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G.G. Buonocore & E. Torrieri

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This Special Issue of the Italian Journal of Food Science collects the presentations given at the "SLIM 2019, Shelf-Life International Meeting" organized by the Italian Scientific Group of Food Packaging (GSICA), the Department Of Agricultural Science, University Of Naples Federico II and the Institute Of Polymers, Composites And Biomaterials, National Research Council, held in Naples, Italy, on June 17-20, 2019.

These papers were reviewed by the Scientific Committee of SLIM 2019 before their presentation but they did not undergo the conventional reviewing system of the Italian Journal of Food Science.

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Aim

The Italian Journal of Food Science is an international journal publishing original, basic and applied papers, reviews, short communications, surveys and opinions on food science and technology with specific reference to the Mediterranean Region. Its expanded scope includes food production, food engineering, food management, food quality, shelf-life, consumer acceptance of foodstuffs, food safety and nutrition, energy and environmental aspects of food processing on the whole life cycle.

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INTRODUCTION

The current volume includes the selected manuscripts peer-reviewed by the Scientific Committee of the 9th Shelf Life International Meeting (SLIM 2019), which was held in Naples, ITALY on 17-20 June 2019. The conference was organized by the Department of Agricultural Science, University of Naples Federico II and the Institute of Polymers, Composites and Biomaterials, National Research Council, in collaboration with the Italian Scientific Group of Food Packaging (GSICA).

The focus of the 9th SLIM was on *Shelf life assessment, prediction and extension by applying new, safe and sustainable materials and technologies*. The conference purposed to offer a knowledge sharing platform for experts around the world with the aim to disseminate the fundamental aspects, research findings as well as industry applications and innovation on food shelf life and sustainability. The diversity of the attendees and the careful selection of the contributes from both industries and academic institutions significantly contributed to the advancement of knowledge and to promote scientific discussions in the fields of food science, packaging and shelf life.

The Conference Proceedings, published once again with the support of Chiriotti Publisher as a special issue of the Italian Journal of Food Science, contain research reports presented as oral and poster papers during SLIM 2019. The conference was organized into five sessions: Shelf Life Assessment and Prediction, New Technologies for Shelf Life Extension, Safety Issues of Packaging Materials, New Materials for Shelf Life Extension, Sustainability and Shelf Life. The conference features multidisciplinary lectures from five distinguished keynote speakers, 37 oral presentations, and 55 poster presentations; and the participants who contribute to the forum are from fourteen countries, which are Belgium, Brazil, Colombia, Germany, Greece, Italy, Mexico, Philippine, Portugal, Korea, Spain, UK, USA and Thailand.

As it was officially announced within the final remarks of the conference, the 10th Shelf Life International Meeting (SLIM 2022) will be held in Bogotà, Colombia. The Instituto de Ciencia y Tecnología de Alimentos (ICTA) of the National University of Colombia confirmed its commitment to organize the next conference. The local organizing committee is chaired by Prof. Carlos Alberto Fuenmayor. Further useful information will be disclosed soon. Hope to see you at our next SLIM 2022 meeting!

G.G. Buonocore & E. Torrieri

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ANTIMICROBIAL NANOFIBERS IN FOOD ACTIVE PACKAGING

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ABSTRACT

Among encapsulation techniques of antimicrobial substances, electrospinning outstands for enabling the synthesis of polymeric nanofibers that act as micro- or nanocapsules, and release systems. A myriad of polymers has been successfully electrospun to obtain ultra-thin fibers, including synthetic polymers, biomacromolecules, and their composites. In the context of food packaging, these materials have advantages such as mechanical resistance, large surface areas/porosities, and responsiveness to external stimuli. Ultra-thin fibers have been used to incorporate antimicrobial substances. The resulting functionalized nanofibers have been proved as promising devices in a shelf-life extension of various food models. The target microorganisms against which these materials have been tested comprise *S. aureus*, *E. coli*, *Salmonella* spp., *Pseudomonas* sp., *Rhizoctonia*. In this review, a brief literature examination of the experimental evidence of electrospun nanofibers containing antimicrobials as food shelf life extenders is presented

Keywords: nanofibers, electrospinning, food active packaging, antimicrobial compounds

1. INTRODUCTION

Active packaging materials and devices are designed in order to have a relevant role in the conservation of food, beyond being a barrier between the product and the external environment (MAJID *et al*., 2016). Essential oils, polyphenol-rich plant extracts, silver nanoparticles, and antimicrobial polymers and peptides are among antimicrobial agents that have been used for active packaging purposes. These agents inhibit microorganism cellular processes, thus contributing to the improvement of food shelf life, and might represent an alternative to the use of preservatives or even thermal processing; however, many of these substances are themselves prompt to deterioration (ZHANG *et al*., 2018).
The use of nanomaterials to encapsulate antimicrobial substances represents a step forward in the design of packaging systems with controlled release of food protective agents. In this context, electrospinning is an effective and versatile electrohydrodynamic technique, used to manufacture fibers on a sub-micron to nano-scale from various polymeric materials (FUENMAYOR and COSIO, 2016). For the elaboration of these structures, a solution containing the dissolved polymer is pumped at a controlled flow rate towards a needle (spinneret) where a high voltage is applied (Sullivan *et al*., 2014). In this polymer solution, antimicrobial agents can be incorporated, in order to obtain functionalized polymer nanofibers. Thus, structures with hydrophilic or hydrophobic character will be obtained, depending on the features of the polymer and bioactive compounds incorporated in the electrospinning solution/dispersion, offering an advantage in terms of controlled release of active agents (SOARES *et al*., 2018). The principle and mechanism of the technique have been widely studied (ZHANG *et al*., 2018; WEN *et al*., 2017), and are beyond the scope of this review. Therefore, this article presents current developments in the field of antimicrobial compounds encapsulation in nanofibers intended for food shelf life extension.

2. ENCAPSULATION AND RELEASE OF NATURAL ANTIMICROBIALS

Antimicrobial substances, especially those of natural origin, such as natural essential oils, absolutes, essences, extracts, resins, infusions, etc. are of great interest for the active packaging industry. Nevertheless, their efficient encapsulation and release represent a major challenge, considering the fact that they are very sensitive to heat, oxygen, and light. Because of their submicron to nano-scale diameter and very large surface area, electrospun fibers may offer additional advantages compared to film and sheet carriers, as they are more responsive to changes in the surrounding atmosphere, which enhances a tunable release of the entrapped compounds (VEGA-LUGO and LIM, 2009). Moreover, since the electrospinning process takes place at ambient conditions, the produced fibers are more suitable to encapsulate thermally-labile substances than fibers prepared by conventional processes, or other encapsulation methods, such as spray drying and fluid bed coating (LESMES and MCCLEMENTS 2009; XU *et al*., 2006). In this framework, electrospun nanofibers of PVA have been used to encapsulate allyl isothiocyanate (AITC) (AYTAC *et al*., 2014). Pullulan and β-cyclodextrin emulsions in water have also been electrospun for the encapsulation of volatile antimicrobials limonene (FUENMAYOR *et al*., 2013) and perillaldehyde (MASCHERONI *et al*., 2013), allowing for a controlled release of the antimicrobial, triggered by humidity. Other examples include electrospun zein, which was used to encapsulate rosehip seed oil (REO). Electrospun REO-loaded zein fibers improved the shelf-life of peeled and segmented bananas, demonstrating its potential as active packaging material (YAO *et al*., 2016).

3. ELECTROSPUN NANOFIBERS WITH *IN VITRO* EVIDENCE AS ANTIMICROBIAL FOOD PACKAGING MATERIALS

Most of the existing evidence on the potential of electrospun nanofibers as encapsulation systems for food preservation against microbial spoilage, relies on *in vitro* antimicrobial testing, as presented in Table 1.

Interestingly, most of the electrospun polymer materials within this group of reports are edible or food-grade biopolymers. *S. aureus* and *E. coli* are the most common target microorganisms for testing the antimicrobial activity of electrospun nanofibers, being representative of Gram-positive and Gram-negative bacteria, respectively (Jenab *et al.*, 2017). The *in vitro* analytical methods for evaluating the antimicrobial activity of electrospun nanofibers are diverse semi-quantitative tests aimed at measuring the microbial growth after contact with the antimicrobial packaging material.

The disk diffusion method is a technique often selected. However, according to Espitia and Andrade (2015), this method might present slight variations from one experiment to another due to target microorganisms, and experimental variables, such as incubation time and temperature. Other microbiological techniques include the optical density (OD) measurement, the colony counting method and the broth microdilution method for determining inhibitory minimum concentration (MIC). In other studies, viability and bacterial adherence have been determined qualitatively in terms of biofilm formation capacity (CLAVIJO-GRIMALDO *et al.*, 2019).

Table 1. Electrospun nanofibers intended as antimicrobial food packaging tested *in vitro*.

Polymeric nature of nanofibers	Incorporated compounds	Target microorganisms	Antimicrobial test*	Reference
Chitosan nanofibers	Poly(ethylene oxide) and silver nitrate, as a co-electrospinning polymer and silver nanoparticle precursor	*E. coli*	Disk diffusion method	(Annur *et al.*, 2015)
Blend of Poly(lactide-co-glycolide) (PLGA) and Chitosan	The nanofiber was functionalized with graphene oxide decorated with silver nanoparticles	*E. coli* *Pseudomonas aeruginosa* *S. aureus*	Colony counting method	(Faria *et al.*, 2015)
Chitosan–polyethylene oxide	zeolitic imidazolate framework nanoparticles	*S. aureus* *E. coli*	Colony counting method - AATCC test method 100–2004	(Kohsari *et al.*, 2016)
PLA and glycidyl methacrylate	Cellulose nanocrystals Lignin nanoparticles	*Pseudomonas syringae pv. tomato*	Colony counting method	(Yang *et al.*, 2016)
Cellulose	Lysozyme	*Listeria monocytogenes* *Yersinia enterocolitica*	OD measurement	(Bayazid *et al.*, 2018)
Pullulan	Palindromic peptide Lfcin B	*E. coli* *S. aureus*	Disk diffusion method to determinate the MIC	(Román *et al.*, 2019)
Tragacanth	Peppermint oil	*E. coli* *S. aureus*	Disk diffusion method	(Ghayempour and Montazer, 2019)
Zein	Curcumin	*E. coli* *S. aureus*	OD measurement	(Wang *et al.*, 2019)

*OD: Optical density; TSB broth: Tryptic soy broth; Minimum Inhibitory Concentration (MIC).

4. ELECTROSPUN NANOFIBERS FOR FOOD SHELF LIFE EXTENSION

The application of these materials in food matrixes is more important, but still limited, as presented in Table 2. Target microorganisms include Gram-positive such as *L. monocytogenes* and *S. aureus*, as well as Gram-negative such as *E. coli* and *Salmonella* (Erbay *et al*., 2017). Antimicrobial studies in food matrixes also include the electrospun nanofibers effect against fungi, such as *Aspergillus niger* and *Penicillium* (Table 2).

Table 2. Electrospun nanofibers potential applications in food preservation.

Polymeric nature of the electrospun nanofiber	Incorporated substances	Target microorganisms	Food matrix	Reference
Polyvinyl alcohol	cinnamon essential oil /β-cyclodextrin inclusion complex	*E. coli* *S. aureus*	Strawberries	(Wen *et al*., 2016b)
Poly(ε-caprolactone)	*Urtica dioica* L. extract incorporated into Whey Protein Isolated complex at different concentrations	Total aerobic mesophilic bacteria lactic acid bacteria	Rainbow trout fillets	(Erbay *et al*. 2017)
Blend of polyvinyl alcohol and β-cyclodextrin	Cinnamon essential oil and lysozyme	*Penicillium* *Salmonella enteritidis* *Aspergillus niger*	Strawberries	(Feng *et al*. 2017)
Gelatin	Rosemary essential oil	*Campylobacter jejuni*	Chicken	(Lin *et al*., 2018)
Chitosan	Chrysanthemum essential oil	*L. monocytogenes*	Meat	(Lin *et al*. 2019)
Gelatin	Moringa oil	*L. monocytogenes* *S. aureus*	Cheese	(Lin *et al*. 2019)
Silk fibroin	Thyme essential oil	*Salmonella typhimurium*	Poultry meat	(Lin *et al*. 2019)

Results from the application of antimicrobial nanofibers in packaging with food matrixes ensure the potential application of these materials in food preservation. However, more studies are needed in order to elucidate the release mechanism of antimicrobial agents from the packaging material to the food matrix, as well as the molecular interaction between the antimicrobial agent, the target microorganisms and the macro and microstructural components of the food matrix.

CONCLUSIONS AND FUTURE PERSPECTIVES

There is substantial evidence on the potential of antimicrobial nanofibers for food preservation. However, further experimental evidence on wider variety of food models is needed. Moreover, studies on the use of nanofibers for bioactive peptides and beneficial microorganism encapsulation is limited, which highlights a future trend. Finally, the lack of actual evidence on the toxicity of nanofibers as food contact materials, as well as the availability of electrospinning setups for industrial applications, are important challenges of this technology.

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