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# PACKAGING **SCIENCE**

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FONDAZIONE™ CARTA ETICA del Packaging

# Nanoparticelle a base di metallo nelle tecnologie di confezionamento e rivestimento alimentare: Review

La sicurezza alimentare ha continuato ad essere un argomento di interesse nel nostro mondo a causa della crescente domanda di alimenti. Molte tecnologie sono state adottate per migliorare l'offerta alimentare e ridurre il divario della domanda. Pertanto, il tentativo di utilizzare la nanotecnologia per migliorare la sicurezza alimentare e aumentare l'offerta è emerso a causa delle gravi carenze delle tecnologie convenzionali, che le hanno rese insufficienti per soddisfare la continua domanda di prodotti alimentari. Pertanto, le nanoparticelle sono state identificate per svolgere un ruolo importante nelle aree che coinvolgono la produzione alimentare, la protezione e le estensioni della durata di conservazione.

*biomolecules* MDPI

*Review*

## Metal-Based Nanoparticles in Food Packaging and Coating Technologies: A Review

**Jerry O. Adeyemi * and Olaniyi A. Fawole ***

Postharvest and Agroprocessing Research Centre, Department of Botany and Plant Biotechnology, University of Johannesburg, P.O. Box 524, Auckland Park, Johannesburg 2006, South Africa
* Correspondence: jerryadeyemi1st@gmail.com (J.O.A.); olaniyif@uj.ac.za (O.A.F.)

**Abstract:** Food security has continued to be a topic of interest in our world due to the increasing demand for food. Many technologies have been adopted to enhance food supply and narrow the demand gap. Thus, the attempt to use nanotechnology to improve food security and increase supply has emerged due to the severe shortcomings of conventional technologies, which have made them insufficient to cater to the continuous demand for food products. Hence, nanoparticles have been identified to play a major role in areas involving food production, protection, and shelf-life extensions. Specifically, metal-based nanoparticles have been singled out to play an important role in manufacturing materials with outstanding properties, which can help increase the shelf-life of different food materials. The physicochemical and biological properties of metal-based nanoparticles, such as the large surface area and antimicrobial properties, have made them suitable and adequately useful, not just as a regular packaging material but as a functional material upon incorporation into biopolymer matrices. These, amongst many other reasons, have led to their wide synthesis and applications, even though their methods of preparation and risk evaluation remain a topic of concern. This review, therefore, briefly explores the available synthetic methods, physicochemical properties, roles, and biological properties of metal-based nanoparticles for food packaging. Furthermore, the associated limitations, alongside quality and safety considerations, of these materials were summarily explored. Although this area of research continues to garner attention, this review showed that metal-based nanoparticles possess great potential to be a leading material for food packaging if the problem of migration and toxicity can be effectively modulated.

**Keywords:** food security; nanoparticles; food packaging; biopolymers; biological properties

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## Progressi della ricerca sulle sostanze perfluoroalchiliche nell′olio commestibile: Review

Le sostanze perfluoroalchiliche (PFAS) sono state ampiamente utilizzate in diversi tipi di applicazioni di consumo e industriali come tensioattivi, prodotti per la pulizia della casa, tessuti, tappeti, cosmetici, schiume antincendio e imballaggi alimentari a causa della loro buona stabilità e speciali proprietà fisico-chimiche di idrofobicità, oleofobicità, resistenza alle alte temperature, ecc. Nel frattempo, i PFAS sono considerati un inquinante organico emergente a causa della loro persistenza e potenziale tossicità per la salute umana. I PFAS si verificano nell′olio commestibile, una componente importante della dieta globale, principalmente in tre modi: contaminazione delle materie prime, contaminazione del processo e migrazione dai materiali a contatto con l′olio.

foods MDPI

*Review*

# Research Progress of Perfluoroalkyl Substances in Edible Oil—A Review

**Yingyi Han and Xueli Cao ***

Beijing Advanced Innovation Center for Food Nutrition and Human Health, Beijing Technology and Business University, Beijing 100048, China; hanyi@btbu.edu.cn
* Correspondence: caoxl@th.btbu.edu.cn; Tel.: +86-010-68984485

**Abstract:** Perfluoroalkyl substances (PFASs) have been widely used in different types of consumer and industrial applications such as surfactants, household cleaning products, textiles, carpets, cosmetics, firefighting foams, and food packaging because of their good stability and special physicochemical properties of hydrophobicity, oleophobicity, high temperature resistance, etc. Meanwhile, PFASs are considered an emerging organic pollutant due to their persistence and potential toxicity to human health. PFASs occur in edible oil, an important component of the global diet, mainly in three ways: raw material contamination, process contamination, and migration from oil contact materials. Thus, the occurrence of PFAS in edible oils has drawn more and more attention in recent years. In this work, the pertinent literature of the last two decades from the Web of Science database was researched. This review systematically addressed the potential sources, the contamination levels, and the progress of the determination of PFASs in edible oil. It aims to provide a relatively whole profile of PFASs in edible oil, render assistance to minimise human exposure to PFASs, and standardise the detection methods of perfluoroalkyl substances in edible oil.

**Keywords:** perfluoroalkyl substances; edible oil; pre-treatment; determination

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## Thymol@Natural nanoibridi di zeolite per idrogel a base di chitosano/polivinilalcol-alcol applicati come tamponi attivi.

Attualmente, il risparmio alimentare, un′economia circolare e zero impronte ambientali sono di grande interesse. Sono stati intensificati gli sforzi scientifici per migliorare la conservazione degli alimenti utilizzando metodi ″verdi″. Anche se le sostanze chimiche potrebbero raggiungere tali obiettivi in modo efficace, la tendenza globale contro l′″effetto serra″ suggerisce l′uso di materiali biobased rispettosi dell′ambiente per questo scopo. In questo studio, il promettente biopolimero chitosano è incorporato con il promettente polimero polivinilico biodegradabile per produrre una matrice biopolimerica migliorata. Questo biopolimero biodegradabile è stato ulteriormente miscelato in modo omogeneo con materiale nanoibrido al 15% di timolo/nano-zeolite.

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# Thymol@Natural Zeolite Nanohybrids for Chitosan/Polyvinyl-Alcohol-Based Hydrogels Applied as Active Pads

**Constantinos E. Salmas [1,*], Eleni Kollia [2], Learda Avdylaj [2], Anna Kopsacheili [2], Konstantinos Zaharioudakis [3], Stavros Georgopoulos [3], Areti Leontiou [3], Katerina Katerinopoulou [3], George Kehayias [3], Anastasios Karakassides [1], Charalampos Proestos [2,*] and Aris E. Giannakas [3,*]**

[1] Department of Material Science and Engineering, University of Ioannina, 45110 Ioannina, Greece; tasos.karakassides@gmail.com

[2] Laboratory of Food Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, Zografou, 15771 Athens, Greece; elenikollia@chem.uoa.gr (E.K.); leardaavdy@chem.uoa.gr (L.A.); akopsacheili@chem.uoa.gr (A.K.)

[3] Department of Food Science and Technology, University of Patras, 30100 Agrinio, Greece; zacharioudakis.k@upatras.gr (K.Z.); sgeorgop@upatras.gr (S.G.); aleontiu@upatras.gr (A.L.); akaterin@upatras.gr (K.K.); gkechagi@upatras.gr (G.K.)

* Correspondence: ksalmas@uoi.gr (C.E.S.); harpro@chem.uoa.gr (C.P.); agiannakas@upatras.gr (A.E.G.)

**Abstract:** Currently, food saving, a circular economy, and zero environmental fingerprints are of major interest. Scientific efforts for enhanced food preservation using "green" methods have been intensified. Even though chemicals could achieve such targets effectively, the global trend against the "greenhouse effect" suggests the use of environmentally friendly biobased materials for this purpose. In this study, the promising biopolymer chitosan is incorporated with the promising biodegradable polymer polyvinyl alcohol to produce an improved biopolymeric matrix. This biodegradable biopolymer was further mixed homogeneously with 15% thymol/nano-zeolite nanohybrid material. The properties of the final developed film were improved compared to the relevant values of chitosan/polyvinyl alcohol film. The mechanical properties were enhanced significantly, i.e., there was a 34% increase in Young's modulus and a 4.5% increase in the ultimate tensile strength, while the antioxidant activity increased by 53.4%. The antibacterial activity increased by 134% for *Escherichia coli*, 87.5% for *Staphylococcus aureus*, 32% for *Listeria monocytogenes*, and 9% for *Salmonella enterica*. The water vapor diffusion coefficient and the oxygen permeability coefficient decreased to −51% and −74%, respectively, and thus, the water vapor and oxygen barrier increased significantly. The active pads were used in strawberries, and the antimicrobial activity evaluation against the mold of fungi was carried out. The visual evaluation shows that the active pads could extend the shelf life duration

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## Realizzazione di film ecologici a base di sodio-alginato resistenti all'acqua miscelati con un estratto acquoso polifenolico da scarti di vinacce d'uva per potenziali applicazioni di imballaggio alimentare

Sono stati studiati film a base di sodio-alginato resistenti all'acqua e rispettosi dell'ambiente per sviluppare materiali funzionali per prolungare la durata di conservazione degli alimenti. È stato preparato un film a base di alginato stabile all'acqua, utilizzando sia l'approccio di gelificazione interno che esterno in presenza di CaCl2. Per applicare questo film agli imballaggi alimentari e preservare così la qualità degli alimenti, lo scopo di questo lavoro è quello di eseguire una caratterizzazione chimico-fisica dei materiali proposti, evidenziandone le caratteristiche principali e la stabilità nelle diverse condizioni di lavoro.

International Journal of *Molecular Sciences* MDPI

*Article*

# Realizing Eco-Friendly Water-Resistant Sodium-Alginate-Based Films Blended with a Polyphenolic Aqueous Extract from Grape Pomace Waste for Potential Food Packaging Applications

**Jennifer Gubitosa [1,*,†], Vito Rizzi [1,†], Cosma Marasciulo [1], Filippo Maggi [2], Giovanni Caprioli [2], Ahmed M. Mustafa [2], Paola Fini [3], Nicoletta De Vietro [4], Antonella Maria Aresta [4] and Pinalysa Cosma [1,3,*]**

1 Dipartimento di Chimica, Università degli Studi "Aldo Moro" di Bari, Via Orabona, 70126 Bari, Italy; vito.rizzi@uniba.it (V.R.); c.marasciulo3@studenti.uniba.it (C.M.)
2 Chemistry Interdisciplinary Project (ChIP) Research Center, School of Pharmacy, University of Camerino, Via Ma-donna delle Carceri 9/B, 62032 Camerino, Italy; filippo.maggi@unicam.it (F.M.); giovanni.caprioli@unicam.it (G.C.); ahmed.mustafa@unicam.it (A.M.M.)
3 Consiglio Nazionale delle Ricerche CNR-IPCF, UOS Bari, Via Orabona, 70126 Bari, Italy; p.fini@ba.ipcf.cnr.it
4 Dipartimento di Bioscienze, Biotecnologie e Ambiente, Università degli Studi "Aldo Moro" di Bari, Via Orabona, 70126 Bari, Italy; nicoletta.devietro@uniba.it (N.D.V.); antonellamaria.aresta@uniba.it (A.M.A.)
* Correspondence: jennifer.gubitosa@uniba.it (J.G.); pinalysa.cosma@uniba.it (P.C.)
† These authors contributed equally to this work.

**Abstract:** Water-resistant and environmentally friendly sodium-alginate-based films have been investigated to develop functional materials to extend the food's shelf-life. A water-stable alginate-based film was prepared, employing both the internal and external gelation approach in the presence of $CaCl_2$. To apply this film to food packaging and thus preserve food quality, the aim of this work is to perform a chemical and physical characterization of the proposed materials, evidencing the main features and stability under different work conditions. Water contact angle measurements showed a value of 65°, suggesting an important reduced hydrophilic character of the obtained alginate films due to the novel $CaCl_2$-induced compacted polymer network. The film's stability was thus checked through swelling measurements in water after varying pH, temperature, and ionic strength. The film was stable at high temperatures and not pH-responsive. Only highly concentrated salt-based solutions negatively affected the proposed packaging, causing a large swelling. Furthermore, a

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## Adsorbimento delle proteine del latte su superfici metalliche di ferro.

La lavorazione e il consumo di alimenti comportano molteplici contatti tra fluidi biologici e materiali solidi dei dispositivi di lavorazione, di cui l'acciaio è uno dei più comuni. A causa della complessità di queste interazioni, è difficile identificare i principali fattori di controllo nella formazione di depositi indesiderati sulle superfici del dispositivo che possono influire sulla sicurezza e sull'efficienza dei processi. La comprensione meccanicistica delle interazioni biomolecola-metallo che coinvolgono le proteine alimentari potrebbe migliorare la gestione di questi processi industriali pertinenti e la sicurezza dei consumatori nell'industria alimentare e oltre.

*nanomaterials* MDPI

*Article*

# Milk Protein Adsorption on Metallic Iron Surfaces

**Parinaz Mosaddeghi Amini, Julia Subbotina * and Vladimir Lobaskin ***

School of Physics, University College Dublin, Dublin 4, D04 V1W8 Dublin, Ireland; parinaz.mosaddeghiamini@ucdconnect.ie
* Correspondence: yulia.subbotina@ucd.ie (J.S.); vladimir.lobaskin@ucd.ie (V.L.)

**Abstract:** Food processing and consumption involves multiple contacts between biological fluids and solid materials of processing devices, of which steel is one of the most common. Due to the complexity of these interactions, it is difficult to identify the main control factors in the formation of undesirable deposits on the device surfaces that may affect safety and efficiency of the processes. Mechanistic understanding of biomolecule-metal interactions involving food proteins could improve management of these pertinent industrial processes and consumer safety in the food industry and beyond. In this work, we perform a multiscale study of the formation of protein corona on iron surfaces and nanoparticles in contact with cow milk proteins. By calculating the binding energies of proteins with the substrate, we quantify the adsorption strength and rank proteins by the adsorption affinity. We use a multiscale method involving all-atom and coarse-grained simulations based on generated ab initio three-dimensional structures of milk proteins for this purpose. Finally, using the adsorption energy results, we predict the composition of protein corona on iron curved and flat surfaces via a competitive adsorption model.

**Keywords:** nanoparticle; potential of mean force; protein adsorption; protein corona; bio–nano interface; multiscale modeling

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# Effetto duttile della miscelazione di materie plastiche PGA / PCL utilizzando un nuovo estensore di catena ionica con legami non covalenti.

L'acido poliglicolico (PGA) è un polimero promettente nel campo dell′imballaggio grazie alle sue eccellenti proprietà di idrolisi, resistenza al calore e barriera ai gas, ma è limitato nell′applicazione a causa della sua scarsa tenacità. Per questo motivo, viene introdotto un estensore di catena legato covalentemente per aumentare la compatibilità con i polimeri flessibili. Tuttavia, i legami covalenti sono sfavorevoli per l′applicazione su plastiche degradabili a causa dell′energia richiesta per le reazioni inverse. Pertanto, intendevamo controllare efficacemente la duttilità della miscelazione delle materie plastiche utilizzando un nuovo estensore di catena ionica con un legame non covalente relativamente più debole rispetto al legame covalente esistente.

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## Ductile Effect of PGA/PCL Blending Plastics Using a Novel Ionic Chain Extender with Non-Covalent Bonds

**Hyuk-Jun Kwon [1,2], Joseph Jang [2], Won-Gun Koh [1], Jun-Young Lee [2,*] and Kiseob Hwang [2,*]**

1 Department of Chemical and Biomolecular Engineering, Yonsei University, Seoul 03722, Republic of Korea; hyukjun@kitech.re.kr (H.-J.K.); wongun@yonsei.ac.kr (W.-G.K.)
2 Green and Sustainable Materials R&D Department, Korea Institute of Industrial Technology, Cheonan 31056, Republic of Korea; jangy@kitech.re.kr
* Correspondence: jaylee@kitech.re.kr (J.-Y.L.); ks_hwang@kitech.re.kr (K.H.); Tel.: +82-41-568-8236 (K.H.)

**Abstract:** Polyglycolic acid (PGA) is a promising polymer in the packaging field owing to its excellent hydrolysis, heat resistance, and gas barrier properties, but it is limited in application due to its poor toughness. For this reason, a covalently bonded chain extender is introduced to increase compatibility with flexible polymers. However, covalent bonds are unfavorable for application to degradable plastics because of the energy required for reverse reactions. Therefore, we intended to effectively control the ductility of blending plastics by using a novel ionic chain extender with a relatively weaker non-covalent bond than the existing covalent bond. Polycaprolactone (PCL), which has biodegradability and flexibility, was selected as a blending polymer. For comparison, a covalently reactive chain extender (G-CE) and a non-covalently ionic chain extender (D-CE) were synthesized and compounded with blending plastics. Each chain extender improved the compatibility between PGA and PCL, and the ductility of the PGA/PCL blending plastics was more greatly enhanced with non-covalently bonded D-CE than with covalently bonded G-CE. At this time, the ductility of the PGA/PCL(90/10) blending plastic without CE was 7.2%, the ductility of blending plastic with D-CE (10D) was 26.6%, and the ductility of blending plastic with G-CE (10G) was 18.6%. Therefore, it was confirmed that the novel ionic chain extender inducing non-covalent bonds improves the

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## Co-digestione anaerobica su scala pilota di rifiuti alimentari e acido polilattico.

Le bioplastiche sono spesso utilizzate nella vita quotidiana, in particolare per gli imballaggi alimentari e i sacchetti di trasporto. Possono essere conferiti agli impianti di biogas attraverso una raccolta differenziata della frazione organica dei rifiuti urbani (FORSU). L'aumento della domanda e dell'uso di bioplastiche volte a mitigare l'inquinamento da plastica solleva questioni significative riguardanti il loro ciclo di vita e la compatibilità con le unità di gestione dei rifiuti. La digestione anaerobica (AD) in FORSU è una risorsa preziosa per la produzione di biogas. In questo lavoro, la valorizzazione dell'acido poli-L-lattico (PLLA) composto da rifiuti alimentari all'interno del quadro del progetto Biowaste to Bioplastic (B2B) è stata studiata in condizioni di liquido anaerobico in laboratorio e su scala pilota.

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Article

# Pilot-Scale Anaerobic Co-Digestion of Food Waste and Polylactic Acid

Angeliki Maragkaki [1,*], Christos Tsompanidis [2], Kelly Velonia [3] and Thrassyvoulos Manios [1]

[1] Department of Agriculture, School of Agricultural Science, Hellenic Mediterranean University, 71401 Crete, Greece
[2] ENVIROPLAN S.A., 23 Perikleous & Iras Str., Gerakas, 15344 Athens, Greece
[3] Department of Materials Science and Technology, University of Crete, 71003 Heraklion, Greece
[*] Correspondence: amaragkaki@hmu.gr

**Abstract:** Bioplastics are frequently utilized in daily life, particularly for food packaging and carrier bags. They can be delivered to biogas plants through a separate collection of the organic fraction of municipal waste (OFMSW). The increased demand for and use of bioplastics aimed at mitigating plastic pollution raises significant questions concerning their life cycle and compatibility with waste management units. Anaerobic digestion (AD) in OFMSW is a valuable resource for biogas production. In this work, the valorization of poly-L-lactic acid (PLLA) composed of food waste within the Biowaste to Bioplastic (B2B) Project framework was studied in laboratory and pilot-scale anaerobic liquid conditions. Taking into account that the addition of PLLA to biowaste can increase biogas production, we performed laboratory-scale anaerobic tests on food waste enriched with different molecular-weight PLLAs produced from food waste or commercial PLLA at a mesophilic temperature of 37 °C. PLLA with the highest molecular weight was subjected to AD on the pilot scale to further validate our findings. The addition of PLLA increased biogas production and had no apparent negative impact on the operation of the reactors used in the laboratory or on the pilot scale. Biogas production was higher when using PLLA with the lowest molecular weight. In the pilot-scale experiments, co-digestion of FW with PLLA increased biogas production by 1.1 times. When PLLA was added to the feed, biomethane was 8% higher, while volatile solids (VS) and total chemical oxygen demand (TCOD) removal were almost the same. Importantly, no effect was observed in the operation of the digesters.

**Keywords:** biogas; anaerobic digestion; food waste; PLLA

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Via Cosimo Del Fante 10 - 20122 Milano - Tel. +39 02 58319624
C.F: 97870780158
segreteria@fondazionepackaging.org - www.fondazionecartaeticapackaging.org