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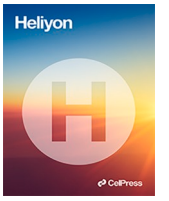

Mechanical, biocompatibility and antibacterial studies of gelatin/polyvinyl alcohol/silkfibre polymeric scaffold for bone tissue engineering

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ABSTRACT

The current study focuses on the incorporation of natural polymers (gelatin, silk fibre) and synthetic (polyvinyl alcohol) polymer towards the fabrication of a novel composite for bone tissue engineering. The Electrospinning method was used to fabricate the novel gelatin/polyvinyl alcohol/silk fibre scaffold. XRD, FTIR and SEM-EDAX analysis was performed to characterize the composite. The characterized composite was investigated for its physical properties (porosity and mechanical studies) and biological studies (antimicrobial activity, hemocompatibility, bioactivity). The fabricated composite showed high porosity and the highest tensile strength of 34 MPa, with elongation at a break of 35.82 for the composite. The antimicrobial activity of the composite was studied and the zone of inhibition was measured around 51 ± 0.54 for *E. coli*, 48 ± 0.48 for *S. aureus* and 50 ± 0.26 for *C. albicans*. The hemolytic % was noted around 1.36 for the composite and the bioactivity assay revealed the formation of apatite on composite surfaces.

1. Introduction

Worldwide, four million operations are performed using various bone alternatives in each year on bone and it was the second most transplanted tissue [1]. To repair bone, scarce bioactive and osteoconductive materials are available commercially [2]. In recent years in the field of bone tissue engineering, the material which is used as a scaffold should help in bone formation around the tissue and also perform as a matrix for cell growth in bone tissue restoration because of its advantages above autografting and allografting [3]. An increase in the demand for tissue repair and regeneration has promoted tissue engineering as a method for restoring, maintaining, reconstructing, and even improving the natural function of tissues [4]. In the whole human body, bone is having prominent regenerative potential [5]. The bone cell is one of the most critical types of cell in the human body that requires a well-designed scaffold to allow the engineered living bone to form [6]. An important aspect of bone tissue engineering is the choice of scaffold material and its surface properties [7]. Implanted materials should provide an environment and functions close to native hosts [8]. In this case, another challenge is to develop scaffolds that can prevent infections and maintain or promote cell-tissue interactions in a desired manner at the same time [9]. Polymeric composites have excellent properties in tissue engineering, drug delivery and regenerative medicine [10]. In this approach, composite/mimicked grafts are prepared on a micro and nanoscale with a hierarchical arrangement [11]. The novel composite should have biocompatibility and excellent mechanical stability to provide structural strength, osteoconductive and osteointegrative properties [12]. Many methods are available to fabricate a scaffold but through the electrospinning process, a scaffold

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Table 1
Weight % and code of Gelatin-Polyvinyl alcohol-silk fibre composite.

Gelatin (wt %)	PVA (wt %)	Silk fibre (wt %)	Sample code
30	40	30	GPS1
20	70	10	GPS2
10	70	20	GPS3

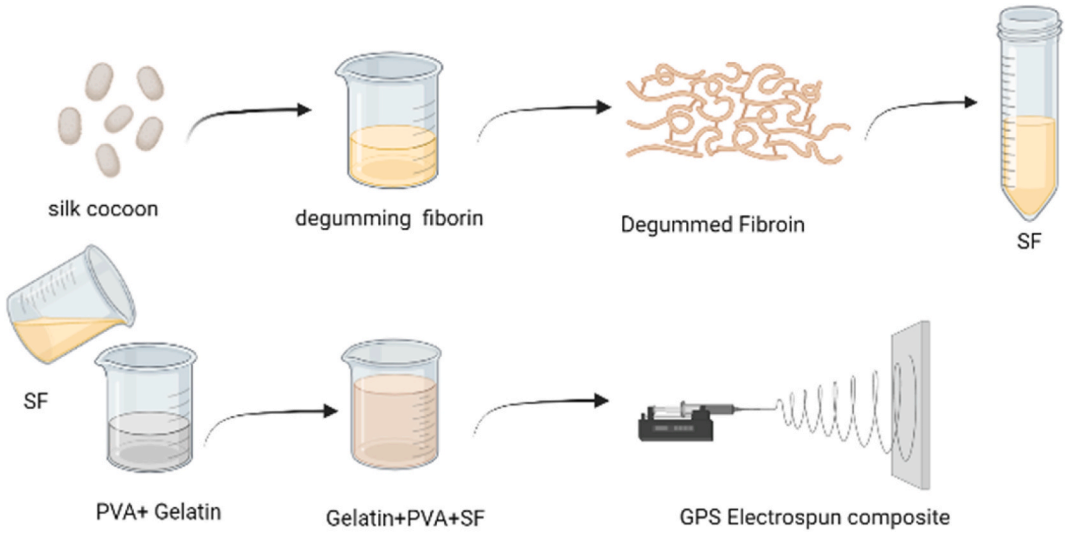

Fig. 1. Scheme for fabrication of electrospun Gelatin-PVA-Silkfibre composite.

with a highly porous structure with interconnected pores and a high surface-to-volume ratio could be achieved [13,14]. The method is mainly suitable for bone tissue engineering and bone regeneration [15]. In recent times researchers have mainly focused on the fabrication of a scaffold by using two or more polymers to achieve the predominant properties of the extracellular matrix, more over this extracellular matrix contains multi-polymers as well [16].

Silk fibroin is a naturally derived protein polymer and it has excellent potential in tissue engineering [17]. Silk fibroin (SF) is made from silkworm cocoons and 18 types of amino acids are linked with amide bonds. SF- based biomaterials can then be degraded into amino acids that are vital to the body. Also, SF has good biocompatibility, excellent biodegradability and low toxicity. Therefore, SF has been considered as one of the most promising biomaterials for tissue engineering [18]. A few limitations bound the clinical application of SF in bone tissue engineering, such as its poor mechanical properties, osteoinductivity and osteoconductivity [19]. Hence there is a need to combine SF with another polymer like gelatin.

Gelatin is derived from polypeptide by hydrolysis and it contains a huge number of three peptide groups such as Arg-Gly-Asp (RGD) that interact with a cell surface to improve the cell adherence to the matrix. Gelatin is soluble in hot water, there is a necessity to enhance its stability in order to confirm its bioavailability after implantation [20]. And also an easily available polymer with a low cost, biodegradable, biocompatible and low antigenicity. So, it is chosen as a suitable polymer which is used to fabricate a scaffold in the field of tissue engineering [21]. Suitable composite materials should possess both mechanical and biological properties in the field of bone tissue engineering. To improve the mechanical strength of the natural polymers, synthetic polymer is incorporated [22]. Polyvinyl alcohol is a synthetic polymer that dissolves in water. As a result of its properties such as excellent mechanical strength, good biodegradability, great chemical resistance, inherent low toxicity, high hydrophilicity, biocompatibility [23] physicochemical stability, jelly nature [24] and several biomedical applications [25–27], it is widely used in tissue engineering applications.

So the addition of suitable synthetic polymer is necessary for the improvement of both mechanical and biological properties. Many reports are available on polyme composites such as chitosan/gelatin [28], chitosan/polyvinyl alcohol [29], gelatin/polyvinyl alcohol [21], SF/methyl cellulose [30], SF/cellulose [31], SF/collagen blend films [32], SF/poly (ethylene glycol) [33], polyvinyl alcohol/-collagen [34], chitosan/collagen/gelatin [35], chitosan/guar gum/polyvinyl alcohol [36], lignin/chitosan/polyvinyl alcohol [37], chitosan/gelatin/polyvinyl alcohol [38], PLA/SF/gelatin [39], chitosan/SF/PVA [40] so far. From the findings, two natural polymers (silk fibre, gelatin) and one synthetic polymer (PVA) are selected to improve the biological and mechanical properties of the composite to achieve the requirement of bone tissue engineering application. Individually Silk fibre, PVA and gelatin polymers are well established and also in combination. But a ternary composite of SF/Gelatin/PVA is not reported so far. To understand the synergic effect of these polymers on mechanical and biocompatibility this work is initiated and studied extensively on these aspects.

In the present study, the Gelatin-Polyvinyl alcohol-Silk fibre (GPS) electrospun composite was prepared by the electrospinning method. The prepared GPS electrospun composite was characterized by XRD, FTIR and SEM-EDAX techniques. Physical and biological

studies such as porosity, mechanical strength, antimicrobial activity, hemocompatibility and biomineralization were also carried out for the characterized GPS electrospun composite.

2. Experimental section

2.1. Materials

Polyvinyl alcohol (PVA) was procured from SD fine India, Gelatin (GS) was acquired from Sigma Aldrich India, *Bombyx mori* silk fibre (SF) was supplied from an Indian silk shop, Bangalore, (99.9), Calcium chloride ($CaCl_2$) was obtained from Sigma Aldrich India. All the reagents were used without any purification. Ethanol and water were used for polymer dissolution.

2.2. Preparation of gelatin/polyvinyl alcohol/silk fibre electrospinning composite

10 wt % of gelatin was dissolved in double distilled water and stirred for 5 h. Then 70 wt % of polyvinyl alcohol was dissolved in double distilled and stirred for 5 h. According to the literature the *Bombyx mori* silk fibre solution was prepared. Before that bombyx mori cocoon was degummed in 0.05 wt % of aqueous sodium carbonate solution for 45 min at 80 °C to remove sericines. After that silk fibre was washed using distilled water, degummed several times and dried at 37 °C overnight. The dried SF was cut in a length of 3 mm and 2 wt % of it was dissolved in a tricomponent system containing calcium chloride/ethanol/water (1:2:8) which was heated for 2 h at 70 °C [41]. To remove the undissolved, the SF solution was centrifuged at around 6000 rpm for 5 min. According to Table 1, the polymer wt % was varied. The SF was added to the PVA-Gelatin mixture to form a homogenised mixture solution. The homogenised mixture was filled in a plastic syringe and kept in the electrospinning machine for the fabrication of the Gelatin-PVA-SF composite (Fig. 1). The collector was rotated at 900 rpm and a 20 kV current was applied. The distance between the collector and the syringe was around 15 cm. The sample code and different radios of the polymers are mentioned in Table 1.

2.3. Characterization

The crystalline or amorphous nature of the prepared composites was characterized by using Bruker D8 advanced X-ray diffractometer (Karlsruhe, Germany) with an operating voltage of 40 kV and a current of 30 mA. The scanning range was from 10° to 70° and the copper K-alpha range was around 1.54 Å. The Fourier transform infrared spectroscopy (Shimadzu IR affinity-1) was used to analyse the functional groups in the range 400 cm^{-1} to 4000 cm^{-1}. The surface image of the composite and elemental analysis was carried out by using Carl Zeiss Evo 18, (Germany) scanning electron microscope and energy-dispersive X-ray analyser.

2.4. Porosity measurement

The liquid displacement method was utilised for calculating the porosity (%). In this study displacement solvent was ethanol and the sample was cut into uniform sizes. The known volume of ethanol (V1) was taken and samples were dipped in the above ethanol at various time intervals 24 h, 48 h and 72 h. The sample containing ethanol was weighed as (V2). After the time interval, the sample was taken out and the remaining ethanol (V3) was weighed. The porosity measurement was calculated using the formula mentioned below [42].

$$\text{Porosity } (\%) = \frac{v1 - v3}{v2 - v3} \times 100$$

2.5. Mechanical studies

Through the mechanical studies the tensile strength, elongation at break and young's modulus were calculated for the prepared composites. For this study uniaxial machine (Model-H5KS) was used and the composite was cut into 5 × 1.5 cm. The load given was 50 N and the extension rate applied was 1 mm/min. The tensile strength of the composite was measured using the formula [43].

$$\text{TS} = \frac{Fmax}{A}$$

where F_{max} = maximum load is given and A = cross-sectional area.

The elongation at break (%) of the composites was calculated using the following formula [20].

$$\text{E } (\%) = \frac{L}{L0} \times 100$$

where, L_0 = initial length of the composite, L = variation between original and breaking point.

2.6. In-vitro antimicrobial studies

The antimicrobial study was carried out by using the well-diffusion method. Different weight % of gelatin-polyvinyl alcohol-silk

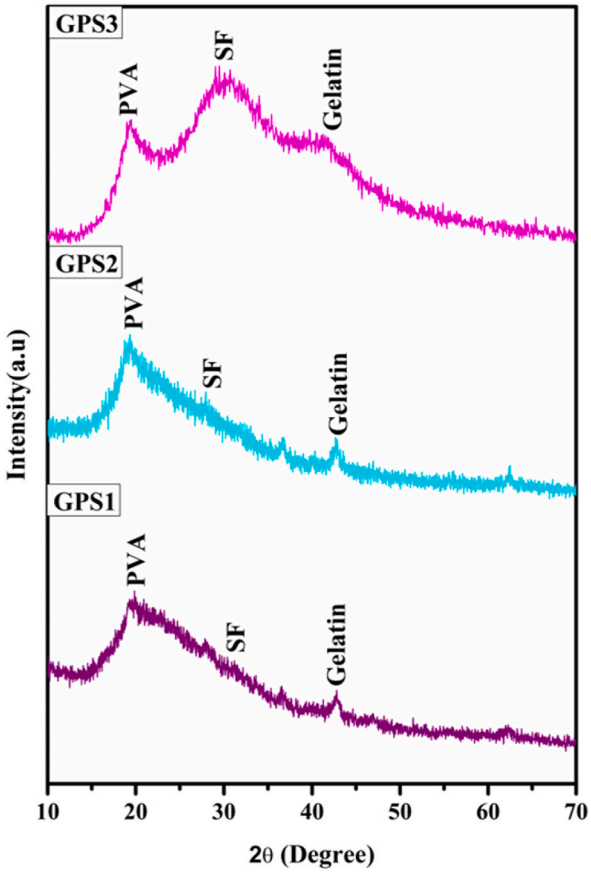

Fig. 2. XRD pattern of prepared composite GPS1, GPS2, GPS3.

fibre (GPS) were taken for the antimicrobial studies. In this study two bacteria such as *S. aureus* (gram-positive), *E. coli* (gram-negative) and one fungus *C. albicans* were taken. Well diffusion method was utilised as per the procedure mentioned in the literature [44]. Muller Hinton agar was used as a medium for bacterial studies and sabouraud dextrose agar was used as a medium for fungal studies. The petri-dish was taken and sterilised. Later, the medium was poured into the dish and allowed to cool and solidify. The surface of the media was swapped using the microbial medium. The sterile borer was used to cut the wells in the solidified media. The prepared 1 mg/mL composites were sonicated around 10 h then 50 μL was added into the wells. After that, the Petri plates were kept in the incubator at 37 °C for 24 h. The same protocol was followed for the fungus (*C. albicans*) and plates were kept in the incubator at 37 °C for 48 h. After the stimulated time the plates were examined by callipers and recorded the zone of inhibiton. The same protocol was continued for triplicate and noted the average value of inhibition.

2.7. In-vitro hemocompatibility studies

The prepared composite (GPS1, GPS2, GPS3) was cut into 1 × 1 cm, 0.8 mL of PBS solution and 0.2 mL of blood were taken in the Eppendorf. To prepare + Ve control, 0.2 mL of blood was mixed with 0.8 mL of water and to prepare -Ve control 0.2 mL of blood was mixed with 0.8 mL of PBS solution. The solution was kept in the shaker at 37 °C for 1 h. After the stimulated time the solution was centrifuged at 10,000 rpm for 3 min. This procedure was repeated. After that, the solution was used to measure the OD values on the ELISA READER in the wavelength of 570 nm. The following formula was used to calculate the Hemolytic (%) [45].

$$\text{Hemolytic } (\%) = \frac{OD\ sample - OD\ negative\ control}{ODpossitive\ control - ODnegative\ control} \times 100$$

This work involves human participant for hemocompatibility studies and the human ethical clearance certificate number is VIT/1ECH/XII/2022/09.

2.8. Bioactivity

The SBF (simulated body fluid) solution at pH 7.4 was utilised for the bioactivity studies. The procedure was followed as per

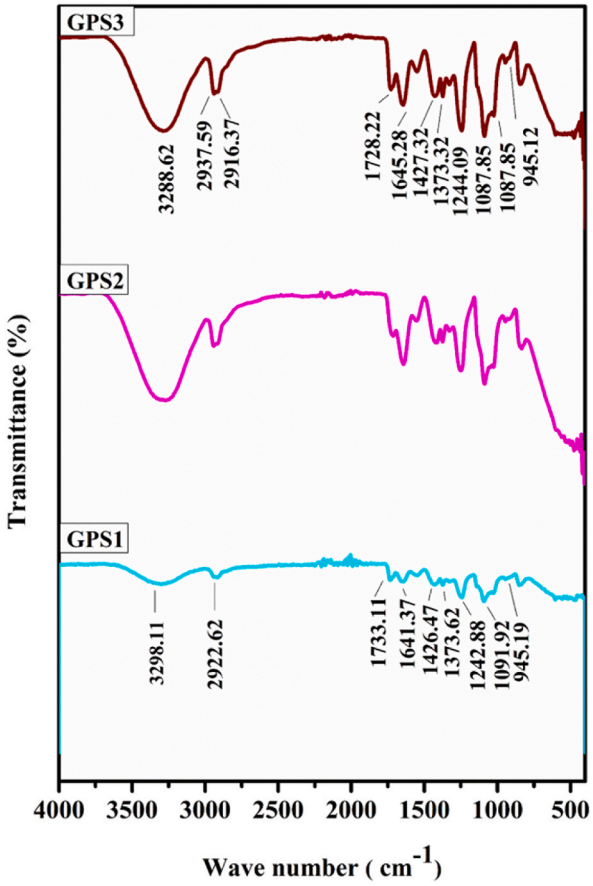

Fig. 3. FT-IR spectra of the prepared composites (GPS1, GPS2, GPS3).

previous literature [46]. This study was carried out at different time intervals 0, 7, 14 and 28 days. After the different time intervals, the sample was removed and dried. The apatite deposition on the composite surface was analysed by XRD, FTIR and SEM-EDAX techniques.

3. Results and discussion

3.1. Powder XRD analysis

The XRD pattern of the prepared composites (GPS1, GPS2, GPS3) is shown in Fig. 2. The 2-theta range for SF was noted at 30° [40] and gelatin was noted in the 2-theta range 41° (JCPDS file number: 00-064-1605) and PVA was noted at 2 theta range 19° [47] (JCPDS file number 00-064-1616). The XRD pattern confirms the presence of Gelatin-PVA-SF in the prepared composite. While increasing the wt % of PVA and decreasing the gelatin wt % the SF and gelatin peaks were shifted slightly to a lower angle. The XRD pattern indicates the incorporation of the Gelatin-PVA-Silk fibre in the composite.

3.2. FTIR spectroscopy

Fig. 3 shows the FT-IR spectra of the obtained composite. The stretching vibration of asymmetric CH_2 groups and O–H group of PVA are noticed at 2937.59 cm^{-1} and 3288.62 cm^{-1} respectively [40]. The strong absorption peak of the C–O stretching mode for PVA is denoted in the range of 1087.85 cm^{-1} and CH–OH is attributed at around 1373.32 cm^{-1}. The C–O stretching of acetate in PVA is depicted from 1641.37 to 1645.28 cm^{-1} [38]. The C═O and N–H bending vibrations were obtained around 1645.28 cm^{-1} and 1427.32 cm^{-1} which confirms the presence of gelatin [38]. The peaks of amide III present in the range of 1242.88 cm^{-1} to 1244.09 cm^{-1} belong to SF [48]. The polymer incorporation was confirmed by the FT-IR spectra.

3.3. SEM-EDAX analysis

Fig. 4 shows the morphology of obtained composites (GPS1, GPS2, GPS3). SEM images display that composite is randomly arranged

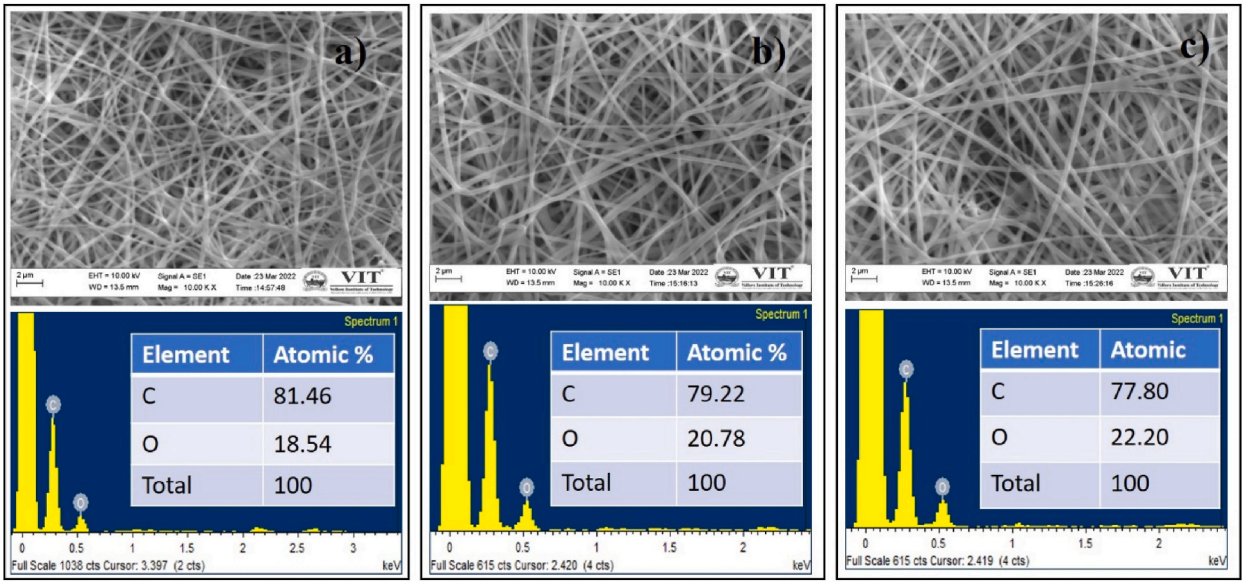

Fig. 4. SEM images of prepared composites a) GPS1, b) GPS2, c) GPS3.

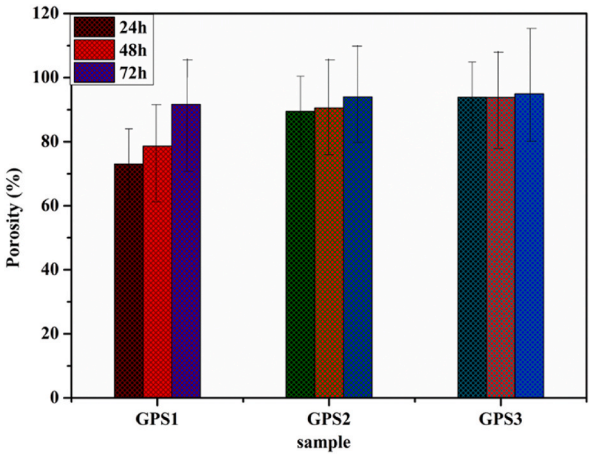

Fig. 5. Porosity (%) of the composite (GPS1, GPS2, GPS3).

with interconnected pores. Aysen Akturk et al. witnessed an initial decrease and then an increase in composite diameter with PVA/Gelatin-silver nanocomposite when PVA content was increased [49]. In contrast, while increasing PVA content in gelatin-SF composite the diameter decreased gradually. The diameter of the fibre was calculated using image J software. It showed both 70% of PVA-containing composites GPS2 (298.33 nm), and GPS3 (299.33 nm) depicted less fibre diameter compared to the GPS1 (531.96 nm) composite. Carbon and oxygen were noted from the elemental analysis.

3.4. Porosity measurement

The porosity studies were carried out using the liquid displacement method. The porosity of composite is essential to assist cell adhesion and cell growth and also plays a vital role in *in-vivo* cum *in-vitro* cellular studies. Moreover, essential elements and other minerals are transported through the pores of the composite. At regular time intervals (24 h, 48 h, 72 h) the porosity (%) was calculated and depicted in Fig. 5. Porosity of the composite was increased with a decrease in gelatin content and an increase in time intervals. GPS1 and GPS2 composites showed 91.63 ± 2.8 and 93 ± 2.1 respectively. GPS3 composite exhibited the highest porosity (94.99 ± 4.69) when compared to other composites. The porosity of the obtained composite is a major characteristic of biomaterial in the field of tissue engineering [50].

Table 2
Mechanical properties of prepared (GPS1, GPS2, GPS3) composites.

Sample	Proportionality limit (MPa)	Tensile strength (MPa)	Young's modulus (MPa)	Elongation at break (%)	Breaking point (MPa)
GSP1	16.48	17.57	307.63	18.44	61.69
GPS2	22.68	23.54	971.73	32.76	36.59
GPS3	32.55	34.19	626.68	35.82	22.46

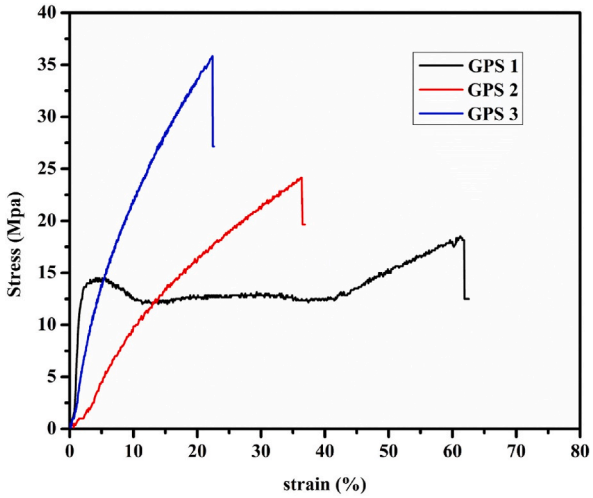

Fig. 6. The stress Vs strain curve of (GPS1, GPS2, GPS3) composite.

Table 3
Antimicrobial assay for (GPS1, GPS2, GPS3) composite.

Sample	Organisms (bacteria and fungus)		
	Zone of inhibition (mm)		
	Bacteria		Fungus
	E. coli	*S. aureus*	C. albicans
GPS1	48 ± 0.31	34 ± 0.24	40 ± 0.18
GPS2	50 ± 0.28	45 ± 0.21	43 ± 0.19
GPS3	51 ± 0.54	48 ± 0.48	50 ± 0.26
Streptomycin (standard)	23 ± 0.38	27 ± 0.36	
Amphotericin (standard)			24 ± 0.24

3.5. Mechanical properties

Table 2 shows the tensile strength, proportionality limit, Elongation at break (%) breaking point (MPa) and young's modulus (MPa). The stress-strain curves are shown in Fig. 6. The GPS1 and GPS2 composite showed a tensile strength of 17.57 MPa and 23.54 MPa and elongation at break 18.44 and 32.76 respectively. The highest tensile strength (34 MPa) and elongation at a break of 35.82 were observed using GPS3 composite**.** Lihong fan et al. reported the tensile strength of the gelatin-PVA composite was enhanced to 2.2 MPa after adding chitosan in the aforementioned composite [38]. Sheik et al., reported the tensile strength of 30.3 MPa using SF-PVA/PVP films [51]. But in this current work the addition of SF into gelatin-PVA enhanced the tensile strength up to 34 MPa. While comparing with previous literature the tensile strength was enhanced. So it could be a potential candidate for bone tissue engineering application.

4. *In-vitro* biological studies

4.1. In-vitro antimicrobial studies

The antimicrobial activity of obtained composites was assessed by using the well-diffusion method. Gram + Ve *S. aureus* and Gram -Ve *E. coli*, were used for bacterial studies and *C. albicans* was used for fungal studies. Streptomycin was used as a standard for bacteria and amphotericin was used as a standard for fungal studies. The zone of inhibition and images are depicted in Table 3 and Fig. 7.

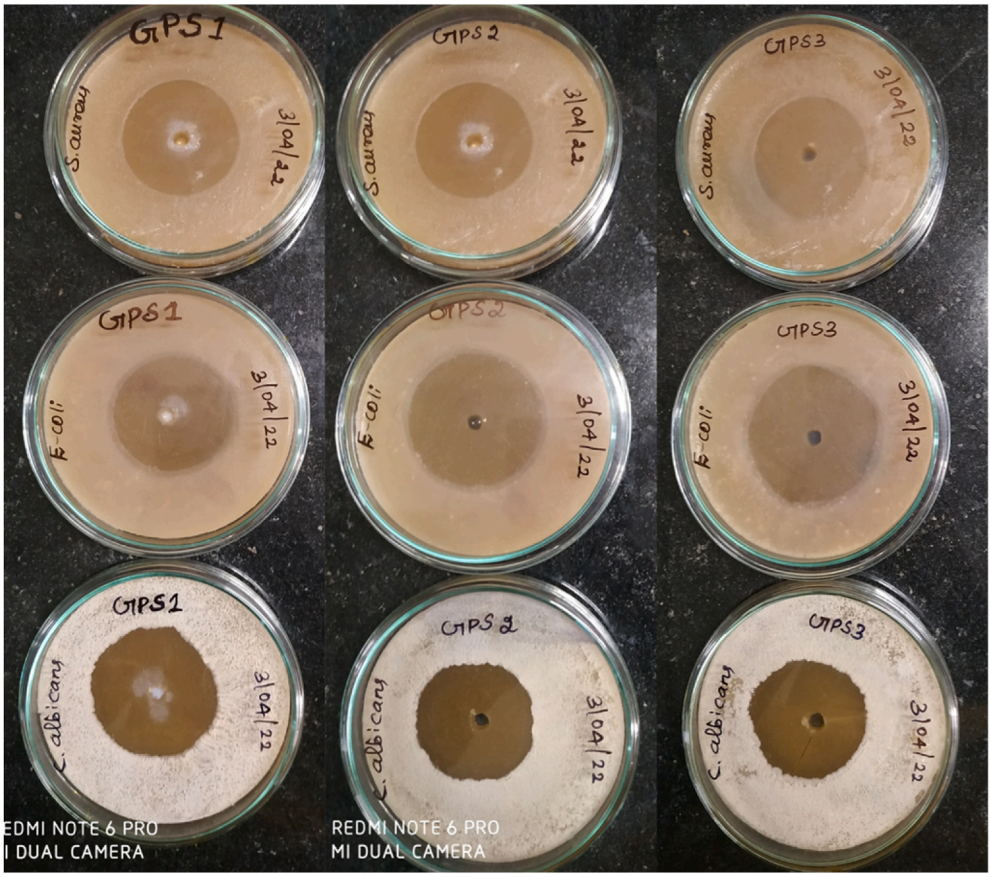

Fig. 7. Antimicrobial activity of prepared (GPS1, GPS2, GPS3) composites.

Table 4
Comparison of results with literature.

Bone tissue engineering materials	Type of materials	Methods	Studies	Ref
Chitosan/guar gum/PVA	hydrogel	Blending	Antimicrobial activity – zone of inhibition - 18 ± 1.69, 22 ± 4.49, 16 ± 2.35 and 20 ± 4.36 against *P. multocida, S. aureus, E. coli, and B. subtilis*	[36]
Lignin–chitosan–PVA	hydrogel	Freeze-thaw method	The tensile strength of 44.3 MPa with elongation of 300%, and the elastic modulus was found to be 46.87 Mpa, water contact angle-36.20°	[59]
Chitosan (CS)/Gelatin (Gel)/ Polyvinyl alcohol (PVA)	Hydrogels	gamma irradiation method	Tensile strength −2.2Mpa	[38]
PLA/silk fibroin-gelatin	Fibre mat	Electrospinning	Breaking Tenacity (MPa) (Mpa) 2.22 ± 0.24, Elongation at Break (%) 7.30 ± 2.05, porosity ranges from 87 to 89%, Hemolysis (%) - 3.1%	[60]
Chitosan-grafted silk fibre-reinforced PVA films	Films	solution casting technique	Degradation (%) - 30 ± 2, hemolytic (%) - (79.0 ± 1.8)	[40]
Gelatin/PVA/Silk fibre (Present work)	Fibre mat	Electrospinning	Tensile strength - 34 Mpa, elongation at a break of 35.82, antimicrobial activity against *E. coli* 51 ± 0.54, 48 ± 0.48 for *S. aureus* and 50 ± 0.26 for *C. albicans,* hemolytic % - 1.36	Present work

Among all composites highest zone of inhibition was noted for GPS3 (*E. coli*- 51 ± 3.81) (*S. aureus* - 27 ± 5.45) and (*C. albicans* - 50 ± 3.64). From previous literature, it was noticed that silver hydroxyapatite/gelatin/alginate/polyvinyl alcohol-based scaffolds showed a zone of inhibition against *Bacillus* around 22 mm and for *E. coli*. around 24 mm [52]. Less zone of inhibition was noted in the mentioned literature compared to the current work. The comparison of results with the literature is given in Table 4. As a result, the synthesized composite can be utilised to treat infections caused by microorganisms, and the obtained result clearly indicates that the composite of these three polymers showed excellent antimicrobial activity. If the composite is having excellent antimicrobial activity, it could be a potential candidate in bone tissue engineering applications.

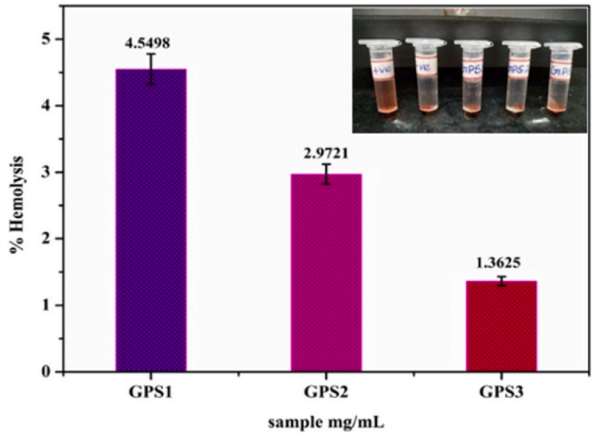

Fig. 8. Hemolytic (%) of the prepared composites (GPS1, GPS2, GPS3).

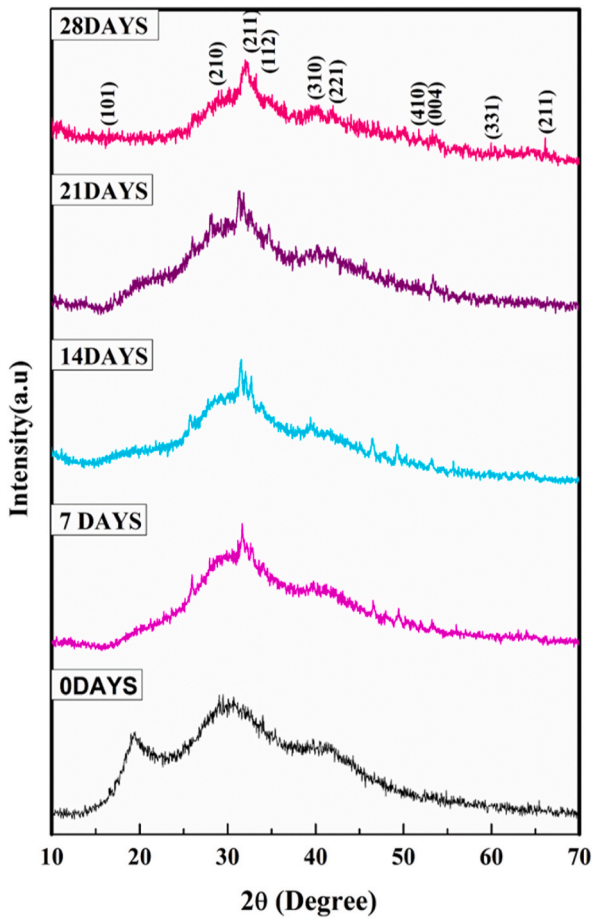

Fig. 9. XRD pattern of the optimised composite GPS3 before and after immersion in SBF.

4.2. In-vitro hemocompatibility studies

In BTE application hemocompatibility plays a crucial role. A hemocompatibility study is used to check the compatibility of the sample with human blood. Blood cells are damaged during hemolysis, which results in haemoglobin liberation, which can be detected with a spectrophotometer at a wavelength of 570 nm [53]. From ASTM standard report if the material displays lesser than 5% of hemolysis it could be highly hemocompatible. Here GPS3 exhibited 1.36% and was found to be more hemocompatible than other

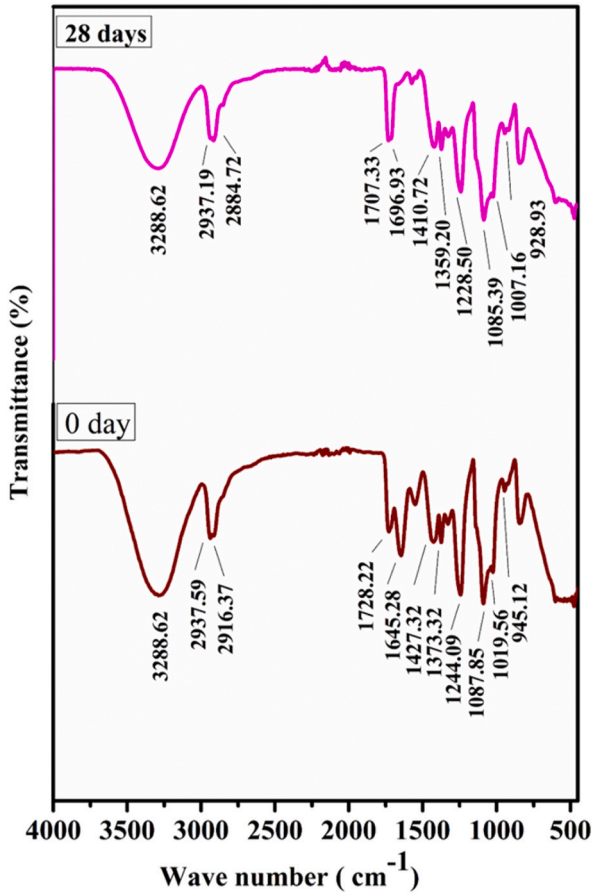

Fig. 10. FT-IR spectra of the optimised GPS3 before soaking and after soaking for 28 days.

composites [54]. The result (Fig. 8) revealed that synthesized composites are highly hemocompatible with blood. It could be a suitable material for all biomedical-related applications.

4.3. In vitro bioactivity assay

One of the most important properties of scaffolds is it bioactivity, which is the ability to form a bone bonding interference with a bone tissue [55,56]. To investigate the bioactivity of materials, the material was soaked in SBF. GPS3 composite has shown high mechanical strength, excellent antimicrobial activity and less hemolytic (%). So GPS3 was chosen for the bioactivity assay. Bioactivity was carried out for 7, 14, 21 and 28 days and samples were analysed by the XRD, FTIR and SEM-EDAX techniques. Fig. 9 shows the XRD pattern of the optimised GPS3 before and after soaking in SBF. From the 7th day, the apatite formation was started on the sample. In GPS3, the peaks in the XRD pattern were associated with HAP particles after 28 days, indicating HAP has successfully formed. The peaks were matched with the JCPDS: 09–0432 [30]. Fig. 10 shows the FTIR spectrum of the optimised composite before and after 28 days of soaking. After 28 days of soaking some of the peaks were shifted to lower wavenumber. In this case, as immersion time increases the peak shifts towards the lowest which is indicating the formation of apatite on the composite surface [57]. Fig. 11 shows the morphology of the composite after 7, 14 and 28 days of soaking. Moreover, after 7 days of soaking, the apatite started to deposit on the surface. While increasing the soaking time the apatite layer was deposited on the layer and it started to cover the whole composite surface. Hence it is proved from the morphology analysis that apatite deposition happened on the sample surface.

According to the literature reports, apatite-like deposits would form on the surface, allowing bone-bonding facility when the prepared composites are immersed in SBF. The apatite formation mechanism in contact with SBF has been extensively investigated. And also, calcium ions played an important role in nucleation in the present study [30]. The functional groups like hydroxyl and carboxylic acid in the GPS composite ionized in SBF solution and the negative charge on the surface enhanced which attracts the positively charged calcium ion from SBF solution and the surface of the composite became more positively charged and which in turn attract the negatively charged phosphate ion rom SBF solution and hence resulted in the hydroxyapatite formation on the surface [58].

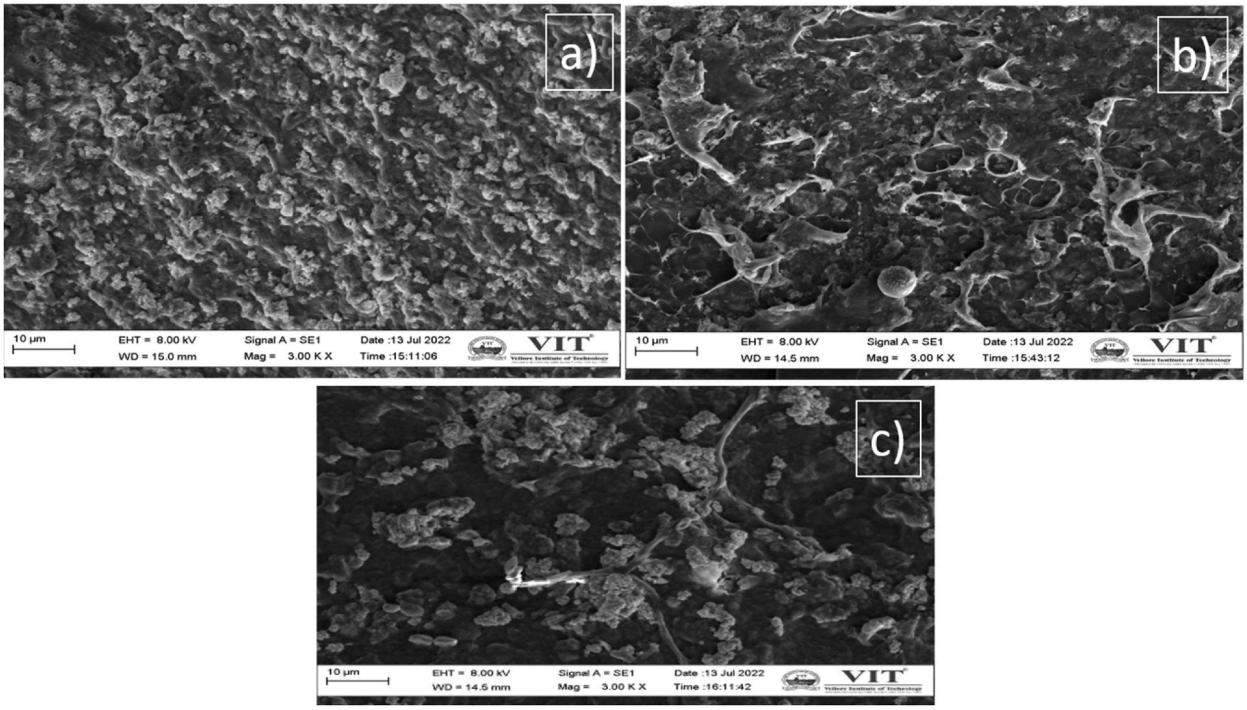

Fig. 11. SEM images of optimised GPS3 after soaking a) 7 days b) 21 days c) 28 days.

5. Conclusion

The novel gelatin-polyvinyl alcohol-silk fibre composite was fabricated by the electrospinning method. The fabricated composite was characterised by X-ray diffraction, Fourier transformation infrared spectroscopy, Scanning electron microscopy and Energy dispersive X-ray analysis techniques. The XRD shows the presence of Gelatin-PVA-silk fibre diffraction peaks. The FT-IR spectra depicted the corresponding functional groups due to Gelatin-PVA-Silk fibre presence in the composite. In SEM analysis the composite was randomly arranged with interconnected pores which leads to high porosity. From the mechanical studies, the GPS3 composite exhibited the highest tensile strength (34.19 MPa) and elongation at break (35.82%). The antimicrobial activity showed a high zone of inhibition for GPS3 compared to other composites. The GPS3 composite showed 1.36% of hemocompatibility so it could be a highly hemocompatible composite as reported by ASTM standards. The bioactivity assay depicted the apatite formation on the composite surface. The fabricated Gelatin-Polyvinyl alcohol-Silk fibre composite via the electrospinning method possesses a wide range of applications in regenerative medicine.

Author contribution statement

Sabareeswari Kalidas: Performed the experiments; Analysed and interpreted the data; Wrote the paper.
Shanmugam Sumathi: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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