Journal of Materials and Electronic Devices 5 (2020) 29-40



Production and Characterization of New Generation Hybrid Food Packaging Material Made of Polymer Nanofiber Containing Pomegranate Peel Powder

Erdi Bulus[1,2*], Gulseren Sakarya Bulus[3], Necla Yucel[4], Cihan Mehmet Altintas[5], Baris Akdeniz[6], Fahrettin Yakuphanoğlu[7]

[1]Polymer Science and Technology Program, Institute of Science and Technology, Kocaeli University, Kocaeli 41000, Turkey
[2]ArelPOTKAM (Polymer Technologies and Composite Applications and Research Center), Istanbul Arel University, Istanbul 34500, Turkey
[3]Silivri District Health Directorate, Istanbul 34570, Turkey
[4]Nanoscience and Nanoengineering Master's Program, Graduate Education Institute, Istanbul Medeniyet University, Istanbul 34720, Turkey
[5]Istanbul Biotechnology and Laboratory Services Ltd. Şti., Istanbul 34320, Turkey
[6]Tekafos Technological Systems Tic. Ltd. Şti., Istanbul 34746, Turkey
[7] Department of Physics, Faculty of Science,, Firat University, Elazig, 23169, Turkey

Antioxidants, which are known as the effects of free radicals, have become increasingly popular in the health and food industries due to the problems of trust in synthetic based products. Since the early times of human history, it has many uses such as food, medicine and cosmetics. In recent years, the demand for naturally derived antioxidants has increased, and therefore the number of researches on naturally derived antioxidants has been increasing. During the industrial processing of agricultural raw materials and in domestic use, a significant amount of waste and by-products are generated. Among these, pomegranate by-products (pomegranate seed, peel, flower, etc.) come to the fore with high amounts of bioactive ingredients due to their high phenolic content. In this study, the production of nanofiber containing polylactic acid (PLA) polymer containing pomegranate peel powder (PPP) was carried out by electrospinning technique. Material properties were determined by applying morphological-SEM-scanning electron microscopy, mechanical-tensile and biological-antioxidant test processes to the produced membranes. These membranes produced will be able to show hybrid material properties that prevent free radical formation and extend the shelf life of food.

Keywords: *Free radical, antioxidant, pomegranate peel, polylactic acid, electrospinning, hybrid food packaging material*

Submission Date: 08 October 2020
Acceptance Date: 17 December 2020

**Corresponding author: buluserdi@gmail.com (Erdi Bulus) Tel: +905346321017*

1. Introduction

Food packaging is a part of the food production stages that ensure the safe delivery of food to the end user, the consumer. It is possible to choose materials suitable for

different food products with food packaging techniques and applications. Thanks to the right material and technique, it can preserve the freshness of the food and extend its shelf life. The prevalence of food packages that come into direct contact with food produced with new technologies and the fact that these packages have antioxidant and antimicrobial properties in terms of food safety have increased their importance. Due to the formation of free radicals in foods, healthy people are easily passed on and these free radicals have both direct and indirect effects in the occurrence of cancer, vascular occlusion, Alzheimer's disease, Parkinson's disease and many other diseases [1].

Free radicals are molecules that usually contain an oxygen atom that has lost an electron. This situation makes them unstable (reactive). They work to supplement their missing electrons from the electrons of neighboring molecules. Meanwhile, they can attack DNA and cause dysfunction, mutation, and cancer. By attacking enzymes and proteins, they can disrupt normal cellular activities. This kind of damage to the membranes of the cells that line our blood vessels can lead to hardening and thickening of the arteries and, ultimately, heart attacks and strokes. Free radicals attack the protein in the collagen, causing cross-links between protein molecules and tissue stiffness [2].

Antioxidants can be produced by our body or taken from outside by food. The most important antioxidants taken from outside through food are vitamins A, C, E and Selenium. When these chemicals are taken into the body, they prevent the formation of free radicals formed as a result of metabolic activities. Antioxidants prevent free radicals from damaging the cell. The air we draw into our lungs causes the formation of harmful substances called free radicals in our body. Antioxidants, on the other hand, fight these free radicals and prevent them from damaging our body. Antioxidants protect the body against all the ailments that free radicals may cause. In addition, antioxidants are used in the preservation of foods. When we look at the food ingredients, we can see antioxidants. They are very beneficial for human health, not only in terms of preserving nutrients without spoiling, but also preventing the oxidation (or deterioration) of the food we eat during the interaction with oxygen in our blood. Consuming foods containing antioxidant substances is a health imperative [3-4].

Antioxidant or antibacterial packaging is an application of active packaging. With active packaging, components with various properties are included in the packaging material, and the desired properties can be given to the packaging. The use of antimicrobial agents prevents the growth of pathogenic microorganisms on the surface as a result of contamination in food and fungal spoilage in large portions. Controlled release of antimicrobial substances to the food surface during distribution and storage in such packaging is permitted [5].

Many natural antioxidant substances emerge as a result of agriculturally sourced industrial and domestic wastes. The use of these as antioxidants contributes both to the reduction of environmental pollution and to the economy of the country indirectly. Among these wastes, pomegranate peel (PPP) has attracted attention in recent years with its high antioxidant properties.

The pomegranate (*Punica granatum L.)*, which has been a symbol of life, health, longevity, fertility, knowledge, morality, immortality and spirituality for centuries, is a perennial plant belonging to the Punica genus of the Lythraceae family (Canines) [6]. The pomegranate peel image is given in Figure 1.1.



Figure 1.1. *Pomegranate peel image [6]*

Cultural history BC. Dating back 3,000 years, it is among the oldest known fruit types. It has an important place for cultural life as well as its benefits to human health and industrial value. Homeland, Turkey, the Middle East, mainly to cover the south-southeast Iran, the Caucasus and India, expressed as a northern climate is tropical and subtropical plants. Its ability to adapt to the ambient conditions and the lack of soil selectivity enabled the pomegranate to spread over a wide area. However, the areas where it is commonly grown are the regions where the Mediterranean precipitation regime is effective, with rainy winters and hot and dry summers. In our country, it grows in the Mediterranean, Aegean and Southeastern Anatolia Regions, especially Antalya, from sea level to 1000 m high altitudes. A remarkable increase in pomegranate cultivation in the world and Turkey were observed depending on the developments in the fruit growing sector. Standing out with important developments in cultivation, storage, transportation and processing, pomegranate has become a fruit with increased production, consumption and trade. Turkey, one of the leading manufacturer of pomegranate.

Pomegranate fruit consists of three parts: core, water and shell. The edible part, ie the grains, constitute 52% of the fruit and 78% of the grains consist of fruit flesh and 22% of the seeds.

The therapeutic properties of fruit, bark, root and leaves have been evaluated in different studies. Pomegranate, flavonoids (anthocyanins, catechins and other complex flavonoids), hydrolyzable tannins (punikalin, pedunculagine, punicalagin, gallic and ellagic acid esters of glucose), polyphenols, fatty acids (conjugated and non-conjugated), aromatic compounds, amino acids, tocopherols It is a rich source of phenolic compounds such as sterols, terpenoids, alkaloids that make up 92% of its antioxidant activity. Due to these properties of PPP, it acts as a free radical scavenger, protects the intestinal flora and shows a strong anti-bacterial

effect against pathogens. The fact that PPP has a high level of antimicrobial and antioxidants has been deemed suitable for use in food packaging [6].

In addition to the environmental waste problems caused by non-biodegradable petrochemical-based plastic packaging materials, consumers' demand for high quality food products has brought the development of biodegradable packaging materials using renewable natural biopolymers such as polysaccharides and proteins annually. Biodegradable, ie biodegradable plastics; It is produced from natural polymers such as starch, cellulose and protein. Because they can degrade in nature, they pollute the environment less and are preferred because they reduce the waste problem. Biopolymer-based packaging materials have some beneficial features such as improving food quality and extending shelf life by minimizing microbial growth in the product [7].

These materials serve not only as a barrier against moisture, water vapor, gases and solutes, but also as carriers of some active substances. They are also excellent tools for combining a large variety of additives such as antioxidants, antifungal agents, antimicrobials, coloring agents and other food ingredients. In addition to being biodegradable and renewable, natural biopolymers have advantages over synthetic polymers because they are edible. As a biopolymer, an aliphatic, biodegradable polyester polylactic acid (PLA) has been preferred as a food packaging material in recent years [8]. The chemical structure of PLA is shown in Figure 1.2.

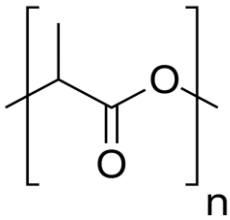


Figure 1.2. *Chemical structure of PLA [8]*

"Nanotechnology" concept; It is a combination of the words nano and technology. Technology is the body of information used to produce useful products and to design new products. Nano means "dwarf" in Greek. Expressions defined by nano represent one billionth of any measure. For example; Nanometer refers to one billionth of a meter (1 nm = 10^{-9} m). When nanostructures are viewed in terms of length, they correspond to systems of approximately 10-100 atoms (10^{-9} meters). Any size (length, width or thickness) between 100 and 1 nanometers (nm) (1/10 million meters to 1/1 billion meters) is expressed for materials covered by nanotechnology [9-10]. The areas where nanotechnology is applied are shown in Figure 1.3.



Figure 1.3. *Areas where nanotechnology is applied [10]*

It can be defined as fibers of one micron in diameter and below. Today, nanofiber can be produced from many ceramic and polymer materials using various production methods. Fibers produced from polymer solution and polymer melt at sub-micrometer dimensions using various methods are called nanofibers.

Today, there are many nanofiber production methods. These methods; fibrillation, meltblowing, bicomponent, spunbond and electrospinning.

Electrospinning method is the process of transforming the fluid into nano-sized fibers by applying a voltage of kilovolt to viscous liquids at very small flow rates. Polymer solution or melt is used as a viscous liquid in its application. The solution arriving at the tip of the medical syringe at uniform flow forms a spherical droplet under the influence of surface tensions, where, under the effect of electrical forces, it is tapered (taylor cone) and transferred as nanofibers to the grounded collector at a certain distance. In recent years, electrospinning technique has been preferred in the production of new generation food packaging materials [11-12]. Figure 1.4. shows the working principle of electrospinning technique.

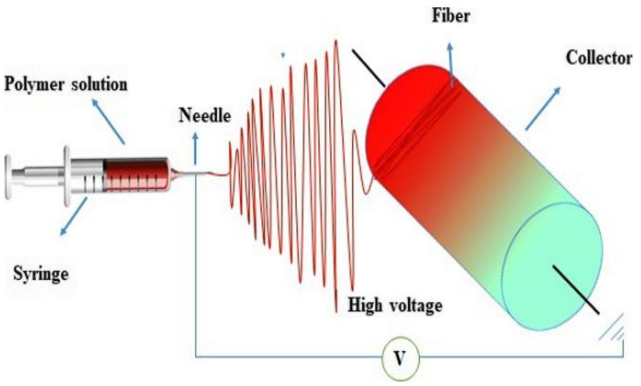


Figure 1.4. *The working principle of electrospinning technique [13]*

PLA hybrid packaging materials containing PPP powder were produced by nanotechnological electrospinning technique in order to prevent food spoilage and increase shelf life.

2. Experimental Studies

2.1. Materials

Ak-Kim Kimya San. ve Tic. Inch., 10-15 kDa polylactic acid (PLA), dimethylformamide (DMF) to dissolve the polymer, acetone solvents and greaseproof paper as the substrate in the electrospinning process. Waste pomegranate peels were collected after domestic use.

2.2. Preparation of pomegranate peel powder (PPP)

After domestic use, pomegranate skins were collected. The collected pomegranate peels (PPs) were kept in tap water for 48 hours. It was then washed with distilled water. Washed pomegranate peel wastes were kept in a deep freezer at -80 °C for 24 hours. Frozen pomegranate peels were dried in a lyophilizer and the liquid contained was evaporated. Completely dried pomegranate skins were pounded in a ceramic mortar and ground. After the grinding process, it was pulverized by grinding in a ball mill for 5 minutes at 500 rpm in order to make the coarse powders into a finer powder. The processes of pulverizing the waste pomegranate peels are shown in Figure 2.1.



Figure 2.1. *Processing of pulverizing waste pomegranate peels*

2.3. Preparation of composite solutions

10 gr of PLA polymer by weight was made into solution in DMF /Aceton (50-50) solvent with a heated magnetic stirrer at 60 °C mixing temperature and 60 minutes mixing time. By adding 1%, 5%, 8% PPP to the formed PLA solution, a solution in four different compositions was obtained. Table 2.1. shows the preparation values of composite solutions.

Table 2.1.: Preparation values of composite solutions

Sample Name	Solution Mixing Time (min.)	Solution Mixing Temperature (°C)
10% PLA	60	80
10% PLA-1% PPP	60	80
10% PLA-5% PPP	65	90
10% PLA-8% PPP	65	90

2.4. Production of new generation hybrid food packaging nanofiber membrane with electrospinning method

The new generation food packaging hybrid nanofiber membranes were produced by applying the electrospinning operating parameters in Table 2.2. to the prepared solutions. Electrospinning operating parameters are shown in Table 2.2. The device image of FYTRONIX ELECTROSPINNING SYSTEM is given in Figure 2.2. The realization stages of the new generation food packaging hybrid nanofiber membrane production are shown in Figure 2.3.



Figure 2.2. *Device image of FYTRONIX ELECTROSPINNING SYSTEM*

Table 2.2.: *Electrospinning parameters applied for nanofiber membrane production*

Sample Name	*Flow Rate (ml/hr.)*	*High Voltage (kV)*	*Working Distance (cm)*
10% PLA	*3.0*	*30.0*	*15*
10% PLA-1% PPP	*3.0*	*30.0*	*15*
10% PLA-5% PPP	*3.0*	*35.0*	*15*
10% PLA-8% PPP	*3.0*	*35.0*	*15*

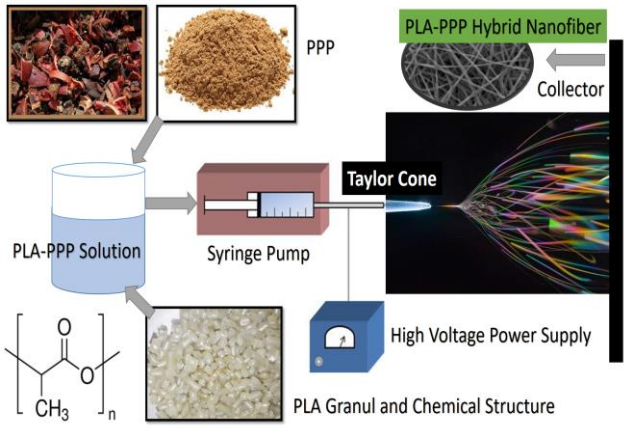


Figure 2.3. *The realization stages of the new generation food packaging hybrid nanofiber membrane production*

2.5. Characterization of hybrid nanofiber membrane

The new generation food packaging hybrid nanofiber membranes placed in the holders were examined and photographed with the Thermoscientific Phenom XL G2 Desktop microscope. For the SEM analysis of the produced rechargeable nanofiber membranes, x12000 times magnified images at 15 kV potential were examined. The fiber dimensions of the nanofibers were determined by measuring an average of 200 nanofibers with the device software on the images obtained.

Samples of 1x4 cm were prepared for the mechanical characterization studies of the new generation hybrid nanofiber membranes for food packaging. Digital micrometer (795.1 MEXFL-25, Starrett, USA) was used for thickness measurements of rechargeable nanofiber membranes cut in appropriate sizes. The thickness values obtained were entered into the analysis program before mechanical analysis and used to determine the elastic modulus. The mechanical properties of the nanofibers formed were determined with a Zwickline (Zwick / Roell Ltd., Germany) analyzer. Studies have been done in room conditions. The samples are separated from the backing material and attached to the device clamps. The device is 5 mm / min under 500 N load. Mechanical properties were determined by adjusting the drawing speed and 10 mm jaw spacing. Cupric Reducing Antioxidant Capacity (CUPRAC); Cu (II) Ion Reducing Antioxidant Capacity Method

- 1 mL copper (II) chloride + 1 mL neocuproin + 1 mL ammonium acetate + x mL antioxidant solution + 1.1 –x mL water are mixed.
- After 30 minutes at room temperature, absorbance is measured at 450 nm.
- Trolox is used as standard and the concentration range for trolox is 10 - 100 µmol / L.
- Total antioxidant capacity results are expressed in mM Trolox / kg.

Preparation of Solutions;

- $CuCl_2$ solution, $1x10^{-2}$ M, was prepared by dissolving 0.4262 g $CuCl_2.2H_2O$ in water, and diluting to 250 mL.
- Ammonium acetate buffer at pH 7.0, 1.0 M, was prepared by dissolving 19.27 g NH_4Ac in water and diluting to 250 mL.
- Neocuproine (Nc) solution, $7.5x10^{-3}$ M, was prepared daily by dissolving 0.039 g Nc in 96% ethanol, and diluting to 25 mL with ethanol.
- Trolox, $1x10^{-3}$ M, was prepared in 96% ethanol.

In this method developed by Apak et al., The copper (II) - neocuproin complex [Cu (II) -Nc] formed by Cu (II) of 2,9-dimethyl-1, 10-phenanthroline (Neokuproin-Nc) is The antioxidant capacity is calculated by using the ability to be reduced to copper (I)-neocuproin [Cu (I)-Nc] chelate, which gives maximum absorbance.

3. Result and Discussion

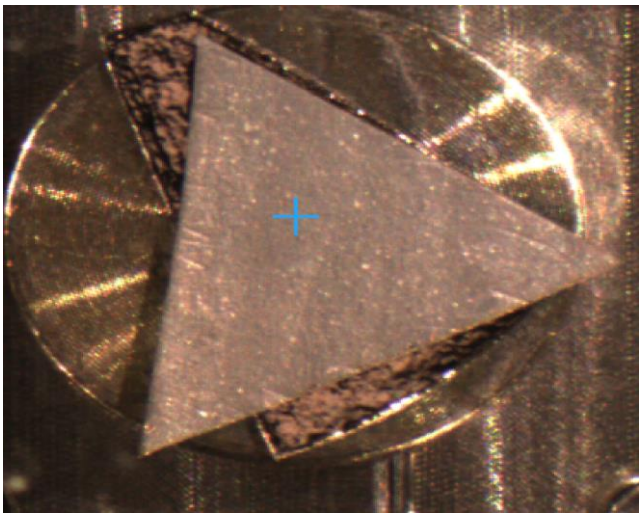
3.1. Morphological (SEM) analysis

Nanofiber formation was observed in all samples. From the SEM image taken, 200 pieces of nanofiber were measured with software. According to the measurement results, as the PPP additive ratio increased compared to the 10% PLA sample, the nanofibers became thinner. The thinnest fibers in the study emerged in a 10% PLA-5% PPP sample. Average fiber diameter is 175 nm. When the pore diameters of the nanofibers were examined, the pore ratio of all samples was determined as 2048.45 nm^2 by pore analysis taken from SEM images. The tightest porous sample in the study was determined to be 10% PLA-5% PPP [14-20]. The Thermoscientific Phenom XL G2 Benchtop microscope image is shown in Figure 3.1. Figure 3.2. (a) 10% PLA sample, (b) 12000X SEM, (c) measurement of 200 fibers, (d) fiber distribution and (e) pore distribution images, In Figure 3.3. (f) 10% PLA-1% PPP sample, (g) 12000X SEM, (h) 200 fibers measurement, (i) fiber distribution and (j) pore distribution images, In Figure 3.4. (k) 10% PLA-5% PPP sample, (l) 12000X SEM, (m) 200 fibers measurement, (n) fiber distribution and (o) pore distribution images and Figure 3.5. shows (p) 10% PLA-8% PPP sample, (r) 12000X SEM,

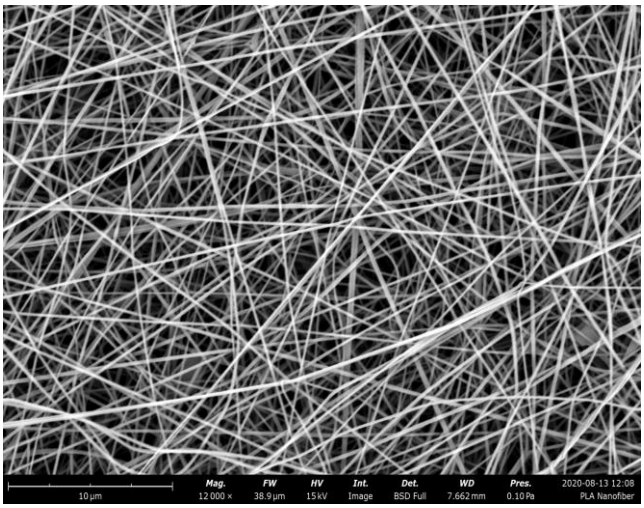
(s) 200 fibers measurement, (t) fiber distribution and (u) pore distribution images. Table 3.1. shows the nanofiber size distribution range of nanofiber membranes.



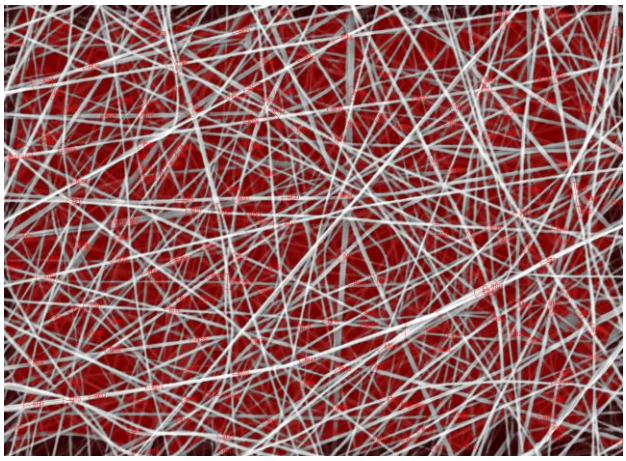
Figure 3.1. *Thermoscientific Phenom XL G2 Benchtop microscope image*



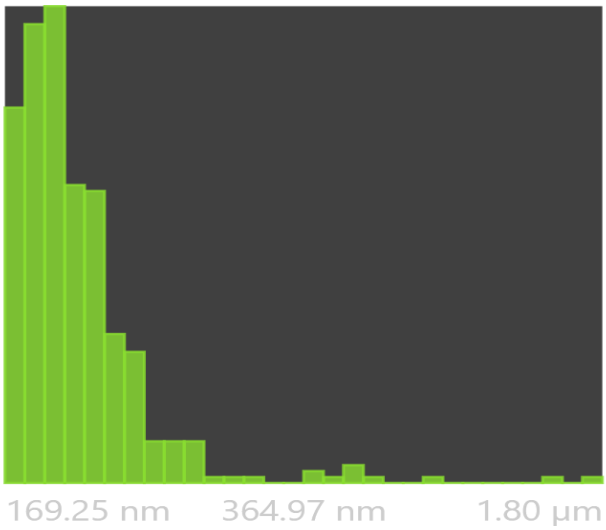
(a)



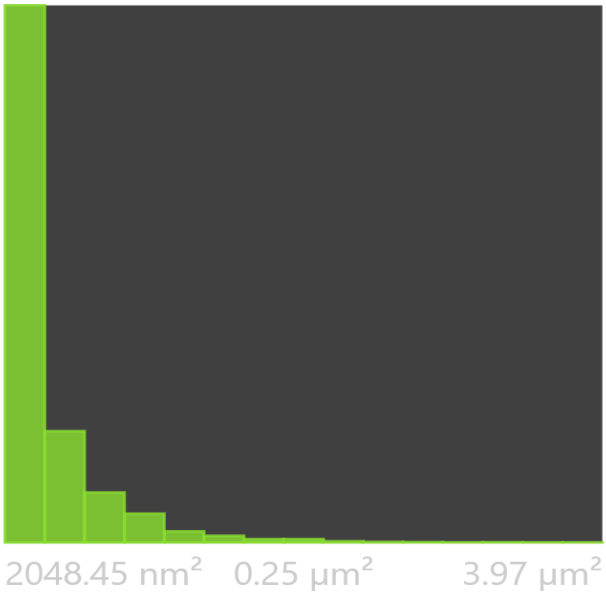
(b)



(c)

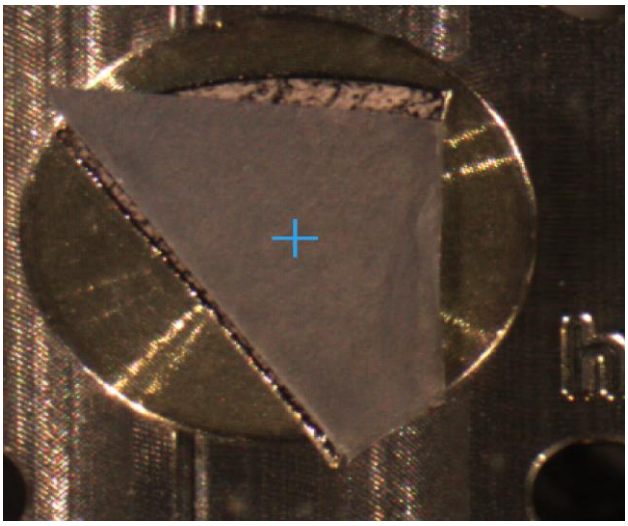


(d)

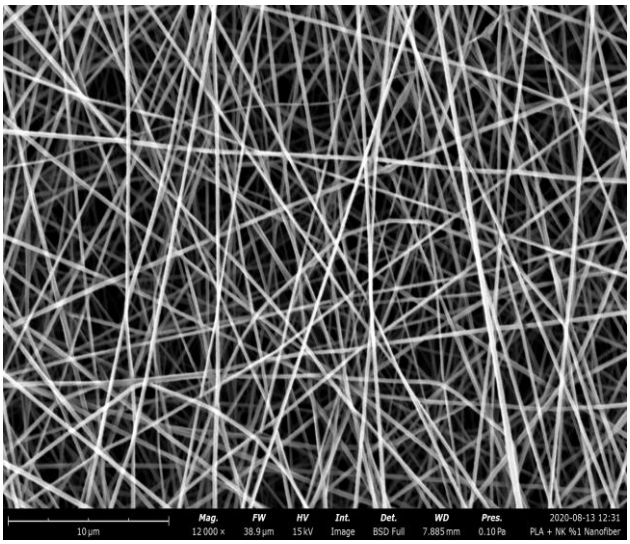


(e)

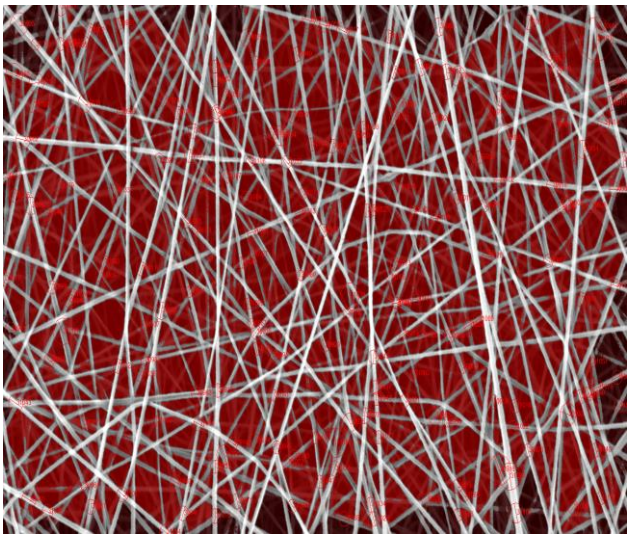
Figure 3.2. ***(a)*** *10% PLA sample,* ***(b)*** *12000X SEM,* ***(c)*** *measurement of 200 fibers,* ***(d)*** *fiber distribution and* ***(e)*** *pore distribution images*



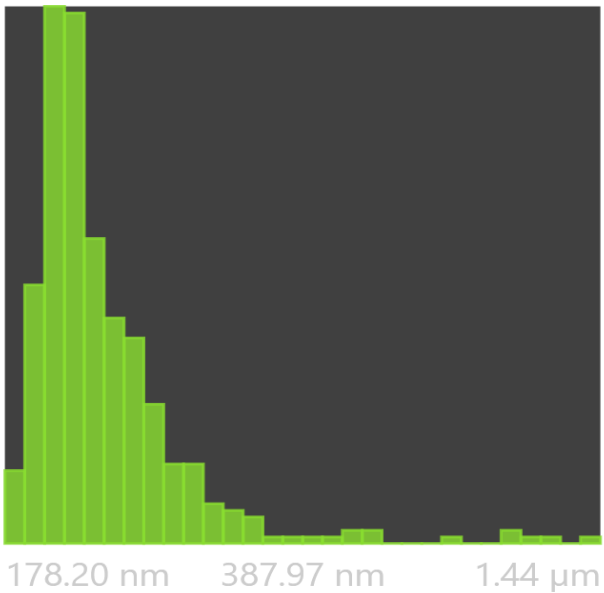
(f)



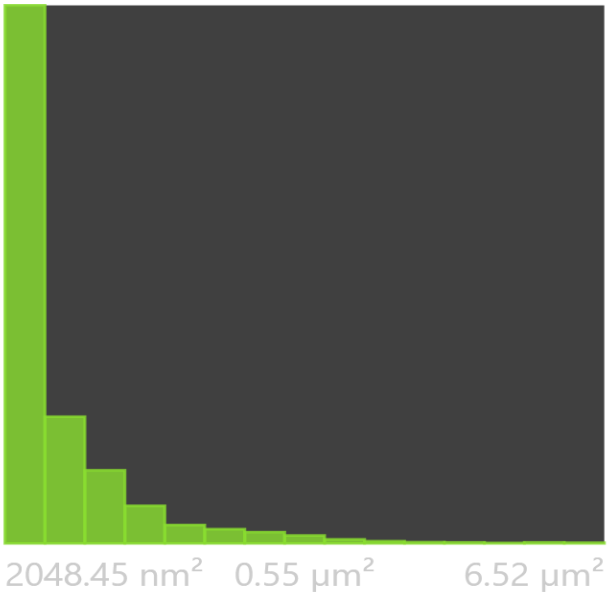
(g)



(h)

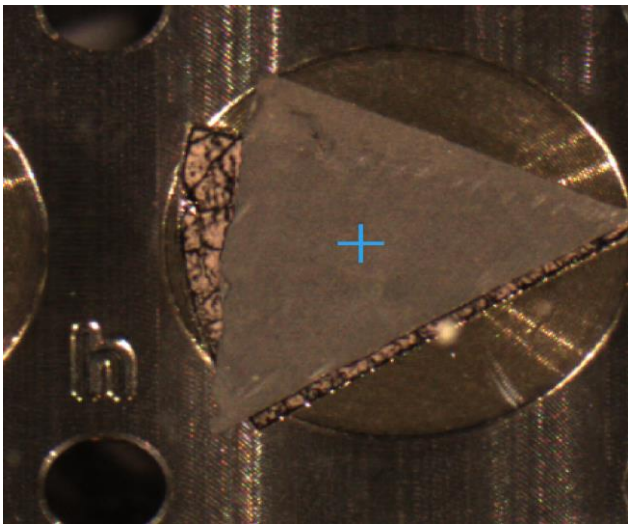


(i)

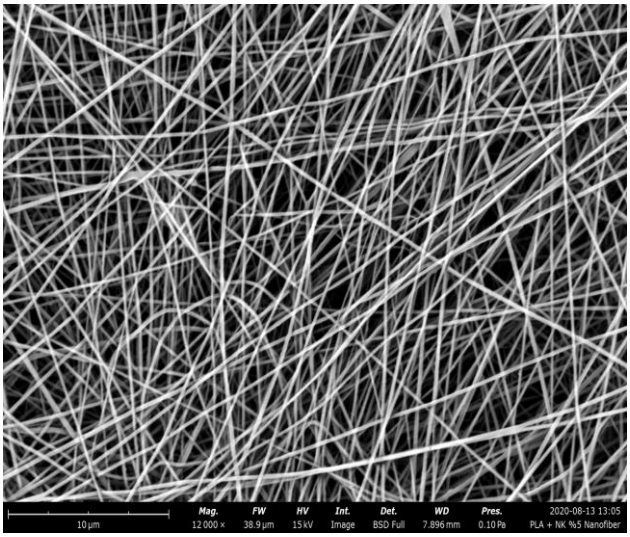


(j)

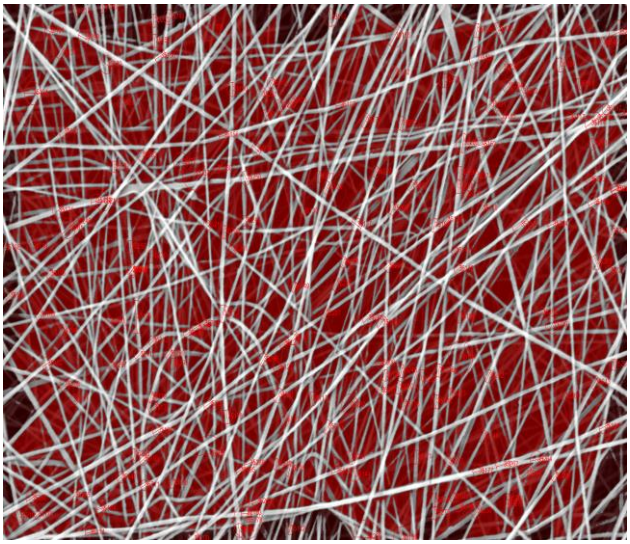
Figure 3.3. ***(f)*** *10% PLA-1% PPP sample,* ***(g)*** *12000X SEM,* ***(h)*** *measurement of 200 fibers,* ***(i)*** *fiber distribution and* ***(j)*** *pore distribution images*



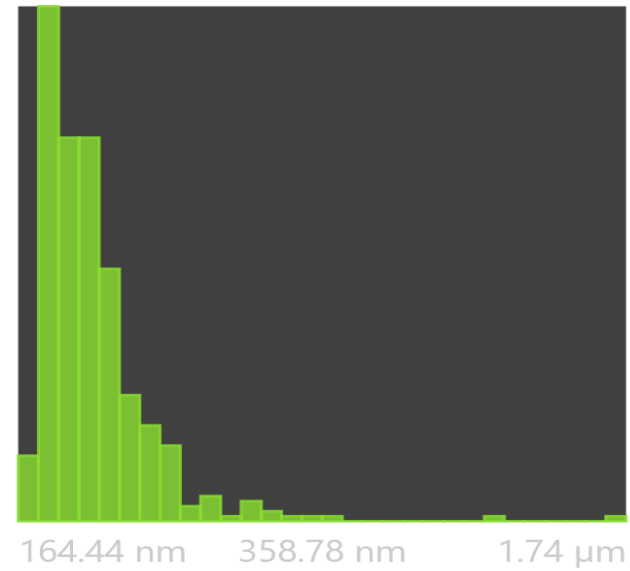
(k)



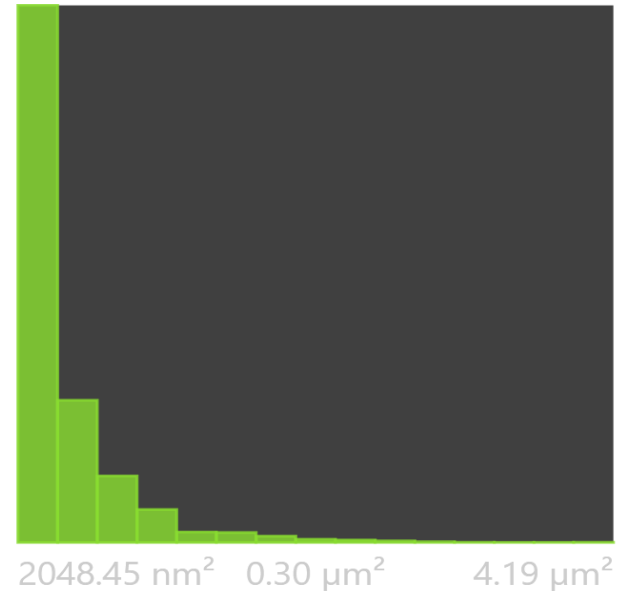
(l)



(m)

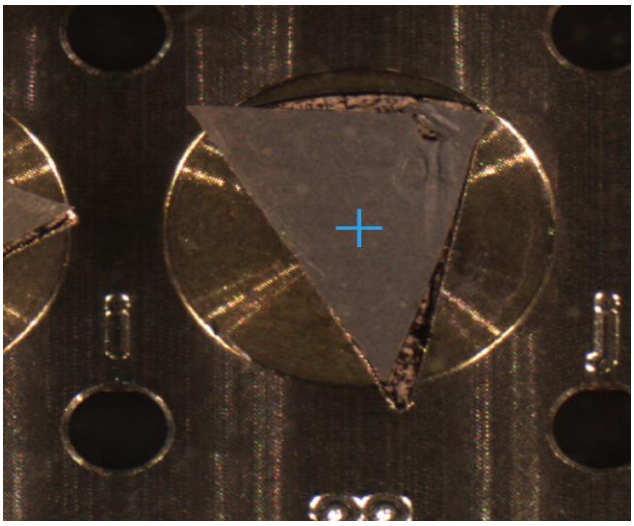


(n)

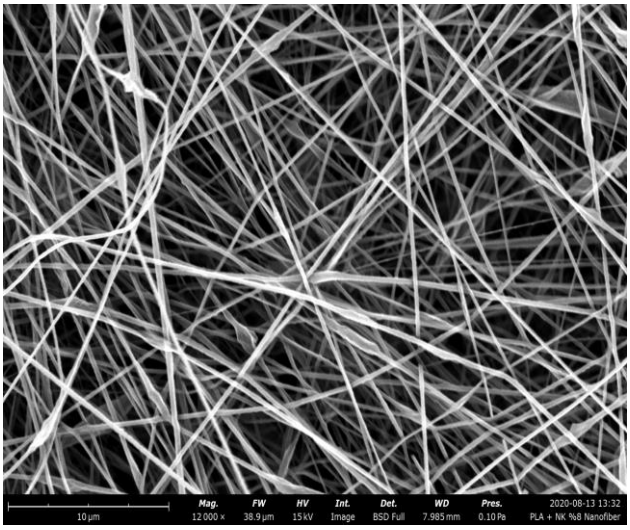


(o)

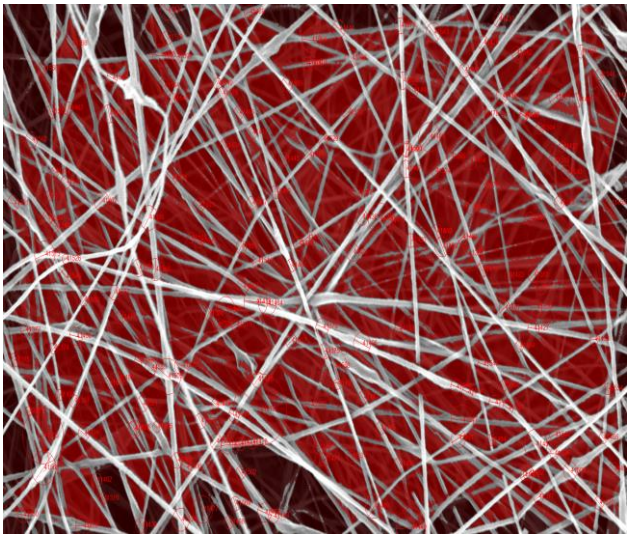
Figure 3.4. ***(k)*** *10% PLA-5% PPP sample,* ***(l)*** *12000X SEM,* ***(m)*** *measurement of 200 fibers,* ***(n)*** *fiber distribution and* ***(o)*** *pore distribution images*



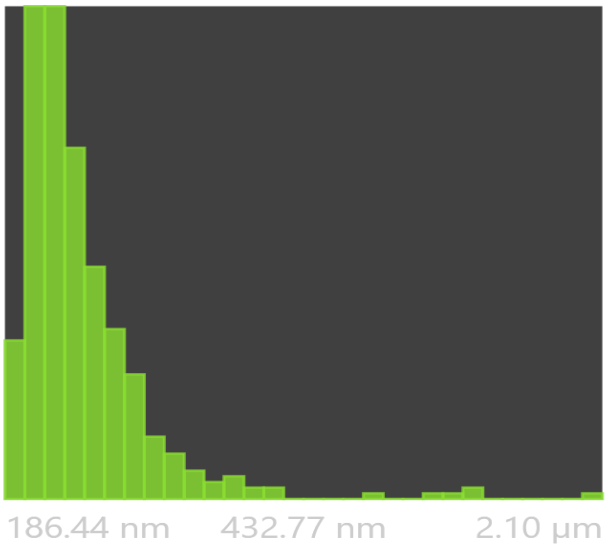
(p)



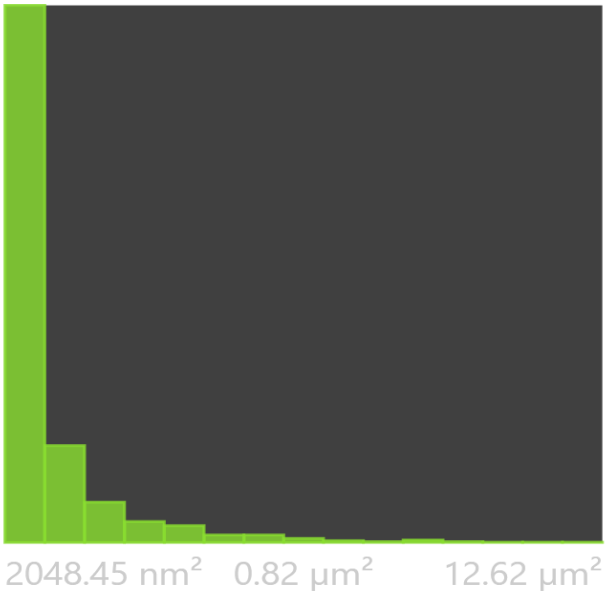
(r)



(s)



(t)



(u)

Figure 3.5. (p) *10% PLA-8% PPP sample,* ***(r)*** *12000X SEM,* ***(s)*** *measurement of 200 fibers,* ***(t)*** *fiber distribution and* ***(u)*** *pore distribution images*

Table 3.1.: Nanofiber size distribution range of nanofiber membranes

Sample Name	Nanofiber avarage size (nm)
10% PLA	250
10% PLA-1% PPP	230
10% PLA-5% PPP	175
10% PLA-8% PPP	190

3.2. Mechanical (Tensile) analysis

Tensile tests were performed by repeating all samples in triplicate. According to the mechanical analysis results, as the PPP additive ratio increased, the strength increased, and the most durable membrane in the study was found in the 10% PLA-8% PPP sample. It was observed from the SEM images that as the PPP additive rate increased, a homogeneous morphology was obtained by wrapping around the PLA nanofibers. Consequently, homogeneous fibers have created a tightly packed morphology as well as a more durable membrane structure [14-22]. The tensile strength values of composite membranes are given in Table 3.2.

Table 3.2.: Tensile strength values of composite membranes

Sample Name	Membrane Thickness (mm)	Tensile Strength (MPa)
10% PLA	0.18	12.8
10% PLA-1% PPP	0.19	25.9
10% PLA-5% PPP	0.24	29.5
10% PLA-8% PPP	0.28	38.1

3.3. Biological (Antioxidant) analysis

Total antioxidant capacity analysis was performed according to the CUPRAC (Cupric Reducing Antioxidant Capacity) method. In this method, the results are expressed as trolox equivalence. First, tetrahydrofuran (THF) was added to the nanofiber membranes and PLA was added, then ethanol was added to dissolve PPP. According to the analysis results, PLA does not have antioxidant capacity, so no intervention was made in the analysis. As the rate of PPP additives increased, the antioxidant value of the membranes increased linearly [23-26]. Antioxidant test results of nanofiber membranes are given in Table 3.3.

Table 3.3.: Antioxidant test results of nanofiber membranes

Sample	Abs 1	(-)Kör	Sonuç - Trolox µM	µmol Trolox/ gr
10% PLA-1% PPP	1,079	0,885	170,13	170,0
10% PLA-5% PPP	2,216	2,022	388,81	388,8
10% PLA-8% PPP	2,569	2,376	456,91	456,9

4.Conclusion

Nanofiber formation was observed in all samples. Morphological Analysis was thinner diameter distribution of the nanofibers is analyzed PPP contribution ratio increases. The thinnest nanofiber structure was observed in the 10% PLA-5% PPP sample. Regarding fiber distribution and pore structure, the most ideal structure was determined in 10% PLA-5% PPP composite membrane. According to the mechanical analysis results, PPP homogeneously wrapped around the PLA fibers observed in the SEM images, resulting in a tightly packed material structure. The strongest sample was provided at 5% PPP additive. According to the antioxidant tests performed in biological characterization studies, the presence of antioxidants was not observed in the PLA sample. As well as increased presence of antioxidant PPP contribution rate increases membranes. When the results of the study are examined, the hybrid nanofiber membranes obtained can increase the shelf life of food and exhibit the feature of a new generation food packaging material.

Acknowledgements

We would like to thank the managers and employees of Tekafos Technological Systems Tic. Ltd. Şti. company for their assistance in the morphological imaging of the new generation hybrid nanofiber membranes for food packaging with scanning electron microscopy and FYTRONIX for their contribution to the material supply of nanofiber membranes and the determination of their mechanical properties in production.

References

[1] da Silva Filipini, G., Romani, V. P., & Martins, V. G. (2020). Biodegradable and active-intelligent films based on methylcellulose and jambolão (Syzygium cumini) skins extract for food packaging. *Food Hydrocolloids*, *109*, 106139.

[2] Lukic, I., Vulic, J., & Ivanovic, J. (2020). Antioxidant activity of PLA/PCL films loaded with thymol and/or carvacrol using scCO2 for active food packaging. *Food Packaging and Shelf Life*, *26*, 100578.

[3] Bulus, E., Ismik, D., Mansuroglu, D. S., Sahin, Y. M., & Tosun, G. (2017). Synthesis and characterization of hydroxyapatite powders from eggshell for functional biomedical application. In 2017 Electric Electronics, Computer Science, Biomedical Engineerings' Meeting, EBBT 2017. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/EBBT.2017.7956782

[4] Bulus, E., Ismik, D., Mansuroğlu, D. S., Findikoğlu, M. S., Bozkurt, B., Şahin, Y. M., … Sakarya, G. (2019). Electrohydrodynamic atomization (EHDA) technique for the health sector of polylactic acid (PLA) nanoparticles. In 2019 Scientific Meeting on Electrical-

Electronics and Biomedical Engineering and Computer Science, EBBT 2019. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/EBBT.2019.8742004

[5] Guerrero-Solano, J. A., Jaramillo-Morales, O. A., Jiménez-Cabrera, T., Urrutia-Hernández, T. A., Chehue-Romero, A., Olvera-Hernández, E. G., & Bautista, M. (2020). Punica protopunica Balf., the Forgotten Sister of the Common Pomegranate (Punica granatum L.): Features and Medicinal Properties—A Review. Plants, 9(9), 1214.

[6] El-Hamamsy, S. M. A., & El-khamissi, H. A. Z. (2020). Phytochemicals, Antioxidant Activity and Identification of Phenolic Compounds by HPLC of Pomegranate (Punica granatum L.) Peel Extracts. Journal of Agricultural Chemistry and Biotechnology, 11(4), 79-84.

[7] Syafiq, R., Sapuan, S. M., Zuhri, M. Y. M., Ilyas, R. A., Nazrin, A., Sherwani, S. F. K., & Khalina, A. (2020). Antimicrobial Activities of Starch-Based Biopolymers and Biocomposites Incorporated with Plant Essential Oils: A Review. Polymers, 12(10), 2403.

[8] Khosravi, A., Fereidoon, A., Khorasani, M. M., Naderi, G., Ganjali, M. R., Zarrintaj, P., ... & Gutiérrez, T. J. (2020). Soft and hard sections from cellulose-reinforced poly (lactic acid)-based food packaging films: A critical review. Food Packaging and Shelf Life, 23, 100429.

[9] Tripathi, M., Parthasarathy, S., & Roy, P. K. (2020). Mechanically robust polyurea nanofibers processed through electrospinning technique. Materials Today Communications, 22, 100771.

[10] Ismik, D., Findikoğlu, M. S., Mansuroğlu, D. S., Buluş, E., & Şahin, Y. M. (2019). Synthesis of aloe vera loaded chitosan nanoparticle with ionic gelling method. In 2019 Scientific Meeting on Electrical-Electronics and Biomedical Engineering and Computer Science, EBBT 2019. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/EBBT.2019.8742077

[11] Bulus, E., Mansiroglu, D. S., Ismik, D., Sahin, Y. M., Oktar, F. N., Gunduz, O., & Gokce, H. (2018). Bioceramic synthesis and characterization to be used in major tissue engineering applications. In 2018 Electric Electronics, Computer Science, Biomedical Engineerings' Meeting, EBBT 2018 (pp. 1–4). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/EBBT.2018.8391433

[12] Zhan, F., Yan, X., Li, J., Sheng, F., & Li, B. (2020). Encapsulation of tangeretin in PVA/PAA crosslinking electrospun fibers by emulsion-electrospinning: Morphology characterization, slow-release, and antioxidant activity assessment. Food Chemistry, 337, 127763.

[13] Buluş, E., Buluş, G. S., & Yakuphanoğlu, F. (2020). Production of polylactic acid-activated charcoal nanofiber membranes for COVID-19 pandemic by electrospinning technique and determination of filtration efficiency. *Journal of Materials and Electronic Devices*, *4*(1), 21-26.

[14] Yucel, N., Buluş, E., Bulus, G. S., Khan, A., Xhibo, F., Turan, S., ... & Yakuphanoglu, F. (2020). Synthesis and Characterization of Novel Nanomaterials for SERS Biomedical/Environmental Application. *Journal of Materials and Electronic Devices*, *4*(1), 38-43.

[15] Buluş, E., Bulus, G. S., & Yakuphanoglu, F. (2020). Production and Characterization of Novel Nature-Friendly Organic Fertilizer Covers Based on Nanotechnology for the Agricultural Sector. *JOURNAL OF MATERIALS AND ELECTRONIC DEVICES*, *5*(1), 12-16.

[16] Ismik, D., Mansuroglu, D. S., Buluş, E., & Sahin, Y. M. (2020). The Use of Chitosan Nanoparticles Obtained by Ionic Gelation Method as a Drug Delivery System. *JOURNAL OF MATERIALS AND ELECTRONIC DEVICES*, *5*(1), 6-11.

[17] Buluş, E., Buluş, G. S., Çelik, H., Somunkıran, İ., & Çelik, E. (2020). Sintering Effect on Cutting Tool Material. *JOURNAL OF MATERIALS AND ELECTRONIC DEVICES*, *5*(1), 1-5.

[18] Bulus, E., Bulus, G. S., & Yakuphanoglu, F. (2020). Production and Characterization of Rechargeable Composite Nanofiber Membranes. *JOURNAL OF MATERIALS AND ELECTRONIC DEVICES*, *4*(1), 32-37.

[19] Duymaz, B. T., Erdiler, F. B., Alan, T., Aydogdu, M. O., Inan, A. T., Ekren, N., … Gunduz, O. (2019). 3D bio-printing of levan/polycaprolactone/gelatin blends for bone tissue engineering: Characterization of the cellular behavior. European Polymer Journal, 119, 426–437. https://doi.org/10.1016/j.eurpolymj.2019.08.015

[20] Bulus, E., Sahin, Y. M., Darici, H., & Sener, L. T. Investigation of the Cellular Behavior of Polycaprolactone-Hydroxyapatite Tissue Materials Produced with Bioprinter, International Journal of Scientific and Technological Research, 5(1), 148-161. ISSN (online) 2422-8702,

[21] Buluş, E., Sakarya Buluş, G., & Şahin, Y. M. (2020). Production and Characterization of Nanotechnological Tape for Wounds Caused by Diabetes. JOURNAL OF MATERIALS AND ELECTRONIC DEVICES, 5(1), 20-24.

[22] Buluş, E., & Sakarya Buluş, G. (2020). The Effect of Ozone and Platelet Rich Plasma (PRP) Methods on Hip Prosthesis Healing Process. JOURNAL OF MATERIALS AND ELECTRONIC DEVICES, 5(1), 17-19.

[23] Surendhiran, D., Li, C., Cui, H., & Lin, L. (2020). Fabrication of high stability active nanofibers encapsulated with pomegranate peel extract using chitosan/PEO for meat preservation. *Food Packaging and Shelf Life*, *23*, 100439.

[24] Chen, J., Liao, C., Ouyang, X., Kahramanoğlu, I., Gan, Y., & Li, M. (2020). Antimicrobial Activity of

Pomegranate Peel and Its Applications on Food Preservation. *Journal of Food Quality*, *2020*.

[25] Topuz, F., & Uyar, T. (2020). Antioxidant, antibacterial and antifungal electrospun nanofibers for food packaging applications. *Food Research International*, *130*, 108927.

[26] Valdés García, A., Juárez Serrano, N., Beltrán Sanahuja, A., & Garrigós, M. C. (2020). Novel Antioxidant Packaging Films Based on Poly (ε-Caprolactone) and Almond Skin Extract: Development and Effect on the Oxidative Stability of Fried Almonds. *Antioxidants*, *9*(7), 629.