

## *Resistance of 3D - printed PVA filaments to bacterial degradation*

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**Abstract.** This study systematically evaluates the resistance of 3D-printed PVA filaments (Bambu Lab) to bacterial biodegradation and their potential antimicrobial activity against two widespread environmental strains: *Bacillus subtilis* (Gram-positive) and *Pseudomonas aeruginosa* (Gram-negative). Using the standardized agar diffusion method, a 15% PVA solution was tested against a positive control (gentamicin). The results showed no inhibition zones around the PVA samples for either bacterial strain, which clearly confirmed the lack of statistically significant antimicrobial activity ( $p > 0.05$ ). These findings unambiguously demonstrate that under the experimental conditions, the 3D-printed PVA material not only lacks bactericidal or bacteriostatic properties but also exhibits resistance to the metabolism of the test microorganisms. From an engineering and ecological perspective, this implies that although PVA is water-soluble, its ultimate biodegradation in nature may be slow and inefficient in the absence of specialized microbial consortia. Consequently, the widespread use of PVA in 3D printing could contribute to its accumulation in soil and aquatic ecosystems. This highlights the need for a re-evaluation of its environmental compatibility and the development of improved composite formulations or end of life management strategies aimed at ensuring true biodegradability.

**Key words:** PVA filament, bacterial degradation.

### **Introduction**

Polyvinyl alcohol (PVA) is a key material in 3D printing, particularly in the context of sustainable manufacturing, where minimizing environmental impact is essential (Basa et al., 2021; Dakova et al., 2025). As a water-soluble polymer, PVA serves as an alternative to conventional plastics such as PLA and ABS, offering substantial environmental advantages when used for support structures and complex forms (Duran et al., 2015; Goh & Hashimoto, 2018a).

Although marketed as biodegradable, the actual degradation of PVA depends on specific microorganisms and enzymes, sufficient time, and suitable environmental conditions like temperature and oxygen (Chareonying et al., 2020; Hadzhiev, 2023). Its hydrophilic nature facilitates water penetration and microbial activity under controlled conditions (Chareonying et al., 2020), which enables its application in outdoor environ-

ments and biomedical contexts where proper disposal after use is critical (Basa et al., 2021; Li et al., 2019).

The mechanical and viscoelastic properties of PVA are also of significance. Studies on sub-zero printed cryogels demonstrate that PVA structures retain orthotropic viscoelastic behavior (Crolla et al., 2021), while composite formulations with cellulose and alginate improve thermal stability and structural performance (Ni et al., 2017; Sailah et al., 2022). Such results highlight the capacity of PVA to serve in environments where both durability and controlled degradability are important.

Composite formulations significantly enhance the functionality and environmental profile of PVA. Cellulose-based composites improve both degradation rates and mechanical properties (Li et al., 2014; Stolz & Mülhaupt, 2020). Structures combining boron nitride and bacterial cellulose have found application in bone tissue engineering (Aki

et al., 2021), while additives such as boric acid confer antimicrobial properties without compromising transparency (Zhang et al., 2023). Parallel to these developments, water-soluble bio-composites enriched with polyphenols have been investigated as potential food packaging alternatives, offering controlled biodegradability and improved barrier properties (Grigorov & Viraneva, 2025). These findings indicate that PVA and related polymers could be integrated into a broader class of environmentally responsive materials.

The application of PVA in tissue engineering further extends its scientific and practical value, as 3D printed scaffolds enable regeneration strategies and biomedical implant design (Do et al., 2015). In addition, PVA has been widely studied as a sacrificial support for microfluidic channels, including complex overhangs and helical geometries (Goh & Hashimoto, 2018a,b). Such versatility demonstrates that the material is not only relevant for prototyping but also for highly specialized biomedical and engineering applications.

Advances in fused deposition modeling (FDM) highlight how solubilizing aids, layer thickness, and print width affect the performance of PVA filaments. Incorporating solubilizing agents alters filament entrapment and dissolution (Mahmood et al., 2020), while optimization of processing parameters can significantly improve structural integrity and support removal (Moradi et al., 2023). These insights emphasize the importance of process-material interactions for ensuring functional outcomes.

As a support material in dual-extrusion 3D printing, PVA enables the fabrication of complex geometries in biomedical devices and microfluidic channels (Duran et al., 2015; Goh & Hashimoto, 2018a,b; Li et al., 2019). However, the manufacturing processes raise environmental concerns related to water consumption, the use of chemical additives (Duran et al., 2015; Hadzhiev, 2023), and unresolved aspects such as the actual biodegradability of PVA in soil and aquatic ecosystems, its interactions with local microbial consortia, and potential environmental toxicity. These issues resonate with current discussions on circular economy strategies, which emphasize waste prevention, recycling, and the extension of product life cycles as essential mechanisms for sustainable development (Dakova et al., 2025). Furthermore,

ecological and legal analyses stress the importance of aligning material science innovation with conservation policies and environmental protection frameworks, ensuring that novel polymers do not contribute to biodiversity loss or ecosystem degradation (Hadzhiev, 2023).

Recent studies further underline the ecological perspective. Soil microbial assessments using Eco-Plate techniques highlight the variability of bacterial activity during seasonal transitions, suggesting that environmental conditions strongly modulate microbial responses to polymeric substrates (Dimitrova, 2024). At the same time, research on functional food bioproducts demonstrates how particle size and formulation affect material stability and moisture dynamics, illustrating the broader principle that material structure and environmental factors jointly determine degradation and persistence (Terziyska et al., 2023). Together, these insights frame the need for more comprehensive evaluations of PVA in natural ecosystems.

Given the unresolved questions regarding PVA's actual biodegradability and potential environmental persistence, this study directly addresses the critical need to evaluate the resistance of 3D-printed PVA filaments to bacterial degradation by common environmental microorganisms.

### Materials and methods

For the present study, PVA filament manufactured by Bambu Lab was used. This filament is easily water-soluble, provides smooth surface finishes after removal, and is recommended as a support material for all PLA and PETG filaments. It features a filament diameter of  $1.75 \text{ mm} \pm 0.03 \text{ mm}$ . Bambu PVA employs a high-quality formulation that dissolves efficiently in water, enabling effortless removal of support structures and eliminating the need for manual post-processing (Fig. 1). The recommended printing settings and physical properties are presented in Table 1.

For the purposes of this study, samples were printed using a Bambu Lab P1S 3D printer (Fig. 2).

The recommended maximum concentration of PVA dissolved in water is 10-15%. The samples were dissolved in 100 mL of distilled water to achieve the target concentration of 15% for testing (Fig. 3).

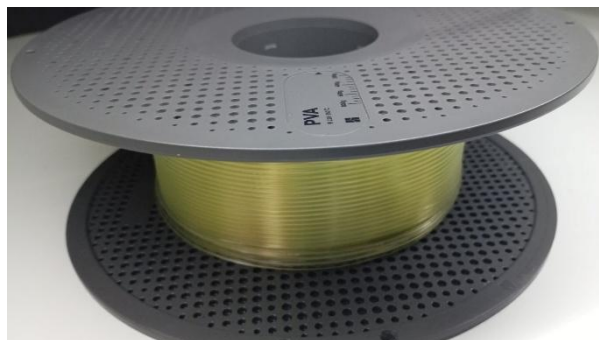


Fig. 1. PVA filament.

Table 1. Recommended printing settings and physical properties.

Recommended Printing Settings		Physical Properties	
Drying Settings (Blast Drying Oven)	80°C, 12 h	Density	1.27 g/cm <sup>3</sup>
Printing and keeping Container's Humidity	< 20% RH (Sealed, with Desiccant)	Vicat Softening Temperature	N/A
Nozzle Temperature	220 - 250°C	Heat Deflection Temperature	N/A
Bed Temperature (with Glue)	35 - 45°C	Melting Temperature	202°C
Printing Speed	< 200 mm/s	Melt Index	7.2 ± 1.1 g/10 min

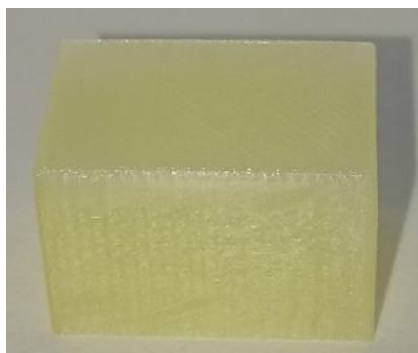


Fig. 2. The 3D printed PVA sample.



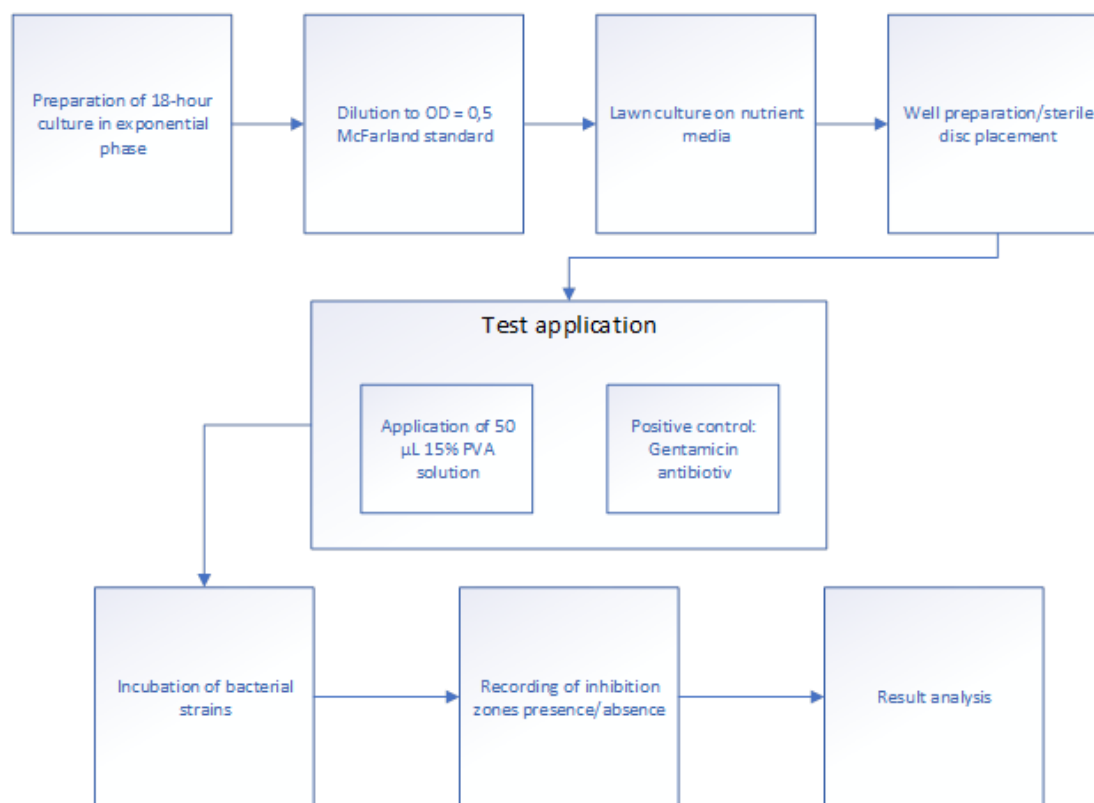
Fig. 3. PVA sample dissolution.

Since the present study aims to determine the biodegradability of 3D-printed PVA filament by bacterial action, as well as its potential antimicrobial properties, two environmentally widespread bacterial strains were used - *Bacillus subtilis* (Gram positive) and *Pseudomonas aeruginosa* (Gram negative). These strains serve as suitable model organisms for assessing ecological compatibility and potential toxicity toward microbial populations.

An 18-hour culture (in exponential growth phase) of each bacterial strain was diluted densitometrically to an optical density of 0.5 according to the McFarland standard. A lawn culture was prepared on Petri dishes containing nutrient media appropriate to the growth requirements of each species. Using a sterile cork borer, wells were ma-

de or sterile paper discs were placed. Under sterile conditions, 50  $\mu\text{L}$  of the test sample-diluted 15% PVA filament-was applied to each well or disc. After incubation of the bacterial cultures, the presence or absence of an inhibition zone was recorded. As a positive control, the antibiotic gentamicin was applied.

The methodological procedure for evaluating the antibacterial properties of 3D-printed PVA filament is visually summarized in Fig. 4. The experimental design followed standardized microbiological protocols to ensure reproducible and reliable results. The studies were carried out at the "Stefan Angelov" Institute of Microbiology at the Bulgarian Academy of Sciences, in a cellular microbiology laboratory.



**Fig. 4.** The methodological procedure for evaluating the antibacterial properties of 3D-printed PVA filament.

### Results and Discussion

The obtained results showed no evidence of sensitivity of the tested bacterial strains to the treatment sample, as indicated by the absence of inhibition zones. The lack of growth suppression zones, in contrast to the positive control, indicates that both strains were resistant to the applied concentration of the PVA filament. The experi-

ment was performed in duplicate in the presence of a positive control sample containing the antibiotic gentamicin (Fig 5). The quantitative results of the antimicrobial activity testing are summarized in Table 2. These results conclusively demonstrate the absence of inhibitory effects against both Gram-positive and Gram-negative bacterial strains.

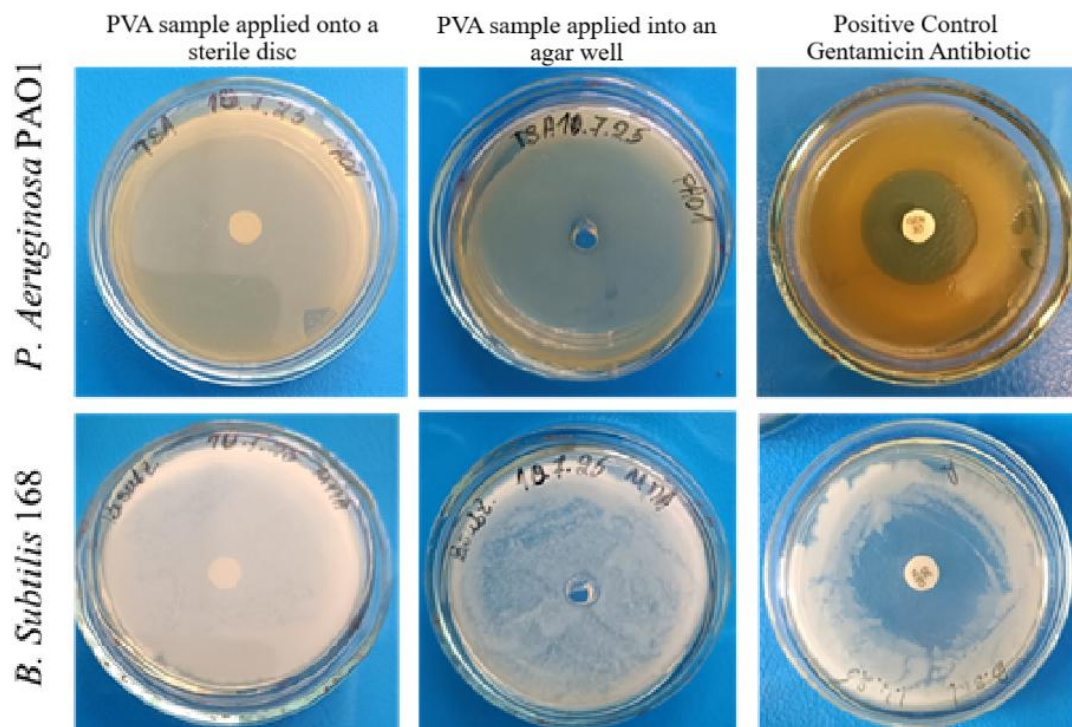


Fig. 5. Determination of the antimicrobial activity of PVA filament.

Table 2. The quantitative results of antimicrobial activity testing.

Test Sample	Concentration	<i>Bacillus subtilis</i> (Gram+)	<i>Pseudomonas aeruginosa</i> (Gram-)	Interpretation
PVA Filament	15%	No inhibition zone	No inhibition zone	No antimicrobial activity
Gentamicin (Positive Control)	10 µg/disc	Clear inhibition zone (25 mm)	Clear inhibition zone (22 mm)	Strong antimicrobial activity
Sterile Water (Negative Control)	-	No inhibition zone	No inhibition zone	No antimicrobial activity

### Conclusions

This study demonstrates that the 3D-printed PVA filament (Bambu Lab) does not exhibit antimicrobial activity against *Bacillus subtilis* (Gram-positive) and *Pseudomonas aeruginosa* (Gram-negative) under the tested conditions. The absence of inhibition zones around the PVA samples unlike the clear zone observed around the gentamicin control confirms that the material does not inhibit the growth of the test strains at a 15% concentration and does not possess bactericidal or bacteriostatic properties under the agar diffusion method.

These findings suggest that the PVA filament resists bacterial degradation by the studied microorganisms. In the context of environmental impact, this indicates a potential for persistence in aquatic and soil ecosystems, as the lack of bacterial metabolic activity limits its natural breakdown.

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