Biopolymeric scaffold enriched with tannic acid and ferulic acid as a potential material for periodontal regeneration

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Introduction

Periodontitis is a chronic multi-factorial inflammatory disease associated with dysbiotic plaque biofilms and characterized by the progressive destruction of the tooth-supporting apparatus, including the gingiva, periodontal ligament, and alveolar bone [1]. If left untreated, it leads to tooth loss and may contribute to systemic health complications. This condition is primarily provoked by the accumulation of pathogenic bacteria (dental plaque), which triggers a host immune response [2]. This persistent inflammation leads to excessive oxidative stress, further accelerating tissue degradation and preventing natural healing [3].

Research Objective

1.To develop chitosan–collagen (CTS/Coll) composite hydrogels modified with phenolic acids (tannic acid - TA and ferulic acid - FA).
2.To evaluate the physicochemical and mechanical properties of the obtained scaffolds.
3.To investigate antioxidant activity and polyphenols release.

Methods

Multifunctional composites were fabricated via lyophilization using a chitosan–collagen matrix modified with tannic (TA) and ferulic (FA) acids (Figure 1). The chemical structure and successful integration of polyphenols were verified by ATR-FTIR spectroscopy using a Nicolet iS5 spectrometer (Thermo Fisher Scientific). Mechanical properties were assessed through compression testing using a Shimadzu EZ-Test EZ-SX machine (Kyoto, Japan), while the stability of the scaffolds was monitored via degradation studies for 7 days in phosphate-buffered saline (PBS). Additionally, the release concentrations of TA and FA from the polymer network were investigated over time using the Folin-Ciocalteu method.

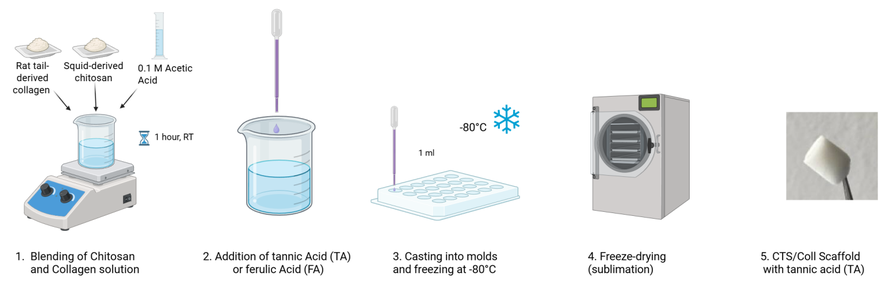
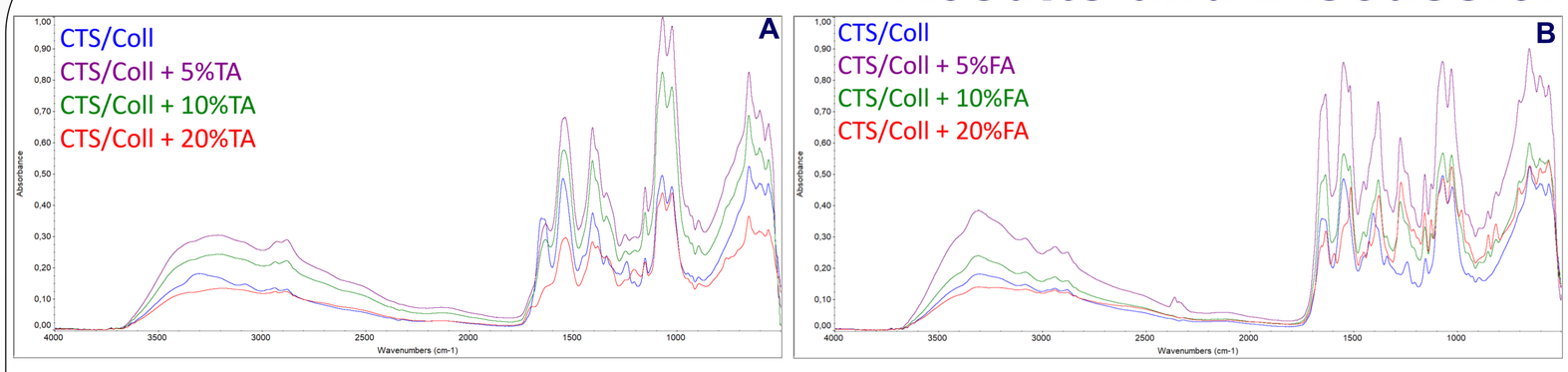


Fig. 1. Fabrication workflow for CTS/Coll composite scaffolds and final 3D porous structure

Results and Discussion



ATR-FTIR spectroscopy confirmed the successful incorporation of tannic (TA) and ferulic (FA) acids into the CTS/Coll matrix. The spectra display characteristic peaks for Amide I (~1630 cm^{-1}) and Amide II (~1540 cm^{-1}), typical for collagen and chitosan. The addition of polyphenols led to shifts in the hydroxyl (-OH) and amino ($-NH_2$) vibration regions, indicating the formation of new hydrogen bonds. These chemical interactions are responsible for the stable structure and controlled release profile of the composites.

Fig. 2. ATR-FTIR spectra of chitosan/collagen (CTS/Coll) scaffolds modified with: (a) tannic acid (TA) and (b) ferulic acid (FA). Note the characteristic amide peaks and shifts due to polyphenol cross-linking

Table 1. Average mass loss (Average mass loss Δm (mg) ± SD) of chitosan/collagen scaffolds modified with tannic (TA) and ferulic (FA) acids after 7 days of incubation in PBS

Sample	Average mass loss Δm [mg]
CTS/Coll	6.700 ± 4.107
CTS/Coll + 20%TA	7.500 ± 1.375
CTS/Coll + 20%FA	3.800 ± 0.557
CTS/Coll +10%TA	7.000 ± 1.752
CTS/Coll +10%FA	3.430 ± 0.208

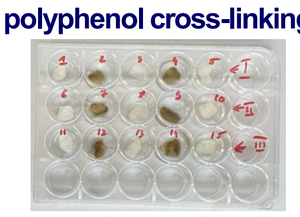


Fig. 3. Visual monitoring of scaffold degradation in a 24-well plate after 7 days in PBS.

The degradation study revealed that the incorporation of polyphenols significantly influences the stability of chitosan/collagen scaffolds. Samples modified with ferulic acid (FA) exhibited the highest stability, with a mass loss of only ~3.4–3.8 mg after 7 days in PBS. In contrast, scaffolds with tannic acid (TA) showed higher degradation rates, similar to the pure CTS/Coll control. Visual observation (Table 1) confirms that all scaffolds maintained their physical integrity, although a characteristic color change was observed in polyphenol-modified groups due to the natural pigment of the cross-linkers develop chitosan–collagen (CTS/Coll) composite hydrogels modified with phenolic acids (tannic acid - TA and ferulic acid - FA).

Table 2. Concentration of polyphenols released from the scaffolds over time [mg/ml]

Sample name	Concentration [mg/ml]			
	1h	3h	5h	7h
CTS/Coll	—	—	—	—
CTS/Coll + 20%FA	0.293 ± 0.046	0.301 ± 0.060	0.285 ± 0.068	0.247 ± 0.041
CTS/Coll + 20%TA	0.205 ± 0.035	0.171 ± 0.007	0.170 ± 0.008	0.170 ± 0.009
CTS/Coll + 10%FA	0.252 ± 0.014	0.277 ± 0.010	0.250 ± 0.003	0.224 ± 0.008
CTS/Coll + 10%TA	0.123 ± 0.002	0.139 ± 0.004	0.140 ± 0.002	0.145 ± 0.007

Release profiles of ferulic (FA) and tannic (TA) acids demonstrated a sustained delivery mechanism. The amount of released compounds was directly proportional to their initial concentration in the scaffold, with Group II (20%) showing the highest release. The absence of an initial burst effect indicates that the active compounds are uniformly distributed and chemically bound within the polymer network, ensuring a prolonged therapeutic effect.

Conclusions

This study successfully developed chitosan–collagen composites modified with tannic (TA) and ferulic (FA) acids. TA-enriched scaffolds demonstrated superior mechanical strength and slower degradation compared to FA. Both formulations showed high antioxidant activity and controlled polyphenol release, essential for modulating oxidative stress in periodontal defects. Due to its efficient hydrogen bonding, the TA-modified composite is the most promising candidate for tissue regeneration. Future work in 2026 will focus on cytotoxicity and hemocompatibility assays.

References

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