ELECTROSPUN POLY (Ɛ-CAPROLACTONE) NANOFIBER MEMBRANES BLENDED WITH NATURAL ANTIBACTERIAL AGENTS FOR POTENTIAL WOUND DRESSING APPLICATIONS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy in Chemistry

Choose an item.

Faculty of Science
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DECEMBER 2022

DEDICATION

This thesis is dedicated to my late father, Alhaji Adamu DanMalam, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my late mother, Malama A'isha Muhammad who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

I want to express my sincere appreciation to Allah (SWT) for granting me the opportunity to pursue my study at PhD level. I am grateful to have the strength, patience and courage from Him that made it successfully. I wish to express my highest gratitude and sincere appreciation to Supervisor Dr Faizuan Abdullah, Co-Supervisors Assoc. Prof Dr Nik Ahmad Nizam Nik Malek, and Dr Khairunnadwa Binti Jemon for your extensive supervision, guidance, and encouragement. Your valuable suggestions and patience are well commendable. I am also thankful to Prof Dr Abdull Rahim Bin Mohd Yusoff, my Main Supervisor before his retirement, for his advice, critics, continuous support, and encouragement. I cannot forget the help I received from Dr Palanivel Sathishkumar, who ensured that some of my articles were published in high impact journals.

I am indebted to Universiti Teknologi Malaysia for funding my PhD study. I am also thankful to the Management of College of Education, Zing, Taraba State, Nigeria, for granting me the opportunity of pursuing the Ph D. I am also grateful to TETFund, Nigeria, for sponsoring my study in Malaysia.

I am extending my sincere appreciation to my entire family, especially my wife, Fatima Usman Kyari, for your overwhelming support, patience, and motivation, which gave me the courage to pursue the Ph.D. I am also very appreciative of my research group, especially Tan Yong Chee and others who help with valuable advice and support at various instances. I would also like to express my thanks to all the Lecturers and Staff of the Department of Chemistry, Faculty of Science, for your support.

ABSTRACT

The present study aims to produce natural drug-loaded poly(Ɛ-caprolactone) (PCL) nanofibrous membranes as potential wound dressing material using the electrospinning technique. The production of continuous jets that yield beads-free, smooth, and uniform fibers is an indication of good nanofiber morphology. Poly(Ɛ-caprolactone)/eggshell membrane (PCL/ESM), poly(Ɛ-caprolactone)/eggshell (PCL/ES), poly(Ɛ-caprolactone)/curcumin (PCL/Cur), and poly(Ɛ-caprolactone)/Ɛ-poly-L-lysine (PCL/Ɛ-PL) nanofiber membranes of various concentrations have been successfully fabricated. Fourier transform infrared spectroscopy (FTIR), field emission scanning electron microscopy (FESEM), tensile strength test (TT), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and water contact angle measurement (WCA) were used to investigate the physical, chemical, and mechanical properties of each of the nanofiber membranes. Similarly, the membranes were evaluated for their water uptake ability, degradability, water vapour transmission rate, water retention capacity, cell viability, and antibacterial activity. The FESEM results of the membranes revealed bead less and uniform fibers, suggesting good dispersion of the active agents. The various formulations have confirmed molecular interactions via a change in peak intensities, shifting of peak positions, and the appearance of the additional peak as demonstrated by the ATR-FTIR and XRD analyses. The membrane incorporated with 6% ES showed the highest tensile strength of 4.85±0.63 MPa than the other active agents. The WCA of various formulations decreased with the addition of active agents such as PCL/ES 6% nanofiber membrane demonstrated the least WCA of 99.98±2.70°. The results of the water uptake ability of the various membranes indicated a decrease according to their active agents and their concentrations with PCL/ Ɛ-PL 3.5% demonstrating the highest water uptake of 429% after 72 h due to the presence of hydrophilic functional groups. The degradation process of the membranes occurred mainly on the membrane's surface and the highest weight loss was exhibited after 14 days by the degradation of PCL/Ɛ-PL 3.5%. Overall porosity is 79.79±2.47%, as indicated by PCL/Ɛ-PL 1.5%, while PCL revealed the lowest value, which is 37.85±7.41% due to the material's strong hydrophobicity. The highest antibacterial activity was shown by the membranes with the highest concentration in the various formulations, in the following order: PCL/ESM 2.5% < PCL/Cur 18% < PCL/ES 2% < PCL/Ɛ-PL 3.5%. The results have shown that PCL/ESM 2.5%, PCL/Cur 18%, PCL/ES 2%, and PCL/Ɛ-PL 3.5% can be used as potential wound dressing materials, with PCL/Ɛ-PL 3.5% nanofiber membranes demonstrating the most favourable performance. This is based on the physicochemical, mechanical, and biochemical properties of the electrospun nanofiber membranes. The L929 fibroblast cells did not exhibit any cytotoxic effects and had the maximum antibacterial activity above 99% against bacterial strains, with cell viability values of 92.42±1.63% and 81.57±0.52% after 24 h and 74 h of incubation, respectively. According to the study, the PCL/ESM 2.5%, PCL/Cur 18%, PCL/ES 2%, and PCL/Ɛ-PL 3.5% membranes can be possible candidates for potential wound dressing applications.

ABSTRAK

Kajian ini bertujuan untuk menghasilkan membran nanofiber poli(Ɛ-kaprolakton) (PCL) yang dimuatkan dadah semula jadi sebagai bahan pembalut luka yang berpotensi menggunakan teknik pemutaran elektro. Penghasilan jet berterusan yang menghasilkan gentian bebas manik, licin dan seragam adalah petunjuk morfologi gentian nano yang baik. Membran nanofiber poli(Ɛ-kaprolakton)/membran kulit telur (PCL/ESM), poli(Ɛ-kaprolakton)/kulit telur (PCL/ES), poli(Ɛ-kaprolakton)/kunyit (PCL/Cur), dan poli(Ɛ-kaprolakton)/Ɛ-poli-L-lisin (PCL/Ɛ-PL) pelbagai kepekatan telah berjaya direka. Spektroskopi inframerah transformasi fourier (FTIR), mikroskopi elektron pengimbasan pelepasan medan (FESEM), ujian kekuatan tegangan (TT), pembelauan sinar-X (XRD), spektroskopi fotoelektron sinar-X (XPS), dan pengukuran sudut sentuhan air (WCA) telah digunakan untuk mengkaji sifat fizikal, kimia dan mekanikal bagi setiap membran nanofiber. Begitu juga, membran dinilai untuk keupayaan pengambilan air, kebolehan terdegradasi, kadar penularan wap air, kapasiti pengekalan air, daya maju sel, dan aktiviti antibakteria. Keputusan FESEM membran mendedahkan gentian tidak manik dan seragam, mencadangkan penyebaran agen aktif yang baik. Pelbagai formulasi telah mengesahkan interaksi molekul melalui perubahan dalam intensiti puncak, peralihan kedudukan puncak, dan penampilan puncak tambahan seperti yang ditunjukkan oleh analisis ATR-FTIR dan XRD. Membran yang digabungkan dengan 6% ES menunjukkan kekuatan tegangan tertinggi iaitu 4.85±0.63 MPa berbanding agen aktif yang lain. WCA dari pelbagai formulasi berkurangan dengan penambahan agen aktif sehingga membran nanofiber PCL/ES 6% menunjukkan WCA paling sedikit sebanyak 99.98±2.70°. Keputusan keupayaan pengambilan air pelbagai membran menunjukkan penurunan mengikut agen aktif dan kepekatan dengan PCL/Ɛ-PL 3.5% menunjukkan pengambilan air tertinggi sebanyak 429% selepas 72 jam, disebabkan kehadiran kumpulan berfungsi hidrofilik. Proses degradasi membran berlaku terutamanya pada permukaan membran dan penurunan berat tertinggi ditunjukkan selepas 14 hari oleh degradasi PCL/Ɛ-PL 3.5%. Keliangan keseluruhan ialah 79.79±2.47%, seperti yang ditunjukkan oleh PCL/Ɛ-PL 1.5%, manakala PCL mendedahkan nilai terendah iaitu 37.85±7.41% disebabkan oleh hidrofobisiti bahan yang kuat. Aktiviti antibakteria tertinggi ditunjukkan oleh membran dengan kepekatan tertinggi dalam pelbagai formulasi dalam susunan berikut: PCL/ESM 2.5% < PCL/Cur 18% < PCL/ES 2% < PCL/Ɛ-PL 3.5%. Keputusan telah menunjukkan bahawa PCL/ESM 2.5%, PCL/Cur 18%, PCL/ES 2%, dan PCL/Ɛ-PL 3.5% boleh digunakan sebagai bahan pembalut luka yang berpotensi, dengan membran nanofiber PCL/Ɛ-PL 3.5% menunjukkan prestasi yang paling menggalakkan. Ini berdasarkan sifat fizikokimia, mekanikal dan biokimia membran nanofiber elektroputaran. Sel fibroblast L929 tidak menunjukkan sebarang kesan sitotoksik dan mempunyai aktiviti antibakteria maksimum melebihi 99% terhadap strain bakteria, dengan nilai daya maju sel masing-masing 92.42±1.63 dan 81.57±0.52% selepas 24 jam dan 74 jam pengeraman. Menurut kajian itu, membran PCL/ESM 2.5%, PCL/Cur 18%, PCL/ES 2%, dan PCL/Ɛ-PL 3.5% boleh menjadi calon untuk aplikasi pembalut luka yang berpotensi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ε -PL	-	ε-poly-L-lysine
CA	-	cellulose acetate
Cur	-	Curcumin
CS	-	Chitosan
DMAc	-	Dimethylacetamide
DSC	-	Differential scanning calorimetry
ES	-	Eggshell
ESM	-	Eggshell membrane
EMNM	-	eggshell membrane-based nano wrinkled microfibers
FESEM	-	field emission scanning electron microscopy
FTIR-	-	Fourier transforms infrared spectroscopy fitted with
ATR		attenuated total reflectance
NaCl		Sodium Chloride
PCL		Poly(ε-caprolactone)
PVDF		polyvinylidene difluoride
PVC		polyvinyl chloride
PVA		polyvinyl alcohol
PVAc		polyvinyl acetate
PVDF		polyvinylidene difluoride
PAN		polyacrylonitrile
PEO		polyethylene oxide
PLA		poly (lactic acid)
XPS		X-ray photoelectrons spectroscopy
XRD		X-ray diffraction analysis
WCA		water contact angle measurement

LIST OF SYMBOLS

°C	-	Degree Celsius
cm	-	Centimeter
g/mol	-	Gram per mol
kV	-	Kilovolt
K Da	-	Kilo Dalton
mL/h	-	Milliliter per hour
Mw	-	Molecular weight
nm	-	Nanometer

LIST OF APPENDICES

APPENDIX **TITLE** **PAGE**

CHAPTER 1

INTRODUCTION

1.1 Problem Background

The human skin has been one of the body's essential organs, which comprises three primary layers: the stratified epidermis, the dermis, and the hypodermis (Borena et al., 2015). It separates the human body from the environment, provides the body with some basic protections against microbial infections, and performs additional functions, including metabolic, immune, and biochemical. However, when a skin sustained acute or chronic injuries, the human body immediately begins repairing the affected portion of the skin (Akbik et al., 2014) by adopting the following steps: hemostasis, inflammation, proliferation, and remodeling of the tissue (Harper, Young, and McNaught, 2014; Liu et al., 2018). Nonetheless, when wounds receive inadequate treatment, they can be susceptible to high population of bacteria that results in pathogenic infections, thereby making the wounds seems chronic. So, it became imperative to develop ideal wound-dressing materials with potent antibacterial property to protect wounds from bacterial infiltration, prevent pathogenic infection, outstanding biocompatibility and biodegradability, excellent mechanical strength with enhance flexibility, good water retention capacity, and induce cell attachment, migration, and proliferation to enhance the reconstruction of the affected tissue (Dhivya et al., 2015; Perumal et al., 2017).

There is quite a plethora of various wound dressing materials available in markets currently used. These include among others, polymeric films (Tegaderm, Silon-TSR), polymeric forms (Flexzan, Biopatch), polymeric hydrogels (Cultinova gel, Biolex), polymeric alginates (AlgiSite, Kaltostat), and polymeric hydrocoloides (Iodosorb, Debrisan) (Kamoun et al., 2017). All the current wound dressing materials have some inherent limitations associated with wound healing.

Over time, various techniques have been reported as being utilized for producing polymeric nanofiber. These include, among others, solvent casting (Kamel et al., 2018), solvent-casting/particulate-leaching technique combined with thermally induced phase separation (Kucinska-Lipka et al., 2019), electron beam irradiation technique (Jawun et al., 2017), pulsed laser deposition technique (Li et al., 2016), freeze-drying technique (Mehrabani et al., 2018), freeze-thawing method (Khorasani et al., 2018), and electrospinning technique (Kamel et al., 2018). Among these methods, electrospinning technique has recently emerged as the technique widely used in fabricating nanofibers from a variety of materials, including polymers, composite structures, and inorganic materials. This could have been because the technique is used in producing continuous polymer fibers with dimensional control within the nanometer scale, variety of polymers are used in the formation of the electrospun nanofiber membranes, it allows the nanofiber formation in different orientations, as well as, it produces the nanofibers in large quantities (Quirós, Boltes, and Rosal, 2016).

There are currently many studies of electrospun nanofibrous membranes using various carriers, which included natural or synthetic polymers, such as polyvinyl alcohol, poly-Ɛ-caprolactone, polyurethane, polylactic acid, poly- ethyl oxide as well as hybrid blends of two polymers. Poly(ε-caprolactone) (PCL) has been widely used by researchers due to its excellent biocompatibility, sustained biodegradability, processability with different polymers, and enhanced mechanical properties (Liao et al., 2015). The continued prominence of the PCL due to its potential applications in biomedical and wound dressing applications has been widely investigated (Bartnikowski et al., 2019). Natural antibacterial agents, Eggshell membrane (ESM), Eggshell (ES), Curcumin (Cur), and ε-poly-L-lysine (ε -PL) electrospun nanofibrous membranes have also been widely used in biomedical and wound dressing applications due to their high antibacterial efficiency (Alibolandi et al., 2017; Li et al., 2016; Ushimaru et al., 2017). Nonetheless, PCL/ESM (0.5%, 1.5&, 2.5%,), PCL/ES (2%, 4%, 6%), PCL/Cur (12%, 15%, 18%), and PCL/ε -PL (1.5%, 2.5%, 3.5%) nanofiber membranes were not yet found in literature. Therefore, this study aims to fabricate PCL, PCL/ESM (0.5%, 1.5&, 2.5%,), PCL/ES (2%, 4%, 6%), PCL/Cur (12%, 15%, 18%), and PCL/ε -PL (1.5%, 2.5%, 3.5%) nanofiber membranes using the electrospinning technique, characterize, and evaluate their antibacterial efficacy and biocompatibility to determine their potentials for wound dressing applications.

1.2 Problem Statement

Chronic wounds are vulnerable to the risk of infections by a complex population of bacteria, most especially if proper care is not given to the wounds. The longer the wound receives insufficient medical attention, the more likely, it will be colonized by microbial organisms whose sources may be from the surrounding skin, the environment, or endogenous origin (Khalifa, 2016). Hence, tissue inflammation in chronic wounds can further be prolonged due to the immune response and the presence of bacteria, thereby delaying the healing process. Therefore, the pains due to the chronic wound makes the life of the patients unbearable (Simões et al., 2018

Nowadays, there are various wound dressing materials currently available in markets. For instance, the use of polymeric films has been identified as a means of treating wounds in our various hospitals. However, the dressings have some limitations which include adherence to wound bend, and poor exudates absorption. Similarly, polymeric foams are known for their poor stability, semi-permeability to gases, and its adherence to wounds. Polymeric hydrogels are also known for been poor in protecting bacterial infiltration and sometimes poor mechanical stability. Other dressings applicable in the therapeutic approaches are polymeric alginates and polymeric hydrocolloids. Nevertheless, the risks associated with these approaches includes very costly, have unpleasant odor, impermeable to gases and have poor exudates absorption (Kamoun et al., 2017).

To overcome the aforementioned limitations, the use of naturally based antibacterial agents such as ESM, ES, Cur, and ε -PL of particular concentrations will not only prevent pathogenic infections but will also safely promotes rapid wound healing mechanisms.

1.3 Research Goal

The research goal was to produce PCL nanofiber membranes blended with natural antibacterial agents (ESM, ES, Cur, and Ɛ-PL), for potential wound dressing applications, using the electrospinning technique.

1.3.1 Research Objectives

The objectives of the research are:

(a) To synthesize natural antibacterial agents loaded PCL nanofiber membranes.

(b) To investigate the physical, chemical and mechanical properties of the electrospun nanofiber membranes.

(c) To determine water uptake capacity, degradation ability, water vapour transmission rate, and water retention capacity of the nanofiber membranes.

(d) To evaluate the cells viability and antibacterial efficiency of the nanofiber membranes using in vitro approach.

1.4 Scope of The Study

To achieve the research objectives, the following scope was considered: The first stage involved the fabrication of the nanofiber membranes. The fabrication of PCL/ESM and the nanofiber blends of other antibacterial agents were prepared using the electrospinning technique. The various concentrations for the polymer and the antibacterial agents were carefully selected. The antibacterial agents used to blend the PCL at different concentrations are ESM, ES, Cur, and Ɛ-PL. The various electrospinning parameters, including the solution, process, and ambient, were adequately controlled to fabricate the nanofiber membranes.

The second stage of the research was the characterization of the different fabricated nanofiber membranes. The nanofibers were characterized by using Field emission scanning electron microscopy (FESEM), Fourier transforms infrared spectroscopy fitted with Attenuated total reflectance (FTIR-ATR), Mechanical test, Differential scanning calorimetry (DSC), X-ray diffraction analysis (XRD), X-ray photoelectrons spectroscopy (XPS), and Water contact angle measurement (WCA). The characterization of the nanofiber membranes seeks to determine the physical, chemical, and mechanical properties of the membranes and their interactions with water.

The third stage involves the in vitro water uptake study, degradability study, water vapour transmission rate study, and porosity measurement. In this case, the water uptake study was performed to determine the water uptake ability of the nanofibrous membranes. At the same time, the degradability analysis was carried out to determine the degree of degradation of the membranes. Similarly, the water vapour transmission rate measures the degree of transmission of water vapour through the membranes, and porosity was also measured to determine the water retention capacity of the as-spun nanofibrous membranes.

The fourth stage involves the cell viability and antibacterial activity analyses. In this case, the in vitro cell viability study was performed on the electrospun nanofiber membranes to determine the cells viability nature of the membranes using L929 mouse fibroblast cells. The percentage cell viability was used to demonstrate the degree of cells viability of the membranes. The antibacterial activity test is the analysis carried out against bacterial strains. The Colony count measurement was used as a test for antibacterial activity. The bacterial strains that were used are the gram-positive ATCC 6538 Staphylococcus aureus (S. aureus) and the gram-negative ATCC 11229 Escherichia coli (E. coli). Percent Reduction was used to determine the antibacterial activity for the various membranes. The flow chart of the research is presented in Fig. 1.1.

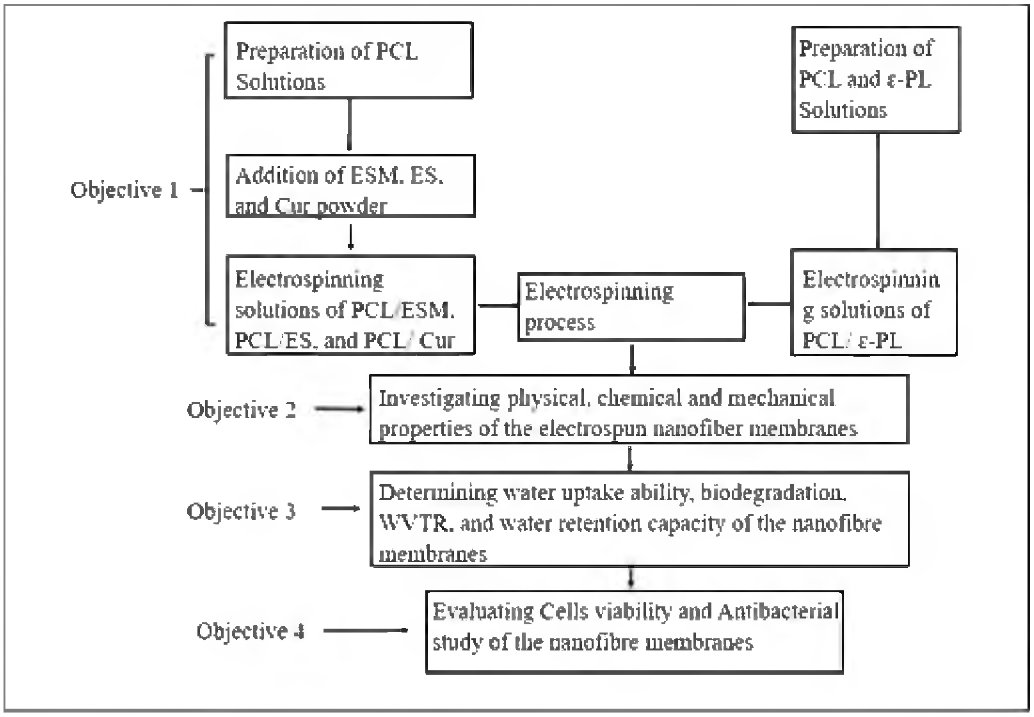

Figure 1.1 Flow chart of the research

1.5 Significance of The Study

The overuse of antibiotics and metallic nanoparticles in the production of nanofibers, which most often leads to the formation of antibiotic-resistant bacteria (Super bacteria) and the risk of contracting pulmonary and heart diseases, will be significantly reduced by the use of natural antibacterial agents for wound dressing application (Grigore et al., 2017).

Furthermore, the community, particularly those with chronic wounds, will benefit from the innovative membranes because of their exceptional capacity to ease their pain by fostering speedy wound healing. If successfully produced, using the electrospinning technique, the blended ESM-loaded PCL and the PCL/ES nanofiber membranes will provide a complete view on the possibility of converting waste derived from eggs into functional biomedical materials to be used for wound dressing applications. Therefore, our environment will become friendlier by converting large quantity of egg wastes into biomedical materials for wound dressing applications.

1.6 Limitations of The Study

Despite the wide scope of this research, however, the study was bedeviled with some cogent limitations as outlined as follows:

1. The antibacterial property of wound dressing material has been one of the essential requirements for wound healing. However, this research was limited to the use of natural antibacterial agents.

2. In this research, the nanofibrous membranes' fabrication would have employed both the uniaxial and coaxial electrospinning techniques. However, the research was limited to using the uniaxial electrospinning technique due to its simplicity, versatility, and cost-effectiveness.

3. The research was also limited to developing wound dressing devices that can be proved to exhibit cytocompatibility and antibacterial activity via in vitro analysis.

REFERENCES

Abdelgawad, A. M., Hudson, S. M., & Rojas, O. J. (2014). Antimicrobial wound dressing nanofiber mats from multicomponent (chitosan/silver-NPs/polyvinyl alcohol) systems. *Carbohydrate Polymers*, *100*, 166–178. https://doi.org/10.1016/j.carbpol.2012.12.043

Abrigo, M., McArthur, S. L., & Kingshott, P. (2014). Electrospun nanofibers as dressings for chronic wound care: Advances, challenges, and future prospects. *Macromolecular Bioscience*, *14*(6),772–792. https://doi.org/10.1002/mabi.201300561

Adeli, H., Khorasani, M. T., & Parvazinia, M. (2019). Wound dressing based on electrospun PVA/chitosan/starch nanofibrous mats: Fabrication, antibacterial and cytocompatibility evaluation and in vitro healing assay. *International Journal of Biological Macromolecules*, *122*,238–254. https://doi.org/10.1016/j.ijbiomac.2018.10.115

Ahmed, R., Tariq, M., Ali, I., Asghar, R., Noorunnisa Khanam, P., Augustine, R., & Hasan, A. (2018). Novel electrospun chitosan/polyvinyl alcohol/zinc oxide nanofibrous mats with antibacterial and antioxidant properties for diabetic wound healing. *International Journal of Biological Macromolecules*, *120*, 385–393. https://doi.org/10.1016/j.ijbiomac.2018.08.057

Akbik, D., Ghadiri, M., Chrzanowski, W., & Rohanizadeh, R. (2014). Curcumin as a wound healing agent. *Lıfe Sciences,* 116(1), pp. 1–7. https://doi.org/10.1016/j.lfs.2014.08.016

Alavarse, A. C., de Oliveira Silva, F. W., Colque, J. T., da Silva, V. M., Prieto, T., Venancio, E. C., & Bonvent, J. J. (2017). Tetracycline hydrochloride-loaded electrospun nanofibers mats based on PVA and chitosan for wound dressing. *Materials Science and Engineering C*, *77*, 271–281. https://doi.org/10.1016/j.msec.2017.03.199

Alibolandi, M., Mohammadi, M., Taghdisi, S. M., Abnous, K., & Ramezani, M. (2017). Synthesis and preparation of biodegradable hybrid dextran hydrogel incorporated with biodegradable curcumin nanomicelles for full thickness wound healing. *International Journal of Pharmaceutics*, *532*(1), 466–477. https://doi.org/10.1016/j.ijpharm.2017.09.042

Alippilakkotte, S., Kumar, S., & Sreejith, L. (2017). Fabrication of PLA/Ag nanofibers by green synthesis method using Momordica charantia fruit extract for wound dressing applications. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *529*, 771–782. https://doi.org/10.1016/j.colsurfa.2017.06.066

Amariei, G., Kokol, V., Vivod, V., Boltes, K., Letón, P., & Rosal, R. (2018).

Biocompatible antimicrobial electrospun nanofibers functionalized with ε-poly- L-lysine. *International Journal of Pharmaceutics*, *553*(1–2), 141–148. https://doi.org/10.1016/j.ijpharm.2018.10.037

Asmatulu, R., & Khan, W. S. (2019). Historical background of the electrospinning process. *Synthesis and Applications of Electrospun Nanofibers*, 17–39. https://doi.org/10.1016/b978-0-12-813914-1.00002-x

Augustine, R., Kalarikkal, N., & Thomas, S. (2016). Electrospun PCL membranes incorporated with biosynthesized silver nanoparticles as antibacterial wound dressings. *Applied Nanoscience (Switzerland)*, *6*(3), 337–344. https://doi.org/10.1007/s13204-015-0439-1

Aytac, Z., & Uyar, T. (2017). Core-shell nanofibers of curcumin/cyclodextrin inclusion complex and polylactic acid: Enhanced water solubility and slow release of curcumin. *International Journal of Pharmaceutics*, *518*(1–2), 177–184. https://doi.org/10.1016/j.ijpharm.2016.12.061

Bahrami, S. H., & Gholipour Kanani, A. (2011). Effect of changing solvents on poly(ε-Caprolactone) nanofibrous webs morphology. *Journal of Nanomaterials*, *2011*. https://doi.org/10.1155/2011/724153

Baláž, M. (2014). Eggshell membrane biomaterial as a platform for applications in materials science. *Acta Biomaterialia*, *10*(9), 3827–3843. https://doi.org/10.1016/j.actbio.2014.03.020

Balouiri, M., Sadiki, M., & Ibnsouda, S. K. (2016). Methods for in vitro evaluating antimicrobial activity: A review. *Journal of Pharmaceutical Analysis,* 6(2), 71–79. https://doi.org/10.1016/j.jpha.2015.11.005

Bartnikowski, M., Dargaville, T. R., Ivanovski, S., & Hutmacher, D. W. (2019). Degradation mechanisms of polycaprolactone in the context of chemistry, geometry and environment. In *Progress in Polymer Science,* 96, 1–20. https://doi.org/10.1016/j.progpolymsci.2019.05.004

Biscaia, S. I., Viana, T. F., Almeida, H. A., & Bártolo, P. J. (2015). Production and Characterisation of PCL/ES Scaffolds for Bone Tissue Engineering. *Materials Today: Proceedings*, *2*(1), 208–216. https://doi.org/10.1016/j.matpr.2015.04.024

Borena, B. M., Martens, A., Broeckx, S. Y., Meyer, E., Chiers, K., Duchateau, L., & Spaas, J. H. (2015). Regenerative Skin wound healing in mammals: State-of-the- art on growth factor and stem cell-based treatments. In *Cellular Physiology and Biochemistry,* 36(1), 1–23. https://doi.org/10.1159/000374049

Bortolotti, M., Lutterotti, L., & Pepponi, G. (2017). Combining XRD and XRF analysis in one Rietveld-like fitting. *Powder Diffraction*, *32*(S1), S225–S230. https://doi.org/10.1017/S0885715617000276

Bui, H. T., Chung, O. H., Dela Cruz, J., & Park, J. S. (2014). Fabrication andcharacterization of electrospun curcumin-loaded polycaprolactone-polyethylene glycol nanofibers for enhanced wound healing. *Macromolecular Research*, *22*(12), 1288–1296. https://doi.org/10.1007/s13233-014-2179-6

Bunaciu, A. A., Udriştioiu, E. gabriela, & Aboul-Enein, H. Y. (2015). X-Ray Diffraction: Instrumentation and Applications. *Critical Reviews in Analytical Chemistry,* 45(4), 289–299. https://doi.org/10.1080/10408347.2014.949616

Buzgo, M., Plencner, M., Rampichova, M., Litvinec, A., Prosecka, E., Staffa, A., Kralovic, M., Filova, E., Doupnik, M., Lukasova, V., Vocetkova, K., Anderova, J., Kubikova, T., Zajicek, R., Lopot, F., Jelen, K., Tonar, Z., Amler, E., Divin, R., & Fiori, F. (2019). Poly-ϵ-caprolactone and polyvinyl alcohol electrospun wound dressings: Adhesion properties and wound management of skin defects in rabbits. *Regenerative Medicine*, *15*(5), 423–445. https://doi.org/10.2217/rme-2018-0072

Cacciotti, I., Chronopoulou, L., Palocci, C., Amalfitano, A., Cantiani, M., Cordaro, M., Lajolo, C., Calla, C., Boninsegna, A., Lucchetti, D., Gallenzi, P., Sgambato, A., Nocca, G., & Arcovito, A. (2018). Controlled release of 18-β-glycyrrhetic acid by nanodelivery systems increases cytotoxicity on oral carcinoma cell line. *Nanotechnology*, *29*(28), 285101. https://doi.org/10.1088/1361-6528/aabecc

Cao, Z., Shen, Z., Luo, X., Zhang, H., Liu, Y., Cai, N., Xue, Y., & Yu, F. (2017).Citrate-modified maghemite enhanced binding of chitosan coating on cellulose porous membranes for potential application as wound dressing. *Carbohydrate Polymers*, *166*, 320–328. https://doi.org/10.1016/j.carbpol.2017.03.012

Cheng, H. H., Xiong, J., Xie, Z. N., Zhu, Y. T., Liu, Y. M., Wu, Z. Y., Yu, J., & Guo,Z. X. (2018). Thrombin-Loaded Poly(butylene succinate)-Based Electrospun Membranes for Rapid Hemostatic Application. *Macromolecular Materials and Engineering*, *303*(2), 1–9. https://doi.org/10.1002/mame.201700395

Chevalier, M. T., García, M. C., Gonzalez, D., Gomes-Filho, S. M., Bassères, D. S., Farina, H., & Alvarez, V. A. (2017). Preparation, characterization and in vitro evaluation of ε-polylysine-loaded polymer blend microparticles for potential pancreatic cancer therapy. *Journal of Microencapsulation*, *34*(6), 582–591. https://doi.org/10.1080/02652048.2017.1370028

Choi, Jawun, Pant, B., Lee, C., Park, M., Park, S. J., & Kim, H. Y. (2017). Preparation and characterization of eggshell membrane/PVA hydrogel via electron beam irradiation technique. *Journal of Industrial and Engineering Chemistry*, *47*, 41– 45. https://doi.org/10.1016/j.jiec.2016.11.014

Choi, Jeongmin, Lee, J., Shin, M. E., Been, S., Lee, D. H., & Khang, G. (2020). Eggshell membrane/gellan gum composite hydrogels with increased degradability, biocompatibility, and anti-swelling properties for effective regeneration of retinal pigment epithelium. *Polymers*, *12*(12), 1–16. https://doi.org/10.3390/polym12122941

Chotimah, Rianjanu, A., Winardianto, B., Munir, M., Kartini, I., & Triyana, K. (2016).Electrical conductivity improvement of polyvinyl alcohol nanofiber by solvent vapour treatment. *International Journal on Advanced Science, Engineering and Information Technology*, *6*(5), 675–681. https://doi.org/10.18517/ijaseit.6.5.1055

Chui, C. Y., Mouthuy, P. A., & Ye, H. (2018). Direct electrospinning of poly (vinyl butyral) onto human dermal fibroblasts using a portable device. *Biotechnology Letters*, *40*(4), 737–744. https://doi.org/10.1007/s10529-018-2522-7

Clinton, J. M. (2019). Tensile Testing Principles: Fundamentals, Methods and Challenges Tensile testing can determine the component' s suitability for use and its. *Quality Magazine*,*57*(8),1–5.

Colmenares-Roldán, G. J., Quintero-Martínez, Y., Agudelo-Gómez, L. M., Rodríguez-Vinasco, L. F., & Hoyos-Palacio, L. M. (2017). Influence of the molecular weight of polymer, solvents and operational condition in the electrospinning of polycaprolactone. *Revista Facultad de Ingenieria*, *2017*(84), 35–45. https://doi.org/10.17533/udea.redin.n84a05

CR, R., PS, S., Manaf, O., PP, S., & Sujith, A. (2018). Nanochitosan enriched poly ε-caprolactone electrospun wound dressing membranes: A fine tuning of physicochemical properties, hemocompatibility and curcumin release profile. *International Journal of Biological Macromolecules*, *108*, 1261–1272. https://doi.org/10.1016/j.ijbiomac.2017.11.035

Dai, X., An, J., Wang, Y., Wu, Z., Zhao, Y., Guo, Q., Zhang, X., & Li, C. (2015).Antibacterial amphiphiles based on ε-polylysine: Synthesis, mechanism of action, and cytotoxicity. *RSC Advances*, *5*(85), 69325–69333. https://doi.org/10.1039/c5ra10393b

Dehghan, S. F., Golbabaei, F., Maddah, B., Latifi, M., Pezeshk, H., Hasanzadeh, M., & Akbar-Khanzadeh, F. (2016). Optimization of electrospinning parameters for polyacrylonitrile-MgO nanofibers applied in air filtration. *Journal of the Air and Waste Management Association*, *66*(9), 912–921. https://doi.org/10.1080/10962247.2016.1162228

Dhivya, S., Padma, V. V., & Santhini, E. (2015). Wound dressings - A review. In *BioMedicine,* 5(4), 24–28. https://doi.org/10.7603/s40681-015-0022-9

Didekhani, R., Mahmoud, ·, Sohrabi, R., Soleimani, M., Seyedjafari, · Ehsan, & Hanaee-Ahvaz, H. (2020). *Incorporating PCL nanofibers with oyster shell to improve osteogenic differentiation of mesenchymal stem cells*. *77*, 701–715. https://doi.org/10.1007/s00289-019-02750-x

Dodd, A., Swanevelder, D., Zhou, N., Brady, D., Hallsworth, J. E., & Rumbold, K. (2018). Streptomyces albulus yields ε-poly-l-lysine and other products from salt- contaminated glycerol waste. *Journal of Industrial Microbiology and Biotechnology*, *45*(12), 1083–1090. https://doi.org/10.1007/s10295-018-2082-9

Doustgani, A. (2015). Effect of electrospinning process parameters of polycaprolactone and nanohydroxyapatite nanocomposite nanofibers. *Textile Research Journal*, *85*(14), 1445–1454. https://doi.org/10.1177/0040517514566109

Dwiwedi, S. K., Srivastava, A. K., Sugimoto, K., & Chopkar, M. (2018). Microstructural and Mechanical Characterization of Chicken Eggshell-Reinforced Al6061 Matrix Composites. *Open Journal of Metal*, *08*(01), 1–13. https://doi.org/10.4236/ojmetal.2018.81001

Fallah, M., Bahrami, S. H., & Ranjbar-Mohammadi, M. (2016). Fabrication and characterization of PCL/gelatin/curcumin nanofibers and their antibacterial properties. *Journal of Industrial Textiles*, *46*(2), 562–577. https://doi.org/10.1177/1528083715594978

Fan, H., Liang, Y., Jiang, B., Li, X., Xun, H., Sun, J., He, W., Lau, H. T., & Ma, X. (2016). Curcumin inhibits intracellular fatty acid synthase and induces apoptosis in human breast cancer MDA-MB-231 cells. *Oncology Reports*, *35*(5), 2651– 2656. https://doi.org/10.3892/or.2016.4682

Farahana, R. N., Supri, A. G., & Teh, P. L. (2015). Tensile and Water Absorption Properties of Eggshell Powder Filled Recycled High-Density Polyethylene/Ethylene Vinyl Acetate Composites: Effect of 3-Aminopropyltriethoxysilane. *Journal of Advanced Research in Materials Science*, *10*(1), 1–11.

Ferreira, J. L., Gomes, S., Henriques, C., Borges, J. P., & Silva, J. C. (2014a). Electrospinning polycaprolactone dissolved in glacial acetic acid: Fiber production, nonwoven characterization, and in Vitro evaluation. *Journal of Applied Polymer Science*, *131*(22). https://doi.org/10.1002/app.41068

Ferreira, J. L., Gomes, S., Henriques, C., Borges, J. P., & Silva, J. C. (2014b). Electrospinning polycaprolactone dissolved in glacial acetic acid: Fiber production, nonwoven characterization, and in Vitro evaluation. *Journal of Applied Polymer Science*, *131*(22), 41068. https://doi.org/10.1002/app.41068

Fouad, S., K, G. (2015). *Fabrication and characterization of antibacterial herbal drug- loaded polylactic acid/cellulose acetate composite nanofibers for wound dressing applications*. M.Sc. (Chemistry). American University Cairo; 2015.

Freire, M. N., & Holanda, J. N. F. (2006). Caracterização de resídua de casca de ovo visando seu aproveitamento em revestimento cerâmico poroso. *Ceramica*, *52*(324), 240–244. https://doi.org/10.1590/S0366-69132006000400004

Ganesh, M., Aziz, A. S., Ubaidulla, U., Hemalatha, P., Saravanakumar, A., Ravikumar, R., Peng, M. M., Choi, E. Y., & Jang, H. T. (2016). Sulfanilamide and silver nanoparticles-loaded polyvinyl alcohol-chitosan composite electrospun nanofibers: Synthesis and evaluation on synergism in wound healing. *Journal of Industrial and Engineering Chemistry*, *39*, 127–135. https://doi.org/10.1016/j.jiec.2016.05.021

Garcia-Orue, I., Gainza, G., Gutierrez, F. B., Aguirre, J. J., Evora, C., Pedraz, J. L., Hernandez, R. M., Delgado, A., & Igartua, M. (2017). Novel nanofibrous dressings containing rhEGF and Aloe vera for wound healing applications. *International Journal of Pharmaceutics*, *523*(2), 556–566. https://doi.org/10.1016/j.ijpharm.2016.11.006

Gianino, E., Miller, C., & Gilmore, J. (2018). Smart wound dressings for diabetic chronic wounds. *Bioengineering,* 5)3), 51. https://doi.org/10.3390/bioengineering5030051

Gizaw, M., Thompson, J., Faglie, A., Lee, S. Y., Neuenschwander, P., & Chou, S. F. (2018). Electrospun fibers as a dressing material for drug and biological agent delivery in wound healing applications. *Bioengineering,* 5(1), 9. https://doi.org/10.3390/bioengineering5010009

Grigore, M.E., Grumezescu A. M., Holban A. M., Mogosanu G. D., & Andronescu E. (2017). Collagen-Nanoparticles Composites for Wound Healing and Infection Control. *Metals 2017, Vol. 7, Page 516*, 7(12), https://www.mdpi.com/2075-4701/7/12/516/htm

Guarino, V., Gentile, G., Sorrentino, L., & Ambrosio, L. (2017). Polycaprolactone: Synthesis, Properties, and Applications. In *Encyclopedia of Polymer Science and Technology* (pp. 1–36).. https://doi.org/10.1002/0471440264.pst658

Güneş, S., & Tıhmınlıoğlu, F. (2017). Hypericum perforatum incorporated chitosan films as potential bioactive wound dressing material. *International Journal of Biological Macromolecules*, *102*, 933–943. https://doi.org/10.1016/j.ijbiomac.2017.04.080

Gupta, A., Kowalczuk, M., Heaselgrave, W., Britland, S. T., Martin, C., & Radecka,
I. (2019). The production and application of hydrogels for wound management: A review. *European Polymer Journal*, *111*, 134–151. https://doi.org/10.1016/j.eurpolymj.2018.12.019

Gupta, A., Low, W. L., Radecka, I., Britland, S. T., Mohd Amin, M. C. I., & Martin, C. (2016). Characterisation and in vitro antimicrobial activity of biosynthetic silver-loaded bacterial cellulose hydrogels. *Journal of Microencapsulation*, *33*(8), 725–734. https://doi.org/10.1080/02652048.2016.1253796

Guy, O. J., & Walker, K. A. D. (2016). Graphene Functionalization for Biosensor Applications. In *Silicon Carbide Biotechnology: A Biocompatible Semiconductor for Advanced Biomedical Devices and Applications: Second Edition* (pp. 85– 141). Elsevier Inc. https://doi.org/10.1016/B978-0-12-802993-0.00004-6

Haider, A., Haider, S., & Kang, I. K. (2018). A comprehensive review summarizing the effect of electrospinning parameters and potential applications of nanofibers in biomedical and biotechnology. *Arabian Journal of Chemistry,* 11(8), 1165–1188. https://doi.org/10.1016/j.arabjc.2015.11.015

Han, G., & Ceilley, R. (2017). Chronic Wound Healing: A Review of Current Management and Treatments. *Advances in Therapy,* 34(3), 599– 610. https://doi.org/10.1007/s12325-017-0478-y

Harper, D., Young, A., & McNaught, C. E. (2014). The physiology of wound healing. *Surgery (United Kingdom)*, *32*(9), 445–450. https://doi.org/10.1016/j.mpsur.2014.06.010

Hassiba, A. J., El Zowalaty, M. E., Webster, T. J., Abdullah, A. M., Nasrallah, G. K., Khalil, K. A., Luyt, A. S., & Elzatahry, A. A. (2017). Synthesis, characterization, and antimicrobial properties of novel double layer nanocomposite electrospun fibers for wound dressing applications. *International Journal of Nanomedicine*, *12*, 2205–2213. https://doi.org/10.2147/IJN.S123417

He, F., Jiao, H., Tian, Y., Zhao, L., Liao, X., Fan, Z., & Liu, B. (2018). Facile and large-scale synthesis of curcumin/PVA hydrogel: effectively kill bacteria and accelerate cutaneous wound healing in the rat. *Journal of Biomaterials Science, Polymer Edition*, *29*(4), 325–343. https://doi.org/10.1080/09205063.2017.1417002

Hejna, A., Piszcz-Karaś, K., Filipowicz, N., Cieśliński, H., Namieśnik, J., Marć, M., Klein, M., & Formela, K. (2018). Structure and performance properties of environmentally-friendly biocomposites based on poly(ε-caprolactone) modified with copper slag and shale drill cuttings wastes. *Science of the Total Environment*, *640–641*, 1320–1331. https://doi.org/10.1016/j.scitotenv.2018.05.385

Hewlings, S., & Kalman, D. (2017). Curcumin: A Review of Its' Effects on Human Health. *Foods*, *6*(10), 92. https://doi.org/10.3390/foods6100092

Hokmabad, V. R., Davaran, S., Aghazadeh, M., Alizadeh, E., Salehi, R., & Ramazani,A. (2018). A Comparison of the Effects of Silica and Hydroxyapatite Nanoparticles on Poly(ε-caprolactone)-Poly(ethylene glycol)-Poly(ε- caprolactone)/Chitosan Nanofibrous Scaffolds for Bone Tissue Engineering. *Tissue Engineering and Regenerative Medicine*, *15*(6), 735–750. https://doi.org/10.1007/s13770-018-0140-z

Hsieh, S., Chou, H. H., Hsieh, C. W., Wub, D. C., Kuo, C. H., & Lin, F. H. (2013). Hydrogen peroxide treatment of eggshell membrane to control porosity. *Food Chemistry*, *141*(3), 2117–2121. https://doi.org/10.1016/j.foodchem.2013.04.115

Huan, S., Liu, G., Han, G., Cheng, W., Fu, Z., Wu, Q., & Wang, Q. (2015). Effect of experimental parameters on morphological, mechanical and hydrophobic properties of electrospun polystyrene fibers. *Materials*, *8*(5), 2718–2734. https://doi.org/10.3390/ma8052718

Huang, Z. M., Zhang, Y. Z., Kotaki, M., & Ramakrishna, S. (2003). A review on polymer nanofibers by electrospinning and their applications in nanocomposites. In *Composites Science and Technology* (Vol. 63, Issue 15, pp. 2223–2253). https://doi.org/10.1016/S0266-3538(03)00178-7

Jabur, A. R., Najim, M. A., & Al-Rahman, S. A. A. (2018). Study the effect of flow rate on some physical properties of different polymeric solutions. *Journal of Physics: Conference Series*, *1003*(1). https://doi.org/10.1088/1742-6596/1003/1/012069

Jacob, J., Haponiuk, J. T., Thomas, S., Peter, G., & Gopi, S. (2018). Use of gingernanofibers for the preparation of cellulose nanocomposites and their antimicrobial activities. *Fibers*, *6*(4), 79. https://doi.org/10.3390/fib6040079

Jiang, T., Carbone, E. J., Lo, K. W. H., & Laurencin, C. T. (2015). Electrospinning of polymer nanofibers for tissue regeneration. *Progress in Polymer Science*, *46*, 1– 24. https://doi.org/10.1016/j.progpolymsci.2014.12.001

Kamel, N. A., Soliman, A. A. F., Rozik, N. N., & Abd-Elmessieha, S. L. (2018). Biophysical investigation of curcumin based nanocomposite for wound dressing application. *Journal of Applied Pharmaceutical Science*, *8*(5), 35–44. https://doi.org/10.7324/JAPS.2018.8505

Kamoun, E. A., Chen, X., Mohy Eldin, M. S., & Kenawy, E. R. S. (2015). Crosslinked poly(vinyl alcohol) hydrogels for wound dressing applications: A review of remarkably blended polymers. In *Arabian Journal of Chemistry,* 8(1), 1–14. https://doi.org/10.1016/j.arabjc.2014.07.005

Kang, H., Wang, Z., Zhao, S., Wang, Q., & Zhang, S. (2018). Reinforced soy protein isolate–based bionanocomposites with halloysite nanotubes via mussel-inspired dopamine and polylysine codeposition. *Journal of Applied Polymer Science*, *135*(18), 46197. https://doi.org/10.1002/app.46197

Karri, V. V. S. R., Kuppusamy, G., Talluri, S. V., Mannemala, S. S., Kollipara, R., Wadhwani, A. D., Mulukutla, S., Raju, K. R. S., & Malayandi, R. (2016). Curcumin loaded chitosan nanoparticles impregnated into collagen-alginate scaffolds for diabetic wound healing. *International Journal of Biological Macromolecules*, *93*, 1519–1529. https://doi.org/10.1016/j.ijbiomac.2016.05.038

Khandelwal, P., Alam, A., Choksi, A., Chattopadhyay, S., & Poddar, P. (2018). Retention of Anticancer Activity of Curcumin after Conjugation with Fluorescent Gold Quantum Clusters: An in Vitro and in Vivo Xenograft Study. *ACS Omega*, *3*(5), 4776–4785. https://doi.org/10.1021/acsomega.8b00113

Kharaghani, D., Gitigard, P., Ohtani, H., Kim, K. O., Ullah, S., Saito, Y., Khan, M. Q., & Kim, I. S. (2019). Design and characterization of dual drug delivery based on in-situ assembled PVA/PAN core-shell nanofibers for wound dressing application. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-49132- x

Khorasani, M. T., Joorabloo, A., Moghaddam, A., Shamsi, H., & MansooriMoghadam, Z. (2018). Incorporation of ZnO nanoparticles into heparinised polyvinyl alcohol/chitosan hydrogels for wound dressing application. *International Journal of Biological Macromolecules*, *114*, 1203–1215. https://doi.org/10.1016/j.ijbiomac.2018.04.010

Kim, J. F., Kim, J. H., Lee, Y. M., & Drioli, E. (2016). Thermally induced phase separation and electrospinning methods for emerging membrane applications: A review. *AIChE Journal*, *62*(2), 461–490. https://doi.org/10.1002/aic.15076

Komur, B., Bayrak, F., Ekren, N., Eroglu, M. S., Oktar, F. N., Sinirlioglu, Z. A., Yucel, S., Guler, O., & Gunduz, O. (2017). Starch/PCL composite nanofibers by co-axial electrospinning technique for biomedical applications. *BioMedical Engineering Online*, *16*(1). https://doi.org/10.1186/s12938-017-0334-y

Kouhi, M., Fathi, M., Prabhakaran, M. P., Shamanian, M., & Ramakrishna, S. (2018). Poly L lysine-modified PHBV based nanofibrous scaffolds for bone cell mineralization and osteogenic differentiation. *Applied Surface Science*, *457*, 616– 625. https://doi.org/10.1016/j.apsusc.2018.06.239

Kuchi, C., Harish, G. S., & Reddy, P. S. (2018). Effect of polymer concentration, needle diameter and annealing temperature on TiO2-PVP composite nanofibers synthesized by electrospinning technique. *Ceramics International*, *44*(5), 5266– 5272. https://doi.org/10.1016/j.ceramint.2017.12.138

Kucinska-Lipka, J., Gubanska, I., Lewandowska, A., Terebieniec, A., Przybytek, A., & Cieśliński, H. (2019). Antibacterial polyurethanes, modified with cinnamaldehyde, as potential materials for fabrication of wound dressings. *Polymer Bulletin*, *76*(6), 2725–2742. https://doi.org/10.1007/s00289-018-2512-x

Li, J., Zhai, D., Lv, F., Yu, Q., Ma, H., Yin, J., Yi, Z., Liu, M., Chang, J., & Wu, C. (2016). Preparation of copper-containing bioactive glass/eggshell membrane nanocomposites for improving angiogenesis, antibacterial activity and wound healing. *Acta Biomaterialia*, *36*,254–266. https://doi.org/10.1016/j.actbio.2016.03.011

Li, X., Cai, Z., Ahn, D. U., & Huang, X. (2019). Development of an antibacterial nanobiomaterial for wound-care based on the absorption of AgNPs on the eggshell membrane. *Colloids and Surfaces B: Biointerfaces*, *183*. https://doi.org/10.1016/j.colsurfb.2019.110449

Li, X., Ma, M., Ahn, D. U., & Huang, X. (2019). Preparation and characterization of novel eggshell membrane-chitosan blend films for potential wound-care dressing: From waste to medicinal products. *International Journal of Biological Macromolecules*, *123*, 477–484. https://doi.org/10.1016/j.ijbiomac.2018.10.215

Li, Z., & Wang, C. Effects of Working Parameters on Electrospinning. *In:* Li, Z., & Wang, C. *One-Dimensional Nanostructures. Springer*. pp. 15– 28. 2013. https://doi.org/10.1007/978-3-642-36427-3_2

Liang, C., Yuan, F., Liu, F., Wang, Y., & Gao, Y. (2014). Structure and antimicrobial mechanism of ε-polylysine-chitosan conjugates through Maillard reaction. *International Journal of Biological Macromolecules*, *70*, 427–434. https://doi.org/10.1016/j.ijbiomac.2014.07.012

Liao, N., Unnithan, A. R., Joshi, M. K., Tiwari, A. P., Hong, S. T., Park, C. H., & Kim, C. S. (2015). Electrospun bioactive poly (e{open}-caprolactone)-cellulose acetate-dextran antibacterial composite mats for wound dressing applications. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *469*, 194– 201. https://doi.org/10.1016/j.colsurfa.2015.01.022

Lin, L., Xue, L., Duraiarasan, S., & Haiying, C. (2018). Preparation of ε-polylysine/chitosan nanofibers for food packaging against Salmonella on chicken. *Food Packaging and Shelf Lıfe*, *17*, 134–141. https://doi.org/10.1016/j.fpsl.2018.06.013

Liu, H., Wang, C., Li, C., Qin, Y., Wang, Z., Yang, F., Li, Z., & Wang, J. (2018). A functional chitosan-based hydrogel as a wound dressing and drug delivery system in the treatment of wound healing. In *RSC Advances* (Vol. 8, Issue 14, pp. 7533– 7549). Royal Society of Chemistry. https://doi.org/10.1039/c7ra13510f

Liu, M., Duan, X. P., Li, Y. M., Yang, D. P., & Long, Y. Z. (2017). Electrospun nanofibers for wound healing. *Materials Science and Engineering C*, *76*, 1413–1423. https://doi.org/10.1016/j.msec.2017.03.034

Liu, X., You, L., Tarafder, S., Zou, L., Fang, Z., Chen, J., Lee, C. H., & Zhang, Q. (2019). Curcumin-releasing chitosan/aloe membrane for skin regeneration. *Chemical Engineering Journal*, *359*,1111–1119. https://doi.org/10.1016/j.cej.2018.11.073

Liu, Y., Zhou, S., Gao, Y., & Zhai, Y. (2019). Electrospun nanofibers as a wound dressing for treating diabetic foot ulcer. *Asian Journal of Pharmaceutical Sciences*. 14(2), 130–143. https://doi.org/10.1016/j.ajps.2018.04.004

Liverani, L., Lacina, J., Roether, J. A., Boccardi, E., Killian, M. S., Schmuki, P., Schubert, D. W., & Boccaccini, A. R. (2018). Incorporation of bioactive glass nanoparticles in electrospun PCL/chitosan fibers by using benign solvents. *Bioactive Materials*, *3*(1), 55–63. https://doi.org/10.1016/j.bioactmat.2017.05.003

Lopez-Esparza, J., Francisco Espinosa-Cristobal, L., Donohue-Cornejo, A., & Reyes-Lopez, S. Y. (2016). Antimicrobial activity of silver nanoparticles in polycaprolactone nanofibers against gram-positive and gram-negative bacteria. *Industrial and Engineering Chemistry Research*, *55*(49), 12532–12538. https://doi.org/10.1021/acs.iecr.6b02300

Mehrabani, M. G., Karimian, R., Mehramouz, B., Rahimi, M., & Kafil, H. S. (2018). Preparation of biocompatible and biodegradable silk fibroin/chitin/silver nanoparticles 3D scaffolds as a bandage for antimicrobial wound dressing. *International Journal of Biological Macromolecules*, *114*, 961–971. https://doi.org/10.1016/j.ijbiomac.2018.03.128

Metwally, H. A., Ardazishvili, R. V., Severyukhina, A. N., Zaharevich, A. M., Skaptsov, A. A., Venig, S. B., Sukhorukov, G. B., & Gorin, D. A. (2014). The Influence of Hydroxyapatite and Calcium Carbonate Microparticles on the Mechanical Properties of Nonwoven Composite Materials Based on Polycaprolactone. *BioNanoScience*, *5*(1), 22–30. https://doi.org/10.1007/s12668-014-0158-1

Michels, L., Richter, A., Chellappan, R. K., Røst, H. I., Behsen, A., Wells, K. H., Leal, L., Santana, V., Blawid, R., da Silva, G. J., Cooil, S. P., Wells, J. W., & Blawid, S. (2021). Electronic and structural properties of the natural dyes curcumin, bixin and indigo. *RSC Advances*, *11*(23), 14169–14177. https://doi.org/10.1039/d0ra08474c

Miguel, S. P., Figueira, D. R., Simões, D., Ribeiro, M. P., Coutinho, P., Ferreira, P., & Correia, I. J. (2018). Electrospun polymeric nanofibers as wound dressings: A review. *Colloids and Surfaces B: Biointerfaces.* 169, 60–71. https://doi.org/10.1016/j.colsurfb.2018.05.011

Miguel, S. P., Sequeira, R. S., Moreira, A. F., Cabral, C. S. D., Mendonça, A. G., Ferreira, P., & Correia, I. J. (2019). An overview of electrospun membranes loaded with bioactive molecules for improving the wound healing process. *European Journal of Pharmaceutics and Biopharmaceutics.* 139, 1–22. https://doi.org/10.1016/j.ejpb.2019.03.010

Minakshi, M., Higley, S., Baur, C., Mitchell, D. R. G., Jones, R. T., & Fichtner, M. (2019). Calcined chicken eggshell electrode for battery and supercapacitor applications. *RSC Advances*, *9*(46), 26981–26995. https://doi.org/10.1039/c9ra04289j

Mittal, A., Teotia, M., Soni, R. K., & Mittal, J. (2016). Applications of egg shell and egg shell membrane as adsorbents: A review. *Journal of Molecular Liquids*, *223*, 376–387. https://doi.org/10.1016/j.molliq.2016.08.065

Mohammadzadeh, L., Rahbarghazi, R., Salehi, R., & Mahkam, M. (2019). A novel egg-shell membrane based hybrid nanofibrous scaffold for cutaneous tissue engineering. *Journal of Biological Engineering*, *13*(1). https://doi.org/10.1186/s13036-019-0208-x

Moradkhannejhad, L., Abdouss, M., Nikfarjam, N., Mazinani, S., & Sayar, P. (2017). Electrospun Curcumin Loaded Poly(lactic acid) Nanofiber Mat on the Flexible Crosslinked PVA/PEG Membrane Film: Characterization and in vitro Release Kinetic Study. *Fibers and Polymers*, *18*(12), 2349–2360. https://doi.org/10.1007/s12221-017-7543-7

Morgado, P. I., Aguiar-Ricardo, A., & Correia, I. J. (2015). Asymmetric membranes as ideal wound dressings: An overview on production methods, structure, properties and performance relationship. In *Journal of Membrane Science.* 490, 139–151. https://doi.org/10.1016/j.memsci.2015.04.064

Motamedi, A. S., Mirzadeh, H., Hajiesmaeilbaigi, F., Bagheri-Khoulenjani, S., & Shokrgozar, M. (2017). Effect of electrospinning parameters on morphological properties of PVDF nanofibrous scaffolds. *Progress in Biomaterials*, *6*(3), 113– 123. https://doi.org/10.1007/s40204-017-0071-0

Mutlu, G., Calamak, S., Ulubayram, K., & Guven, E. (2018). Curcumin-loaded electrospun PHBV nanofibers as potential wound-dressing material. *Journal of Drug Delivery Science and Technology*, *43*, 185–193. https://doi.org/10.1016/j.jddst.2017.09.017

Nhi, T. T., Khon, H. C., Hoai, N. T. T., Bao, B. C., Quyen, T. N., Van Toi, V., & Hiep, N. T. (2016). Fabrication of electrospun polycaprolactone coated withchitosan-silver nanoparticles membranes for wound dressing applications. *Journal of Materials Science: Materials in Medicine*, *27*(10), 156. https://doi.org/10.1007/s10856-016-5768-4

Ohshima, Y., Takada, D., Namai, S., Sawai, J., Kikuchi, M., & Hotta, M. (2015). Antimicrobial characteristics of heated eggshell powder. *Biocontrol Science*, *20*(4), 239–246. https://doi.org/10.4265/bio.20.239

Park, B. K., & Um, I. C. (2018). Effect of molecular weight on electro-spinning performance of regenerated silk. *International Journal of Biological Macromolecules*, *106*, 1166–1172. https://doi.org/10.1016/j.ijbiomac.2017.08.115

Park, S., Choi, K. S., Kim, W., Lee, D., Kim, D., Kim, M. S., Kim, K., & Kim, J. (2018). Engineering nanowrinkled microfibers composed of eggshell membrane and graphene. *Materials Letters*, *229*,78–81. https://doi.org/10.1016/j.matlet.2018.06.113

Park, S., Choi, K. S., Lee, D., Kim, D., Lim, K. T., Lee, K. H., Seonwoo, H., & Kim,J. (2016). Eggshell membrane: Review and impact on engineering. *Biosystems Engineering*, *151*, 446–463. https://doi.org/10.1016/j.biosystemseng.2016.10.014

Perumal, G., Pappuru, S., Chakraborty, D., Maya Nandkumar, A., Chand, D. K., & Doble, M. (2017). Synthesis and characterization of curcumin loaded PLA—Hyperbranched polyglycerol electrospun blend for wound dressing applications. *Materials Science and Engineering C*, *76*, 1196–1204. https://doi.org/10.1016/j.msec.2017.03.200

Pervez, M. N., & Stylios, G. K. (2018). Investigating the synthesis and characterization of a novel "green" H2 O2-assisted, water-soluble chitosan/polyvinyl alcohol nanofiber for environmental end uses. *Nanomaterials*, *8*(6), 395. https://doi.org/10.3390/nano8060395

Petras, D., Slobodian, P., Pavlínek, V., Sáha, P., & Kimmer, D. (2011). The effect of PVAc solution viscosity on diameter of PVAc nanofibers prepared by technology of electrospinning. *AIP Conference Proceedings*, *1375*, 312–319. https://doi.org/10.1063/1.3604491

Quina, M. J., Soares, M. A. R., & Quinta-Ferreira, R. (2017). Applications of industrial eggshell as a valuable anthropogenic resource. *Resources, Conservation and Recycling*, *123*, 176–186. https://doi.org/10.1016/j.resconrec.2016.09.027

Quirós, J., Boltes, K., & Rosal, R. (2016). Bioactive Applications for Electrospun Fibers. *Polymer Reviews*, *56*(4), 631–667. https://doi.org/10.1080/15583724.2015.1136641

Rahman, M. R., Hamdan, S., & Chang Hui, J. L. (2017). Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) of Wood polymer nanocomposites. *MATEC Web of conferences*, *87*. https://doi.org/10.1051/matecconf/20178703013

Ranjbar-Mohammadi, M., & Bahrami, S. H. (2016). Electrospun curcumin loaded poly(ε-caprolactone)/gum tragacanth nanofibers for biomedical application. *International Journal of Biological Macromolecules*, *84*, 448–456. https://doi.org/10.1016/j.ijbiomac.2015.12.024

Ravikumar, R., Ganesh, M., Ubaidulla, U., Young Choi, E., & Tae Jang, H. (2017). Preparation, characterization, and in vitro diffusion study of nonwoven electrospun nanofiber of curcumin-loaded cellulose acetate phthalate polymer. *Saudi Pharmaceutical Journal*, *25*(6) ,921–926. https://doi.org/10.1016/j.jsps.2017.02.004

Ray, P. G., Pal, P., Srivas, P. K., Basak, P., Roy, S., & Dhara, S. (2018). Surface modification of eggshell membrane with electrospun chitosan/polycaprolactone nanofibers for enhanced dermal wound healing. *ACS Applied Bio Materials*, *1*(4), 985–998. https://doi.org/10.1021/acsabm.8b00169

Rezvani Ghomi, E., Khalili, S., Nouri Khorasani, S., Esmaeely Neisiany, R., & Ramakrishna, S. (2019). Wound dressings: Current advances and future directions. In *Journal of Applied Polymer Science* (Vol. 136, Issue 27, p. 47738). John Wiley and Sons Inc. https://doi.org/10.1002/app.47738

Ribeiro, C. A. S., de Castro, C. E., Albuquerque, L. J. C., Batista, C. C. S., & Giacomelli, F. C. (2017). Biodegradable nanoparticles as nanomedicines: are drug-loading content and release mechanism dictated by particle density? *Colloid and Polymer Science*, *295*(8), 1271–1280. https://doi.org/10.1007/s00396-016-4007-3

Sadeghianmaryan, A., Yazdanpanah, Z., Soltani, Y. A., Sardroud, H. A., Nasirtabrizi,M. H., & Chen, X. (2020). Curcumin-loaded electrospun polycaprolactone/montmorillonite nanocomposite: wound dressing application with anti-bacterial and low cell toxicity properties. *Journal of Biomaterials Science, Polymer Edition*, *31*(2), 169–187. https://doi.org/10.1080/09205063.2019.1680928

Saeed, S. M., Mirzadeh, H., Zandi, M., & Barzin, J. (2017). Designing and fabrication of curcumin loaded PCL/PVA multi-layer nanofibrous electrospun structures as active wound dressing. *Progress in Biomaterials*, *6*(1–2), 39–48. https://doi.org/10.1007/s40204-017-0062-1

Sampath, M., Lakra, R., Korrapati, P. S., & Sengottuvelan, B. (2014). Curcumin loaded poly (lactic-co-glycolic) acid nanofiber for the treatment of carcinoma. *Colloids and Surfaces B: Biointerfaces*, *117*, 128–134. https://doi.org/10.1016/j.colsurfb.2014.02.020

Santos, K. O., Barbosa, R. C., da Silva Buriti, J., Bezerra Junior, A. G., de Sousa, W.

J. B., de Barros, S. M. C., de Oliveira, R. J., & Fook, M. V. L. (2019). Thermal, chemical, biological and mechanical properties of chitosan films with powder of eggshell membrane for biomedical applications. *Journal of Thermal Analysis andCalorimetry*, *136*(2), 725–735. https://doi.org/10.1007/s10973-018-7666-0

Saveleva, M. S., Ivanov, A. N., Kurtukova, M. O., Atkin, V. S., Ivanova, A. G., Lyubun, G. P., Martyukova, A. V., Cherevko, E. I., Sargsyan, A. K., Fedonnikov,

A. S., Norkin, I. A., Skirtach, A. G., Gorin, D. A., & Parakhonskiy, B. V. (2018). Hybrid PCL/CaCO3 scaffolds with capabilities of carrying biologically active molecules: Synthesis, loading and in vivo applications. *Materials Science and Engineering C*, *85*, 57–67. https://doi.org/10.1016/j.msec.2017.12.019

Semnani, D. (2017). Geometrical characterization of electrospun nanofibers. In: Mehdi Afshari. *Electrospun Nanofibers*. Elsevier Inc. 151-180- 2017. https://doi.org/10.1016/B978-0-08-100907-9.00007-6

Sequeira, R. S., Miguel, S. P., Cabral, C. S. D., Moreira, A. F., Ferreira, P., & Correia,I. J. (2019). Development of a poly(vinyl alcohol)/lysine electrospun membrane-based drug delivery system for improved skin regeneration. *International Journal ofPharmaceutics*, *570*. https://doi.org/10.1016/j.ijpharm.2019.118640

Shafiei, S., Omidi, M., Nasehi, F., Golzar, H., Mohammadrezaei, D., Rezai Rad, M., & Khojasteh, A. (2019). Egg shell-derived calcium phosphate/carbon dot nanofibrous scaffolds for bone tissue engineering: Fabrication and characterization. *Materials Science and Engineering: C*, *100*, 564–575. https://doi.org/10.1016/j.msec.2019.03.003

Shen, Z., Cai, N., Xue, Y., Yu, B., Wang, J., Song, H., Deng, H., & Yu, F. (2020). Porous SBA-15/cellulose membrane with prolonged anti-microbial drug release characteristics for potential wound dressing application. *Cellulose*, *27*(5), 2737– 2756. https://doi.org/10.1007/s10570-020-02967-4

Shi, C., Zhao, X., Liu, Z., Meng, R., Chen, X., & Guo, N. (2016). Antimicrobial, antioxidant, and antitumor activity of epsilon-poly-L-lysine and citral, alone or in combination. *Food and Nutrition Research*, *60*. https://doi.org/10.3402/fnr.v60.31891

Shi, R., Geng, H., Gong, M., Ye, J., Wu, C., Hu, X., & Zhang, L. (2018). Long-acting and broad-spectrum antimicrobial electrospun poly (ε-caprolactone)/gelatin micro/nanofibers for wound dressing. *Journal of Colloid and Interface Science*, *509*, 275–284. https://doi.org/10.1016/j.jcis.2017.08.092

Simões, D., Miguel, S. P., Ribeiro, M. P., Coutinho, P., Mendonça, A. G., & Correia, I. J. (2018). Recent advances on antimicrobial wound dressing: A review. In *European Journal of Pharmaceutics and Biopharmaceutics*. *127*, 130– 141. https://doi.org/10.1016/j.ejpb.2018.02.022

Singh, A. K., Yadav, S., Sharma, K., Firdaus, Z., Aditi, P., Neogi, K., Bansal, M., Gupta, M. K., Shanker, A., Singh, R. K., & Prakash, P. (2018). Quantum curcumin mediated inhibition of gingipains and mixed-biofilm of Porphyromonas gingivalis causing chronic periodontitis. *RSC Advances*, *8*(70), 40426–40445. https://doi.org/10.1039/C8RA08435A

Soares, M. A. R., Quina, M. J., & Quinta-Ferreira, R. M. (2015). Immobilisation of lead and zinc in contaminated soil using compost derived from industrial eggshell. *Journal of Environmental Management*, *164*, 137–145. https://doi.org/10.1016/j.jenvman.2015.08.042

Sudheesh Kumar, P. T., Lakshmanan, V. K., Anilkumar, T. V., Ramya, C., Reshmi, P., Unnikrishnan, A. G., Nair, S. V., & Jayakumar, R. (2012). Flexible and microporous chitosan hydrogel/nano ZnO composite bandages for wound dressing: In vitro and in vivo evaluation. *ACS Applied Materials and Interfaces*, *4*(5), 2618–2629. https://doi.org/10.1021/am300292v

Suharty, N. S., Almanar, I. P., Sudirman, Dihardjo, K., & Astasari, N. (2012). Flammability, Biodegradability and Mechanical Properties of Bio-Composites Waste Polypropylene/Kenaf Fiber Containing Nano CaCO3 with Diammonium Phosphate. *Procedia Chemistry*, *4*, 282–287. https://doi.org/10.1016/j.proche.2012.06.039

Sun, X. Z., Williams, G. R., Hou, X. X., & Zhu, L. M. (2013). Electrospun curcumin-loaded fibers with potential biomedical applications. *Carbohydrate Polymers*, *94*(1), 147–153. https://doi.org/10.1016/j.carbpol.2012.12.064

Susheel Chaudhary, L., & Ravindra Ghatmale, P. (2016). Characterization Technique of Nanofibers. *IJSRD-International Journal for Scientific Research & Development*. 4(3). 2321-0613.

Suwantong, O. (2016). Biomedical applications of electrospun polycaprolactone fiber mats. *Polymers for Advanced Technologies*. 27(10),1264–1273. https://doi.org/10.1002/pat.3876

Tan, Z., Shi, Y., Xing, B., Hou, Y., Cui, J., & Jia, S. (2019). The antimicrobial effects and mechanism of ε-poly-lysine against Staphylococcus aureus. *Bioresources and Bioprocessing*, *6*(1). https://doi.org/10.1186/s40643-019-0246-8

Tarus, B., Fadel, N., Al-Oufy, A., & El-Messiry, M. (2016). Effect of polymer concentration on the morphology and mechanical characteristics of electrospun cellulose acetate and poly (vinyl chloride) nanofiber mats. *Alexandria Engineering Journal*, *55*(3), 2975–2984. https://doi.org/10.1016/j.aej.2016.04.025

Tavakoli, J., & Tang, Y. (2017). Honey/PVA hybrid wound dressings with controlled release of antibioticsStructural, physico-mechanical and in-vitro biomedical studies. *Materials Science and Engineering C*, *77*, 318–325. https://doi.org/10.1016/j.msec.2017.03.272

Thenmozhi, S., Dharmaraj, N., Kadirvelu, K., & Kim, H. Y. (2017). Electrospun nanofibers: New generation materials for advanced applications. *Materials Science and Engineering B: Solid-State Materials for Advanced Technology*, *217*, 36–48. https://doi.org/10.1016/j.mseb.2017.01.001

Thomas, R., Soumya, K. R., Mathew, J., & Radhakrishnan, E. K. (2015). Electrospun Polycaprolactone Membrane Incorporated with Biosynthesized Silver Nanoparticles as Effective Wound Dressing Material. *Applied Biochemistry and Biotechnology*, *176*(8), 2213–2224. https://doi.org/10.1007/s12010-015-1709-9

Thompson, J., Gizaw, M., & Chou, S. (2018). *Fabrication and Characterization of Electrospun Drug-eluting Nanofibers from Polycaprolactone/Chitosan Blends*. 4–7. https://peer.asee.org/fabrication-and-characterization-of-electrospun-drug- eluting-nanofibers-from-polycaprolactone-chitosan-blends.pdf

Tiwari, A. P., & Rohiwal, S. S. Synthesis and Bioconjugation of Hybrid Nanostructures for Biomedical Applications. In: Bohara, R. A. & Thorat, N. *Hybrid Nanostructures for Cancer Theranostics. Elsevier.* 1–10. 2019. https://doi.org/10.1016/B978-0-12- 813906-6.00002-0

Trakoolwannachai, V., Kheolamai, P., & Ummartyotin, S. (2019). Characterization of hydroxyapatite from eggshell waste and polycaprolactone (PCL) composite for scaffold material. *Composites Part B: Engineering*, *173*. https://doi.org/10.1016/j.compositesb.2019.106974

Tummalapalli, M., Berthet, M., Verrier, B., Deopura, B. L., Alam, M. S., & Gupta, B. (2016). Composite wound dressings of pectin and gelatin with aloe vera and curcumin as bioactive agents. *International Journal of Biological Macromolecules*, *82*, 104–113. https://doi.org/10.1016/j.ijbiomac.2015.10.087

Unalan, I., Endlein, S. J., Slavik, B., Buettner, A., Goldmann, W. H., Detsch, R., & Boccaccini, A. R. (2019). Evaluation of electrospun poly(ε-caprolactone)/gelatin nanofiber mats containing clove essential oil for antibacterial wound dressing. *Pharmaceutics*, *11*(11). https://doi.org/10.3390/pharmaceutics11110570

Velasco Barraza, R. D., Álvarez Suarez, A. S., Villarreal Gómez, L. J., Paz González,J. A., Iglesias, A. L., & Vera Graziano, R. (2016). Designing a low-cost electrospinning device for practical learning in a Bioengineering Biomaterials course. *Revista Mexicana de Ingenieria Biomedica*, *37*(1), 7–16. https://doi.org/10.17488/RMIB.37.1.1

Waghmare, V. S., Wadke, P. R., Dyawanapelly, S., Deshpande, A., Jain, R., & Dandekar, P. (2018). Starch based nanofibrous scaffolds for wound healing applications. *Bioactive Materials*, *3*(3), 255–266. https://doi.org/10.1016/j.bioactmat.2017.11.006

Wang, F., Hu, S., Jia, Q., & Zhang, L. (2020). Advances in Electrospinning of Natural Biomaterials for Wound Dressing. *Journal of Nanomaterials*. 2020, 1–14. https://doi.org/10.1155/2020/8719859

Wang, H., Hao, L., Wang, P., Chen, M., Jiang, S., & Jiang, S. (2017). Release kinetics and antibacterial activity of curcumin loaded zein fibers. *Food Hydrocolloids*, *63*, 437–446. https://doi.org/10.1016/j.foodhyd.2016.09.028

Wang, L., Tang, B., Zhou, J., Zhao, H., Chen, W., & Wang, J. (2019). Sunlight-Driven Photothermal Effect of Composite Eggshell Membrane Coated with Graphene Oxide. *Applied Sciences, 9(20), 4384. https:// 10.3390/app9204384*

Wang, R., Zhou, B., Xu, D. L., Xu, H., Liang, L., Feng, X. H., Ouyang, P. K., & Chi, B. (2016). Antimicrobial and biocompatible ϵ-polylysine-γ-poly(glutamic acid)- based hydrogel system for wound healing. *Journal of Bioactive and Compatible Polymers*, *31*(3), 242–259. https://doi.org/10.1177/0883911515610019

Wiegand, C., Abel, M., Ruth, P., Elsner, P., & Hipler, U. C. (2015). In vitro assessment of the antimicrobial activity of wound dressings: influence of the test method selected and impact of the pH. *Journal of Materials Science: Materials in Medicine*, *26*(1). https://doi.org/10.1007/s10856-014-5343-9

Xiang, H., Sun-waterhouse, D., Cui, C., Wang, W., & Dong, K. (2018). Modification of soy protein isolate by glutaminase for nanocomplexation with curcumin. *Food Chemistry*, *268*, 504–512. https://doi.org/10.1016/j.foodchem.2018.06.059

Xu, R., Luo, G., Xia, H., He, W., Zhao, J., Liu, B., Tan, J., Zhou, J., Liu, D., Wang, Y., Yao, Z., Zhan, R., Yang, S., & Wu, J. (2015). Novel bilayer wound dressing composed of silicone rubber with particular micropores enhanced wound re-epithelialization and contraction. *Biomaterials*, *40*, 1–11. https://doi.org/10.1016/j.biomaterials.2014.10.077

Xu, R., Xia, H., He, W., Li, Z., Zhao, J., Liu, B., Wang, Y., Lei, Q., Kong, Y., Bai, Y.,

Yao, Z., Yan, R., Li, H., Zhan, R., Yang, S., Luo, G., & Wu, J. (2016). Controlled water vapor transmission rate promotes wound-healing via wound re-epithelialization and contraction enhancement. *Scientific Reports*, *6*(1), 1–12. https://doi.org/10.1038/srep24596

Xu, T., Liang, Z., Ding, B., Feng, Q., & Fong, H. (2018). Polymer blend nanofibers containing polycaprolactone as biocompatible and biodegradable binding agent to fabricate electrospun three-dimensional scaffolds/structures. *Polymer*, *151*, 299–306. https://doi.org/10.1016/j.polymer.2018.07.074

Xu, Z., Xu, Z., Feng, X., Xu, D., Liang, J., & Xu, H. (2016). Recent advances in the biotechnological production of microbial poly(ε-l-lysine) and understanding of its biosynthetic mechanism. *Applied Microbiology and Biotechnology*, *100*(15), 6619–6630. https://doi.org/10.1007/s00253-016-7677-3

You, R., Zhang, J., Gu, S., Zhou, Y., Li, X., Ye, D., & Xu, W. (2017). Regenerated egg white/silk fibroin composite films for biomedical applications. *Materials Science and Engineering C*, *79*, 430–435. https://doi.org/10.1016/j.msec.2017.05.063

Yu, B., He, C., Wang, W., Ren, Y., Yang, J., Guo, S., Zheng, Y., & Shi, X. (2020).

Asymmetric Wettable Composite Wound Dressing Prepared by Electrospinning with Bioinspired Micropatterning Enhances Diabetic Wound Healing. *ACS Applied Biomaterials*, *3*(8), 5383–5394. https://doi.org/10.1021/acsabm.0c00695

Yu, H., Liu, L., Li, X., Zhou, R., Yan, S., Li, C., Luan, S., Yin, J., & Shi, H. (2019). Fabrication of polylysine based antibacterial coating for catheters by facile electrostatic interaction. *Chemical Engineering Journal*, *360*, 1030–1041. https://doi.org/10.1016/j.cej.2018.10.160

Zargham, S., Bazgir, S., Tavakoli, A., Rashidi, A. S., & Damerchely, R. (2012). The effect of flow rate on morphology and deposition area of electrospun nylon 6 nanofiber. *Journal of Engineered Fibers and Fabrics*, *7*(4), 42–49. https://doi.org/10.1177/155892501200700414

Zhang, D., Zhao, H., Fan, Z., Li, M., Du, P., Liu, C., Li, Y., Li, H., & Cao, H. (2015). A highly sensitive and selective hydrogen peroxide biosensor based on gold nanoparticles and three-dimensional porous carbonized chicken eggshell membrane. *PLoS ONE*, *10*(6), e0130156. https://doi.org/10.1371/journal.pone.0130156

Zhang, L., Li, R., Dong, F., Tian, A., Li, Z., & Dai, Y. (2015). Physical, mechanical and antimicrobial properties of starch films incorporated with ε-poly-l-lysine. *Food Chemistry*, *166*, 107–114. https://doi.org/10.1016/j.foodchem.2014.06.008

Zhang, Q., Oh, J. H., Park, C. H., Baek, J. H., Ryoo, H. M., & Woo, K. M. (2017). Effects of Dimethyloxalylglycine-Embedded Poly(ε-caprolactone) Fiber Meshes on Wound Healing in Diabetic Rats. *ACS Applied Materials and Interfaces*, *9*(9), 7950–7963. https://doi.org/10.1021/acsami.6b15815

Zhang, Y. Z., Su, B., Venugopal, J., Ramakrishna, S., & Lim, C. T. (2007). Biomimetic and bioactive nanofibrous scaffolds from electrospun composite nanofibers. *International Journal of Nanomedicine*, *2*(4), 623–638. http://www.ncbi.nlm.nih.gov/pubmed/18203429

Zhao, R., Wang, H., Ji, T., Anderson, G., Nie, G., & Zhao, Y. (2015). Biodegradable cationic ε-poly-L-lysine-conjugated polymeric nanoparticles as a new effective antibacterial agent. *Science Bulletin*, *60*(2), 216–226. https://doi.org/10.1007/s11434-014-0704-9

Zhu, G., Zhao, L. Y., Zhu, L. T., Deng, X. Y., & Chen, W. L. (2017). Effect of Experimental Parameters on Nanofiber Diameter from Electrospinning with Wire Electrodes. *IOP Conference Series: Materials Science and Engineering*, *230*(1). https://doi.org/10.1088/1757-899X/230/1/012043

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Bello, M.**, Abdullah, F., Yusoff, A. R. M., Mahmood, M. A. W., Yong Chee, T., Malek, N. A. N. N., Jemon, K., & Sathishkumar, P. (2022). Curcumin-loaded electrospun poly (ε- caprolactone) nanofibrous membrane: an efficient and biocompatible wound- dressing material. *Material Letters,*315, *http://doi.org/10.1016/j.matlet.2022.131910.* ***(Q2, IF: 3.423)***

2. **Bello, M.**, Abdullah, F., Yusoff, A. R. M., Mahmood, M. A. W., Yong Chee, T., Malek, N. A. N. N., Jemon, K., Siddiquee, S., K., & Sathishkumar, P. (2022). Electrospun poly (ε- caprolactone)-eggshell membrane nanofibrous mat as a wound- dressing material. Biochemical Engineering Journal, http://doi.org/10.1016/j.bej.2022.108563. **(Q2, IF: 4.447)**

Non-Indexed Conference Proceedings

1. **Bello, M.**, Yusoff, A. R. M., Malek, N. A. N. N., Jemon, K., Abdullah, F., Yong Chee, T., & Pui Pui, W. (2020). Fabrication of Polymeric Nanofibers of Poly(ε-caprolactone) blended with Curcumin using Electrospinning Technique. In 2020 IGCESH 8th International Graduate Conference on Engineering, Science and Humanities (pp. 273-276)