BAGHDAD JOURNAL OF BIOCHEMISTRY AND APPLIED BIOLOGICAL SCIENCES
2024, VOL. 5, NO. 4, 266 - 274, e-ISSN: 2706-9915, p-ISSN: 2706-9907
https://doi.org/10.47419/bjbabs.v5i04.305

ORIGINAL ARTICLE

Designing a simple electrospinning device to produce nanofibers from polymeric and organic sources

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Electrospinning is one of the important technologies that has contributed a lot to the development of science. Electrospinning usually requires an electrical voltage generator with a value of 10 - 60 kilovolts, and this voltage requires expensive and energy-consuming electrical devices. The raw materials of nanofibers usually use various polymeric materials, but mixing polymeric materials and finding a stable mixture with the desired properties is difficult and requires many experiments and studies. In this research, a safe electrospinning system with capabilities similar to those of a standard electrospinning device applying a mixture of PVP and honey that can be further tested in wound healing was being constructed. Several mixtures were tested to see which one is more approachable and materials to construct the electrospinning device included lithium battery and medical syringe and an energy booster with an aluminum foil and a rubber band to create a steady flowrate of the polymer. The method described achieved a successful formation of nanofibers by electrospinning using honey and PVP 1:1 and PVP 40%, and the designed device is portable and can be installed in any part of the laboratory, whether large or small making nanofibers production more democratized to low-income countries and labs with minimal budgets.

Received 11-05-2024
Revised 21-05-2024
Accepted 30-05-2024
Published 30-12-2024

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DOI https://doi.org/10.47419/bjbabs.v5i04.305

Pages: 266 - 274

Keywords: Nanofibers, Electrospinning, Honey, PVP, Hyaluronic acid, Gelatin, low budget

INTRODUCTION

The production of nanofibers is a scientific manufacturing process that has been continuously developed to produce fibers with a nano-diameter that is many times less than the diameter of a human hair. Electrospinning emerged as a popular method to produce fibers in 1900[1], and since the late 1990s nanofibers have been made from a wide range of materials, researchers used it for various applications in filtration, biosensors, wound dressings, and drug delivery systems.[2 3 4].

The principle of electrospinning is to draw polymeric materials through a small opening. In conjunction with exposure to an electrical charge, it helps to form polymeric fibers with diameters of the order of nanometers on a metal platform.[5 6].

Electrospinning is not applied in low-budget labs because for it usually requires an electrical voltage generator of 10-60 kilovolts, and this voltage requires expensive and energy-consuming electrical devices that cost 10,000$ for the lowest quality devices, in addition to the need for special insulating rooms to obtain the fibers resulting from electrospinning and collect them on a usually metal surface, but finding the right mixture of polymers and setting the parameters of electrospinning is considered difficult[7]. Also, the electrospinning device needs a robotic pusher to determine the flow rate of the polymer, it usually costs 50-60$. These costly devices and basic structures for electrospinning prevent research in the field of nano and microfiber production in underdeveloped countries, and this requires a frugal alternative to benefit from this technologys diverse applications.

MATERIALS AND METHODS

Materials used to construct the electrospinning device included:

- Plastic containers, used for storing the needle and aluminum assembly.
- Medical syringe, used for pumping solutions.
- Rubber, utilized for pushing solutions.
- An aluminum foil is used for spinning nanofibers.
- A lithium battery provides initiative DC power to the generator.
- A high voltage generator (booster), used to produce high voltage for nanofiber production.
- Wood, for insulation.
- Laboratory tubes are used for preparing solutions.
- A vortex shaker for mixing substances.

Figure 1 Shape of the high voltage generator used to produce nanofibers.

The core component in the electrospinning device is the high voltage generator, and these generators differ by continuous working time, ignition distance of the output lines, size, input/output voltage, input and output cable length, working current, and ignition distance, etc. [9] in our case we used a power booster, these boosters are sold as 400 kilovolt high voltage modules but they actually produce between 10 to 50 kilovolts[10]. it consists of several internal parts like the transformer that converts current from low voltage to high voltage, capacitors that store energy, switches that allow current to be controlled, electrical coils that generate magnetic fields, resistors that control the flow of current, and diode switches that direct the flow of current correctly. It is commercially available at low cost, with a simple structure and high efficiency for power transformation. One of its disadvantages is that it needs a break after 30-40 seconds of usage to prevent it from overheating, and the user must be cautious when handling them.

The device is connected as follows:

• The Red line must be connected to the positive to input voltage source, typically a DC power supply or battery. The input voltage range is typically 3.7V-7.4V

• The Green line is connected to the negative pole of the battery.

• The Output golden color lines (HV+ HV are the output of high voltage output terminal[11].

Solution preparation

Several solutions and mixtures were tested, and they include:

• PVP and water: Dry PVP was dissolved in water to create 40% concentration (w/v), then mixed using a vortex until the mixture was homogenized with a viscous texture.

• Honey and PVP: Dry PVP was dissolved in water to create 40% concentration, as the previous solution, Then pure honey was combined with of the PVP solution (1:1 ratio) and mixed with a spoon several times along with microwaving the mixture for approximately 2 minutes to make the solution homogeneous.

• HA (Hyaluronic acid) and PVA mix: A 1.4% concentration of PVA was prepared in the same manner as previously mentioned and 1.5% concentration in water solution (w/v) of HA were used, with a ratio of 75% PVA to 25% HA. The mixture was mixed using a vortex and it didnt give a viscous texture.

• Honey and gelatin solution: 0.8 grams of animal gelatin was dissolved in 50 ml of hot water and stirred at 70 degrees Celsius to create a 1.6% gelatin solution. Afterward, the gelatin-water mixture was combined with of pure honey (2:3) respectively, then microwaved and mixed with mini spoon to homogenize for 2 minutes. Vortexing created bubbles when honey was used, so spoon stirring was found better.

• HA and gelatin solution: The gelatin solution was prepared the same as previous way 1.6%. Next, the gelatin-water mixture was mixed with of hyaluronic acid (2:3) respectively.

Method

The pre-equipped solution was inserted into a medical needle (syringe) and the device was installed as follows:

a. The aluminum foil was fastened onto a circular ring with two plastic containers as a collecting surface[12].

The syringe was placed on another plastic container, positioned towards the Aluminum foil

c. The distance between the compound and the needle was adjusted to be no more than 5cm.

d. One output pole from the converter was connected to the needle, and the other pole to the aluminum foil.

The high voltage generator was connected to a lithium battery 3 7V and turned on

f. The needle was ejected automatically by a rubber band installed on the pusher; it was calibrated to pump water before 0.1 ml a second which gave a continuous and controlled flowrate.

g. The needle was pumped with the rubber in for around 30 seconds while the power supply booster was connected. Followed by a 2-5 minutes break to prevent the booster from overheating.

h. Once a sufficient amount of nanofibers membrane was collected, it was examined under a light microscope.

Room temperature was maintained at 20 degrees Celsius, with humidity levels between 30-50%[13] and a visual representation of the device is displayed in figure 2.

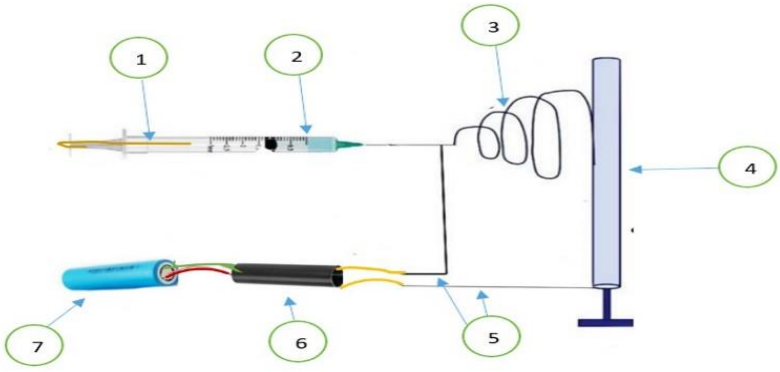

Figure 2 A general diagram of the installed electrospinning device, which includes the following parts; 1- a rubber band to adjust the flow rate of the mixture from the syringe 2- The mixture consisting of honey and polyvinylpyrrolidone. 3-The nanofibers that are spun at a distance of 5 cm between the syringe head and the aluminum foil. 4- The aluminum foil where the nanofibers are collected. 5- The wires connected between the enhanced power unit and the tip of the syringe needle and the aluminum foil 6- The power booster unit. 7- A lithium battery is connected with its positive pole to the positive pole of the power unit and its negative pole to the negative pole of the power unit.

RESULTS AND DISCUSSION

One of the best results we obtained was from the PVP 40% mixture with water, its viscous consistency aided obtaining consistent microfibers and then later enhanced to produce nanofibers. The polarity of the mixture also played an important role in the success of the experiment, as was the case for the honey and PVP mixture which gave similar results3was considered a promising result.

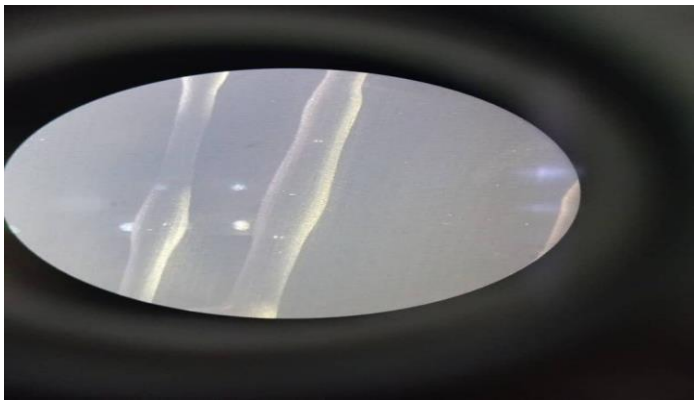

Figure 3 HA/PVA and water solution microfibers, x60 magnification.

Despite the gelatin having a viscous property, its extension and mixing with hyaluronic or honey reduced its viscosity, resulting in a liquid consistency, and therefore the experiment was not successful. From results it is shown that the more viscous the consistency and the higher the charges of the mixture, the greater the chance of obtaining nanofibers in larger quantities

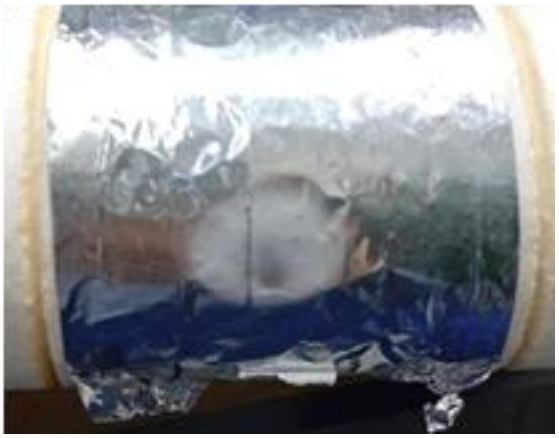

Figure 4 The white spot on the aluminum foil is nanofibers accumulating from PVP/Honey mixture 1:1.

[14]. The successful PVP/honey mixture was placed 5 cm away from the aluminum collector as well as other mixtures as shown in figure 4, results are summarized in Table 1, where a schematic view for several mixtures used to produce nanofibers, and it compares many parameters to show what mixture gave the best results and the possible applications of the produced nanofibers.

Table -1 Experiment Results of several mixtures

Solution	Cost	Diameter	Required time	Applications	Result
PVP and water	affordable	~Nm	5 min	the development of hydrogels, wound dressings, nanofibers/scaffolds, drug, and gene delivery systems. [15]	The fibers that were created were of high quality, however, in order to utilize them effectively in wound healing, the addition of an antibiotic is necessary.
PVP solution and Honey	affordable	~Nm	15 min	They absorb exudates and retain moisture in the wound bed. Due to the honey's low toxicity. the more honey you use, the more benefits you get.[16]	The fibers were at their peak quality and the honey was included to serve as a powerful antibiotic.
HA and gelatin solution	affordable	~um	20 min	HA helps cell migration and cell proliferation and keeps the skin moist Therefore, HA with gelatin may be advantageous to prepare scaffolds that can mimic the ECM in terms of topography and chemical composition because of the inherent properties of gelatin and the unique characteristics of the electrospun fibers. [17]	N/A
HA and PVA	affordable	~um	5 min	The physical and chemical crosslinks in the combination of these two polymers yield excellent biomaterial systems that have their applications in various engineered materials. [18]	Microfibers were formed instead of nanofibers. therefore, it's not applicable, but remain a promising result
Honey and gelatin solution	affordable	~um	25 min	This mix could be used for drug delivery, and to create advanced scaffolds in regenerative medicine. [19]	N/A

In order to test the results further we compared a nanofibers sample of PVP and honey to the diameter of a human hair, because an electron microscope is not available in our lab, and the results are shown in figure 5, where the complex of nanofibers accumulation is immensely smaller that the human hair that has an approximate diameter of 50 micrometer [20].

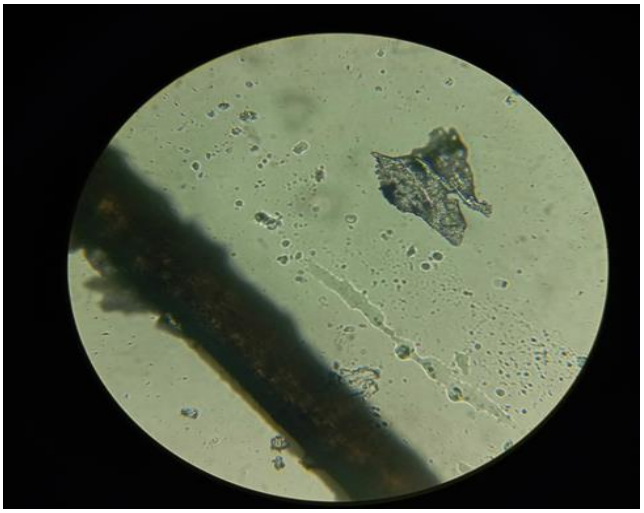

Figure 5 60x magnification of a human hair compared to the sample of nanofibers (PVP/Honey) shows a substantial difference in size, knowing that the sample consisted of several lines that was more viewable while changing the microscope control wheel.

CONCLUSIONS

The results that immerged showed that it is possible to manufacture nanofibers at a small cost not exceeding $10 and with materials that are highly available in laboratories, which opens the way for the application of this technology in many laboratories with a limited budget that wants to develop their nanoscale field, but further studies and enhancements are required.

Abbreviations

- PVP: Polyvinylpyrrolidone
- HA: Hyaluronic acid
- N/A: Not Applicable

DECLARATIONS

1. Authors' contributions

Contributor Role	Degree of Contribution		
	Lead	Equal	Supporting
Conceptualization		K.S. J.S	
Data curation		K.S,J.S	
Formal analysis		K.S, J.S	
Funding acquisition		K.S, J.S	
Investigation		K.S, J.S, A.S, N.Z.K, A.K	
Methodology		K.S, J.S, A.S, N.Z.K, A.K	
Project administration		K.S, J.S, A.S, N.Z.K, A.K	
Resources		K.S, J.S, A.S, N.Z.K, A.K	
Software		K.S, J.S, A.S, N.Z.K, A.K	
Supervision		K.S, J.S	
Validation		K.S, J.S	
Visualization		K.S, J.S	
Writing-original draft		K.S, J.S, A.S, N.Z.K, A.K	
Writing-review & editing	K.S	J.S	A.S, N.Z.K, A.K

2. Conflict of interest

The authors declare no conflict of interest

3 .Ethical approvals (institutional ethical approvals and informed consent)
This research does not conflict with our university's ethical standards, nor with any known ethical criteria.

4. Funding resources

This research is self-funded.

REFERENCES

1. Keirouz A, Wang Z, Reddy VS, Nagy ZK, Vass P, Buzgo M, et al. The history of electrospinning: Past, present, and future developments. Advanced Materials Technologies. 2023;8(11):2201723–2201723. doi.org/10.1002/admt.202201723.
2. Ramakrishna S, Fujihara K, Teo WE, Yong T, Ma Z, Ramaseshan R. Electrospun nanofibers: solving global issues. Materials Today. 2006;9:40–50. doi.org/10.1016/S1369-7021(06)71389-X.
3. Liu H, Zhu Y, Zhang C, Zhou Y, Yu DG. Electrospun nanofiber as building blocks for high-performance air filter: A review. Nano Today. 2024;55:102161–102161. doi.org/10.1016/j.nantod.2024.102161.
4. Zhang Z, Liu H, Yu DG, Bligh SW. Alginate-Based Electrospun Nanofibers and the Enabled Drug Controlled Release Profiles: A Review. Biomolecules. Jul. 2024;3(7):789–789. doi.org/10.3390/biom14070789.
5. Xue J, Wu T, Dai Y, Xia Y. Electrospinning and electrospun nanofibers: Methods, materials, and applications. Chemical reviews. ACS Publications Most Trusted Most Cited Most Read. 2019;119:5298–415. doi.org/10.1021/acs.chemrev.8b00593.
6. Dadol GC, Kilic A, Tijing LD, Lim KJ, Cabatingan LK, Tan NP, et al. Solution blow spinning (SBS) and SBS-spun nanofibers: Materials, methods, and applications. Materials Today Communications. 2020;25:101656–101656. doi.org/10.1016/j.mtcomm.2020.101656.
7. Nosrati H, Khouy A, Nosrati R, Khodaei A, Banitalebi-Dehkordi M, Ashrafi-Dehkordi M, et al. Nanocomposite scaffolds for accelerating chronic wound healing by enhancing angiogenesis. Journal of Nanobiotechnology. 2021;19:1–21. doi.org/10.1186/s12951-020-00755-7.
8. Barraza RDV, Álvarez Suarez, Gómez ASV, J L, González P, Iglesias JA, et al. Design- ing a low-cost electrospinning device for practical learning in a bioengineering biomaterials course. . Revista mexicana de ingeniería biomédica. 2016;37:7–16. doi.org/10.17488/RMIB.37.1.1.
9. Bozhenkov S, Starikovskaia S, Sechenov V, Starikovskii A, Zhukov V. Combustible mixtures ignition in a wide pressure range. Nanosecond high-voltage dis- charge ignition. In41st Aerospace Sciences Meeting and Exhibit. 2003;p. 876–876. doi.org/10.2514/6.2003-876.
10. Ji D, Lin Y, Guo X, Ramasubramanian B, Wang R, Radacsi N, et al. Electrospinning of nanofibres. Nature Reviews Methods Primers. 2024;4(1):1–1. doi.org/10.1038/s43586-023-00278-z.
11. Shen CL, Liang TC. Design and Implementation of a High-Voltage Generator with Output Voltage Control for Vehicle ER Shock-Absorber Applications. Mathematical Problems in Engineering. 2013;2013(1):324590–324590. doi.org/10.1155/2013/324590.

12. Duizer LM, Robertson T, Han J. Requirements for packaging from an ageing consumers perspective. Packaging Technology and Science. An International Journal. 2009;22(4):187–97. doi.org/10.1002/pts.834.
13. Long YZ, Yan X, Wang XX, Zhang J, Yu M. Electrospinning: the setup and procedure. InElectrospinning. Nanofabrication and applications. 2019;p. 21–52. doi.org/10.1016/B978-0-323-51270-1.00002-9.
14. Abdulkadhim MK, Habeeb SA. The possibility of producing uniform nanofibers from blends of natural biopolymers. Materials Performance and Characterization. 2022;11:313–336. doi.org/10.1520/MPC20220045.
15. Kurakula M, Rao GK. Moving polyvinyl pyrrolidone electrospun nanofibers and bio-printed scaffolds toward multidisciplinary biomedical applications. European Polymer Journal. 2020;136:109919–109919. doi.org/10.1016/j.eurpolymj.2020.109919.
16. Kassem LM, El-Deen AG, Zaki AH, El-Dek SI. Electrospun manuka honey@ PVP nanofibers enclosing chitosan-titanate for highly effective wound healing. Cellulose. 2023;30(10):6487–505. doi.org/10.1007/s10570-023-05267-9.
17. Li T, Sun M, Wu S. State-of-the-art review of electrospun gelatin-based nanofiber dressings for wound healing applications. Nanomaterials. 2022;12(5):784–784. doi.org/10.3390/nano12050784.
18. Kodavaty J. Poly (vinyl alcohol) and hyaluronic acid hydrogels as potential biomaterial systems comprehensive review. Journal of Drug Delivery Science and Technology. 2022;71:103298–103298. doi.org/10.1016/j.jddst.2022.103298.
19. Mieles Y, Vyas J, Aslan C, Humphreys E, Diver G, Bartolo C, et al. Honey: An advanced antimicrobial and wound-healing biomaterial for tissue engineering applications. Pharmaceutics. 2022;14(8):1663–1663. 10.3390/pharmaceutics14081663.
20. Dichtel CR, Dichtel JR, Dichtel WR. Experimental measurement of the diameter of a human hair via two-color light diffraction. Psychiatry. 2023;3(3):267–70. doi.org/10.1080/00332747.2020.1768008.