC, **twice as long of fruits washed with chlorinated water**.

Outline

- Objectives of thermal processing
- Importance of thermal processes
- Factors affecting quality changes
- Modelling approaches
- Quality changes kinetics
- Predictive quality
- Combining with other technologies
- Post-harvest treatment
- **Challenges**

Challenges

- ✓ Food quality kinetic studies under dynamic conditions.
- ✓ Use of reverse engineering.
- ✓ Kinetic studies for combined processes.
- ✓ Multiresponse models – mechanistic.
- ✓ More intelligent processing – better process control, design and optimization.
- ✓ Development of a so called "***Predictive Quality***".



Thank you

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