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Review Article

Electrospinning of Crude Plant Extracts for Antibacterial and Wound Healing Applications: A Review

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Abstract

A great progress has been made, since 2000, in the field of electrospinning (ES). ES has been turned out to be the most reliable, simple and cheap technique for the fabrication of nanofibers. The other aspect, associated with ES, is control over certain characteristic features of the nanofibers during the fabrication of nanofibers. Thousands of research studies have been conducted by using both natural and synthetic polymers. ES provides wide options for loading bioactive compounds into the polymers. Plant extracts are reservoir of such bioactive compounds with potential biomedical applications. This review is aimed to provide a brief overview of some recent research work in which plant crude extracts have been loaded with other natural or synthetic polymers for antibacterial and wound healing applications.

Introduction

Electrospinning has been remained the most preferable and attractive method to build nanofibers by using variety of polymeric material [1]. Electrospinning provides various advantages over the other fabricating methods, for nanofibers, in terms of both material selection and control over the process. It is considered more versatile and flexible in its operation [2,3]. Electrospinning results the ultra-fine fibers with desirable characteristics like large surface area to volume ratio, porosity and other surface functionalization. These make the electrospun material as desirable structure to be used in various biomedical applications including wound dressings [4,5], formulation of scaffold for tissue culturing [6-8] and drug delivery [9-11].

Electrospinning provides an option to spin both natural and synthetic polymers. However, many of health concerns are found to be associated with synthetic polymers in recent years. This has dragged the attention of researchers toward using natural compounds especially plant extracts in fabrication of fibers [12]. Treating patients with herbal remedies has been remained an old practice due to extraordinary influence posed by plants in various diseases. A significant percentage of drugs are supposed to be derived from various plants types [13]. Plants offer many potential attributes which make them a suitable source of material for nanofiber fabrication. Many of the phytochemicals have been reported for antimicrobial activities [14,15]. Phytochemical like phenolics, terpenoids and alkaloids are found associated with antimicrobial activity [16]. Encapsulation of plant material, through electrospinning, can accelerate their remedial potential to many folds. This process maximizes the therapeutic potential by improving bioavailability and maintains a steady concentration of drug to the target area [17,18].

Multiple advantages, associated with using plant material and potential of electrospinning to process them for biomedical applications, has led to an increased focus on research in last ten years. However, still publication coming in this area is low as compared to over all publications coming in the field of electrospinning. The major aim of the review is to compile a comprehensive note on use of crude plant extracts for antibacterial and wound healing applications through electrospinning, major developments till now and future prospects of this particular area.

Electrospinning Process

Electrospinning (ES) can be considered as a simple method to prepare nanofibers of various size ranges which are difficult to produce through other standard fabricating techniques. Electrospinning is a promising technique to spin variety of material including natural, synthetic, polymer blends and other composite material. The resultant structure possesses more surface area to volume ratio with wide range of potential applications [19-21]. Due to its potential of spinning natural and biodegradable material, ES has been remained a method of choice for the preparation of material being used in tissue engineering and drug delivery applications.

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The process of ES completes through a very simple working principle which is not only simple but cost effective too. The apparatus include syringe with a nozzle, a power supply system and a collector which is usually a metal plate or rotating mandrel. The process is carried out in room temperature with both horizontal and vertical setups as shown in Figure 1.

Although process seems to be based on very simple principle, however, there are various parameters which affect the characteristics of the products including density, alignment, porosity and mechanical strength etc. The common parameters, found to be associated with the characteristics features of the nanofibers, include solution concentration [23,24], voltage [25], tip to collector distance [26,27], collector composition and geometry, molecular weight and viscosity of the polymer solution [22]. The factors like temperature, humidity and air flow have also to play their significant role in determining the morphology of the resultant structure. One can optimize these parameters to get fibers with desirable features for variety of applications.

ES is flexible enough to spin various kinds of material including plant extracts either separately or blending it with other synthetic and natural polymers. Many of studies have been reported in which crude plant extracts, essential oils and single bioactive isolated compounds were electrospun for various biomedical and industrial applications. In upcoming section, those studies will be summarized in which crude plant extracts were electrospun with various polymer structures to achieve potential applications like antimicrobic and wound healing.

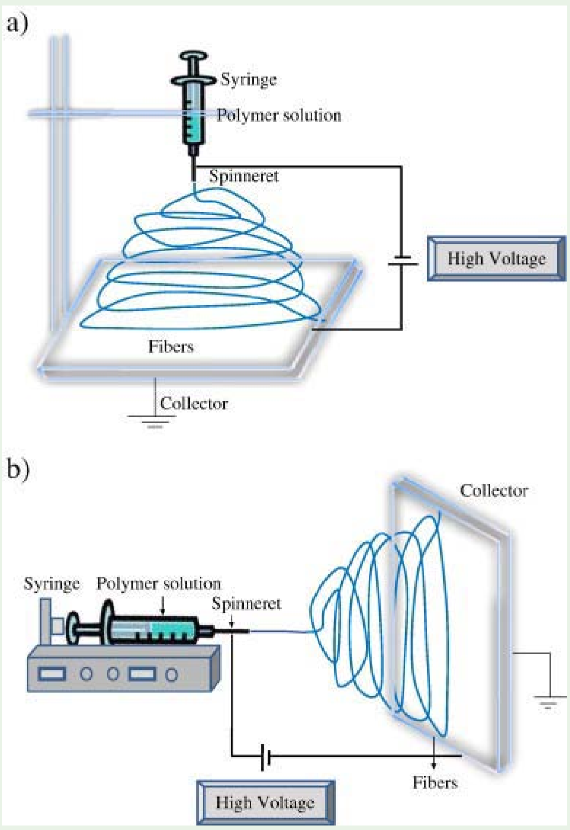

Figure 1: Setup of (a) vertical; (b) horizontal electrospinning apparatus [22].

Electrospun Plant Extracts for Antibacterial and Wound Healing Applications

Tridax procumbens

Many of plant extracts blended with either natural or synthetic polymers have been electrospun and used in various biomedical applications so for [28-35]. *Tridax procumbentsis* one of those plants which have been successfully electrospun to prepare nanofibrous mat by Ganesan P and Paradeepa P (2017) blended with Poly vinyl alcohol (PVA). Physical characters like porosity, density and thickness of the mat were analysed. The result showed that they could achieve the maximum pore size upto 2.26μm, a density of 1.37 g/cc for PVA/TP nanofibrous mat and thickness upto 0.03mm. SEM results indicated a uniform and smooth surface nanofibrous mat with diameter ranging from 108-519 nm. They also tested the nanofibrous mat for antimicrobial activity for both Gram positive and Gram negative bacteria. A 45mm zone of inhibition was achieved for Gram positive (*Staphylococcus aureus*) and 36mm against Gram negative (*Escherichia coli*).These results indicate that the natural potential of plants can be successfully transferred to a structure which can be used for medical applications [36].

Urtica dioica

The antimicrobial potential of plants can also be used in food technology to enhance the shelf life and preserve the quality of the food. In a study conducted by Esan AE et al., a bioactive coating was prepared with the help of nanofibers in which extract of *U. dioica* was blended with PCL. The coating not only showed antimicrobial activity but also antioxidant activity. These two potentials helped to increase the shelf life of the fresh fish fillet. As for the characterization of the nanofiber is concerned, a bead-less ultrathin fibers, having mean diameters of 575 ± 130 nm, were produced. The incorporation of plant extract did not affect the morphology of the fibers compared to fibers produced from PCL only. This indicates a healthy sign for future use of plant extracts [37].

Eucalyptus citriodora

Another antimicrobial activity was tested by Mariana DA et al. by using eucalyptus essential oil (EEO) and β-cyclodextrin (β-CD). They used three concentrations (20, 30 and 40%) of solutions and noted the morphological changes as a result. On 30% zein solution, they got the nanofiber of homogenous morphology without beads which indicates that solution concentration has a significant role in determining the morphology of the electrospun fibers.

The electrospun fiber, containing IC (Inclusion complex)-β-CD/EEO complex, was examined for its antimicrobial activity. At 24% IC - β-CD/EEO loading, 24.3% reduction was noted against *S. aureus* and for *L. monocytogenes*, a reduction was noted upto 28.5%. By increasing the concentration of IC - β-CD/EEO, the inhibition rate increased as compared to zeinfiber without antimicrobial activity. However, nanofibers did not show any significant impact when tested for gram negative bacteria including *S. typhimurium* and *E. coli*. The resultant material is suitable for food packing materials [38].

Chamomilla recutita

The natural wound healing ability of chamomile was explored, through electrospinning, by Behrooz Motealleh et al. (2013). In this study, chamomile extract was loaded into PCL/PS through D- optimal design approach. The prepared material was evaluated for its antimicrobial activity, drug release profile, cell culture and in vivo impact. An average diameter of 175 nm was obtained after incorporating 15% chamomile extract. A gradual drug release was achieved for the material PCL/PS throughout the release time which maintained a steady concentration of about 70% drug on wound area which is a positive sign for wound healing.

Antibacterial and antifungal test revealed an inhibition zone of about 7.6mm against *S. aureus* and Candida albican. The rat wound model examination indicated that almost complete wound closure was achieved on 14th day of treatment. 15% extract loaded sample of PCL/PS also found to be nontoxic [39].

These result indicated selection of suitable polymer and optimization of proper concentration of plant extract can produce desirable results biomaterial applications.

Stryphodedron barbatimao

Electrospinning not only provides an option to incorporate the plant extracts through blending or encapsulating but also a composite material can be prepared. A study was conducted by Ligia MMC et al. in which they prepared a bionanocomposite by using PVA/ pineapple nanofibers/ *S. barbatimao* bark extract. After successful preparation, material was characterized for surface morphology and thermal stability. A significant morphological change was observed in bionanocomposites compared to PVA nanofibers mat as illustrated in Figure 2. Similarly, melting behaviour and thermal properties of the PVA are also affected by *S. barbatimao* bark extract [40].

Plants have been used as remedy for wound healing and skin regeneration for centuries. Plant extract contain some bioactive compounds which are potential wound healers or promote cell growth. Electrospinning is a promising technique through which we can transfer the wound healing potential of specific plant extracts into wound dressings and nanofibers mats. In the upcoming section, emphasis will be towards those studies which have been carried out in this particular area.

Lawsonia inermis

An electrospun nanofibers mat was fabricated by Iman Y et al. by using leaf extract of *L. inermis* (Henna), chitosan and polyethylene oxide (PEO) polymers. SEM characterization confirmed a smooth and ultrafine nanofiberous structure. Addition of leaf extract did not affect the morphology of the blended nanofibers mat (CS and PEO) negatively which indicates the successful incorporation of plant extract through ES. It was noted that, by increasing the concentration of extract, the diameter can be reduced. This is beneficial because low diameter will provide more surface volume. Similar behaviour was also observed in case of porosity. Nanofiber mat showed a slight increase in swelling rate which is beneficial for medical applications. However, a slight increase in rate of loss of mat was seen in case of leaf extract which can be attributed to high porosity and less diameter associated with leaf extract. A decline in tensile strength, however, has been observed as shown in Figure 3. But still the strength remained within required range for dermal tissue regeneration.

Since antimicrobial potential of the scaffold is a vital requirement for wound healing, incorporation of leaf extract can increase the antimicrobial activity which can also be seen in this study. Henna leaf extract, when added with CS/PEO nanofibers mat, showed synergistic antimicrobial effect with chitosan. The result also indicated that mat became effective against gram positive bacterium, *S. aureus* which shows resistance to chitosan because of thick cell wall.

A similar healthy correlation was also seen between leaf extract and cell proliferation and adhesion. This increase can be attributed to additional higher surface area provided due to addition of leaf extract which reduced the fiber diameter.

An in vivo study indicated that leaf extract, in nanofibers form, showed more wound healing potential than henna ointment. It means that polymers have potential to release bioactive compound in steady rate to target area [41].

Juniperus chinensis

A nanocomposite was fabricated by Jeong H K et al. by using the extract of *J. chinesis* and PVA. The loading of extract was

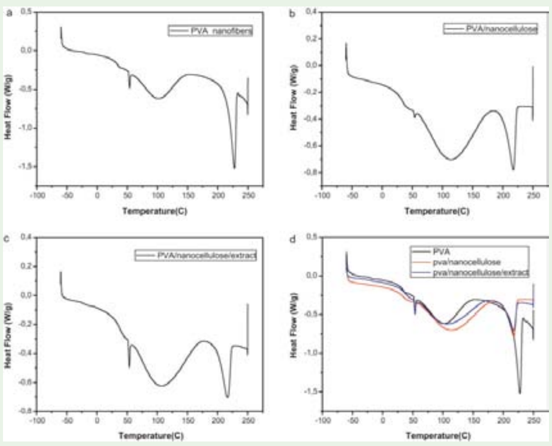

Figure 2: DSC curves during heating systems; (a) PVA nanofibers; (b) PVA/ Stryphnodendronadstringens bark extract; (c) PVA/pineapple nanofibers/ Stryphnodendron adstringens bark extract; (d) All systems plotted [40].

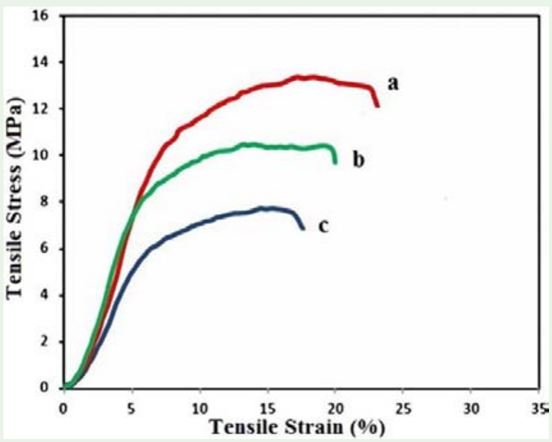

Figure 3: Tensile stress–strain curves of (a) Chitosan, (b) Chitosan with 1% henna extract(c) and Chitosan with 2% henna extract nanofibrous scaffolds at dry condition [41].

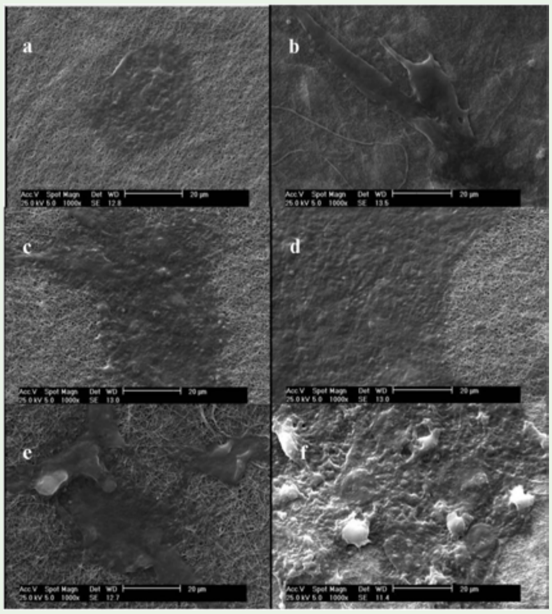

Figure 4: Themorphology of co-cultured H-keratino/MSC on nylon and N-B.VNFM. Morphology of H-keratino/MSC at day 1 on nylon and N-B.VNFM (a, b). Morphology of H-keratino/MSC at day 14 on nylon and N-B.V NFM (c, d) and morphology of H-keratino/MSC at day 21 on nylon and N-B.V NFM (e, f) [44].

confirmed by XRD. SEM results indicated the randomly oriented, bead free and smooth surface morphology of the resultant fibers. However, an increase in fibers diameters was observed with increase in concentration of the extract which was attributed to increase in viscosity. The result showed the effect of plant extract on fibers diameters.

A disk diffusion test was carried out to observe the antibacterial activity of the nanocomposite fiber. Two bacterial strains; *S. aureus* and *Klebsiella pneumonia* were tested for the purpose. The result indicated the antimicrobial activity of fibers, with plant extract, was much higher than PVA pure nanofiber which showed no antibacterial activity. This can be attributed to specific bioactive compounds present in extract. Antimicrobial activity plays much role in wound healing, so resultant composite fiber can be used as wound dressing [42] (Figure 4).

Annona muricata

Another successful fabrication of antibacterial potential of A. muricatawas carried out by Neni M A et al. in which they prepared a fiber material by using leave extract and PVA polymer. Ultrafine fibers with diameter 137,132 and 121 nm were obtained when concentration of SLE was kept 8, 12 and 14 (w/w) respectively. This change was attributed to low concentration of PVA with increase in concentration of SLE [43].

The antibacterial activity was observed against *S. aureus* through zone of inhibition. It was observed that increase in concentration of SLE increased the antibacterial activity as shown in Table 1.

Table 1: Diameters of zone of Inhibition (ZoI) for PVA/SLE composite nanofibers for different concentrations of SLE (8-14%) and SLE solutions [43].

Concentration of PVA/SLE composite nanofibers (%)	ZoI Diameter (mm)
8	1
12	2
14	4
SLE solution	6

Beta vulgaris

Fortunately, ES provides an option to incorporate variety of materials into polymers for the fabrication of nanofibers. Cells cultures can also be successfully loaded into scaffold structure which greatly enhances the regeneration activity. A similar task was achieved by Simzar H et al. in which they successfully fabricated composite scaffold by using herbal extract of *B. vulgaris* and co culture of mesenchymal stem-cells (MSC) and human keratinocyte (h-Keratino). SEM images confirmed a uniformed, bead free and porous structure with high rate of porosity. Addition of *B. vulgaris* has slightly affected the diameter of the fiber. Fig 4 indicates the higher cell proliferation of co cultured on nylon-*B. vulgaris* nanofibrous membrane (N-B.V NFM) compared to N NFM making NFM with *B. vulgaris* extract a suitable candidate for wound dressing. This increase in cell viability and cell proliferation can be attributed to the increase in hydrophilicity associated with compounds present in plant extracts. As plant contain natural material which is considered more biocompatible, in most of the cases, compared to synthetic once. MTT assay also confirmed the biocompatibility in the case of aforementioned experiment. PCR and immune-cytochemical imaging also confirmed cell differentiation, on B.V NFM, monitored through gene expression and specific markers like cytokeratin 14 and lorocrin. This result supports the idea that using plant extracts, along with suitable polymer, can significantly enhance the applications of the resultant material without negatively affecting the morphology of the fibers [44] (Table 2).

Curcuma longa

Curcumin has been used as antibacterial and natural wound healer for centuries. However, poor bio availability and stability of curcumin is a major issue while dealing with wounds. ES provides an option for stability of curcumin and its release in controlled rate through blending it with some suitable polymer and converting this potential biologically active compound into a scaffold structure. A successful incorporation of curcumin into a blend of poly lactic acid (PLA) and hyperbranched polyglycerol (HPG) was carried out by Govindraj P et al. This is another successful story of plant extract incorporation into a scaffold structure without losing the mechanical properties of the polymer.

Concentration of curcumin was optimized upto 10% to get smooth and bead free fibers. Concentration of curcumin showed the

Table 2: Animal tests results.

Sample	Healing percentage			
	Day 3	Day 7	Day 11	Day 16
GT extract	27.79	55.58	86.51	93.34
Blank	10.45	45.91	81.87	90.42
Chitosan	28.48	59.19	89.11	94.21
Chitosan/PEO/GT nanofiber	31.48	62.33	91.49	99.00

effect on diameter of the fiber. HPG was stood out to be an important factor who determines the successful incorporation of curcumin by keeping the structure smooth, aligned and bead free. The presence of HPG also enhances the swelling rate, an important feature required for tissue engineering, by making structure more hydrophilic. This higher swelling feature also enhanced the release profile of the curcumin, an important application of a nanofibrous scaffold. As for as the tissue engineering parameters like cell adhesion, cell proliferation and cell viability is concerned, the blended structure PLA/HPG/Cur fiber provide a suitable profile for these features [45].

Aloe vera

Aloe vera is another promising plant offering variety of medical applications being used for centuries. The natural wound healing property of *A. vera* can not only be preserved but accelerated by incorporating it into a scaffold structure with some suitable polymers. A similar effort was done by Itxaso C-A et al. in which they blended AV extract with PLGA and recombinant human epidermal growth factor (rhEGF)to synergize the effect of rhEGF and AV extract. Former is a growth mediator in tissue engineering and later is found associated with stimulation of cell proliferation and activity of fibroblast.

SEM characterization indicated both uniform and randomly oriented nanofiber with high degree of porosity ranging above 79%. The diameter of the fibers remained low upto 356.03±112.05 nm in the PLGA/rhEGF/AV compared to other two fibers consisting of PLGA and PLGA/AV.

Zone of inhibition test was applied to assess the antibacterial efficacy of AV. The result indicated a remarkable inhibition for the case of PLGA/AV compared to almost no inhibition in case of PLGA alone. A significant increase was also observed in cell proliferation when cells were treated with PLGA/AV/rhEGF compared to control.

An in vivo study was carried out to assess the wound healing potential of the PLGA/AV/rhEGF compared to other combinations of material. By calculating the wound area reduction and histological analysis of the wound, it was established that AV bended with PLGA and rhEGF showed remarkable progression in terms of wound healing and reepithelization. These results again confirmed that ES not only preserve the natural potential of the biological material but also increase the efficiency by controlling the release profile and bio availability of the active compound present [46].

Centella asiatica

As mentioned earlier that ES fiberous structure has many advantages. Among them is the controlled and continuous release of drug to infected area. This property is essential for any scaffold to be the candidate of wound dressing. Another fiber mat was fabricated by Orawan S et al. (2008) by using cellulose acetate (CA) and pure substance (PAC) or crude extract of *C. asiatica* (CACE) .SEM images indicated a smooth fabrication of fiber mat with diameter upto 301±64 nm for neat CA fiber and 545±96 nm for CACE. This shows that plant extract have some effects on diameter of the fiber. However, surface remained smooth in all the cases indicating the successful loading of plant extract during ES.

The release profile of asiaticoside (AC) was investigated through total immersion and the transdermal diffusion method. Two releasing medium, A/B/M and P/B/M, were used for 32° C and 37° C respectively. The result indicated a release of AC upto ~24 and ~10% in A/B/M medium and to ~26 and ~12%in P/B/M medium. However, a significant decrease in release profile have been noted when mat was placed on top of the piece of pigskin. The result also indicates that the concentration needs to be optimized to avoid cytotoxicity extended by CACE to human dermal fibroblasts due to the presence of triterpenoid compounds. It can be concluded that, suitable release profile and water retention ability, are the two desirable features presented by the above mentioned fibers mat [47].

Grapes

Grape seed extract (GSE) was successfully loaded into SF/ polyethylene oxide (PEO) by Si lin and co-workers (2016) through electrospinning process. The fabricated material was undergone through SEM characterization, drug release profile, cell viability, anti-oxidation activity etc. Their result revealed no significant morphological change in fiber structure after loading GSE in various concentrations. The fiber diameter remained around 420nm for various concentarions. Cytocompatibility of the nanofibrous mat was assessed in vitro through SEM and MTT assay. The result indicated a healthy proliferation of the cells on mat which improves more with the increasing concentration of the GSE. However, 3% GSE loaded mat was found to be optimum in this regard. The mechanism through which grape seed extract acts as potential wound healer is its antioxidant activity. The result revealed the significant survival rate of the cells treated with t-BHP and this rate was also concentration dependent and the optimum concentration of GSE remained in between 3 to 5% in this context [48].

Camellia sinensis

Another plant extract which has been electrospun is green tea plant which is famous for its antibacterial, antioxidant and anti-inflammatory activities. The natural potential of this plant was successfully incorporated into Chitosan/polyethylene oxide to make a antibacterial wound dressing. Material was morphologically characterized through SEM and further analysed for drug release profile, anti bacterial activity and also undergone through animal model tests. SEM images revealed that both diameter and beading is associated with the concentration of the extract. The diameter of 86.18 nm, with few beads, was achieved by chitosan/PEO/GT (2%) concentration. UV-Vis spectrometry was used to study the release profile of extract from composite fiber. The result revealed a moderate and steady release of drug during 13th day of study. Chitosan/PEO/ GT was also tested for its antibacterial activity against Gram-positive bacteria and Gram-negative bacteria and zone of inhibition remained 6 and 4 mm respectively for both strains. The animal test results are shown in table 2 [49].

Garcinia mangostana Linn

An antibacterial wound dressing was prepared by OrawanSuwantong and co-worker in which they had used the extracts of *G. mangostanalinn* [i.e., dichloromethane extract (dGM) and acetone extract (aGM)] and PLLA. The material was analysed for its morphology, antimicrobial activity, drug release and cytotoxicity. A smooth fiber structure with a diameter range of 0.77 and 1.14 μm was achieved. The drug release results indicated a correlation between drug amount and release profile. 50% loaded dGM and aGM release concentration was found higher than 30% loaded dGM and aGM. In comparing the release profile of aGM and dGM, aGM showed higher release profile in both A/T/M and S/T/M mediums. Furthermore, all the GM release profile of S/T/M medium was found higher than A/T/M medium. Moreover, both the extracts showed significant antibacterial activity for various strains of bacteria. However, no zone f inhibition could achieve by 30 % aGM-loaded PLLA fiber mats against *E. coli*. The concentration of 10 mg mL-1 for 50% and 30% dGM loaded PLLA was found toxic for human dermal fibroblasts whereas rest of all concentrations of the two extracts were not found toxic to the cells that proves the antibacterial wound dressing ability of the material [50].

Grewia mollis juss

Methanolic extract of *Grewia mollis Juss* (mGM) was electrospun with poly (D,L-lactide-co-glycolide) (PLGA) by Hanan M and co-workers. SEM and FE-SEM were used to characterize material for its morphological properties. The material was also undergone through antibacterial tests. SEM result revealed a homogenous distribution of extract over polymer surface which appeared smooth. A diameter range of 1.27-2.03 μm was achieved after extract incorporation compared to 0.65-1.0μm without mGMextarcr. EDX spectra confirmed the successful blending of extract into PLGA. To determine the antibacterial activity, growth curve was assessed under various concentration of (0, 6.2, 12.4, 25, 50, and 100μg/mL) mGM. Both *E. coli* cells and *S. aureus* were lagged to 3-4 h, respectively under various concentrations. It was also observed that increase in concentration further delayed lag phase. MIC found for the bacterial strain was 12.5 μg/mL whereas 100 μg/mL was found to be more toxic. After incorporation into PLGA, the fibrous mat containing mGM showed significant inhibition indicating that structure is promising for antibacterial wound dressing [51].

Calendula officinalis

The extract of *calendula officinalis*, as natural wound healing and anti-inflammatory agent, was successfully blended with hyperbranched polyglycerol (HPGL) to produce elctrospun nanofibrous structure as active drug delivery system by E.A. Torres vargas and co-worker. The material's morphology was determined by SEM and drug release profile was exhibited by HPLC. They could achieve an ultra-fine fibrous structure with the diameter range of 58-80nm. The structure of HPGL was found to be sensitive to the concentration of *C. officinalis*. Furthermore, the mechanical property of the fiber was also affected positively by *C. officinalis* incorporation which turned out to be more elastic and soft.

A rapid release of drug was observed which can be attributed to high degree of swelling rate and large surface area. The biocompatibility evaluation was carried to determine cytotoxicity. The result indicated high cell viability. Invivo testing of the material indicated a fast degree of re-epithelialisation and low inflammatory reaction [52]. All these results confirm that natural potential of plant material can be executed into a biomaterial through electrospinning process.

Conclusion

Human have been using plant products, for remedial purposes, for centuries. Thousands of studies indicate the potential of plants as cure for multiple disorders. Hundreds of drugs available in the market containing plant origin compounds. However, there is difference in potential of medicinal effects for using herbal products in multiple forms. A relatively new method of using medicinal potential of plant products, especially for tissue engineering, is electrospinning. ES provides a wide range of options to load and incorporate plant products (essential oils, single isolated compounds, crude extracts) into some suitable polymer to fabricate a nanofiber structure for biomedical application. This method, of using plant products, has many proven advantages like stability, controlled release and concentration optimization etc. Many of research studies, although low in proportion to overall ES, indicate that plant extracts can be successfully loaded into variety of other synthetic and natural polymers without negatively affecting the characteristics features of the resultant fiber materials. Most of the studies proved a synergistic role of the plant. Although, plants offer wide range of medical application but their natural wound healing potential can be well transfered into a nanofiber structure through ES. Many of the plants have antibacterial activities due to the presence of specific bioactive compounds toxic for the micro organisms. ES further accelerates this potential by converting plant material into a relatively stable structure and improving release profile compared to use of plant material in pure form.

The use of plant natural material in ES area is new. Not many publications are available in this field. The need is to accelerate the speed of the research in this area so that this renewable, nontoxic, biocompatible and potentially medicinal material can be utilized in the field of tissue engineering. Plants, from extreme environment, need specially to be explored for this field. They have some special features which can be utilized for tissue engineering applications. Another lacking, in the field of ES, is to know the exact mechanism of action by a bioactive compound upon tissues. Finding mechanism of action will be helpful in triggering the effect of bioactive compounds present in plant material.

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