PREPARATION AND CHARACTERIZATION OF CHITOSAN/POLY LACTIC ACID NANOFIBERS USING ELECTROSPINNING PROCESS FOR DRUG DELIVERY APPLICATIONS

NAWZAT DEEB ALJBOUR

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Chemical Engineering.

_____

(Supervisor's Signature)

Full Name : PROF DR. MOHAMMAD DALOUR HOSSEN BEG

Position :

Date :

_____

(Co-supervisor's Signature)

Full Name : ASSOC. PROF.DR. JOLIUS BIN GIMBUN

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name : NAWZAT DEEB ALJBOUR

ID Number : PKC17009

Date :

PREPARATION AND CHARACTERIZATION OF CHITOSAN/POLY LACTIC ACID NANOFIBERS USING ELECTROSPINNG PROCESS FOR DRUG DELIVERY APPLICATIONS

NAWZAT DEEB ALJBOUR

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Chemical and Process Engineering Technology

UNIVERSITI MALAYSIA PAHANG

DECEMBER 2019

ACKNOWLEDGEMENTS

I would like to use this opportunity to appreciate the Almighty God for the sound health and breathe of life He grants me, which made the period of my doctoral study a great success.

I would like to thank my supervisor Professor Mohammad Dalour Hossen Beg for his advice and guidance in the development of this research. It has been pleasured to be your student, I am highly appreciating your continuous support. Without all of your support, advice, and continuous encouragement I will never reach here. My deepest appreciation to my co-supervisor Professor Madya Dr. Jolius Bin Gimbun for his support and experience in this research.

I would like to thank all people in UMP, it was a wonderful place to work in, and the people are very dedicated. Furthermore, special thanks to the academic, managerial, and technical staff in Faculty of Chemical and Natural Resources Engineering, and the staff of the Institute of Postgraduate Studies (IPS).

I would like to express my warm thanks to my senior colleague's Dr Moshiul Alam and Dr. Akindoyo John Olabode for their continuous assistance that cannot be forgotten so easily as well.

I wish to express my warm and sincere thanks to my closest friends Faten Btoush and Aysha Noor Urmy for every moment we spent together, I really love you both.

My deepest gratitude's to my lovely mother, sister, and brothers for their prayers, believe in me, in addition to their continuous encouragement and support.

At last and most importantly, I would like to thank the candle that lit the darkness of my road my beloved husband Eng. Ibrahim Ayasrah for his open mindedness and endless love and support. Special thanks to my kids Elias and Aws who were special partners in this project, they were always here to refresh my soul with their love.

Finally, I'm dedicating this Doctoral Thesis to the soul of my lovely father, who passed away while wishing to see me one day "Dr. Nawzat Deeb AlJbour".

ABSTRAK

Serat nano merupakan bahan baru yang sangat penting dalam bidang bioperubatan, manakala sistem electrospinning menggunakan wayar merupakan salah satu teknologi yang berkebolehan untuk pengeluaran lapisan serat nano secara berterusan dan besar-besaran. Kitosan merupakan polimer bio yang mudah diperolehi, mesra alam dan bioserasi. Walau bagaimanapun, pengeluaran serat nano daripada kitosan adalah sukar kerana penggunaan medan elektrik yang tinggi semasa electrospinning mencetuskan daya tolakan antara kumpulan ionik dalam struktur molekul polimer, menyebabkan penghasilan serat nano bermanik bukannya serat nano yang sekata. Di samping itu, kelarutan kitosan yang rendah dalam pelarut menyukarkan penghasilan serat nano kitosan. Dalam kajian ini kitosan yang mempunyai berat molekul tinggi telah dipecahkan kepada kitosan yang menpunyai berat molekul rendah melalui kaedah pendeasetilan. Pelbagai tahap pendeasetilan menghasilkan kitosan yang berat molekul rendah yang berbeza. Kitosan ini seterusnya dicampur dengan larutan poli (laktik) asid (PLA) dalam diklorometana untuk memudahkan proses electrospinning. Campuran kitosan-PLA melalui proses electrospinning menggunakan wayar bebas untuk menghasilkan serat nano yang kemudianya diperiksa sifat permukaannya menggunakan miscroscopy imbasan elektron (SEM) dan analisis sudut sentuhan. Manakala, struktur kimia dalam serat nano dianalisis menggunakan spektroskopi inframerah transformasi Fourier (FTIR) dan kalorimetri imbasan kebezaan (DSC). Pencirian mekanikal dan fizikokimia juga telah dijalankan bagi serat nano yang dihasilkan. Serat nano yang mempunyai kualiti yang terbaik kemudiannya diubahsuai untuk aplikasi penyampaian ubat dengan memuatkan drug model, iaitu Diclofenac Sodium (DNA), ke dalam serat nano yang seterusnya dianalisis menggunakan pelbagai teknik pengesanan unsur dan fizikokimia. Potensi serat nano direka untuk aplikasi penyampaian ubat telah disahkan melalui kajian pelepasan drug secara in vitro serta kinetik pelepasan drug. Hasil kajian menunjukkan bahawa pendeasetilan 25% kitosan 15 kDa dan 7.5 kDa menghasilkan serat nano lebih berkualiti berbanding dengan berat molekul yang tinggi (30 kDa) chitosan. Serat nano yang dihasilkan menunjukkan sifat-sifat mekanikal lebih baik berbanding dengan nanofibers chitosan yang dilaporkan sebelum ini. Malah, kekuatan tegangan (3 MPa), modulus Young (1.5 MPa), dan% Pemanjangan (10%) adalah setanding dengan nilai yang dilaporkan sebelum ini bagi serat nano yang biasa digunakan untuk aplikasi penyampaian ubat. Sebaliknya, pembelauan sinar-X (XRD) dan X-ray spektroskopi fotoelektron (XPS) keputusan mendedahkan bahawa DNA tersimpan sekata dalam serat nano. Kajian pembebasan drug menunjukkan bahawa serat nano kitosan-PLA yang disediakan dengan menggunakan 25% kitosan (15 kDa) boleh digunakan untuk menyampaikan model drug (DNA) mengikut cara pelepasan terkawal selama 96 h dengan pelepasan letusan kira-kira 25%, dan kinetik pelepasan mengikut difusi Fickian. Oleh itu, serat nano yang dihasilkan dalam penyelidikan ini mempunyai ciri-ciri hidrofilik dan hidrofobik yang sangat baik untuk penyampaian durg yang mempunyai pelbagai darjah kekutuban.

ABSTRACT

Nanofibers are considered as a new class of highly important materials in the biomedical field, whereas free surface wire electrospinning system is one of the most versatile technologies for the continuous and mass production of nanofibrous layers. On the other hand, chitosan is a bio-derived, biodegradable and biocompatible polymer. However, the production of chitosan nanofibers is considered difficult because the application of high electric field during electrospinning triggers the repulsive forces between the ionic groups within the polymer backbone, resulting into formation of beads instead of continuous fibers. In addition, the low solubility of chitosan is another major limitation for the production of chitosan nanofibers. In this study high molecular weight chitosan was converted to low molecular weight chitosan with subsequent deacetylation, to produce low molecular weight chitosan with different degrees of deacetylation. These were further blended with a solution of poly(lactic) acid (PLA) in dichloromethane to facilitate the spinning process. The chitosan-PLA blend was electrospun using the free surface wire electrospinning process and the produced nanofibers were characterized for their surface properties using scanning electron miscroscopy (SEM) and contact angle analysis. In addition, the structural properties were determined through fourier transforms infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC). Furthermore, mechanical and physicochemical characterizations were conducted using different techniques. Fibers with the best performance were then modified for drug delivery applications by loading a model drug, Diclofenac Sodium (DNa), into the nanofibers, after which it was characterized accordingly using different elemental and physicochemical techniques. Then, the potential of the fabricated nanofibers for drug delivery applications was verified through in vitro release studies as well as drug release kinetic studies. Results showed that 25% fully deacetylated chitosan of 15 kDa and 7.5 kDa produces better quality nanofibers compared with the higher molecular weight (30 kDa) chitosan. Significantly, the produced nanofibers showed improved mechanical properties compared with the previously reported chitosan nanofibers prepared using the high molecular weight chitosan. In fact, the tensile strength (3 MPa), Young's modulus (1.5 MPa), and %Elongation (10%) are comparable to the previously reported values of nanofibrous mats produced using different polymers and used for drug delivery applications. On the other hand, X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) results reveal that the incorporated DNa is distributed within the nanofibers. Notably, release results showed that chitosan-PLA nanofibers prepared using 25% chitosan (15 kDa) could be used to deliver the model drug (DNa) in a controlled release manner for 96 h with burst release of about 25%, and release kinetics follow the Fickian Diffusion kinetics. Therefore, the nanofibers produced herein can open up a new type of nanofibers with both hydrophilic and hydrophobic properties which are highly desirable for the delivery of drugs with various degrees of polarity.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

η	Intrinsic viscosity
η_{rel}	Relative viscosity
η°	Solvent viscosity
η_{sp}	Specific viscosity
λ	Lambda
κ	Kappa
ί	Iota
K, a	Mark-Houwink constants
n	Fickian rate constant
K_0	Zero order rate constant
K_1	First order rate constant
K_H	Higuchi dissolution constant
K	Fickian diffusion constant

LIST OF ABBREVIATIONS

AcAc	Acetic Acid
CR	Controlled release
CRDD	Controlled release drug delivery
DCM	Dichloromethane
DDA	Degree of deacetylations
DLS	Dynamic light scattering
DNa	Diclofenac sodium
DSC	Differential scanning calorimetry
EDTA	Ethylenediaminetetraacetic acid
EDX	Energy disoersive X-ray
FDA	Food and drug administration
FDUV	First derivative ultra violet spectroscopy
FTIR	Fourier transform infrared
FSD	Fiber size distribution
Gm	Gram
HA	Hyaluronic acid
HCl	Hydrochloric acid
HMWC	High molecular weight chitosan
HNMR	HNuclear Magnetic Resonance
hr	Hour
kDa	Kilo Dalton
LMWC	Low molecular weight chitosan
Mn	Number average molecular weight
Mv	Viscosity average molecular weight
Mw	Weight average molecular weight
Mt	Amount of drug released at time t
M∞	Amount of drug released at time ∞
NaOH	Sodium Hydroxide
NSAID	Nonsteroidal anti-inflammatory drugs
PCL	Poly caprolactone
PEO	Polyethylene oxide

PET	Polyethylene terephthalate
PLA	Polylactic acid
PLGA	Poly lacticco-glycolic acid
ppm	Parts per million
PVA	Polyvinyl alcohol
PVP	Poly-vinylpyrrolidone
S1	15%CS 30kDa nanofiber
S2	15%CS 15kDa nanofiber
S3	15%CS 7.5kDa nanofiber
S4	25%CS 30kDa nanofiber
S5	25%CS 15kDa nanofiber
S6	25%CS 7.5kDa nanofiber
S7	PLA nanofiber nanofiber
SEM	Scanning electron microscopy
STDEV	Standard deviation
Tc	Crystalization temperature
Tg	Glass transition temperature
Tm	Melting temperature
TM	Tensile modulus
TS	Tensile strength

REFERENCES

Aam, B. B., Heggset, E. B., Norberg, A. L., Sørlie, M., Vårum, K. M. and Eijsink, V. G. (2010). Production of chitooligosaccharides and their potential applications in medicine. *Marine drugs, 8*(5), 1482-1517.

Abdal-Hay, A., Barakat, N. A. and Lim, J. K. (2012). Novel technique for polymeric nanofibers preparation: air jet spinning. *Science of Advanced Materials, 4*(12), 1268-1275.

Agrawal, C. M. and Ray, R. B. (2001). Biodegradable polymeric scaffolds for musculoskeletal tissue engineering. *Journal of Biomedical Materials Research: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials, 55*(2), 141-150.

Agrawal, P. (2013). *Fabrication of chitosan based nanofibrous scaffold using free surface electrospinning for tissue engineering application.*

Ahmed, S. and Ikram, S. (2015). Chitosan & its derivatives: a review in recent innovations. *International Journal of Pharmaceutical Sciences and Research, 6*(1), 14.

Ajalloueian, F., Tavanai, H., Hilborn, J., Donzel-Gargand, O., Leifer, K., Wickham, A. and Arpanaei, A. (2014). Emulsion electrospinning as an approach to fabricate PLGA/chitosan nanofibers for biomedical applications. *BioMed research international, 2014*.

Akindoyo, J. O., Beg, M. D. H., Ghazali, S. B., Islam, M. R. and Mamun, A. A. (2015). Preparation and characterization of poly (lactic acid)-based composites reinforced with poly dimethyl siloxane/ultrasound-treated oil palm empty fruit bunch. *Polymer-plastics technology and engineering, 54*(13), 1321-1333.

Alam, A. M. and Shubhra, Q. T. (2015). Surface modified thin film from silk and gelatin for sustained drug release to heal wound. *Journal of Materials Chemistry B, 3*(31), 6473-6479.

Ameri Bafghi, R. and Biazar, E. (2016). Development of oriented nanofibrous silk guide for repair of nerve defects. *International Journal of Polymeric Materials and Polymeric Biomaterials, 65*(2), 91-95.

Amidi, M., Mastrobattista, E., Jiskoot, W. and Hennink, W. E. (2010). Chitosan-based delivery systems for protein therapeutics and antigens. *Advanced drug delivery reviews, 62*(1), 59-82.

Aramwit, P., Jaichawa, N., Ratanavaraporn, J. and Srichana, T. (2015a). A comparative study of type A and type B gelatin nanoparticles as the controlled release carriers for different model compounds. *Materials Express, 5*(3), 241-248.

Aramwit, P., Ratanavaraporn, J. and Siritientong, T. (2015b). Improvement of physical and wound adhesion properties of silk sericin and polyvinyl alcohol dressing using glycerin. *Advances in skin & wound care, 28*(8), 358-367.

Armentano, I., Dottori, M., Fortunati, E., Mattioli, S. and Kenny, J. (2010). Biodegradable polymer matrix nanocomposites for tissue engineering: a review. *Polymer degradation and stability, 95*(11), 2126-2146.

Arthanari, S., Mani, G., Jang, J. H., Choi, J. O., Cho, Y. H., Lee, J. H., Jang, H. T. (2016). Preparation and characterization of gatifloxacin-loaded alginate/poly (vinyl alcohol) electrospun nanofibers. *Artificial cells, nanomedicine, and biotechnology, 44*(3), 847-852.

Assaf, S. M., Al-Jbour, N. D., Eftaiha, A. a. F., Elsayed, A. M., Al-Remawi, M. M., Qinna, N. A., Badwan, A. A. (2011). Factors involved in formulation of oily delivery system for proteins based on PEG-8 caprylic/capric glycerides and polyglyceryl-6 dioleate in a mixture of oleic acid with chitosan. *Journal of Dispersion Science and Technology, 32*(5), 623-633.

Athamneh, N., Tashtoush, B., Qandil, A., Al-Tanni, B., Obaidat, A., Al-Jbour, N., .Badwan, A. (2013). A new controlled-release liquid delivery system based on diclofenac potassium and low molecular weight chitosan complex solubilized in polysorbates. *Drug development and industrial pharmacy, 39*(8), 1217-1229.

Au, H. T., Pham, L. N., Vu, T. H. T. and Park, J. S. (2012). Fabrication of an antibacterial non-woven mat of a poly (lactic acid)/chitosan blend by electrospinning. *Macromolecular research, 20*(1), 51-58.

Babis, G. C. and Soucacos, P. N. (2005). Bone scaffolds: the role of mechanical stability and instrumentation. *Injury, 36*(4), S38-S44.

Badwan, A., Qandil, A., Marji, T., Al-Taani, B. and Khaled, A. (2018). Depolymerization of High Molecular Weight into a Predicted Low Molecular Weight Chitosan and Determination of the Degree of Deacetylation Coupled with Other Tests to Guarantee its Quality for Research Use. *Journal of Excipients and Food Chemicals, 9*(2), 3717.

Balagangadharan, K., Dhivya, S. and Selvamurugan, N. (2017). Chitosan based nanofibers in bone tissue engineering. *International journal of biological macromolecules, 104*, 1372-1382.

Banga, A. K. (2011). *Transdermal and intradermal delivery of therapeutic agents: Application of physical technologies*: CRC Press.

Bazhban, M., Nouri, M. and Mokhtari, J. (2013). Electrospinning of cyclodextrin functionalized chitosan/PVA nanofibers as a drug delivery system. *Chinese Journal of Polymer Science, 31*(10), 1343-1351.

Beachley, V. and Wen, X. (2009). Effect of electrospinning parameters on the nanofiber diameter and length. *Materials Science and Engineering: C, 29*(3), 663-668.

Behravesh, E., Yasko, A., Engel, P. and Mikos, A. (1999). Synthetic biodegradable polymers for orthopaedic applications. *Clinical Orthopaedics and Related Research (1976-2007), 367*, S118-S129.

Bhardwaj, N. and Kundu, S. C. (2010). Electrospinning: a fascinating fiber fabrication technique. *Biotechnology advances, 28*(3), 325-347.

Biazar, E. (2017). Application of polymeric nanofibers in medical designs, part IV: Drug and biological materials delivery. *International Journal of Polymeric Materials and Polymeric Biomaterials, 66*(2), 53-60.

Biresaw, G. and Carriere, C. (2002). Interfacial tension of poly (lactic acid)/polystyrene blends. *Journal of Polymer Science Part B: Polymer Physics, 40*(19), 2248-2258.

Bisson, I., Kosinski, M., Ruault, S., Gupta, B., Hilborn, J., Wurm, F. and Frey, P. (2002). Acrylic acid grafting and collagen immobilization on poly (ethylene terephthalate) surfaces for adherence and growth of human bladder smooth muscle cells. *Biomaterials, 23*(15), 3149-3158.

Boccaccini, A. R. and Blaker, J. J. (2005). Bioactive composite materials for tissue engineering scaffolds. *Expert review of medical devices, 2*(3), 303-317.

Boguń, M., Krucińska, I., Kommisarczyk, A., Mikołajczyk, T., Błażewicz, M., Stodolak-Zych, E., Ścisłowska-Czarnecka, A. (2013). Fibrous polymeric composites based on alginate fibres and fibres made of poly-ε-caprolactone and dibutyryl chitin for use in regenerative medicine. *Molecules, 18*(3), 3118-3136.

Borchard, G. (2001). Chitosans for gene delivery. *Advanced drug delivery reviews, 52*(2), 145-150.

Boryniec, S., Strobin, G., Struszczyk, H., Niekraszewicz, A. and Kucharska, M. (1997). GPC studies of chitosan degradation. *International Journal of Polymer Analysis and Characterization, 3*(4), 359-368.

Cabrera, J. C. and Van Cutsem, P. (2005). Preparation of chitooligosaccharides with degree of polymerization higher than 6 by acid or enzymatic degradation of chitosan. *Biochemical Engineering Journal, 25*(2), 165-172.

Cai, N., Dai, Q., Wang, Z., Luo, X., Xue, Y. and Yu, F. (2014). Preparation and properties of nanodiamond/poly (lactic acid) composite nanofiber scaffolds. *Fibers and Polymers, 15*(12), 2544-2552.

Cai, Z.-x., Mo, X.-m., Zhang, K.-h., Fan, L.-p., Yin, A.-l., He, C.-l. and Wang, H.-s. (2010). Fabrication of chitosan/silk fibroin composite nanofibers for wound-dressing applications. *International journal of molecular sciences, 11*(9), 3529-3539.

Campana-Filho, S. P., Britto, D. d., Curti, E., Abreu, F. R., Cardoso, M. B., Battisti, M. V., . . . Lavall, R. L. (2007). Extraction, structures and properties of alpha-AND beta-chitin. *Química Nova, 30*(3), 644-650.

Çay, A., Miraftab, M. and Kumbasar, E. P. A. (2014). Characterization and swelling performance of physically stabilized electrospun poly (vinyl alcohol)/chitosan nanofibres. *European Polymer Journal, 61*, 253-262.

Chang, K. L. B., Tai, M.-C. and Cheng, F.-H. (2001). Kinetics and products of the degradation of chitosan by hydrogen peroxide. *Journal of Agricultural and Food Chemistry, 49*(10), 4845-4851.

Chansaengsri, K., Onlaor, K., Tunhoo, B. and Thiwawong, T. (2017). Production of polyvinylidene fluoride nanofibers by free surface electrospinning from wire electrode. *Materials Today: Proceedings, 4*(5), 6085-6090.

Chase, G. G., Varabhas, J. S. and Reneker, D. H. (2011). New Methods to Electrospin Nanofiber*s*. *Journal of Engineered Fabrics & Fibers (JEFF), 6*(3).

Chen, J.-K., Shen, C.-R. and Liu, C.-L. (2010). N-acetylglucosamine: production and applications. *Marine drugs, 8*(9), 2493-2516.

Chen, J., Chu, B. and Hsiao, B. S. (2006). Mineralization of hydroxyapatite in electrospun nanofibrous poly (L-lactic acid) scaffolds. *Journal of Biomedical Materials Research Part A: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials, 79*(2), 307-317.

Chen, R. H., Chang, J. R. and Shyur, J. S. (1997). Effects of ultrasonic conditions and storage in acidic solutions on changes in molecular weight and polydispersity of treated chitosan. *Carbohydrate research, 299*(4), 287-294.

Chmielewska, A., Konieczna, L., Plenis, A., Bieniecki, M. and Lamparczyk, H. (2006). Determination of diclofenac in plasma by high-performance liquid chromatography with electrochemical detection. *Biomedical chromatography, 20*(1), 119-124.

Chu, X.-H., Shi, X.-L., Feng, Z.-Q., Gu, Z.-Z. and Ding, Y.-T. (2009). Chitosan nanofiber scaffold enhances hepatocyte adhesion and function. *Biotechnology letters, 31*(3), 347-352.

Dash, S., Murthy, P. N., Nath, L. and Chowdhury, P. (2010). Kinetic modeling on drug release from controlled drug delivery systems. *Acta Pol Pharm, 67*(3), 217-223.

de Britto, D. and Campana-Filho, S. P. (2007). Kinetics of the thermal degradation of chitosan. *Thermochimica acta, 465*(1-2), 73-82.

De Vrieze, S., Westbroek, P., Van Camp, T. and Van Langenhove, L. (2007). Electrospinning of chitosan nanofibrous structures: feasibility study. *Journal of Materials Science, 42*(19), 8029-8034.

Deitzel, J., Kleinmeyer, J., Hirvonen, J. and Tan, N. B. (2001a). Controlled deposition of electrospun poly (ethylene oxide) fibers. *Polymer, 42*(19), 8163-8170.

Deitzel, J. M., Kleinmeyer, J., Harris, D. and Tan, N. B. (2001b). The effect of processing variables on the morphology of electrospun nanofibers and textiles. *Polymer, 42*(1), 261-272.

Demir, M. M., Yilgor, I., Yilgor, E. and Erman, B. (2002). Electrospinning of polyurethane fibers. *Polymer, 43*(11), 3303-3309.

Dhivya, S., Saravanan, S., Sastry, T. and Selvamurugan, N. (2015). Nanohydroxyapatite-reinforced chitosan composite hydrogel for bone tissue repair in vitro and in vivo. *Journal of nanobiotechnology, 13*(1), 40.

Doshi, J. and Reneker, D. H. (1995). Electrospinning process and applications of electrospun fibers. *Journal of electrostatics, 35*(2-3), 151-160.

Dosunmu, O., Chase, G. G., Kataphinan, W. and Reneker, D. (2006). Electrospinning of polymer nanofibres from multiple jets on a porous tubular surface. *Nanotechnology, 17*(4), 1123.

Duarte, M., Ferreira, M., Marvao, M. and Rocha, J. (2001). Determination of the degree of acetylation of chitin materials by 13 C CP/MAS NMR spectroscopy. *International journal of biological macromolecules, 28*(5), 359-363.

Dwivedi, C., Pandey, I., Pandey, H., Ramteke, P. W., Pandey, A. C., Mishra, S. B. and Patil, S. (2017). Electrospun nanofibrous scaffold as a potential carrier of antimicrobial therapeutics for diabetic wound healing and tissue regeneration *Nano-and Microscale Drug Delivery Systems* (pp. 147-164): Elsevier.

Einbu, A., Grasdalen, H. and Vårum, K. M. (2007). Kinetics of hydrolysis of chitin/chitosan oligomers in concentrated hydrochloric acid. *Carbohydrate research, 342*(8), 1055-1062.

Elnashar, M. M. and Hassan, M. E. (2014). Novel epoxy activated hydrogels for solving lactose intolerance. *BioMed research international, 2014*.

Elsayed, A., Al Remawi, M., Qinna, N., Farouk, A. and Badwan, A. (2009). Formulation and characterization of an oily-based system for oral delivery of insulin. *European Journal of Pharmaceutics and Biopharmaceutics, 73*(2), 269-279.

Esentürk, İ., Erdal, M. S. and Güngör, S. (2016). Electrospinning method to produce drug-loaded nanofibers for topical/transdermal drug delivery applications. *İstanbul Üniversitesi Eczacılık Fakültesi Dergisi, 46*(1), 49-69.

Espíndola-González, A., Martínez-Hernández, A. L., Fernández-Escobar, F., Castaño, V. M., Brostow, W., Datashvili, T. and Velasco-Santos, C. (2011). Natural-synthetic hybrid polymers developed via electrospinning: the effect of PET in

chitosan/starch system. *International journal of molecular sciences, 12*(3), 1908-1920.

Fabbricante, A. S., Ward, G. F. and Fabbricante, T. J. (2000). Micro-denier nonwoven materials made using modular die units: Google Patents.

Fischer, R. L., McCoy, M. G. and Grant, S. A. (2012). Electrospinning collagen and hyaluronic acid nanofiber meshes. *Journal of Materials Science: Materials in Medicine, 23*(7), 1645-1654.

Forward, K. M. and Rutledge, G. C. (2012). Free surface electrospinning from a wire electrode. *Chemical Engineering Journal, 183*, 492-503.

Galed, G., Miralles, B., Paños, I., Santiago, A. and Heras, Á. (2005). N-Deacetylation and depolymerization reactions of chitin/chitosan: Influence of the source of chitin. *Carbohydrate Polymers, 62*(4), 316-320.

Galkina, O., Ivanov, V., Agafonov, A., Seisenbaeva, G. and Kessler, V. (2015). Cellulose nanofiber–titania nanocomposites as potential drug delivery systems for dermal applications. *Journal of Materials Chemistry B, 3*(8), 1688-1698.

Geng, X., Kwon, O.-H. and Jang, J. (2005). Electrospinning of chitosan dissolved in concentrated acetic acid solution. *Biomaterials, 26*(27), 5427-5432.

Ghazali, S., Islam, M., Akindoyo, J. O., Beg, M., Jeyaratnam, N. and Yuvaraj, A. (2017). Polyurethane types, synthesis and applications–a review.

Ghori, M. U., Mahdi, M. H., Smith, A. M. and Conway, B. R. (2015). Nasal drug delivery systems: an overview. *American Journal of Pharmacological Sciences, 3*(5), 110-119.

Giustina, A. and Ventura, P. (1995). Weight-reducing regimens in obese subjects: effects of a new dietary fiber integrator. *Acta Toxicologica et Therapeutica, 16*, 199-214.

Goh, Y.-f., Akram, M., Alshemary, A. and Hussain, R. (2016). Antibacterial polylactic acid/chitosan nanofibers decorated with bioactive glass. *Applied Surface Science, 387*, 1-7.

Gomes, S., Rodrigues, G., Martins, G., Roberto, M., Mafra, M., Henriques, C. and Silva, J. (2015). In vitro and in vivo evaluation of electrospun nanofibers of PCL, chitosan and gelatin: A comparative study. *Materials Science and Engineering: C, 46*, 348-358.

Gómez-Pachón, E., Vera-Graziano, R. and Campos, R. M. (2014). *Structure of poly (lactic-acid) PLA nanofibers scaffolds prepared by electrospinning.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Gonçalves, R. P., Ferreira, W. H., Gouvêa, R. F. and Andrade, C. T. (2017). Effect of chitosan on the properties of electrospun fibers from mixed poly (vinyl alcohol)/chitosan solutions. *Materials Research, 20*(4), 984-993.

Green, T. B., King, S. L. and Li, L. (2010). Apparatus and method for reducing solvent loss for electro-spinning of fine fibers: Google Patents.

Haghi, A. and Akbari, M. (2007). Trends in electrospinning of natural nanofibers. *physica status solidi (a), 204*(6), 1830-1834.

Haider, A., Haider, S. and Kang, I.-K. (2015). A comprehensive review summarizing the effect of electrospinning parameters and potential applications of nanofibers in biomedical and biotechnology. *Arabian Journal of Chemistry*.

Haider, A., Haider, S. and Kang, I.-K. (2018). ***A comprehensive review summarizing the effect of electrospinning paramete***rs and potential applications of nanofibers in biomedical and biotechnology. *Arabian Journal of Chemistry, 11*(8), 1165-1188.

Haider, S. and Park, S.-Y. (2009). Preparation of the electrospun chitosan nanofibers and their applications to the adsorption of Cu (II) and Pb (II) ions from an aqueous solution. *Journal of Membrane Science, 328*(1-2), 90-96.

Hamad, K., Kaseem, M., Yang, H., Deri, F. and Ko, Y. (2015). Properties and medical applications of polylactic acid: A review. *Express Polymer Letters, 9*(5).

Hardiansyah, A., Tanadi, H., Yang, M.-C. and Liu, T.-Y. (2015). Electrospinning and antibacterial activity of chitosan-blended poly (lactic acid) nanofibers. *Journal of Polymer Research, 22*(4), 59.

Hasegawa, T. and Mikuni, T. (2014). Higher-order structural analysis of nylon-66 nanofibers prepared by carbon dioxide laser supersonic drawing and exhibiting near-equilibrium melting temperature. *Journal of Applied Polymer Science, 131*(12).

Hazra, M. K., Roy, S. and Bagchi, B. (2014). Hydrophobic hydration driven self-assembly of curcumin in water: Similarities to nucleation and growth under large metastability, and an analysis of water dynamics at heterogeneous surfaces. *The Journal of chemical physics, 141*(18), 18C501.

Heseltine, P. L., Ahmed, J. and Edirisinghe, M. (2018). Developments in pressurized gyration for the mass production of polymeric fibers. *Macromolecular Materials and Engineering, 303*(9), 1800218.

Hinz, B., Chevts, J., Renner, B., Wuttke, H., Rau, T., Schmidt, A., Werner, U. (2005). Bioavailability of diclofenac potassium at low doses. *British journal of clinical pharmacology, 59*(1), 80-84.

Hirai, A., Odani, H. and Nakajima, A. (1991). Determination of degree of deacetylation of chitosan by 1 H NMR spectroscopy. *Polymer Bulletin, 26*(1), 87-94.

Ho, H.-O., Liu, C.-H., Lin, H.-M. and Sheu, M.-T. (1997). The development of matrix tablets for diclofenac sodium based on an empirical in vitro and in vivo correlation. *Journal of Controlled Release, 49*(2), 149-156.

Ho, M.-H., Liao, M.-H., Lin, Y.-L., Lai, C.-H., Lin, P.-I. and Chen, R.-M. (2014). Improving effects of chitosan nanofiber scaffolds on osteoblast proliferation and maturation. *International journal of nanomedicine, 9*, 4293.

Hofele, C., Gyenes, V., Daems, L., Stypula-Ciuba, B., Wagener, H., Siegel, J. and Edson, K. (2006). Efficacy and tolerability of diclofenac potassium sachets in acute postoperative dental pain: a placebo-controlled, randomised, comparative study vs. diclofenac potassium tablets. *International journal of clinical practice, 60*(3), 300-307.

Homayoni, H., Ravandi, S. A. H. and Valizadeh, M. (2009). Electrospinning of chitosan nanofibers: Processing optimization. *Carbohydrate polymers, 77*(3), 656-661.

Hong, X., Harker, A. and Edirisinghe, M. (2018). Process Modeling for the Fiber Diameter of Polymer, Spun by Pressure-Coupled Infusion Gyration. *ACS Omega, 3*(5), 5470-5479.

Hu, X., Liu, S., Zhou, G., Huang, Y., Xie, Z. and Jing, X. (2014a). Electrospinning of polymeric nanofibers for drug delivery applications. *Journal of Controlled Release, 185*, 12-21.

Hu, X., Zhang, X., Shen, X., Li, H., Takai, O. and Saito, N. (2014b). Plasma-induced synthesis of CuO nanofibers and ZnO nanoflowers in water. *Plasma Chemistry and Plasma Processing, 34*(5), 1129-1139.

Huang, X.-J., Ge, D. and Xu, Z.-K. (2007). Preparation and characterization of stable chitosan nanofibrous membrane for lipase immobilization. *European Polymer Journal, 43*(9), 3710-3718.

Huang, Z.-M., Zhang, Y.-Z., Kotaki, M. and Ramakrishna, S. (2003). A review on polymer nanofibers by electrospinning and their applications in nanocomposites. *Composites science and technology, 63*(15), 2223-2253.

Ignatova, M., Starbova, K., Markova, N., Manolova, N. and Rashkov, I. (2006). Electrospun nano-fibre mats with antibacterial properties from quaternised chitosan and poly (vinyl alcohol). *Carbohydrate research, 341*(12), 2098-2107.

Islam, M. M., Masum, S. M., Rahman, M. M., Molla, M. A. I., Shaikh, A. and Roy, S. (2011). Preparation of chitosan from shrimp shell and investigation of its properties. *International Journal of Basic & Applied Sciences, 11*(1), 77-80.

Jain, K. K. (2008). *Drug delivery systems* (Vol. 437): Springer Science & Business Media.

Jang, S. I., Mok, J. Y., Jeon, I. H., Park, K.-H., Nguyen, T. T. T., Park, J. S., . . . Chai, K. Y. (2012). Effect of electrospun non-woven mats of dibutyryl chitin/poly

(lactic acid) blends on wound healing in hairless mice. *Molecules, 17*(3), 2992-3007.

Jaszkiewicz, A., Bledzki, A., Van Der Meer, R., Franciszczak, P. and Meljon, A. (2014). How does a chain-extended polylactide behave?: a comprehensive analysis of the material, structural and mechanical properties. *Polymer Bulletin, 71*(7), 1675-1690.

Jayakumar, R., Prabaharan, M., Nair, S. and Tamura, H. (2010a). Novel chitin and chitosan nanofibers in biomedical applications. *Biotechnology advances, 28*(1), 142-150.

Jayakumar, R., Prabaharan, M., Nair, S., Tokura, S., Tamura, H. and Selvamurugan, N. (2010d). Novel carboxymethyl derivatives of chitin and chitosan materials and their biomedical applications. *Progress in Materials Science, 55*(7), 675-709.

Jeon, Y.-J. and Kim, S.-K. (2000). Production of chitooligosaccharides using an ultrafiltration membrane reactor and their antibacterial activity. *Carbohydrate polymers, 41*(2), 133-141.

Jirsak, O., Sanetrnik, F., Lukas, D., Kotek, V., Martinova, L. and Chaloupek, J. (2009). Method of nanofibres production from a polymer solution using electrostatic spinning and a device for carrying out the method: Google Patents.

Jirsak, O., Sysel, P., Sanetrnik, F., Hruza, J. and Chaloupek, J. (2010). Polyamic acid nanofibers produced by needleless electrospinning. *Journal of Nanomaterials, 2010*, 49.

Kanawung, K., Panitchanapan, K., Puangmalee, S.-O., Utok, W., Kreua-Ongarjnukool, N., Rangkupan, R., Supaphol, P. (2007). Preparation and characterization of polycaprolactone/diclofenac sodium and poly (vinyl alcohol)/tetracycline hydrochloride fiber mats and their release of the model drugs. *Polymer journal, 39*(4), 369.

Karakaş, H. (2015). Electrospinning of Nanofibers and There Applications. *Istanbul Technical University, Textile Technologies and Design Faculty*.

Karuppuswamy, P., Venugopal, J. R., Navaneethan, B., Laiva, A. L. and Ramakrishna, S. (2015). ***Polycaprolactone nanofibers for the controlled release of tetracycline hydrochloride***. *Materials Letters, 141*, 180-186.

Kasaai, M. R. (2007). Calculation of Mark–Houwink–Sakurada (MHS) equation viscometric constants for chitosan in any solvent–temperature system using experimental reported viscometric constants data. *Carbohydrate polymers, 68*(3), 477-488.

Kenawy, E.-R., Bowlin, G. L., Mansfield, K., Layman, J., Simpson, D. G., Sanders, E. H. and Wnek, G. E. (2002). Release of tetracycline hydrochloride from electrospun poly (ethylene-co-vinylacetate), poly (lactic acid), and a blend. *Journal of controlled release, 81*(1-2), 57-64.

Kenry and Lim, C. T. (2017). Nanofiber technology: current status and emerging developments. *Progress in polymer science, 70*, 1-17.

Khan, T. A., Peh, K. K. and Ch'ng, H. S. (2002). Reporting degree of deacetylation values of chitosan: the influence of analytical methods. *J Pharm Pharmaceut Sci, 5*(3), 205-212.

Kim, G., Cho, Y.-S. and Kim, W. D. (2006). Stability analysis for multi-jets electrospinning process modified with a cylindrical electrode. *European polymer journal, 42*(9), 2031-2038.

Kim, S.-K. (2010). *Chitin, chitosan, oligosaccharides and their derivatives: biological activities and applications*: CRC Press.

Kim, S.-K. and Rajapakse, N. (2005). Enzymatic production and biological activities of chitosan oligosaccharides (COS): A review. *Carbohydrate polymers, 62*(4), 357-368.

Kirk, R. E., Othmer, D. F., Kroschwitz, J. I. and Howe-Grant, M. (1998). *Encyclopedia of Chemical Technology: Antibiotics to batteries* (Vol. 3): Wiley.

Klossner, R. R., Queen, H. A., Coughlin, A. J. and Krause, W. E. (2008). Correlation of chitosan's rheological properties and its ability to electrospin. *Biomacromolecules, 9*(10), 2947-2953.

Knill, C., Kennedy, J., Mistry, J., Miraftab, M., Smart, G., Groocock, M. and Williams, H. (2005a). Acid hydrolysis of commercial chitosans. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 80*(11), 1291-1296.

Knill, C., Kennedy, J., Mistry, J., Miraftab, M., Smart, G., Groocock, M. and Williams, H. (2005b). Acid hydrolysis of commercial chitosans. *Journal of Chemical Technology and Biotechnology, 80*(11), 1291-1296.

Koizumi, R., Azuma, K., Izawa, H., Morimoto, M., Ochi, K., Tsuka, T., Okamoto, Y. (2017). Oral administration of surface-deacetylated chitin nanofibers and chitosan inhibit 5-fluorouracil-induced intestinal mucositis in mice. *International journal of molecular sciences, 18*(2), 279.

Kong, L. and Ziegler, G. R. (2011). Fabrication of κ-Carrageenan Fibers by Wet Spinning: Spinning Parameters. *Materials, 4*(10), 1805-1817.

Kong, L. and Ziegler, G. R. (2013). Fabrication of κ-carrageenan fibers by wet spinning: Addition of ι-carrageenan. *Food hydrocolloids, 30*(1), 302-306.

Korsmeyer, R. W., Gurny, R., Doelker, E., Buri, P. and Peppas, N. A. (1983). Mechanisms of solute release from porous hydrophilic polymers. *International journal of Pharmaceutics, 15*(1), 25-35.

Koski, A., Yim, K. and Shivkumar, S. (2004). Effect of molecular weight on fibrous PVA produced by electrospinning. *Materials Letters, 58*(3-4), 493-497.

Kostakova, E., Meszaros, L. and Gregr, J. (2009). Composite nanofibers produced by modified needleless electrospinning. *Materials Letters, 63*(28), 2419-2422.

Kriegel, C., Kit, K., McClements, D. and Weiss, J. (2008). Nanofibers as carrier systems for antimicrobial microemulsions. Part I: Fabrication and characterization. *Langmuir, 25*(2), 1154-1161.

Kriegel, C., Kit, K., McClements, D. J. and Weiss, J. (2009). Electrospinning of chitosan–poly (ethylene oxide) blend nanofibers in the presence of micellar surfactant solutions. *Polymer, 50*(1), 189-200.

Kroschwitz, J. I. (1989). *Polymers: biomaterials and medical applications*: Wiley-Interscience.

Kubota, N., Tatsumoto, N., Sano, T. and Toya, K. (2000). A simple preparation of half N-acetylated chitosan highly soluble in water and aqueous organic solvents. *Carbohydrate Research, 324*(4), 268-274.

Kulkarni, R., Pani, K., Neuman, C. and Leonard, F. (1966). Polylactic acid for surgical implants: WALTER REED ARMY MEDICAL CENTER WASHINGTON DC ARMY MEDICAL BIOMECHANICAL ….

Kumar, A. B. V., Varadaraj, M. C., Gowda, L. R. and Tharanathan, R. N. (2005). Characterization of chito-oligosaccharides prepared by chitosanolysis with the aid of papain and Pronase, and their bactericidal action against Bacillus cereus and Escherichia coli. *Biochemical Journal, 391*(2), 167-175.

Kumar, A. V. and Tharanathan, R. (2004). A comparative study on depolymerization of chitosan by proteolytic enzymes. *Carbohydrate polymers, 58*(3), 275-283.

Kumar, J. P., Lakshmi, L., Jyothsna, V., Balaji, D., Saravanan, S., Moorthi, A. and Selvamurugan, N. (2014). Synthesis and characterization of diopside particles and their suitability along with chitosan matrix for bone tissue engineering in vitro and in vivo. *Journal of biomedical nanotechnology, 10*(6), 970-981.

Kumar, M. N. R. (2000). A review of chitin and chitosan applications. *Reactive and functional polymers, 46*(1), 1-27.

Kumirska, J., Czerwicka, M., Kaczyński, Z., Bychowska, A., Brzozowski, K., Thöming, J. and Stepnowski, P. (2010). Application of spectroscopic methods for structural analysis of chitin and chitosan. *Marine drugs, 8*(5), 1567-1636.

Kunike, G. (1926). Chitin and chitosan. *J Soc Dyers Colorists, 42*, 318-342.

Kurita, K. (2001). Controlled functionalization of the polysaccharide chitin. *Progress in polymer science, 26*(9), 1921-1971.

Kurita, K. (2006). Chitin and chitosan: functional biopolymers from marine crustaceans. *Marine Biotechnology, 8*(3), 203.

Kuroiwa, T., Ichikawa, S., Hiruta, O., Sato, S. and Mukataka, S. (2002). Factors affecting the composition of oligosaccharides produced in chitosan hydrolysis using immobilized chitosanases. *Biotechnology progress, 18*(5), 969-974.

Kurtz, S. M., Muratoglu, O. K., Evans, M. and Edidin, A. A. (1999). Advances in the processing, sterilization, and crosslinking of ultra-high molecular weight polyethylene for total joint arthroplasty. *Biomaterials, 20*(18), 1659-1688.

Lapitsky, Y., Zahir, T. and Shoichet, M. S. (2007). Modular biodegradable biomaterials from surfactant and polyelectrolyte mixtures. *Biomacromolecules, 9*(1), 166-174.

Lasprilla, A. J., Martinez, G. A., Lunelli, B. H., Jardini, A. L. and Maciel Filho, R. (2012). Poly-lactic acid synthesis for application in biomedical devices—A review. *Biotechnology advances, 30*(1), 321-328.

Laurencin, C. T., Ambrosio, A., Borden, M. and Cooper Jr, J. (1999). Tissue engineering: orthopedic applications. *Annual review of biomedical engineering, 1*(1), 19-46.

Lee, M.-Y., Var, F., Shin-ya, Y., Kajiuchi, T. and Yang, J.-W. (1999). Optimum conditions for the precipitation of chitosan oligomers with DP 5–7 in concentrated hydrochloric acid at low temperature. *Process Biochemistry, 34*(5), 493-500.

Lee, S. H., Suh, J.-S., Kim, H. S., Lee, J. D., Song, J. and Lee, S. K. (2003). MR evaluation of radiation synovectomy of the knee by means of intra-articular injection of holmium-166-chitosan complex in patients with rheumatoid arthritis: results at 4-month follow-up. *Korean journal of radiology, 4*(3), 170-178.

Lembhe, S. and Dev, A. (2016). Trasdermal Drug Delivery System: An Overview.

Li, B., Zhang, J., Bu, F. and Xia, W. (2013). Determination of chitosan with a modified acid hydrolysis and HPLC method. *Carbohydrate research, 366*, 50-54.

Li, J., Du, Y., Yang, J., Feng, T., Li, A. and Chen, P. (2005). Preparation and characterisation of low molecular weight chitosan and chito-oligomers by a commercial enzyme. *Polymer Degradation and stability, 87*(3), 441-448.

Li, L. and Hsieh, Y.-L. (2006). Chitosan bicomponent nanofibers and nanoporous fibers. *Carbohydrate Research, 341*(3), 374-381.

Li, L., Li, H., Qian, Y., Li, X., Singh, G. K., Zhong, L., Yang, L. (2011). Electrospun poly (ε-caprolactone)/silk fibroin core-sheath nanofibers and their potential applications in tissue engineering and drug release. *International journal of biological macromolecules, 49*(2), 223-232.

Li, Z. and Wang, C. (2013). *One-dimensional nanostructures: electrospinning technique and unique nanofibers*: Springer.

Lim, C. T. (2017). Beyond the current state of the syntheses and applications of nanofiber technology. *Progress in polymer science*.

Lim, Y.-M., Gwon, H.-J., Jeun, J. P. and Nho, Y.-C. (2010). Preparation of cellulose-based nanofibers using electrospinning *Nanofibers*: InTech.

Lindblad, M. S., Sjöberg, J., Albertsson, A.-C. and Hartman, J. (2007). Hydrogels from polysaccharides for biomedical applications: ACS Publications.

Liu, H., Bao, J., Du, Y., Zhou, X. and Kennedy, J. F. (2006). Effect of ultrasonic treatment on the biochemphysical properties of chitosan. *Carbohydrate Polymers, 64*(4), 553-559.

Liu, J. and Kerns, D. G. (2014). Suppl 1: mechanisms of guided bone regeneration: a review. *The open dentistry journal, 8*, 56.

Liu, M., Zhang, Y. and Zhou, C. (2013). Nanocomposites of halloysite and polylactide. *Applied Clay Science, 75*, 52-59.

Liu, Y., Wang, S., Zhang, R., Lan, W. and Qin, W. (2017). Development of poly (lactic acid)/chitosan fibers loaded with essential oil for antimicrobial applications. *Nanomaterials, 7*(7), 194.

Lukas, D., Sarkar, A. and Pokorny, P. (2008). Self-organization of jets in electrospinning from free liquid surface: A generalized approach. *Journal of Applied Physics, 103*(8), 084309.

Macchi, G. (1996). A new approach to the treatment of obesity: chitosan's effects on body weight reduction and plasma cholesterol's levels. *Acta Toxicologica et Therapeutica, 17*, 303-322.

Malafaya, P. B., Silva, G. A. and Reis, R. L. (2007). Natural–origin polymers as carriers and scaffolds for biomolecules and cell delivery in tissue engineering applications. *Advanced drug delivery reviews, 59*(4), 207-233.

Manavitehrani, I., Fathi, A., Wang, Y., Maitz, P. K. and Dehghani, F. (2015). Reinforced poly (propylene carbonate) composite with enhanced and tunable characteristics, an alternative for poly (lactic acid). *ACS applied materials & interfaces, 7*(40), 22421-22430.

Mao, S., Shuai, X., Unger, F., Simon, M., Bi, D. and Kissel, T. (2004). The depolymerization of chitosan: effects on physicochemical and biological properties. *International journal of pharmaceutics, 281*(1), 45-54.

Martin, A. and Bustamante, P. (1993). Chun: AHC. *Physical Pharmacy. Fourth edition, BI Publication Ltd, New Delhi, 444*.

Mendes, A. C., Gorzelanny, C., Halter, N., Schneider, S. W. and Chronakis, I. S. (2016a). Hybrid electrospun chitosan-phospholipids nanofibers for transdermal drug delivery. *International journal of Pharmaceutics, 510*(1), 48-56.

Mendes, A. C. L., Shekarforoush, E., Moreno, J. A. S. and Chronakis, I. S. (2016h). *Chitosan/Phospholipids Hybrid Nanofibers and Hydrogels for Life Sciences Applications.* Paper presented at the Sustain-ATV Conference 2016.

Miloh, T., Spivak, B. and Yarin, A. (2009). Needleless electrospinning: Electrically driven instability and multiple jetting from the free surface of a spherical liquid layer. *Journal of Applied Physics, 106*(11), 114910.

Min, B.-M., Lee, S. W., Lim, J. N., You, Y., Lee, T. S., Kang, P. H. and Park, W. H. (2004). Chitin and chitosan nanofibers: electrospinning of chitin and deacetylation of chitin nanofibers. *Polymer, 45*(21), 7137-7142.

Misra, A. (2014). *Applications of Polymers in Drug Delivery*: Smithers Rapra.

Mu, C.-F., Balakrishnan, P., Cui, F.-D., Yin, Y.-M., Lee, Y.-B., Choi, H.-G., Kim, D.-D. (2010). The effects of mixed MPEG–PLA/Pluronic® copolymer micelles on the bioavailability and multidrug resistance of docetaxel. *Biomaterials, 31*(8), 2371-2379.

Murphy, C. M., O'Brien, F. J., Little, D. G. and Schindeler, A. (2013). Cell-scaffold interactions in the bone tissue engineering triad.

Mutlu, E. C., Ficai, A., Ficai, D., Yildirim, A. B., Yildirim, M., Oktar, F. N. and Demir, A. (2018). Chitosan/poly (ethylene glycol)/hyaluronic acid biocompatible patches obtained by electrospraying. *Biomedical Materials, 13*(5), 055011.

Muzzarelli, R. (1977). Chitin Oxford: Pergamon Press.

Muzzarelli, R. and Muzzarelli, C. (2005). Chitosan chemistry: relevance to the biomedical sciences *Polysaccharides I* (pp. 151-209): Springer.

Muzzarelli, R. A. and Rocchetti, R. (1985). Determination of the degree of acetylation of chitosans by first derivative ultraviolet spectrophotometry. *Carbohydrate Polymers, 5*(6), 461-472.

Nain, A. S., Wong, J. C., Amon, C. and Sitti, M. (2006). Drawing suspended polymer micro-/nanofibers using glass micropipettes. *Applied Physics Letters, 89*(18), 183105.

Neamnark, A., Rujiravanit, R. and Supaphol, P. (2006). Electrospinning of hexanoyl chitosan. *Carbohydrate Polymers, 66*(3), 298-305.

Nguyen, T. T. T., Chung, O. H. and Park, J. S. (2011). Coaxial electrospun poly (lactic acid)/chitosan (core/shell) composite nanofibers and their antibacterial activity. *Carbohydrate polymers, 86*(4), 1799-1806.

Nikalje, A. P. (2015). Nanotechnology and its applications in medicine. *Med chem, 5*(2), 185-189.

Nishimura, K., Nishimura, S., Nishi, N., Saiki, I., Tokura, S. and Azuma, I. (1984). Immunological activity of chitin and its derivatives. *Vaccine, 2*(1), 93-99.

No, H., Meyers, S. P., Prinyawiwatkul, W. and Xu, Z. (2007). Applications of chitosan for improvement of quality and shelf life of foods: a review. *Journal of food science, 72*(5), R87-R100.

Notin, L., Viton, C., David, L., Alcouffe, P., Rochas, C. and Domard, A. (2006a). Morphology and mechanical properties of chitosan fibers obtained by gel-spinning: Influence of the dry-jet-stretching step and ageing. *Acta biomaterialia, 2*(4), 387-402.

Notin, L., Viton, C., Lucas, J.-M. and Domard, A. (2006b). Pseudo-dry-spinning of chitosan. *Acta biomaterialia, 2*(3), 297-311.

Obaidat, R., Al-Jbour, N., Al-Sou'd, K., Sweidan, K., Al-Remawi, M. and Badwan, A. (2010). Some physico-chemical properties of low molecular weight chitosans and their relationship to conformation in aqueous solution. *Journal of solution chemistry, 39*(4), 575-588.

Ogawa, K., Yui, T. and Okuyama, K. (2004). Molecular conformations of chitin and chitosan. *Foods and Food Ingredients Journal of Japan*, 209, 311-319.

Ohkawa, K., Minato, K.-I., Kumagai, G., Hayashi, S. and Yamamoto, H. (2006). Chitosan nanofiber. *Biomacromolecules, 7*(11), 3291-3294.

Ojha, S. S., Stevens, D. R., Hoffman, T. J., Stano, K., Klossner, R., Scott, M. C., Gorga, R. E. (2008). Fabrication and characterization of electrospun chitosan nanofibers formed via templating with polyethylene oxide. *Biomacromolecules, 9*(9), 2523-2529.

Olabode, A. J. (2015). *Oil Palm Empty Fruit Bunch (EFB) Fiber Reinforced Poly (lactic) Acid Composites: Effects of Fiber Treatment and Impact Modifier*. UMP.

Oliveira, N. G., Sirgado, T., Reis, L., Pinto, L. F., da Silva, C. L., Ferreira, F. C. and Rodrigues, A. (2014). In vitro assessment of three dimensional dense chitosan-based structures to be used as bioabsorbable implants. *Journal of the mechanical behavior of biomedical materials, 40*, 413-425.

Osorio-Madrazo, A., David, L., Trombotto, S., Lucas, J.-M., Peniche-Covas, C. and Domard, A. (2011). Highly crystalline chitosan produced by multi-steps acid hydrolysis in the solid-state. *Carbohydrate polymers, 83*(4), 1730-1739.

Paipitak, K., Pornpra, T., Mongkontalang, P., Techitdheer, W. and Pecharapa, W. (2011). Characterization of PVA-chitosan nanofibers prepared by electrospinning. *Procedia Engineering, 8*, 101-105.

Patel, V. M., Prajapati, B. G., Patel, H. V. and Patel, K. M. (2007). Mucoadhesive bilayer tablets of propranolol hydrochloride. *AAPS PharmSciTech, 8*(3), E203-E208.

Pelipenko, J., Kocbek, P. and Kristl, J. (2015). Critical attributes of nanofibers: preparation, drug loading, and tissue regeneration. *International journal of pharmaceutics, 484*(1), 57-74.

Perumal, G., Pappuru, S., Chakraborty, D., Nandkumar, A. M., Chand, D. K. and 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.

Peter, M. (2002). Chapter 15: Chitin & Chitosan from Animal Sources. *Biopolymers, 6*, 133.

Pharmacopoeia, B. (2015). Specific monograph: British Pharmacopoeia Commission: London.

Piyakulawat, P., Praphairaksit, N., Chantarasiri, N. and Muangsin, N. (2007). Preparation and evaluation of chitosan/carrageenan beads for controlled release of sodium diclofenac. *Aaps PharmSciTech, 8*(4), 120-130.

Prabhakaran, M. P., Venugopal, J. R., Chyan, T. T., Hai, L. B., Chan, C. K., Lim, A. Y. and Ramakrishna, S. (2008). Electrospun biocomposite nanofibrous scaffolds for neural tissue engineering. *Tissue Engineering Part A, 14*(11), 1787-1797.

Prasad, T., Shabeena, E., Vinod, D., Kumary, T. and Kumar, P. A. (2015). Characterization and in vitro evaluation of electrospun chitosan/polycaprolactone blend fibrous mat for skin tissue engineering. *Journal of Materials Science: Materials in Medicine, 26*(1), 28.

Qandil, A. M., Obaidat, A. A., Ali, M. A. M., Al-Taani, B. M., Tashtoush, B. M., Al-Jbour, N. D., Badwan, A. A. (2009). Investigation of the interactions in complexes of low molecular weight chitosan with ibuprofen. *Journal of solution chemistry, 38*(6), 695-712.

Qian, Y.-F., Zhang, K.-H., Chen, F., Ke, Q.-F. and Mo, X.-M. (2011). Cross-linking of gelatin and chitosan complex nanofibers for tissue-engineering scaffolds. *Journal of Biomaterials Science, Polymer Edition, 22*(8), 1099-1113.

Qinna, N., Karwi, Q., Al-Jbour, N., Al-Remawi, M., Alhussainy, T., Al-So'ud, K., .Badwan, A. (2015a). Influence of molecular weight and degree of deacetylation of low molecular weight chitosan on the bioactivity of oral insulin preparations. *Marine drugs, 13*(4), 1710-1725.

Qinna, N. A., Karwi, Q. G., Al-Jbour, N., Al-Remawi, M. A., Alhussainy, T. M., Al-So'ud, K. A., Badwan, A. A. (2015b). Influence of molecular weight and degree of deacetylation of low molecular weight chitosan on the bioactivity of oral insulin preparations. *Marine drugs, 13*(4), 1710-1725.

Quirós, J., Borges, J. P., Boltes, K., Rodea-Palomares, I. and Rosal, R. (2015). Antimicrobial electrospun silver-, copper-and zinc-doped polyvinylpyrrolidone nanofibers. *Journal of hazardous materials, 299*, 298-305.

Qun, G. and Ajun, W. (2006). Effects of molecular weight, degree of acetylation and ionic strength on surface tension of chitosan in dilute solution. *Carbohydrate polymers, 64*(1), 29-36.

Rajangam, T. and An, S. S. A. (2013). Fibrinogen and fibrin based micro and nano scaffolds incorporated with drugs, proteins, cells and genes for therapeutic biomedical applications. *International journal of nanomedicine, 8*, 3641.

Ramakrishna, S. (2005). *An introduction to electrospinning and nanofibers*: World Scientific.

Ramot, Y., Haim-Zada, M., Domb, A. J. and Nyska, A. (2016). Biocompatibility and safety of PLA and its copolymers. *Advanced drug delivery reviews, 107*, 153-162.

Rani, M. and Mishra, B. (2004). Comparative in vitro and in vivo evaluation of matrix, osmotic matrix, and osmotic pump tablets for controlled delivery of diclofenac sodium. *Aaps PharmSciTech, 5*(4), 153-159.

Ravi Kumar, M. (2008). Handbook of particulate drug delivery (2-Volume Set): American Scientific Publishers ISBN.

Reiner, V., Reiner, A., Reiner, G. and Conti, M. (2001). Increased absorption rate of diclofenac from fast acting formulations containing its potassium salt. *Arzneimittelforschung, 51*(11), 885-890.

Ren, L., Ozisik, R. and Kotha, S. P. (2014). Rapid and efficient fabrication of multilevel structured silica micro-/nanofibers by centrifugal jet spinning. *Journal of colloid and interface science, 425*, 136-142.

Ren, L., Ozisik, R., Kotha, S. P. and Underhill, P. T. (2015). Highly efficient fabrication of polymer nanofiber assembly by centrifugal jet spinning: process and characterization. *Macromolecules, 48*(8), 2593-2602.

Ren, L., Pandit, V., Elkin, J., Denman, T., Cooper, J. A. and Kotha, S. P. (2013). Large-scale and highly efficient synthesis of micro-and nano-fibers with controlled fiber morphology by centrifugal jet spinning for tissue regeneration. *Nanoscale, 5*(6), 2337-2345.

Reneker, D., Yarin, A., Zussman, E. and Xu, H. (2007). Electrospinning of nanofibers from polymer solutions and melts. *Advances in applied mechanics, 41*, 43-346.

Rezwan, K., Chen, Q., Blaker, J. and Boccaccini, A. R. (2006). Biodegradable and bioactive porous polymer/inorganic composite scaffolds for bone tissue engineering. *Biomaterials, 27*(18), 3413-3431.

Rhazi, M., Desbrieres, J., Tolaimate, A., Rinaudo, M., Vottero, P. and Alagui, A. (2002). Contribution to the study of the complexation of copper by chitosan and oligomers. *Polymer, 43*(4), 1267-1276.

Rinaudo, M. (2006). Chitin and chitosan: properties and applications. *Progress in polymer science, 31*(7), 603-632.

Rinaudo, M. (2008). Main properties and current applications of some polysaccharides as biomaterials. *Polymer International, 57*(3), 397-430. doi: 10.1002/pi.2378

Roberts, G. Chitin chemistry. 1992. *MacMillan Press Ltd: London*.

Rojas, O. J., Montero, G. A. and Habibi, Y. (2009). Electrospun nanocomposites from polystyrene loaded with cellulose nanowhiskers. *Journal of Applied Polymer Science, 113*(2), 927-935.

Rúnarsson, Ö. V., Malainer, C., Holappa, J., Sigurdsson, S. T. and Másson, M. (2008). tert-Butyldimethylsilyl O-protected chitosan and chitooligosaccharides: useful precursors for N-modifications in common organic solvents. *Carbohydrate Research, 343*(15), 2576-2582.

RUTHERFORD, F. t. (1978). *Marine chitin properties and solvents.* Paper presented at the Proceedings of the 1st Int. Conference on Chitin/Chitosan, 1978.

Sainitya, R., Sriram, M., Kalyanaraman, V., Dhivya, S., Saravanan, S., Vairamani, M., . . . Selvamurugan, N. (2015). Scaffolds containing chitosan/carboxymethyl cellulose/mesoporous wollastonite for bone tissue engineering. *International journal of biological macromolecules, 80*, 481-488.

Sakurai, K., Maegawa, T. and Takahashi, T. (2000). Glass transition temperature of chitosan and miscibility of chitosan/poly (N-vinyl pyrrolidone) blends. *Polymer, 41*(19), 7051-7056.

Sangsanoh, P. and Supaphol, P. (2006). Stability improvement of electrospun chitosan nanofibrous membranes in neutral or weak basic aqueous solutions. *Biomacromolecules, 7*(10), 2710-2714.

Sarhan, W. A., Azzazy, H. M. and El-Sherbiny, I. M. (2016). The effect of increasing honey concentration on the properties of the honey/polyvinyl alcohol/chitosan nanofibers. *Materials Science and Engineering: C, 67*, 276-284.

Sartori, S., Chiono, V., Tonda-Turo, C., Mattu, C. and Gianluca, C. (2014). Biomimetic polyurethanes in nano and regenerative medicine. *Journal of Materials Chemistry B, 2*(32), 5128-5144.

Sedghi, R., Shaabani, A., Mohammadi, Z., Samadi, F. Y. and Isaei, E. (2017). Biocompatible electrospinning chitosan nanofibers: a novel delivery system with superior local cancer therapy. *Carbohydrate polymers, 159*, 1-10.

Semnani, D., Naghashzargar, E., Hadjianfar, M., Dehghan Manshadi, F., Mohammadi, S., Karbasi, S. and Effaty, F. (2017). Evaluation of PCL/chitosan electrospun nanofibers for liver tissue engineering. *International Journal of Polymeric Materials and Polymeric Biomaterials, 66*(3), 149-157.

Sen, A., Bedding, J. and Gu, B. (2005). Process for forming polymeric micro and nanofibers: Google Patents.

Shahidi, F., Arachchi, J. K. V. and Jeon, Y.-J. (1999). Food applications of chitin and chitosans. *Trends in food science & technology, 10*(2), 37-51.

Shalumon, K., Anulekha, K., Chennazhi, K. P., Tamura, H., Nair, S. and Jayakumar, R. (2011). Fabrication of chitosan/poly (caprolactone) nanofibrous scaffold for bone and skin tissue engineering. *International journal of biological macromolecules, 48*(4), 571-576.

Shen, X., Xu, Q., Xu, S., Li, J., Zhang, N. and Zhang, L. (2014). Preparation and transdermal diffusion evaluation of the prazosin hydrochloride-loaded electrospun poly (vinyl alcohol) fiber mats. *Journal of nanoscience and nanotechnology, 14*(7), 5258-5265.

Shen, X., Yu, D., Zhu, L., Branford-White, C., White, K. and Chatterton, N. P. (2011). Electrospun diclofenac sodium loaded Eudragit® L 100-55 nanofibers for colon-targeted drug delivery. *International journal of Pharmaceutics, 408*(1-2), 200-207.

Shin, M. K., Kim, S. I., Kim, S. J., Kim, S.-K., Lee, H. and Spinks, G. M. (2006). Size-dependent elastic modulus of single electroactive polymer nanofibers. *Applied physics letters, 89*(23), 231929.

Shuai, X., He, Y., Asakawa, N. and Inoue, Y. (2001). Miscibility and phase structure of binary blends of poly (l-lactide) and poly (vinyl alcohol). *Journal of Applied Polymer Science, 81*(3), 762-772.

Shukla, S. C., Singh, A., Pandey, A. K. and Mishra, A. (2012). Review on production and medical applications of ε-polylysine. *Biochemical Engineering Journal, 65*, 70-81.

Silva, S. S., Mano, J. F. and Reis, R. L. (2017). Ionic liquids in the processing and chemical modification of chitin and chitosan for biomedical applications. *Green Chemistry, 19*(5), 1208-1220.

Singhvi, G. and Singh, M. (2011). In-vitro drug release characterization models. *Int J Pharm Stud Res, 2*(1), 77-84.

Son, Y. J., Kim, W. J. and Yoo, H. S. (2014). Therapeutic applications of electrospun nanofibers for drug delivery systems. *Archives of pharmacal research, 37*(1), 69-78.

Song, B., Wu, C. and Chang, J. (2012). Controllable delivery of hydrophilic and hydrophobic drugs from electrospun poly (lactic-co-glycolic acid)/mesoporous silica nanoparticles composite mats. *Journal of Biomedical Materials Research Part B: Applied Biomaterials, 100*(8), 2178-2186.

Sowjanya, J., Singh, J., Mohita, T., Sarvanan, S., Moorthi, A., Srinivasan, N. and Selvamurugan, N. (2013). Biocomposite scaffolds containing chitosan/alginate/nano-silica for bone tissue engineering. *Colloids and Surfaces B: Biointerfaces, 109*, 294-300.

Subal, C. (2006). Modelling of Drug release: The Higuchi equation and its application. *Pharmabiz. com*.

Suyatma, N. E., Copinet, A., Tighzert, L. and Coma, V. (2004). Mechanical and barrier properties of biodegradable films made from chitosan and poly (lactic acid) blends. *Journal of Polymers and the Environment, 12*(1), 1-6.

Sweidan, K., Jaber, A.-M., Al-jbour, N., Obaidat, R., Al-Remawi, M. and Badwan, A. (2016). Further investigation on the degree of deacetylation of chitosan determined by potentiometric titration. *Journal of Excipients and Food Chemicals, 2*(1), 1129.

Swindle-Reilly, K. E., Paranjape, C. S. and Miller, C. A. (2014). Electrospun poly (caprolactone)-elastin scaffolds for peripheral nerve regeneration. *Progress in biomaterials, 3*(1), 20.

Tammaro, L., Russo, G. and Vittoria, V. (2009). Encapsulation of diclofenac molecules into poly (ε caprolactone) electrospun fibers for delivery protection. *Journal of Nanomaterials, 2009*, 22.

Tan, S. C., Khor, E., Tan, T. K. and Wong, S. M. (1998). The degree of deacetylation of chitosan: advocating the first derivative UV-spectrophotometry method of determination. *Talanta, 45*(4), 713-719.

Tang, E., Huang, M. and Lim, L. (2003). Ultrasonication of chitosan and chitosan nanoparticles. *International journal of Pharmaceutics, 265*(1-2), 103-114.

Tangsadthakun, C., Kanokpanont, S., Sanchavanakit, N., Banaprasert, T. and Damrongsakkul, S. (2017). Properties of collagen/chitosan scaffolds for skin tissue engineering. *Journal of Metals, Materials and Minerals, 16*(1).

Taylor, G. I. (1932). The viscosity of a fluid containing small drops of another fluid. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, 138*(834), 41-48.

Thangaraju, E., Srinivasan, N. T., Kumar, R., Sehgal, P. K. and Rajiv, S. (2012). Fabrication of electrospun poly l-lactide and curcumin loaded poly l-lactide nanofibers for drug delivery. *Fibers and Polymers, 13*(7), 823-830.

Tharanathan, R. N. and Kittur, F. S. (2003). Chitin—the undisputed biomolecule of great potential.

Theron, S., Yarin, A., Zussman, E. and Kroll, E. (2005). Multiple jets in electrospinning: experiment and modeling. *Polymer, 46*(9), 2889-2899.

Thomas, V., Dean, D. R. and Vohra, Y. K. (2006). Nanostructured biomaterials for regenerative medicine. *Current Nanoscience, 2*(3), 155-177.

Tian, F., Liu, Y., Hu, K. and Zhao, B. (2004). Study of the depolymerization behavior of chitosan by hydrogen peroxide. *Carbohydrate Polymers, 57*(1), 31-37.

Tokoro, A., Kobayashi, M., Tatewaki, N., Suzuki, K., Okawa, Y., Mikami, T., Suzuki, M. (1989). Protective Effect of N-Acetyl Chitohexaose on Listeria monocytogenes Infection in Mice. *Microbiology and immunology, 33*(4), 357-367.

Tømmeraas, K., Vårum, K. M., Christensen, B. E. and Smidsrød, O. (2001). Preparation and characterisation of oligosaccharides produced by nitrous acid depolymerisation of chitosans. *Carbohydrate research, 333*(2), 137-144.

Tong, L. and Mazur, E. (2008). Glass nanofibers for micro-and nano-scale photonic devices. *Journal of Non-Crystalline Solids, 354*(12-13), 1240-1244.

Torobin, L. and Findlow, R. C. (2001). Method and apparatus for producing high efficiency fibrous media incorporating discontinuous sub-micron diameter fibers, and web media formed thereby: Google Patents.

Tripathi, S., Mehrotra, G. and Dutta, P. (2008). Chitosan based antimicrobial films for food packaging applications. *e-Polymers, 8*(1), 1082-1088.

Tsaih, M. L. and Chen, R. H. (1997). Effect of molecular weight and urea on the conformation of chitosan molecules in dilute solutions. *International journal of biological macromolecules, 20*(3), 233-240.

Tsuji, H. (2008). *Degradation of poly (lactide)--based biodegradable materials*: Nova Science Publishers.

Unnithan, A. R., Gnanasekaran, G., Sathishkumar, Y., Lee, Y. S. and Kim, C. S. (2014). Electrospun antibacterial polyurethane–cellulose acetate–zein composite mats for wound dressing. *Carbohydrate Polymers, 102*, 884-892.

Vaidya, P., Grove, T., Edgar, K. J. and Goldstein, A. S. (2015). Surface grafting of chitosan shell, polycaprolactone core fiber meshes to confer bioactivity. *Journal of Bioactive and Compatible Polymers, 30*(3), 258-274.

Van der Schueren, L., De Schoenmaker, B., Kalaoglu, Ö. I. and De Clerck, K. (2011). An alternative solvent system for the steady state electrospinning of polycaprolactone. *European Polymer Journal, 47*(6), 1256-1263.

Van der Schueren, L., Steyaert, I., De Schoenmaker, B. and De Clerck, K. (2012). Polycaprolactone/chitosan blend nanofibres electrospun from an acetic acid/formic acid solvent system. *Carbohydrate polymers, 88*(4), 1221-1226.

Varabhas, J., Chase, G. G. and Reneker, D. (2008). Electrospun nanofibers from a porous hollow tube. *Polymer, 49*(19), 4226-4229.

Varabhas, J., Tripatanasuwan, S., Chase, G. and Reneker, D. (2009). Electrospun jets launched from polymeric bubbles. *Journal of Engineered Fibers and Fabrics, 4*(4), 44-50.

Vårum, K., Ottøy, M. and Smidsrød, O. (2001). Acid hydrolysis of chitosans. *Carbohydrate polymers, 46*(1), 89-98.

Vatankhah, E., Prabhakaran, M. P., Jin, G., Mobarakeh, L. G. and Ramakrishna, S. (2014). Development of nanofibrous cellulose acetate/gelatin skin substitutes for variety wound treatment applications. *Journal of biomaterials applications, 28*(6), 909-921.

Venkatesan, J. and Kim, S.-K. (2010). Chitosan composites for bone tissue engineering—an overview. *Marine drugs, 8*(8), 2252-2266.

Venugopal, J. and Ramakrishna, S. (2005). Applications of polymer nanofibers in biomedicine and biotechnology. *Applied biochemistry and biotechnology, 125*(3), 147-157.

Vert, M., Hellwich, K.-H., Hess, M., Hodge, P., Kubisa, P., Rinaudo, M. and Schué, F. (2012). Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). *Pure and Applied Chemistry, 84*(2), 377-410.

Vikas, K., Arvind, S., Ashish, S., Gourav, J. and Vipasha, D. (2011). Recent Advances In Ndds (Nov el Drug Delivery System) For Delivery Of Anti-Hypertensive Drugs. *International Journal of Drug Development and Research, 3*(1).

Wang, A., Ao, Q., Cao, W., Yu, M., He, Q., Kong, L., Zhang, X. (2006a). Porous chitosan tubular scaffolds with knitted outer wall and controllable inner structure for nerve tissue engineering. *Journal of Biomedical Materials Research Part A, 79*(1), 36-46.

Wang, H.-S., Fu, G.-D. and Li, X.-S. (2009). Functional polymeric nanofibers from electrospinning. *Recent Patents on Nanotechnology, 3*(1), 21-31.

Wang, Q. Z., Chen, X. G., Liu, N., Wang, S. X., Liu, C. S., Meng, X. H. and Liu, C. G. (2006b). Protonation constants of chitosan with different molecular weight and degree of deacetylation. *Carbohydrate polymers, 65*(2), 194-201.

Wang, X., Um, I. C., Fang, D., Okamoto, A., Hsiao, B. S. and Chu, B. (2005). Formation of water-resistant hyaluronic acid nanofibers by blowing-assisted electro-spinning and non-toxic post treatments. *Polymer, 46*(13), 4853-4867.

Wen, H.-F., Yang, C., Yu, D.-G., Li, X.-Y. and Zhang, D.-F. (2016a). Electrospun zein nanoribbons for treatment of lead-contained wastewater. *Chemical Engineering Journal, 290*, 263-272.

Wen, P., Zhu, D.-H., Feng, K., Liu, F.-J., Lou, W.-Y., Li, N., Wu, H. (2016c). Fabrication of electrospun polylactic acid nanofilm incorporating cinnamon essential oil/β-cyclodextrin inclusion complex for antimicrobial packaging. *Food chemistry, 196*, 996-1004.

Whistler, R. L. (1993). Exudate gums *Industrial Gums (Third Edition)* (pp. 309-339): Elsevier.

Xia, W., Song, J., Hsu, D. D. and Keten, S. (2017). Side-group size effects on interfaces and glass formation in supported polymer thin films. *The Journal of chemical physics, 146*(20), 203311.

Xing, X., Wang, Y. and Li, B. (2008). Nanofiber drawing and nanodevice assembly in poly (trimethylene terephthalate). *Optics express, 16*(14), 10815-10822.

Xu, F., Weng, B., Gilkerson, R., Materon, L. A. and Lozano, K. (2015). Development of tannic acid/chitosan/pullulan composite nanofibers from aqueous solution for potential applications as wound dressing. *Carbohydrate Polymers, 115*, 16-24.

Xu, J., Jiao, Y., Shao, X. and Zhou, C. (2011). Controlled dual release of hydrophobic and hydrophilic drugs from electrospun poly (l-lactic acid) fiber mats loaded with chitosan microspheres. *Materials Letters, 65*(17-18), 2800-2803.

Xu, W., Shen, R., Yan, Y. and Gao, J. (2017). Preparation and characterization of electrospun alginate/PLA nanofibers as tissue engineering material by emulsion eletrospinning. *Journal of the mechanical behavior of biomedical materials, 65*, 428-438.

Xu, Z., Mahalingam, S., Basnett, P., Raimi-Abraham, B., Roy, I., Craig, D. and Edirisinghe, M. (2016). Making Nonwoven Fibrous Poly (ε-caprolactone) Constructs for Antimicrobial and Tissue Engineering Applications by Pressurized Melt Gyration. *Macromolecular Materials and Engineering, 301*(8), 922-934.

Yadav, A. and Bhise, S. (2004). Chitosan: A potential biomaterial effective against typhoid. *Current Science, 87*(9), 1176-1178.

Yalcinkaya, F. (2016). Preparation of various nanofiber layers using wire electrospinning system. *Arabian Journal of Chemistry*.

Yan, X., Marini, J., Mulligan, R., Deleault, A., Sharma, U., Brenner, M. P., Pham, Q. P. (2015). Slit-surface electrospinning: a novel process developed for high-throughput fabrication of core-sheath fibers. *PloS one, 10*(5), e0125407.

Yang, C., Yu, D.-G., Pan, D., Liu, X.-K., Wang, X., Bligh, S. A. and Williams, G. R. (2016). Electrospun pH-sensitive core–shell polymer nanocomposites fabricated using a tri-axial process. *Acta biomaterialia, 35*, 77-86.

Yen, M.-T., Yang, J.-H. and Mau, J.-L. (2009). Physicochemical characterization of chitin and chitosan from crab shells. *Carbohydrate polymers, 75*(1), 15-21.

Yördem, O., Papila, M. and Menceloğlu, Y. Z. (2008). Effects of electrospinning parameters on polyacrylonitrile nanofiber diameter: An investigation by response surface methodology. *Materials & Design, 29*(1), 34-44.

Yu, C.-C., Chang, J.-J., Lee, Y.-H., Lin, Y.-C., Wu, M.-H., Yang, M.-C. and Chien, C.-T. (2013). Electrospun scaffolds composing of alginate, chitosan, collagen and hydroxyapatite for applying in bone tissue engineering. *Materials Letters, 93*, 133-136.

Yu, D.-G., Yang, C., Jin, M., Williams, G. R., Zou, H., Wang, X. and Bligh, S. A. (2016). Medicated Janus fibers fabricated using a Teflon-coated side-by-side spinneret. *Colloids and Surfaces B: Biointerfaces, 138*, 110-116.

Zhang, C., Yuan, X., Wu, L., Han, Y. and Sheng, J. (2005a). Study on morphology of electrospun poly (vinyl alcohol) mats. *European polymer journal, 41*(3), 423-432.

Zhang, S., Prabhakaran, M. P., Qin, X. and Ramakrishna, S. (2015). Biocomposite scaffolds for bone regeneration: Role of chitosan and hydroxyapatite within poly-3-hydroxybutyrate-co-3-hydroxyvalerate on mechanical properties and in vitro evaluation. *Journal of the mechanical behavior of biomedical materials, 51*, 88-98.

Zhang, Y., Ni, M., Zhang, M. and Ratner, B. (2003). Calcium phosphate—chitosan composite scaffolds for bone tissue engineering. *Tissue engineering, 9*(2), 337-345.

Zhang, Y., Xue, C., Xue, Y., Gao, R. and Zhang, X. (2005b). Determination of the degree of deacetylation of chitin and chitosan by X-ray powder diffraction. *Carbohydrate Research, 340*(11), 1914-1917.

Zhou, Y., Yang, D. and Nie, J. (2006). Electrospinning of chitosan/poly (vinyl alcohol)/acrylic acid aqueous solutions. *Journal of Applied Polymer Science, 102*(6), 5692-5697.

Ziani, K., Henrist, C., Jérôme, C., Aqil, A., Maté, J. I. and Cloots, R. (2011). Effect of nonionic surfactant and acidity on chitosan nanofibers with different molecular weights. *Carbohydrate polymers, 83*(2), 470-476.

Zografi, G. (1982). Physical stability assessment of emulsions and related disperse systems: a critical review. *J. Soc. Cosmet. Chem, 33*, 345-358.

Zohuriaan-Mehr, M. J. (2005). Advances in chitin and chitosan modification through graft copolymerization: a comprehensive review. *Iran Polym J, 14*(3), 235-265.

Zulkifli, F. H., Hussain, F. S. J., Rasad, M. S. B. A. and Yusoff, M. M. (2014). Nanostructured materials from hydroxyethyl cellulose for skin tissue engineering. *Carbohydrate Polymers*, *114*, 238-245.

Zulkifli, F. H., Jahir Hussain, F. S., Abdull Rasad, M. S. B. and Mohd Yusoff, M. (2015). Improved cellular response of chemically crosslinked collagen incorporated hydroxyethyl cellulose/poly (vinyl) alcohol nanofibers scaffold. *Journal of biomaterials applications, 29*(7), 1014-1027.