

Design, Development and Evaluation of Polyherbal Antimicrobial Discs Using Semisolid Extrusion Based 3D Printing Technology

Suhasini Boddu¹, Karthikeyan Ramadoss^{2,*}, Kiranmai Mandava³, Prakash Katakam⁴

¹School of Pharmacy, Sri Balaji Vidya Peeth, Puducherry, Pilaiyarkuppam, and St. Pauls College of Pharmacy, Turkayamjal, Telangana, INDIA.

²Department of Pharmacognosy, School of Pharmacy, Sri Balaji Vidyapeeth, Pilaiyarkuppam, Puducherry, INDIA.

³Department of Pharmaceutical Chemistry, St. Pauls College of Pharmacy, Turkayamajal, Hyderabad, Telangana, INDIA.

⁴Department of Pharmaceutics, Indira College of Pharmacy, Nanded, Maharashtra, INDIA.

ABSTRACT

Background: 3D printing holds great promise for the development of innovative, individualised approaches to the distribution of medicinal products. The use of 3D printing to create objects with antibiotics has many advantages, such as more precise drug content and better drug distribution. **Aim:** This study aimed to develop polyherbal antimicrobial discs using 3D printing technology. **Materials and Methods:** Using HPMC-K100M and PEG-400, plant extracts of *Artemisia vulgaris*, *Hemionitis arifolia*, and *Piper officinarum* were combined to create drug-loaded gels that could be printed using the solvent-cast process. Prior to being printed onto circular discs using SSE at a head speed of 0.5 mm/s, the gels underwent tests to ensure homogeneity, injection force, and viscosity. A total of nine formulations, denoted as F1-F9, were developed and refined. **Results:** Drug release investigations, FTIR and SEM characterization, compatibility, and desirable surface morphology were all considered when formulas were tested, with particle sizes varying from 467.3 nm to 1.013 μ m. In comparison to regular amoxicillin, the discs showed considerable antibacterial effectiveness against *E. coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans*. The results showed that the discs were effective against a wide variety of bacteria, making them an attractive substitute for more conventional wound care methods. **Conclusion:** Targeted drug administration with fewer excipients improves skin wound and infection treatment and tackles Multidrug-Resistant (MDR) concerns. To create efficient and cost-effective 3D-printed polyherbal DDSs.

Keywords: 3D Printing, Antimicrobial Disc, Semi-Solid Extrusion (SSE), Hydroxypropyl Methylcellulose (HPMC), Polyethylene Glycol (PEG).

Correspondence:

Dr. Karthikeyan Ramadoss

Department of Pharmacognosy, School of Pharmacy, Sri Balaji Vidyapeeth, Pilaiyarkuppam, Puducherry, INDIA.
Email: professorsrkrn@gmail.com

Received: 21-07-2026;

Revised: 18-08-2026;

Accepted: 05-10-2026.

INTRODUCTION

Every year, 700,000 people are found to be resistant to antibiotics. By 2050, this number is expected to rise significantly, despite the availability of many treatments. This highlights the urgent need to find answers to this growing worldwide problem.¹ A bacterial infection is still a leading cause of death and hospitalization. A number of issues, such as antibiotic resistance and inadequate medication penetration to bacterial infection sites, contribute to the clinical failure of antibiotic treatment.² Resistant strains of *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Enterococcus faecalis*, and *Candida albicans* have been reported in

numerous nations.³ New antibiotics or multidrug combinations to stop and cure bacterial growth infusion using cutting-edge technologies like 3D printing are necessary to solve these difficulties.⁴ The medical industry has benefited greatly from the recent advances in 3D printing technology. Some of the benefits of using 3D printing to make structures with antibiotics inside include more accurate dosing and better drug distribution.⁵ There are many different ways that 3D printing is done. When making 3D items with antibiotics embedded in them, we typically use the solvent casting technique in conjunction with Fused Deposition Modelling (FDM). But FDM has been the method that has been utilized most frequently.⁶ The biotechnological focus on the search for antibacterial and antiadhesive qualities has led to the recent emergence of natural chemicals as potential alternatives. Artemisinin, quercetin, gallic acid, and other similar substances have antibiofilm potential, according to research. These compounds have fungicidal and bactericidal effects, which can modify bacterial regulatory pathways and limit biofilm development.⁷



DOI: 10.5530/ijper.20272123

Copyright Information :

Copyright Author (s) 2027 Distributed under
Creative Commons CC-BY 4.0

Publishing Partner : Manuscript Technomedia, [www.mstechnomedia.com]

The presence of secondary metabolites such as flavonoids, sesquiterpene lactones, coumarins, acetylenes, phenolic and organic acids is primarily responsible for *Artemisia vulgaris* (AV) medicinal properties, which include hepatoprotective, antispasmodic, analgesic, estrogenic, antibacterial, and antifungal effects.⁸ One of the most notable features of *Hemionitis arifolia* (HA), or the heart fern, is its ability to fight against microbes, inflammation, and free radicals. The main chemical components consist of polysaccharides, terpenoids, phenolic compounds (particularly tannins), flavonoids (such as quercetin and kaempferol derivatives), and others.⁹ The pharmacological activities of *Piper officinarum* (PO) include activities against bacteria, worms, malaria, insects, and inflammation. It is also used as a central nervous system stimulant, against tuberculosis, hypoglycaemic, against spasmodic attacks, cough suppressor, immunostimulatory, hepatoprotective, analeptic, antinarcotic, and antiulcerogenic. The phytochemicals found in the fruit of Pippali include piperine, triacontane, dihydrostigma sterol, and protein.¹⁰ Using the disc diffusion method, the researchers set out to create polyherbal 3D-printed discs and test their antibacterial activity.¹⁰

MATERIALS AND METHODS

Materials

Analytical grade reagents were utilized in every case. Pharcos Speciality Ltd., of India produces Hydroxypropyl Methyl Cellulose (HPMC) with a viscosity ranging from 75,000 to 140,000 cps and Polyethylene Glycol (PEG 400) with a range of 85 to 105 cs. Benzoic acid with deionized water. This study utilized Mueller Hinton agar media, together with gift samples from IICT, Hyderabad, of *E. coli* (ATCC 25922), *Staphylococcus aureus* (ATCC 29737), *Pseudomonas aeruginosa* (ATCC 12228), and *Candida albicans* (ATCC 6633). Amoxicillin is a beta-lactam antibiotic that is commonly used. The AV, PO, and HA leaves were collected in November and December of 2023 from Komaneri village in Puliankudi region, Tenkasi, Thoothukudi Dist, Tamil Nadu state. Dr. S. Mutheshwaran of the Xavier Research Foundation verified the purchase using voucher number XCM-40561. Soxhlet followed by rotary evaporation was used to extract the plants from their methanol-based solvent after they were defatted using petroleum ether. The desiccator was used to store the extracts for future use.¹¹

3D printing of polyherbal-impregnated discs

Disks measuring 6 mm in diameter and 2 mm thick were printed using the solvent-cast method on 100 gsm non-adhesive polyester films from Misumi, Gurgaon, Haryana, India, using Tinker CAD software and Cura slicing software technology from 3D Fying, Hyderabad, Autodesk Inc., San Francisco, California, USA. A glass beaker was used to dissolve HPMC in deionized water. A magnetic stirrer was then used to agitate the mixture for

1 hr at 500 rpm in order to prepare the formulation. Afterwards, add PEG 400 dropwise while stirring continuously for 2 hr, and then add extracts based on MIC value in the necessary amount of water. The mixture was subsequently transferred to a syringe, which was then placed on the 3D printer horizontally mounted, manufactured glass plate.¹² It was determined through trial and error that the following settings or parameters were necessary to keep the printing process consistent. Conditions such as temperature (40°C), rectilinear infill (20%), layer height (0.2 mm), line distance (1 mm), density (50%) and print and travel speeds (10.0 mm/s and 50.0 mm/s, respectively) are all part of the package. The 3D printer we used was the Prusa I3 MK3, manufactured in Prague, Czechia, by Prusa Research. The discs we used had a working diameter of 6 mm and a height of 2 mm. 3D disc printing subsequently followed.¹³

Disk characterization

Size, thickness, weight fluctuation, visual traits, pliability, and fragility were among the many parameters measured.

Physical evaluation of disc formulations

Uniformity of weight

After the discs had dried for 72 hr, their mean weight ($n=3$) was determined using a calibrated analytical balance. We computed the standard deviation¹⁴ and found the average weight.¹⁴

Thickness and diameter

We used a micrometer screw gauge to measure the diameter and thickness of three discs from each formulation.¹⁵

pH

Placing a pH meter (Global Electronics, India, model: DPH 507) against the disc's surface and giving it 1 min to acclimate allowed us to find the disc's pH.¹⁶

Swelling index

The swelling behaviour of the discs that were developed was examined using the agar-gel plate method. Three discs, each with its own weight, were placed on agar plates that contained 1% water by volume, and then they were incubated at 37°C. At half-hour, 1-, 2-, 3-, 4-, 5-, and 8-hr intervals, we took the discs out, sucked the water out with filter paper, and weighed the bloated ones again. The Swelling Index (SI) was computed in the following way.

$$\text{Swelling (S) index (\%)} = (W1 - W2) / W2 \times 100$$

W1 is the initial weight of the disc and W2 is the weight of the enlarged disc at various time intervals. The values are given as the mean plus or minus the standard deviation, and each formulation was examined three times.¹⁷

Uniformity of drug content

After three precisely measured discs were ground and mixed with 30 mL of methanol, they were subjected to ultrasonication for 15 min. To make the final volume of 100 mL, phosphate buffer with a pH of 5.4-5.9 was added. A UV-visible spectrophotometer (Shimadzu, India) was used to measure the absorbance of the solution at 360 and 240 nm after a 0.45 μ m nylon filter was employed to eliminate contaminants. To determine the concentrations, we used the calibration curve and the drug-free disc as a blank.¹⁸

In vitro drug release studies

Utilizing a Franz diffusion cell with a receptor compartment volume of 150 mL. The egg membrane was positioned between the donor and receptor compartments of the diffusion cell. The prepared patches were bisected and positioned atop the drug release membrane, while the receptor compartment of the diffusion cell was filled with phosphate buffer at pH 5.4, maintained at 37°C with continuous stirring at 50 rpm. 1 mL samples were extracted hourly and analyzed for absorbance spectrophotometrically at 280 nm relative to a blank. The receptor phase was replenished with an equivalent volume of phosphate buffer at each sample withdrawal interval.

Stability studies

$n=3$ discs were selected, then wrapped in aluminum foil and placed at room temperature, in the oven ($40\pm2^\circ\text{C}$), and refrigerator freeze conditions over a period of three months. There was no significant difference in the physicochemical parameters.¹⁹

Kinetics studies

The drug release study was plotted in various kinetic models: Zero-order as % drug released Vs time, first order as log % drug retained Vs time, Higuchi as % drug released Vs $\sqrt{\text{time}}$, Korsmeyer-Peppas as log % drug released Vs log time and Hixson-Crowell as $(\% \text{ drug retained})^{1/3}$ Vs time. By comparing the R-values obtained, the best-fit model was selected.²⁰

Characterization of drug-loaded disc

FTIR analysis

The sample was scanned in Fourier Transform Infrared Spectrophotometer (Bruker optics, Germany) over wavelength range includes $8000\text{--}340\text{ cm}^{-1}$, by dispersing sample in KBr and compressing into the disc by applying 5 tons of hydraulic pressure, resolution of 0.4 cm^{-1} for 5 min. The disc was placed in light path and the spectrum was obtained.²¹

Determination of SEM [Scanning Electron Microscopy]

The surface morphology was observed under optical microscope and high-resolution SEM (EVO18 Research, Zeiss, Germany).

The voltage and working distance were set at 3 kV, 7.2 mm, respectively. Cross-section images of the disc were taken using JSM-840A Scanning Microscope, JEOL GmbH, Germany by placing the sample discs in double-sided carbon tape, mounted on stubs and sputter coated for 1 min prior to imaging using a Polaron E5000 machine with Au/Pd.²²

In vitro antibacterial activity

MIC

The microbroth dilution method was applied applying a 96-well microplate. The wells contained 100 μ L of the Mueller-Hinton Broth culture medium, 10 μ L of the microbial suspension (1×10^7) (at a concentration equivalent to 0.5 McFarland), and 100 μ L of different concentrations of each extract were prepared at a concentration of 100 mg/mL as stock solution. Standard antibiotic at a concentration of 100 μ g/mL was employed as a control. 1% DMSO was used as solvent to dissolve the extracts. After the inoculation of bacteria in the wells, the microplate was placed in an incubator for 24 hr at 37°C. The first well in which no growth was observed was indicative of the Minimum growth Inhibitory Concentration (MIC).²³

Antibacterial activity

The diffusion method was used to evaluate the antibacterial characteristics of a 3D-printed disc that contained polyherbal extracts. The Muller Hinton agar medium was immediately autoclaved for 15 min at 121°C and 15 pounds of pressure after preparation. A total of 100 μ L 10^7 CFU cells of 0.5 McFarland concentration in Densicheck of sterile swabs of the following bacteria were introduced into the media: *E. coli* (ATCC 25922), *Staphylococcus aureus* (ATCC 29737), *Pseudomonas aeruginosa* (ATCC 12228), and *Candida albicans* (ATCC 6633). The media was thereafter transferred to 20 mL sterile petri dishes and allowed to harden for a duration of 15 min. To construct wells on the media, a sterile cork with a diameter of 6 mm was used. Then, test and standard drugs, each with a concentration of 0.1 mg/mL in 1% DMSO, were applied. The microbiological plates were tested for zone of inhibition using a zone reader after 48 hr of incubation at 37°C. All experiments were performed in triplicate.^{24,25}

RESULTS

Evaluation parameters

The composition of the antibiotic disc along with polymer was mentioned in Table 1, and the formulated disc is shown in Figure 1. Physical characteristics like weight variation, thickness, and drug content were summarized in Table 2. The thickness variations of the discs were noted because different polymer portions were used in formulation preparation. HPMC is a high-molecular-weight plasticizer good folding endurance. By increasing the concentration the folding nature, tensile strength

decreased. The percent total drug content of prepared discs was found within the range 0.820 ± 4.34 to 0.961 ± 1.28 . According to B.P. (2009) requirements all the prepared discs are uniform in drug content.

Swelling studies

The rate of disc swelling was directly proportional to the concentration and viscosity grade of polymer. The swelling of the matrix depends rate at which water is enter into matrix. Figure 2 shows swelling index of the disc.

Surface pH

The prepared formulations exhibited surface pH values within limits 5.35-5.79, it was determined by using pH meter. These formulations may not cause irritation to the skin.

In vitro drug release studies

Percentage drug release of formulations F1 to F9 shown in Figure 3, Table 2 sustained drug release up to 8 hr was observed.

Application of Drug Release Data to Mathematical Models

The release curves were also subjected to various studies such as zero order, first order, Higuchi, and Korsmeyer-Peppas models and coefficient value (R^2) in Figure 4. Graphical representations of the cumulative percentage of drug release against time showed that the release from the disc correctly followed the first order kinetics.

FTIR Spectrum analysis

FTIR analysis was performed to analyze agglomeration, stability and determine the key functional groups shown in Figure 5. All

peaks appearing in the spectrum were assigned to O-H of alcohol, C-N of aliphatic amines or alcohol/phenol, N-H deformation of amines, and C-C bending, N-H of amines, N-C=O amide bond of proteins, H-C=O: C-H stretch of aldehydes, $C \equiv N$ stretch of nitriles, C-H of alkanes, C=O of carboxylic acid/aldehydes or ester, N-O of nitro compounds respectively. The functional groups were identified and reported for the extract and excipient are $3155-3033\text{ cm}^{-1}$ O-H stretching, 1593 cm^{-1} , N-H bending, extracts shown 3497 cm^{-1} O-H strong stretch, 3200 cm^{-1} O-H alcohol, 3242 cm^{-1} C-H alkene, 1928 cm^{-1} C=C=C allene, 1262 cm^{-1} C-N amines. Further the strong interactions of the formulation i.e. disc were observed when the peak shift occurred in the following regions. The O-H stretch was shifted from $3310-3276$ to $2988-2916\text{ cm}^{-1}$ due to reduction. The C-O stretching was shifted form $1195-1080$ to $1264-1177\text{ cm}^{-1}$ as vinyl stretching. The C-H bending shift was observed from $2028-1894\text{ cm}^{-1}$. No agglomeration was observed proving the stability if the formulation.

SEM analysis

Figure 6 displays the images of the 3D-printed discs taken at two different magnifications ($100\times$ and $500\times$) for the purpose of studying the surface morphology of polyherbal formulation F9 using Scanning Electron Microscopy (SEM). Figures 5a and 5b showed the disc's cross-section, while Figures 5c and 5d showed the matrix porosity properties and the size of its drug particles 467.3 nm to $1.013\text{ }\mu\text{m}$ range. Which helped it absorb water and exude its contents; these images suggested that a polymeric matrix may be present, formulation showed $400-600\text{ nm}$ particle range this helps in penetration of drug into deeper layers of the skin, which can helps in site specific drug delivery to reduce the infection.²⁶

Table 1: Composition of formulations F1 to F9.

Formulation	HPMC (g)	PEG 400 (g)	Water (mL)
F1	1.0	0.25	17.5
F2	1.25	0.5	19
F3	1.5	0.75	18.5
F4	1.75	1.0	17
F5	1.8	0.5	16.5
F6	2.0	1.0	16
F7	2.5	0.75	15.5
F8	3	1.0	17
F9	3.5	0.5	16

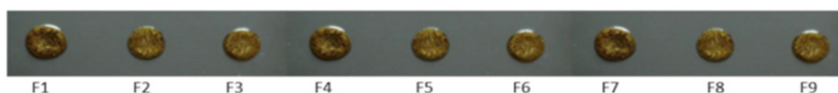


Figure 1: Polyherbal 3D-printed antimicrobial discs of F1-F9 Formulations prepared by semi-solid extrusion technique.

Table 2: Physical properties of 3D discs (F1-F9 formulations).

Formulation	Weight (mg)	Surface pH	Thickness (mm)	Diameter (mm)	% Drug content	% Drug release after 8 hr
F1	18.7±3.09	5.52±0.01	2.05±0.042	6.071±0.006	82.35±4.12	82.0±1.24
F2	20.1±2.64	5.56±0.02	2.17±0.016	6.092±0.012	83.45±2.54	86.2±1.34
F3	24.2±2.23	5.47±0.03	3.09±0.075	6.0±0.012	91.05±3.45	87.9±2.22
F4	26.0±2.16	5.67±0.01	3.03±0.056	6.04±0.01	89.45±2.62	91.0±2.35
F5	22.8±1.85	5.76±0.06	2.10±0.016	6.56±0.006	81.3±4.56	91.6±2.28
F6	28.2±1.38	5.57±0.04	2.02±0.073	6.67±0.017	93.45±1.35	90.3±2.32
F7	20.5±1.24	5.79±0.05	2.40±0.074	6.58±0.001	90.5±2.64	94.7±2.34
F8	19.5±1.15	5.45±0.04	2.06±0.016	6.63±0.021	88.5±5.58	88.7±2.51
F9	18.8±1.05	5.35±0.02	2.03±0.025	6.54±0.006	96.27±3.45	96.1±2.24

Table 2 shows the characteristics like weight variation, thickness, and drug contents of all formulations, the values are in mean $\pm$ standard deviation, Formulation F5, F7, F9, 91.6 $\pm$ 2.28, 94.7 $\pm$ 2.34, 96.1 $\pm$ 2.24 shown sustained drug release up to 8h. All experiments performed in triplicate.

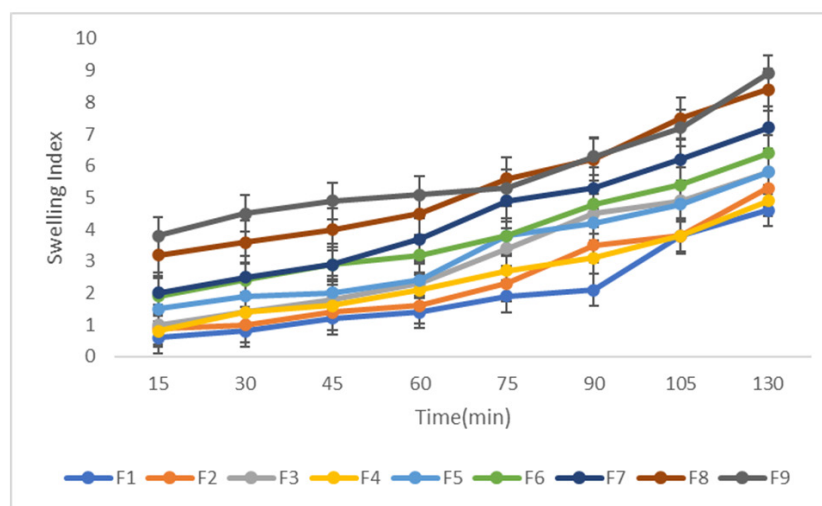


Figure 2: Represents the rate of swelling index of HPMC increases with an increase in the concentration and the viscosity grade of the polymer (F1-F9 Formulations) over 3 H (Mean $\pm$ SEM).

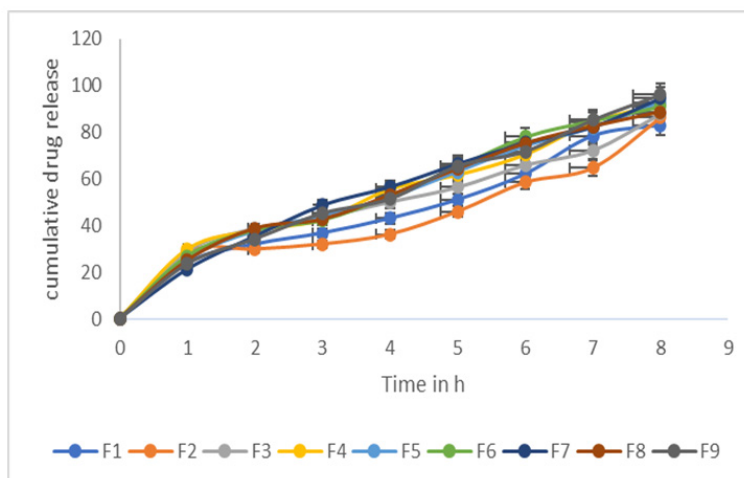


Figure 3: cumulative drug release F1 to F9 up to 8 hr.

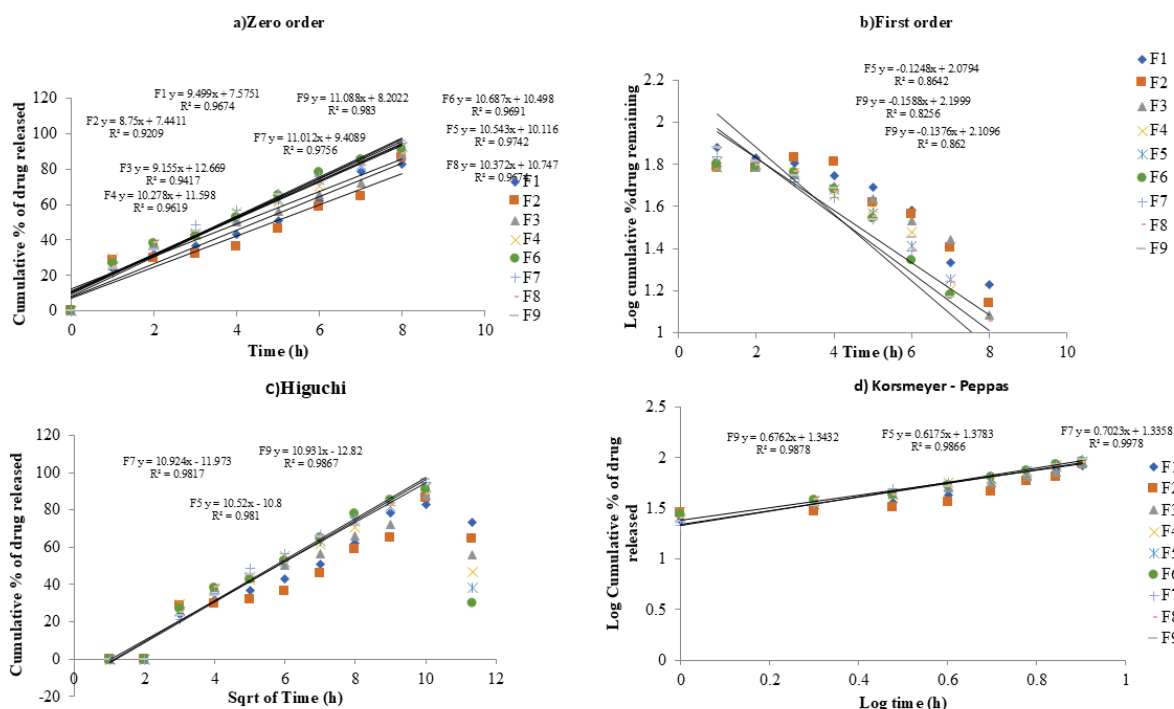


Figure 4: Kinetic release profiles of polyherbal discs: a) Zero order, b) First order, c) Higuchi, d) Korsmeyer-Peppas models.

Table 3: Zone of inhibition (mm) for optimized formulated 3D discs.

Formulation	<i>Escherichia coli</i>	<i>Pseudomonas aeruginosa</i>	<i>Staphylococcus aureus</i>	<i>Candida albicans</i>
F9	20.76±2.25	18.43±1.95	17.3±2.85	16.8±2.7
Standard	22.5±2.7	18.2±3.7	18.4±2.90	18.3±3.80

Represents the zone of inhibition of the standard and test drugs in gram positive, gram negative and fungal microorganisms.

Antimicrobial activity

MIC of each plant extract determined by using 96 well plate method 0.125 mg/mL, 0.325 mg/mL, and 0.625 mg/mL each plant respectively. 3D discs with polyherbal extract and a standard drug (Amoxicillin) has an antibacterial effect on selected microorganisms and produced inhibition. Table 3 and Figure 7 shows the average zone of inhibition in mm. The average inhibition zone diameters of polyherbal and standard-containing 3D discs were calculated for *E. coli*, *Staphylococcus aureus*, *Staphylococcus pneumonia*, and *Candida albicans* relatively high antimicrobial activity was observed for 3D disc with zone of inhibition ranging from 16 to 20 mm, Standard amoxicillin as 18 to 22 mm respectively, experiments were performed in triplicate.²⁷ Mechanism of antibacterial activity of three different plant extracts (AV, PO and HA) were represented in Figure 8.

DISCUSSION

By providing customized, location-specific, and precisely regulated medication delivery systems, 3D printing technology has utterly transformed the biomedical and pharmaceutical industries. Semisolid Extrusion (SSE) is one of the most popular

3D printing methods for making drug-loaded structures, especially hydrogels. This is because SSE is compatible with bioactive substances that are sensitive to temperature changes and can have their formulations easily changed. This research used SSE to create polyherbal antimicrobial discs that combined the antibacterial properties of *Artemisia vulgaris*, *Hemionitis arifolia*, and *Piper officinarum* into matrices based on HPMC-K100M and PEG-400. The biocompatibility, swelling characteristics, and capacity to produce homogeneous gel matrices that are appropriate for extrusion printing made these polymers the top choices. Research has shown that 3D printing using SSE may create antimicrobial dressings and scaffolds with specific surface shape, drug release kinetics, and porosity. As an example, SSE enables the exact deposition of hydrophilic formulations to create multi-layered drug delivery systems with site-specific action, according to Melocchi *et al.* (2020). The use of SSE printing to create sustained-release patches for wound healing with cellulose-based gels was also covered by Windolf *et al.* (2019). This investigation confirms previous findings by showing that formulation F9 is the most optimal in terms of drug release behavior (first-order kinetics), structural compatibility (FTIR), and good Surface Morphology (SEM). One way these 3D-printed

discs can be used therapeutically is by adding herbal bioactives that have antibacterial capabilities. Both conventional medicine and scientific research have shown that the chosen plant extracts have antibacterial properties. As an example, the essential oil of *Artemisia vulgaris* has antibacterial and antifungal activities that may be felt across a wide range of microorganisms. On the other hand, the bioactive alkaloids and phenolic compounds found in *Piper officinarum* are notorious for their anti-infective effects.

Our analysis validated the significant antibacterial activity seen against *E. coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans*, which was likely due to the synergy of these extracts. And with less systemic exposure and better targeted distribution, these discs are just as effective against microbes as traditional antibiotics like amoxicillin-if not more so. Prior studies have highlighted the significance of targeted medication distribution to avoid systemic adverse effects and slow down

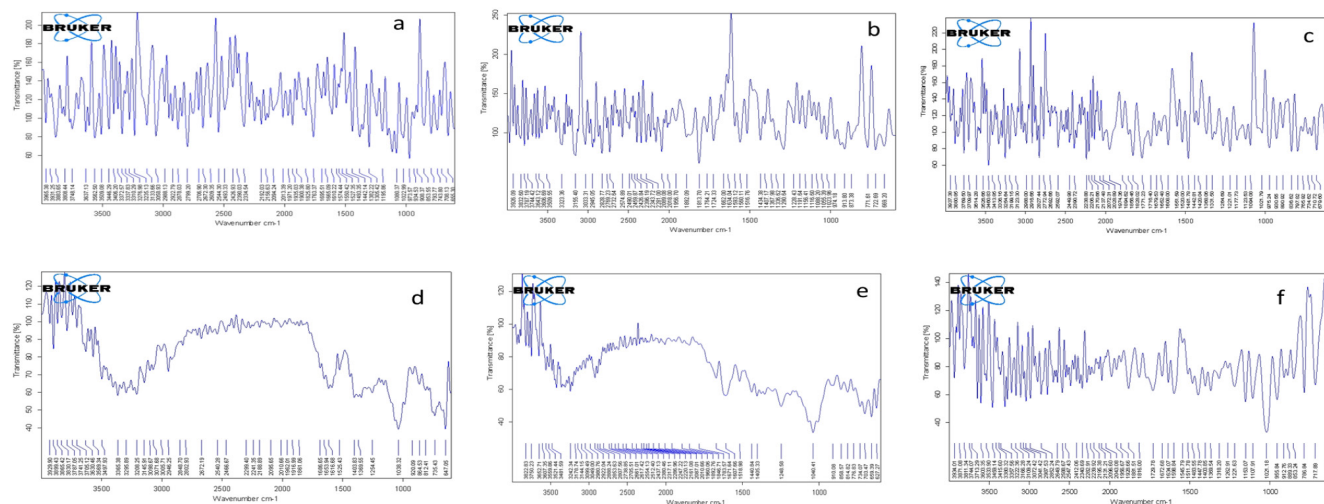


Figure 5: FTIR spectra for a) PEG-400, b) *Piper officinarum*, c) Polyherbal Disc, d) *Artemisia vulgaris*, e) HPMC, and f) *Hemionitis arifolia*.

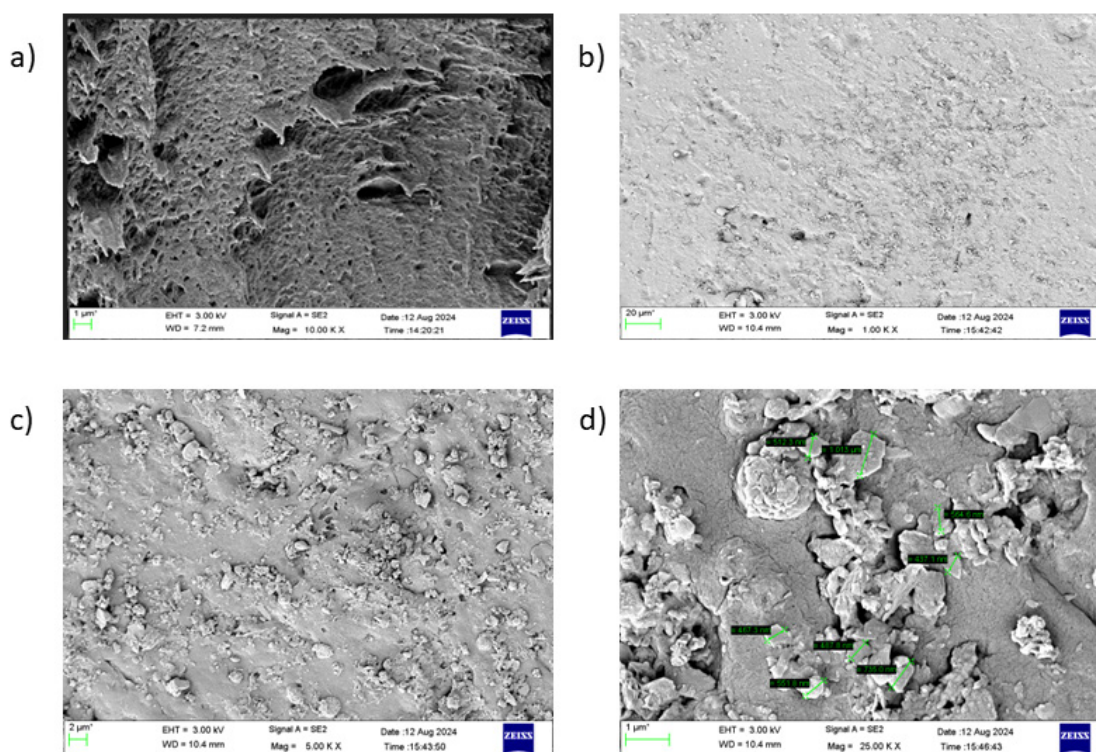


Figure 6: SEM images of the 3D-printed polyherbal discs: at 100× magnification; at 500× magnification; indicates the shape and size of the particle.

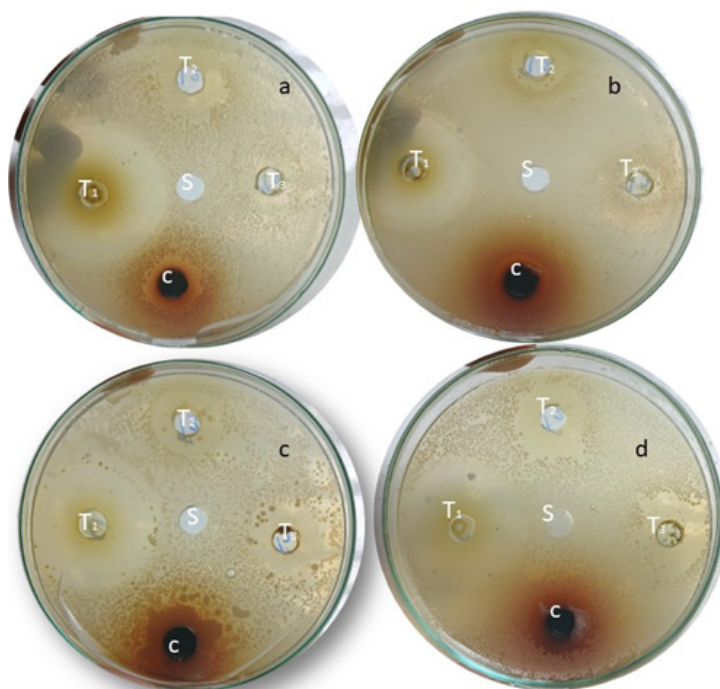
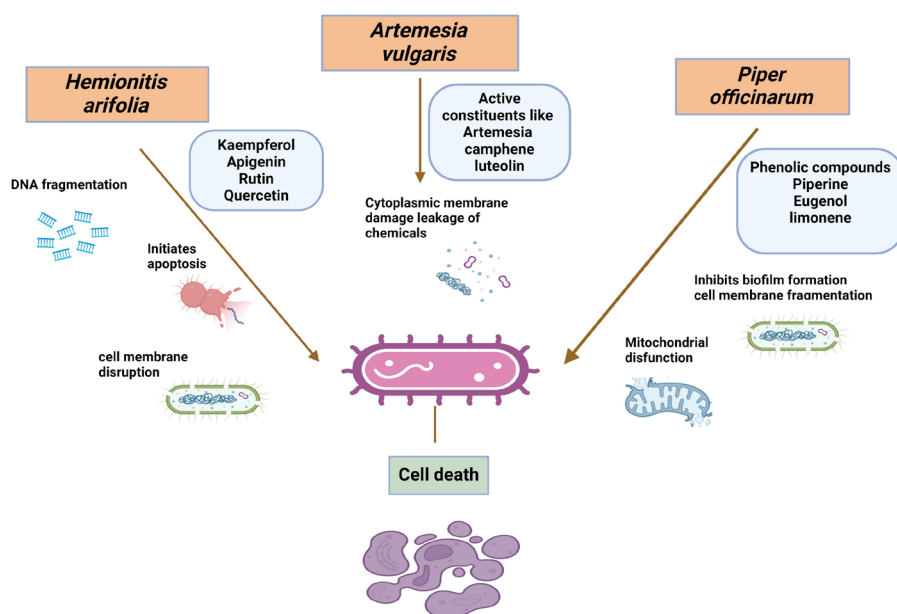


Figure 7: Antibacterial activity of 3D discs against (A) *Escherichia coli*, (B) *Pseudomonasaeruginosa*, (C) *Staphylococcus aureus*, and (D) *Candida albicans* (C = control (amoxicillin) and T = test (disc), S = Solvent used 1% (DMSO).



Created in BioRender.com bio

Figure 8: Mechanisms of antimicrobial action of *Piper officinarum*, *Artemesia vulgaris*, and *Hemionitis arifolia*.

the development of Antimicrobial Resistance (AMR). A study conducted by Khaled *et al.* (2018) found that antimicrobial drugs may be more effectively delivered to infection locations using 3D-printed structures that had programmable release characteristics. This finding is in line with this research.

The consistency and reliability of the preparations were validated by the physicochemical tests, which encompassed particle size distribution (ranging from 467.3 nm to 1.013 μ m), thickness, and consistency. Skin permeability and antibacterial penetration are both improved by the tiny particle size. In addition, SSE's flexibility enabled the adjustment of medication dose and disc diameters, highlighting the possibility of personalized treatment. This study concludes that SSE technology can be used to create polyherbal 3D-printed antimicrobial discs that are tailored, cost-effective, and powerful. To fully utilize their potential in managing Multidrug-Resistant (MDR) infections and expediting wound healing, future research should concentrate on in vivo efficacy investigations, medication absorption through skin layers, and clinical application.

CONCLUSION

The creation of tailored medication delivery systems to fight against Antimicrobial Resistance (AMR) is one area where 3D printing has shown to be a game-changer in healthcare. To reduce the danger of resistance development, preserve the normal microbiota, and minimize systemic exposure, this technology allows for the manufacture of antibiotic-infused polymers that can transport therapeutic agents directly to the site of infection. Treatment can be fine-tuned by including ecologically responsive 3D-printed devices that release antibiotics in reaction to certain stimuli like pH or temperature. Our research centered on this topic, and specifically on the utilization of 3D printing and the solvent casting technique to create polyherbal antimicrobial discs. Tests for drug release kinetics, swelling index, and pH stability were conducted on formulations F1-F9 that had varied amounts of Hydroxypropyl Methylcellulose (HPMC) and Polyethylene Glycol (PEG). Optimal surface shape and sustained, first-order drug release were features of formulation F9, which outperformed the others. A wide variety of bacteria, including *E. coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans*, were all susceptible to the discs broad-spectrum antibacterial action. In view of these results, 3D-printed polyherbal discs may offer a more economical option for the treatment of MDR infections and for improving the healing process once wounds have healed. Their pharmacokinetics, *in vivo* effectiveness, and clinical translational relevance should be the subjects of future research.

ACKNOWLEDGEMENT

The authors would like to acknowledge Sri Balaji Vidyapeeth and St. Pauls College of Pharmacy for providing facilities to carry out this study.

ABBREVIATIONS

3D: Three-dimesional; **SSE:** Semi-solid extrusion; **HPMC:** Hydroxypropyl methylcellulose; **PEG:** Polyethylene glycol; **MDR:** Multidrug-resistant; **FDM:** Fused deposition modelling; **FTIR:** Fourier Transform Infrared Spectrophotometer; **SEM:** Scanning Electron Microscopy; **MIC:** Minimum inhibitory concentration; **MHA:** Muller Hinton agar; **AV:** Artemisia vulgaris; **HA:** Hemionitis arifolia; **PO:** *Piper officinarum*.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ORCID ID

Boddu Suhasini: 0009-0005-7399-0214; **Karthikeyan Ramadoss:** 0000-0001-8954-1361; **Kiranmai Mandava:** 0000-0002-7487-2237; **Prakash katakam:** 0000-0001-7459-8998.

SUMMARY

3D printing technology is transforming pharmaceutical research by facilitating the production of individualized medications according to particular patient requirements. In contrast to traditional dosage forms that frequently result in non-compliance, sub-therapeutic, or overdose complications, 3D printing facilitates accurate medication creation tailored to specific data. It facilitates tailored drug release patterns, multi-compartment systems, and precise dosage, enhancing therapeutic efficacy and patient compliance. Furthermore, it facilitates the fabrication of complex geometries, porous architectures, and diverse dosage forms such as oral tablets, Transdermal Delivery Systems (TDS), and implants, hence expanding opportunities in drug discovery and clinical application. The 3D-printed discs not only equalled standard antibiotics in efficacy but also provided targeted drug administration, minimizing systemic exposure and contributing to the combat against Antimicrobial Resistance (AMR).

REFERENCES

1. Ahovan ZA, Esmaeili Z, Eftekhari BS, Khosravimelal S, Alehosseini M, Orive G, Dolatshahi-Pirouz A, Chauhan NP, Janmey PA, Hashemi A, Kundu SC. Antibacterial smart hydrogels: New hope for infectious wound management. *Materials Today Bio.* 2022;17:100499.
2. Bergonzi C, Bianchera A, Remaggi G, Ossiprandi MC, Bettini R, Elviri L. 3D printed chitosan/alginate hydrogels for the controlled release of silver sulfadiazine in wound healing applications: design, characterization and antimicrobial activity. *Micromachines.* 2023;14(1):137.
3. Machado D, Castro J, Palmeira-de-Oliveira A, Martinez-de-Oliveira J, Cerca N. Bacterial vaginosis biofilms: challenges to current therapies and emerging solutions. *Frontiers in microbiology.* 2016;6:172812.
4. Mathew E, Gilmore BF, Larrañeta E, Lamprou DA. Antimicrobial 3D printed objects in the fight against pandemics. *3D Printing and Additive Manufacturing.* 2021;8(1):79-86.
5. Weiss AV, Koch M, Schneider M. Combining cryo-TEM and energy-filtered TEM for imaging organic core-shell nanoparticles and defining the polymer distribution. *International Journal of Pharmaceutics.* 2019;570:118650.
6. Badica P, Batalu ND, Chifriuc MC, Burdusel M, Grigoroscuta MA, Aldica GV, Pasuk I, Kuncser A, Popa M, Agostino A, Operti L. Sintered and 3D-printed bulks of MgB2-based materials with antimicrobial properties. *Molecules.* 2021;26(19):6045.
7. Blaskovich MA, Elliott AG, Kavanagh AM, Ramu S, Cooper MA. *In vitro* antimicrobial activity of acne drugs against skin-associated bacteria. *Scientific reports.* 2019;9(1):14658.

8. ElMalah NS, Hanafy SA, Osman EM, Aboulgheit SA, Baz AS. Effect of nanomodified 3D printed photopolymerizable resin on flexural strength, color, and antimicrobial efficacy: An in vitro study. *The Journal of Prosthetic Dentistry*. 2024;132(1):268-e1.
9. Doganay MT, Chelliah CJ, Tozluayurt A, Hujer AM, Obaro SK, Gurkan U, Patel R, Bonomo RA, Draz M. 3D printed materials for combating antimicrobial resistance. *Materials Today*. 2023;67:371-98.
10. Katakam P, Bhavaraju ML, Narayana TV, Bhandari K, Sriram N, Sisinty VS, Adiki SK. Navigating the challenges of 3D printing personalized medicine in space explorations: A comprehensive review. *Critical Reviews™ in Therapeutic Drug Carrier Systems*. 2024;41(6).
11. Li W, Hai Y, Yang R, Zheng K, Fang W, Yu J, Xie H, Huang Y, Ni K. Innovations of 3D printing technology in the clinical practice: Strategies against microbial and COVID-19 infection. *International Journal of Bioprinting*. 2024;10(4):2338.
12. Mace MA, Reginatto CL, Soares RM, Fuentefria AM. Three-dimensional printing of medical devices and biomaterials with antimicrobial activity: a systematic review. *Bioprinting*. 2024;38:e00334.
13. Ahmed SK, Hussein S, Qurbani K, Ibrahim RH, Fareeq A, Mahmood KA, Mohamed MG. Antimicrobial resistance: Impacts, challenges, and future prospects. *Journal of Medicine, Surgery, and Public Health*. 2024;2:100081.
14. Paczkowska-Walendowska M, Koumentakou I, Lazaridou M, Bikiaris D, Miklaszewski A, Plech T, Cielecka-Piontek J. 3D-printed chitosan-based scaffolds with *Scutellariae baicalensis* extract for dental applications. *Pharmaceutics*. 2024;16(3):359.
15. Pandey M, Choudhury H, Abdul-Aziz A, Bhattamisra SK, Gorain B, Carine T, Wee Toong T, Yi NJ, Win Yi L. Promising drug delivery approaches to treat microbial infections in the vagina: a recent update. *Polymers*. 2020;13(1):26.
16. Radhakrishnan S, Nagarajan S, Belaid H, Farha C, Iatsunskyi I, Coy E, Soussan L, Huon V, Bares J, Belkacemi K, Teyssier C. Fabrication of 3D printed antimicrobial polycaprolactone scaffolds for tissue engineering applications. *Materials Science and Engineering: C*. 2021;118:111525.
17. Riccio BV, Silvestre AL, Meneguín AB, Ribeiro TD, Klosowski AB, Ferrari PC, Chorilli M. Exploiting polymeric films as a multipurpose drug delivery system: a review. *AAPS PharmSciTech*. 2022;23(7):269.
18. Sa L, Kaiwu L, Shenggui C, Junzhong Y, Yongguang J, Lin W, Li R. 3D printing dental composite resins with sustaining antibacterial ability. *Journal of Materials Science*. 2019;54(4):3309-18.
19. Prabhu P, Shah S, Gundad S. Formulation development and investigation of domperidone transdermal patches. *International journal of pharmaceutical investigation*. 2011;1(4):240.
20. Singh M, Jonnalagadda S. Design and characterization of 3D printed, neomycin-eluting poly-L-lactide mats for wound-healing applications. *Journal of Materials Science: Materials in Medicine*. 2021;32(4):44.
21. Talevi A, Ruiz ME. Korsmeyer-peppas, peppas-sahlin, and brazel-peppas: models of drug release. In *The ADME encyclopedia: A comprehensive guide on biopharmacy and pharmacokinetics 2022* (pp. 613-621). Cham: Springer International Publishing.
22. Zuñiga J, Moscoso M, Padilla-Huamantínco PG, Lazo-Porras M, Tenorio-Mucha J, Padilla-Huamantínco W, Tincopa JP. Development of 3D-printed orthopedic insoles for patients with diabetes and evaluation with electronic pressure sensors. *Designs*. 2022;6(5):95.
23. Wu D, Wei D, Du M, Ming S, Ding Q, Tan R. Targeting antibacterial effect and promoting of skin wound healing after infected with methicillin-resistant *Staphylococcus aureus* for the novel polyvinyl alcohol nanoparticles. *International Journal of Nanomedicine*. 2021;4031-44.
24. Altun E, Yuca E, Ekren N, Kalaskar DM, Ficaí D, Dolete G, Ficaí A, Gunduz O. Kinetic release studies of antibiotic patches for local transdermal delivery. *Pharmaceutics*. 2021;13(5):613.
25. Danaei MR, Dehghankhold M, Ataei S, Hasanazadeh Davarani F, Javanmard R, Dokhani A, Khorasani S, Mozafari YM. Impact of particle size and polydispersity index on the clinical applications of lipidic nanocarrier systems. *Pharmaceutics*. 2018;10(2):57.
26. Goyanes A, Wang J, Buanz A, Martínez-Pacheco R, Telford R, Gaisford S, Basit AW. 3D printing of medicines: engineering novel oral devices with unique design and drug release characteristics. *Molecular pharmaceutics*. 2015;12(11):4077-84.

Cite this article: Boddu S, Ramadoss K, Mandava K, Katakam P. Design, Development and Evaluation of Polyherbal Antimicrobial Discs Using Semisolid Extrusion Based 3D Printing Technology. *Indian J of Pharmaceutical Education and Research*. 2027;61(1):190-9.