

Design of Carvacrol-Based Active Packaging for Extending Fresh Fish Shelf-life

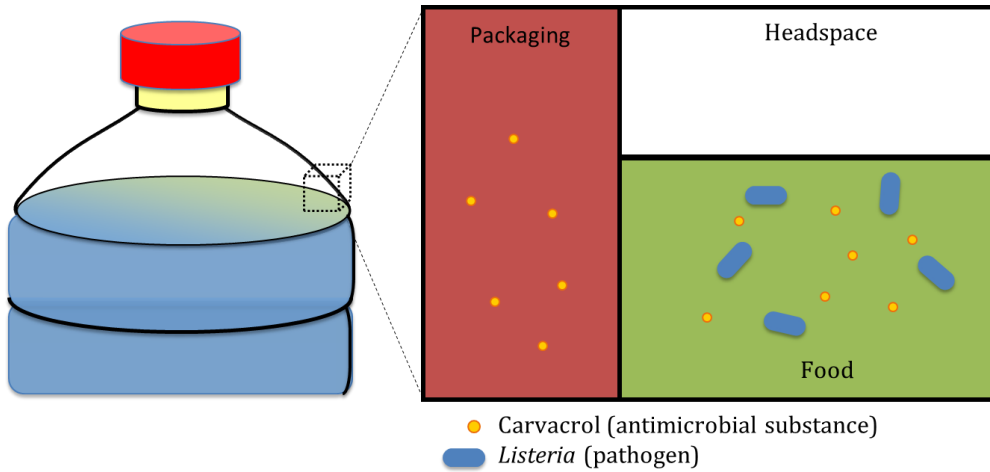
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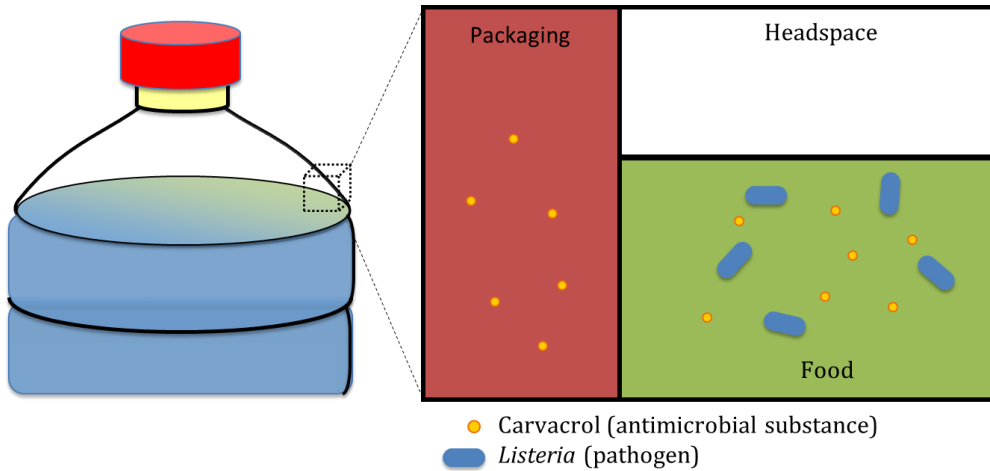
Motivation

- Design of active packaging



Motivation

- Design of active packaging



OBJECTIVES

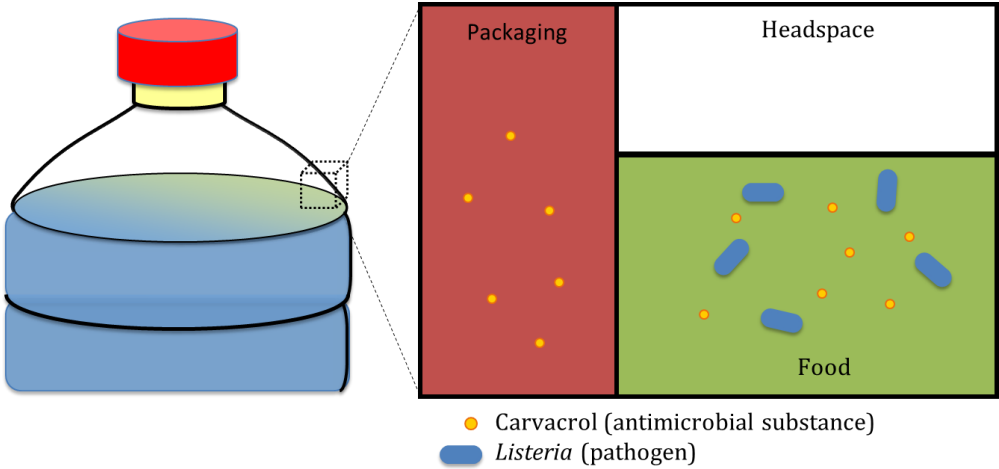
– to extend shelf-life:

Use by
Food Safety

Best Before
Quality

Motivation

- Design of active packaging



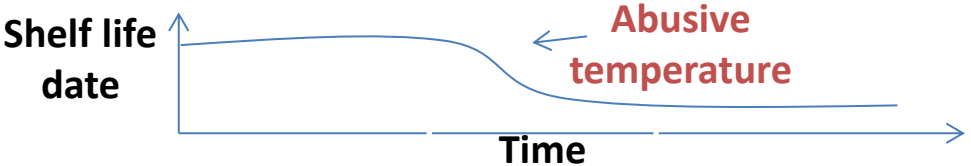
OBJECTIVES

– to extend shelf-life:

Use by
Food Safety

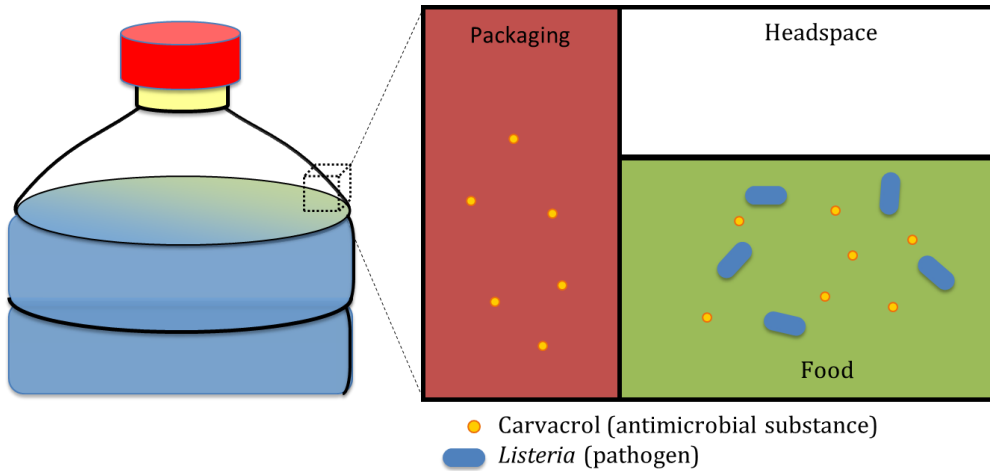
Best Before
Quality

– Smart labels (smart sensor) → update of shelf life



Motivation

- Design of active packaging



TOOLS

Modelling

- ➔ Predictive microbiology
- ➔ Biochemical dynamics
- ➔ Mass transfer (diffusion)

and optimization

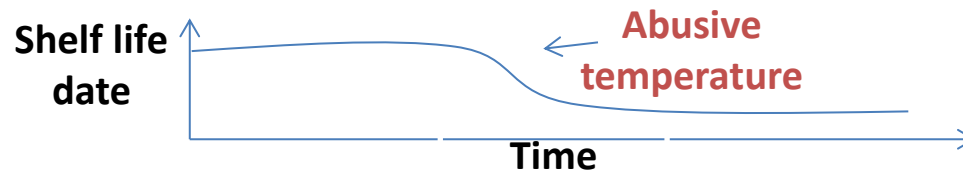
OBJECTIVES


– to extend shelf-life:

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– Smart labels (smart sensor) ➔ update of shelf life





Use by
Food Safety

maximize Use-by date (t_f)
 $t_f, L_i, C_{i,0}$

subject to Safety requirements,
Design constraints.

Fish Safety Requirements → Predictive microbiology

- **Listeria concentration at final time ≤ 2 logs**

- Assumed exponential growth

$$\frac{d \log_{10} L_m}{dt} = \mu^* \gamma_T \gamma_C$$

- Velocity depends on the temperature following (Rosso et al 1995)

$$\gamma_T = \frac{(T - T_-)(T - T_-)^2}{(T_* - T_-)[(T_* - T_-)(T - T_*) - (T_* - T_+)(T_* + T_- - 2T)]}$$

- Inhibition by carvacrol using the square root model (Dalgaard, 1995)

$$\gamma_C = \begin{cases} \left(1 - \frac{C_f}{MIC}\right)^2, & C_f < MIC \\ 0 & C_f \geq MIC \end{cases}$$

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Convenient Model To Describe the Combined Effects of Temperature and pH on Microbial Growth

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International Journal of Food Microbiology
Volume 29, Issues 2-3, April 1996, Pages 201-211



Regular paper

The particular behaviour of *Listeria monocytogenes*

under sub-optimal conditions

S. Bajard^{a,c}, L. Rosso^{a,b}, G. Fardel^c, J.P. Flandrois^c

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International Journal of Food Microbiology
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Regular paper

Modelling of microbial activity and prediction of shelf life for packed fresh fish

Paw Dalgaard^a

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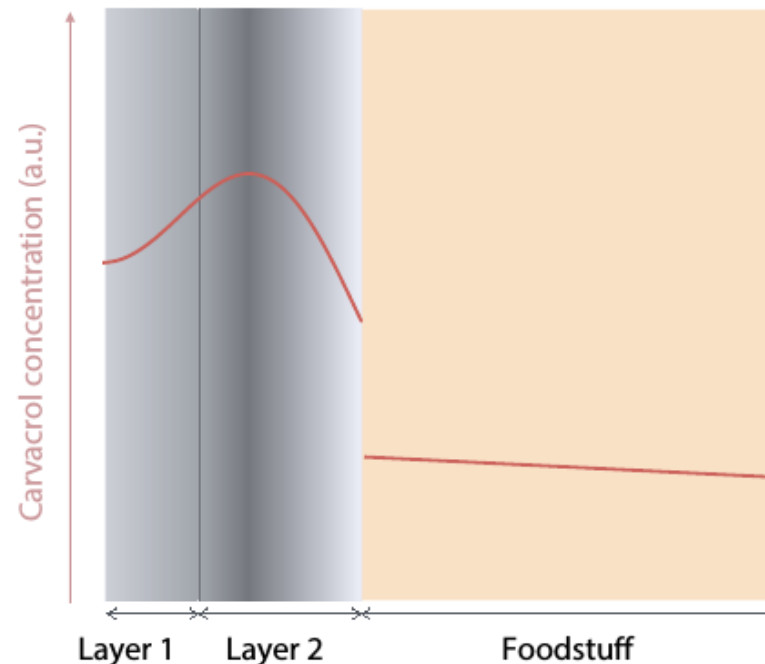
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Design Constraints → Packaging modelling

Packaging constraints

- Concentration of carvacrol in the food at all times $C_f(t) \leq 0.03 \text{ kg/m}^3$.
- Thickness of each layer: $12 \times 10^{-6} \mu\text{m} \leq L_i \leq 70 \times 10^{-6} \mu\text{m}$.
- Total thickness of the active packaging $35 \times 10^{-6} \mu\text{m} \leq L \leq 70 \times 10^{-6} \mu\text{m}$.
- Initial concentration of carvacrol in each layer $C_{i,0} \leq 80 \text{ kg/m}^3$.

→ Partial differential equations (PDEs) modelling the spatial distribution of carvacrol on package and food matrix



Use by

Active packaging desing to extend use-by date

Layer configuration	Use-by date	1 st layer		2 nd layer		3 rd layer	
	t_f	$C_{1,0}$	L_1	$C_{2,0}$	L_2	$C_{3,0}$	L_3
-	13.43	-	-	-	-	-	-

Use by


Active packaging desing to extend use-by date

Layer configuration	Use-by date	1 st layer		2 nd layer		3 rd layer	
	t_f	$C_{1,0}$	L_1	$C_{2,0}$	L_2	$C_{3,0}$	L_3
-	13.43	-	-	-	-	-	-
PP	14.94	49.2	70.0	-	-	-	-
LDPE	15.69	18.2	35.0	-	-	-	-
HDPE	13.51	80.0	70.0	-	-	-	-

Use by

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Layer configuration	Use-by date	1 st layer		2 nd layer		3 rd layer	
	t_f	$C_{1,0}$	L_1	$C_{2,0}$	L_2	$C_{3,0}$	L_3
-	13.43	-	-	-	-	-	-
PP	14.94	49.2	70.0	-	-	-	-
LDPE	15.69	18.2	35.0	-	-	-	-
HDPE	13.51	80.0	70.0	-	-	-	-
PP-LDPE	15.78	3.4	39.1	47.7	12.0	-	-
PP-HDPE	13.51	66.9	56.7	80.0	13.3	-	-
HDPE-LDPE	15.78	3.6	39.1	47.2	12.0	-	-
PP-HDPE-LDPE	15.78	57.0	13.3	3.6	42.2	48.7	12.0
LDPE-PP-LDPE	15.78	3.9	29.8	3.0	16.0	48.8	12.0
LDPE-HDPE-LDPE	15.78	57.0	13.3	3.6	42.2	48.7	12.0
HDPE-PP-LDPE	15.78	15.6	20.6	2.5	13.7	48.5	12.1
HDPE-PP-HDPE	13.51	78.9	33.0	17.0	23.8	80.0	13.3



Best Before Quality

maximize Best-before date (t_f)
 $t_f, L_i, C_{i,0}$

subject to Quality requirements,
Safety requirements,
Design constraints.

Fish Quality Requirements

- k-quality index

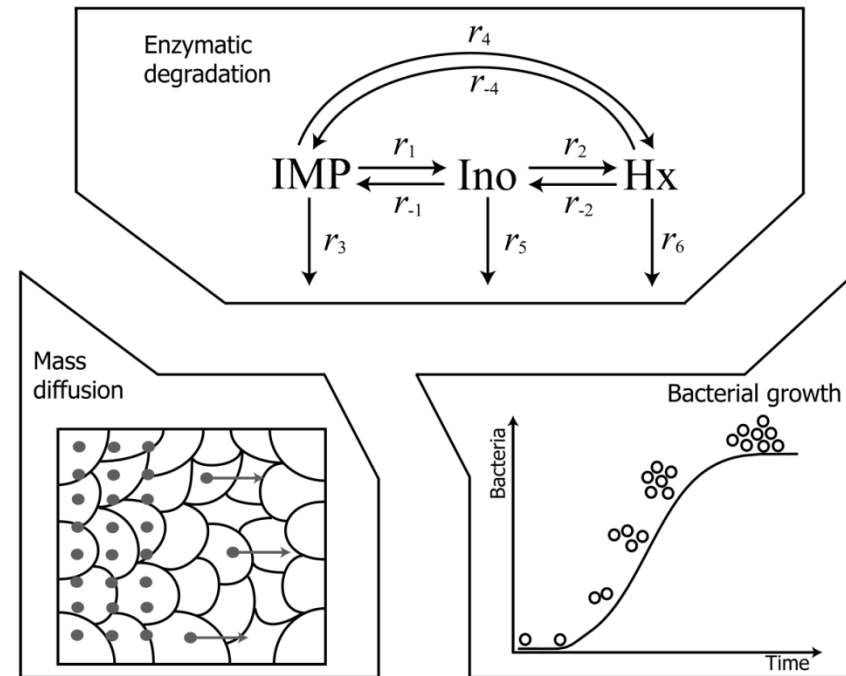
$$K_i(\%) = \frac{[\text{Ino}] + [\text{Hx}]}{[\text{IMP}] + [\text{Ino}] + [\text{Hx}]} \times 100$$

- To develop a mathematical model describing early quality losses in hake including:
 - Enzymatic degradation model
 - Bacterial growth model
 - Mass diffusion through the food matrix (leaching)



A mathematical model to predict early quality attributes in hake during storage at low temperature

C. Vilas ^a, A.A. Alonso ^a, J.R. Herrera ^b, M. Bernárdez ^b, M.R. García ^a



Best
Before

Active packaging to extend use-by and best-before date

Layer configuration	Use-by date	Best-before date	1 st layer		2 nd layer		3 rd layer	
	t_f	t_f	$C_{1,0}$	L_1	$C_{2,0}$	L_2	$C_{3,0}$	L_3
-	13.43	7.40	-	-	-	-	-	-

Best
Before

Active packaging to extend use-by and best-before date

Layer configuration	Use-by date	Best-before date	1 st layer		2 nd layer		3 rd layer	
	t_f	t_f	$C_{1,0}$	L_1	$C_{2,0}$	L_2	$C_{3,0}$	L_3
-	13.43	7.40	-	-	-	-	-	-
PP	14.94	8.58	63.9	70.0	-	-	-	-
LDPE	15.69	9.11	18.2	35.0	-	-	-	-
HDPE	13.51	7.44	80.0	70.0	-	-	-	-

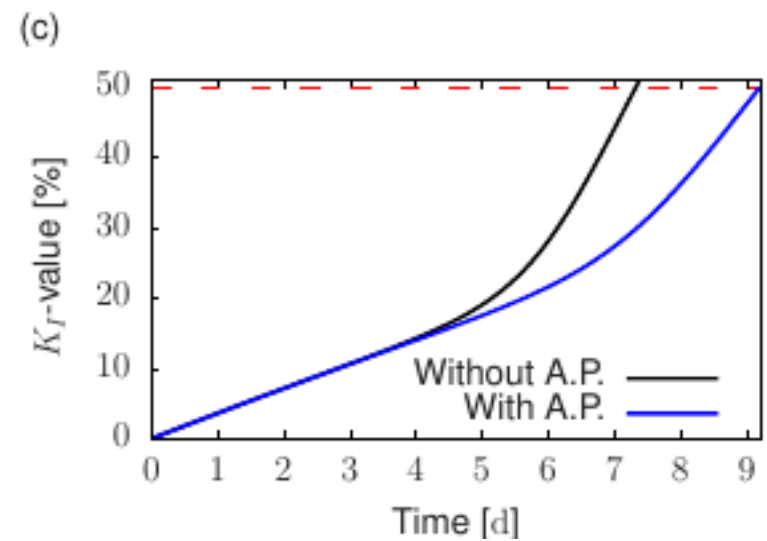
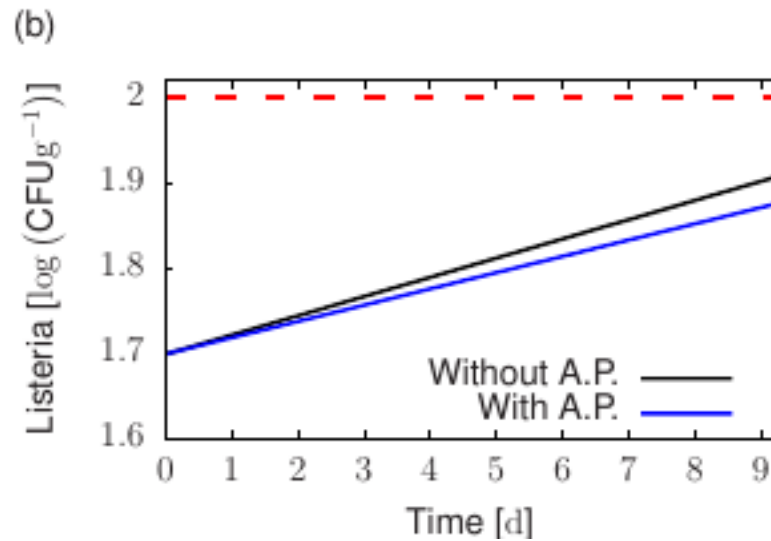
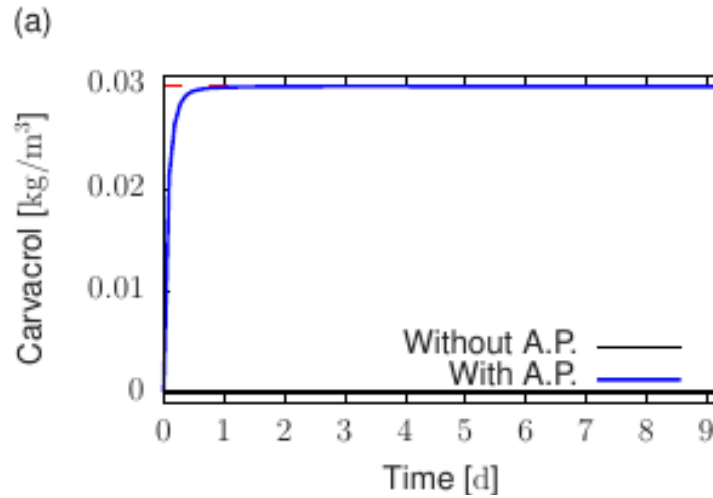
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HDPE-LDPE	15.78	9.20	3.6	37.0	47.2	12.0	-	-
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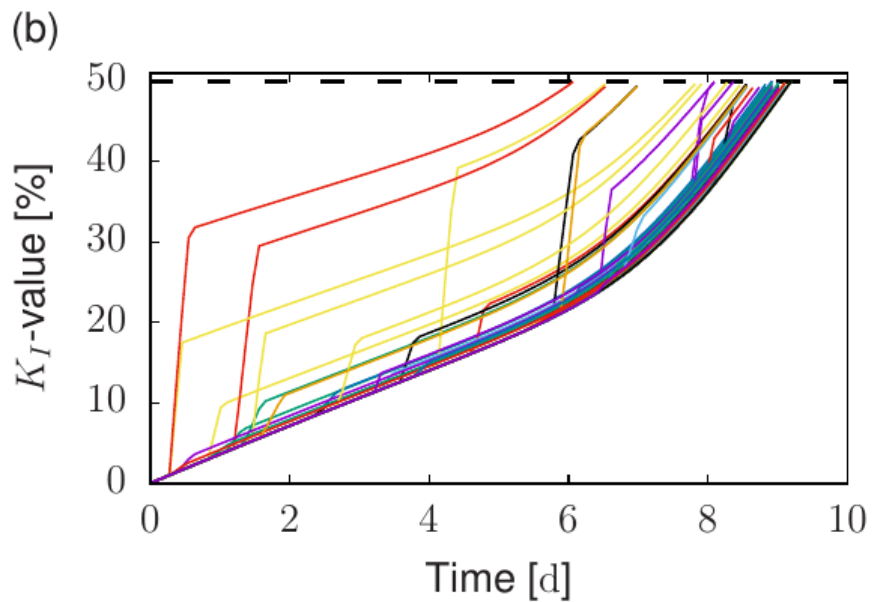
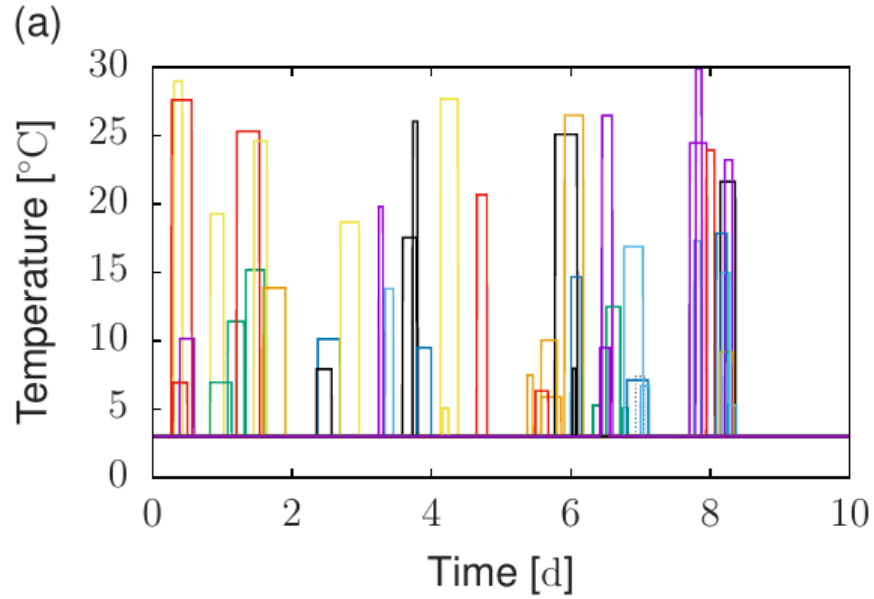
Best
Before

Active packaging to extend use-by and best-before date





Effect of transport/storage temperature on shelf-life







Smart label/sensor → Consumers industry 4.0

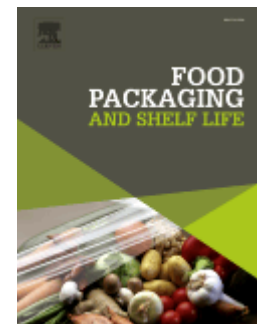


Conclusions

- Tool to optimally design active packaging to extend shelf combining predictive microbiology and diffusion models of active packaging



- Study the effect of transport/storage on shelf life date using active packaging
- Details about software and general methodology:
 - Vilas, Mauricio-Iglesias, García «Model-based design of smart active packaging systems with antimicrobial activity»
submitted to Food Packaging and Shelf Life



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