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FURAN-BASED POLYESTERS LOADED WITH NISIN FOR SUSTAINABLE ANTIMICROBIAL PACKAGING

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SPOKE, WP & TASK

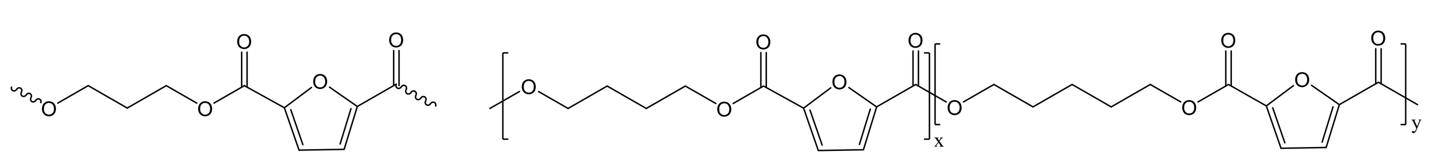
Spoke 8, WP 8.1, Task 8.1.3

INTRODUCTION & AIM OF THE WORK

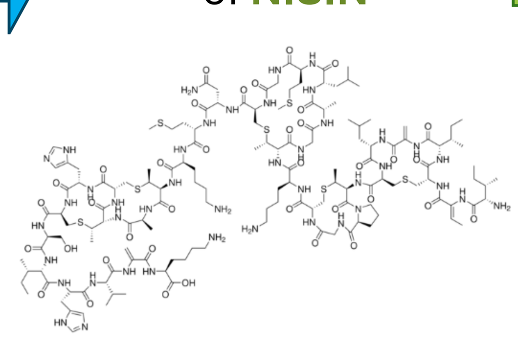
The development of high-performance polymeric materials derived from renewable sources with multifunctional characteristics, is one of the key points to achieve a sustainable economy. This work focuses on the realization of bio-based formulations from two different furan-based polyesters and natural preservatives, to obtain innovative/active food packaging. As preservative, **nisin**, a polycyclic antibacterial peptide produced by *Lactococcus lactis* [1], was mixed in 2.5 wt% amount, with the homopolymer **poly(trimethylene furanoate)**, PTF, and the copolymer **poly(butylene/pentamethylene furanoate)**, P(BPeF). These two polymers belong to the family of materials containing 2,5-furadicaroxylic acid (FDCA), a monomer which is being attracting considerable attention among bio-based building blocks, since it can be derived from cellulosic non-food crops and wastes [2]. More in detail, the mechanical properties of the formulations evidenced a **modulation of flexibility and toughness**, in particular in P(BPeF), due to the presence of nisin, keeping at the same time the **thermal stability**, which is a key feature of these polyesters, as well as their thermal transitions. The evaluation of the functional properties highlighted the preservation of **excellent gas barrier** characteristics of PTF and P(BPeF). Lastly, the addition of nisin allows for the implementation of **antibacterial features**, absent in the pristine polymers, as the prepared formulations showed antimicrobial activity, by disc diffusion assay, against *Lactiplantibacillus plantarum* and *Listeria monocytogenes*. PTF loaded with nisin was tested also in ACE juice, pH 4.5, inoculated with *Listeria monocytogenes* at 10^2 CFU/mL and stored at 4°C. After 8 days of incubation, *L. monocytogenes* growth decreased under the detection limit in the sample with active packaging, while in the control the pathogenic species remained constant during the juice shelf-life.

MATERIALS & METHODS

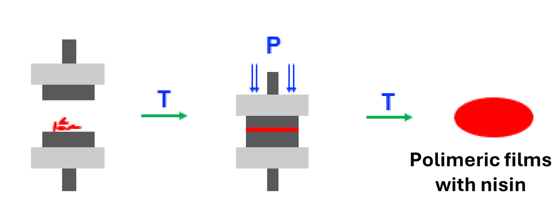
- PTF homopolymer and P(BPeF) copolymer (containing 30 mol% of PeF counits) have been synthesized by **TWO-STEP MELT POLYCONDENSATION** (STEP 1: 180 °C, N_2 flux, p = atm; STEP 2: 220 °C, p = 0.1 mbar) using titanium tetrabutoxide (TBT) as catalyst.
- Molecular characterization by **^{1}H-NMR SPECTROSCOPY** and **GPC**.



Loading with 2.5 wt% of **NISIN**



FILMS by compression moulding



- **THERMAL** (TGA, DSC) & **MECHANICAL** (stress-strain) characterization
- **GAS PERMEABILITY** measurements
- Evaluation of **ANTIBACTERIAL FEATURES**

RESULTS

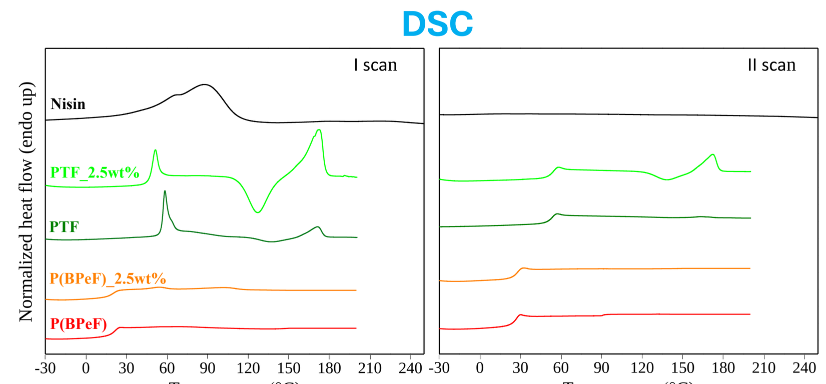
THERMAL CHARACTERIZATION

TGA

	T_{onset} °C	T_{max} °C
PTF	374	388
PTF_2.5wt%	371	392
P(BPeF)	370	391
P(BPeF)_2.5wt%	366	385

High & comparable **thermal stability** for all the samples, not affected by introduction of nisin

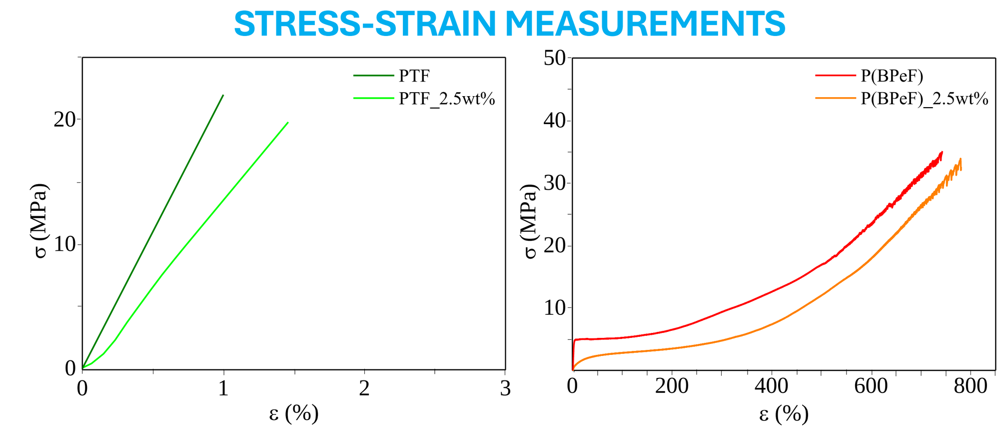
DSC



The main thermal transitions were not altered upon the introduction of nisin

MECHANICAL CHARACTERIZATION

STRESS-STRAIN MEASUREMENTS



Different mechanical response, for different kinds of packaging

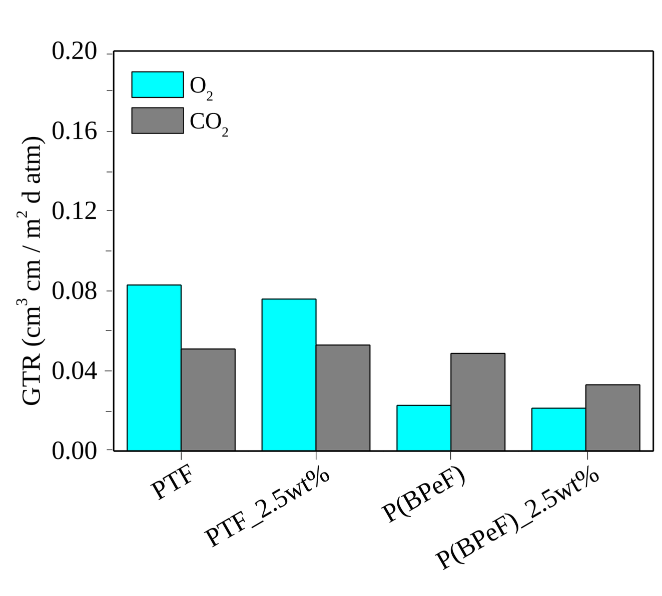
	E MPa	σ_B MPa	ε_B %
PTF	2370±230	21±3	2±1
PTF_2.5wt%	1450±230	22±3	2±1
P(BPeF)	253 ± 19	34 ± 3	737 ± 56
P(BPeF)_2.5wt%	42 ± 6	33 ± 2	751 ± 51

- **Decrease of rigidity** (E↓) due to the presence of nisin;
- P(BPeF): the **exceptional flexibility** is kept.

GAS BARRIER PROPERTIES EVALUATION

GAS TRANSMISSION RATE

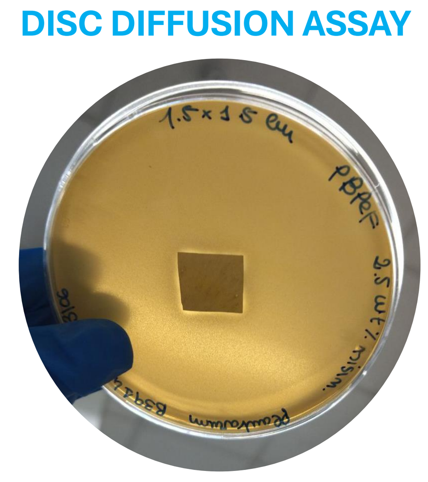
	O_2-TR cm^3 cm m^{-2} d^{-1} atm^{-1}	CO_2-TR cm^3 cm m^{-2} d^{-1} atm^{-1}
PTF	0.083	0.051
PTF_2.5wt%	0.076	0.053
P(BPeF)	0.023	0.049
P(BPeF)_2.5wt%	0.021	0.033



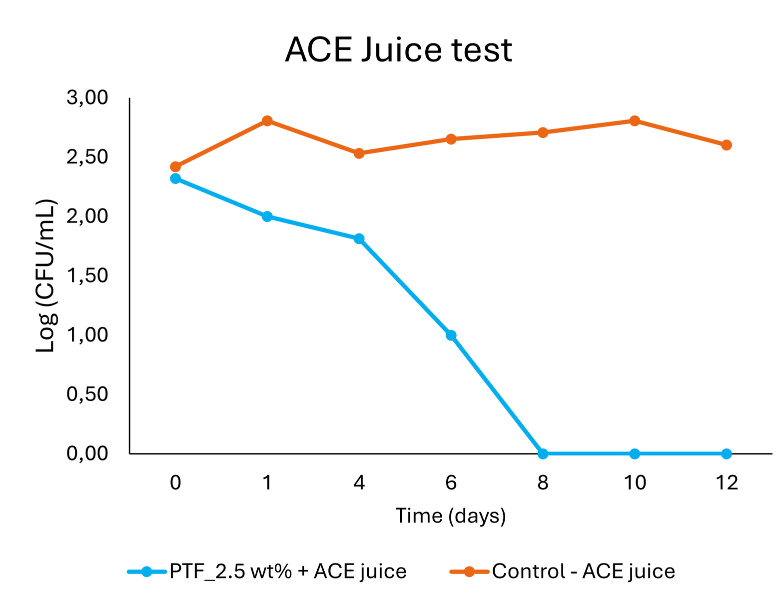
The **excellent barrier properties** of the furan-based polymers are kept in the formulations containing nisin.

ANTIBACTERIAL ACTIVITY

DISC DIFFUSION ASSAY



Halo of inhibition of the film **P(BPeF)_ 2.5 wt%**, against *L. plantarum* B39.1. 4A.



PTF_2.5 wt% was tested in ACE juice (pH 4.5) inoculated with *Listeria monocytogenes* (10^2 CFU/mL) and stored at 4°C. After 8 days, *Listeria* levels in the sample with active packaging fell below the detection limit (1 log CFU/mL), while in the control sample the pathogen remained stable throughout the shelf life of the juice.

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[1] Siroli L, Camprini L, Pisano MB, Patrignani F, Lanciotti R. Volatile Molecule Profiles and Anti-*Listeria monocytogenes* Activity of Nisin Producers *Lactococcus lactis* Strains in Vegetable Drinks. *Front Microbiol.* **2019** Mar 26;10:563. doi: 10.3389/fmicb.2019.00563.
[2] Zhao X, Wang Y, Chen X, Yu X, Li W, Zhang S, Meng X, Zhao ZM, Dong T, Anderson A, Aiyedun A, Li Y, Webb E, Wu Z, Kunc V, Ragauskas A, Ozcan S, Zhu H. Sustainable bioplastics derived from renewable natural resources for food packaging, *Matter* **2023**, 6(1), 97-127. https://doi.org/10.1016/j.matt.2022.11.006.

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