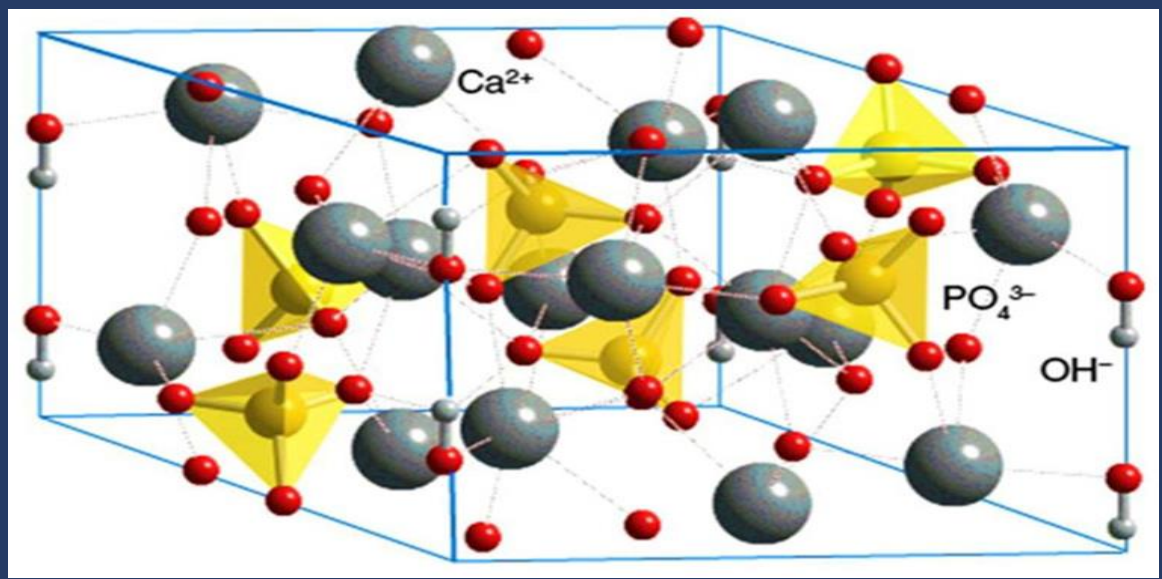


INTRODUCTION

This project studies the formation of Liesegang rings in far-from-equilibrium chemical systems, where self-organization spontaneously creates ordered calcium hydroxyapatite structures capable of promoting bone tissue regeneration.



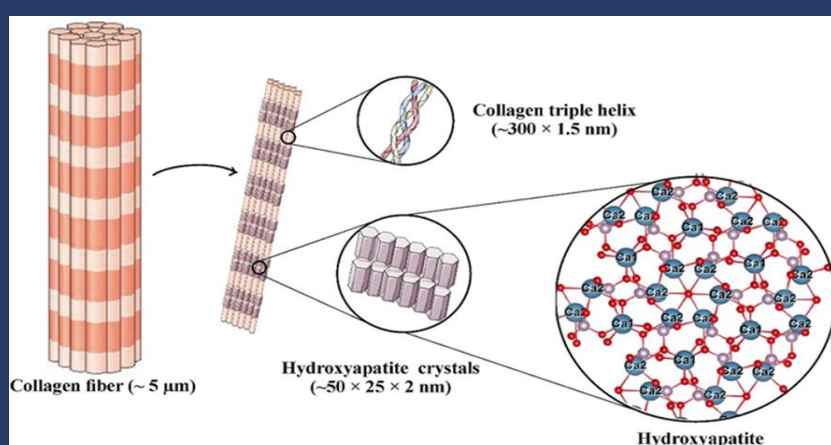
Photo taken by Finalist



Original image from: <https://doi.org/10.3390/ma15196864>

RESEARCH QUESTION

- Can far-from-equilibrium systems be used for bone regeneration and controlled painkiller release?



Original image from: <https://doi.org/10.1016/j.ceram.2021.100122>

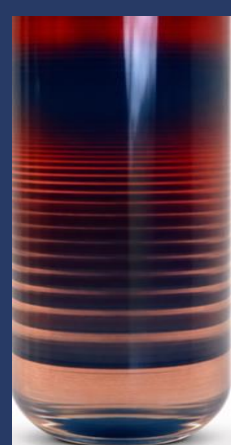


Photo taken by Finalist

ENGINEERING GOALS

- The goal is the study of self-organized systems.
- Liesegang rings are phenomena that develop spontaneously in systems that are far from equilibrium.



Photo taken by Finalist



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EXPERIMENTAL PROCEDURES

First step: Periodic precipitation with $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in 1% agarose gel. External electrolyte NH_4OH .

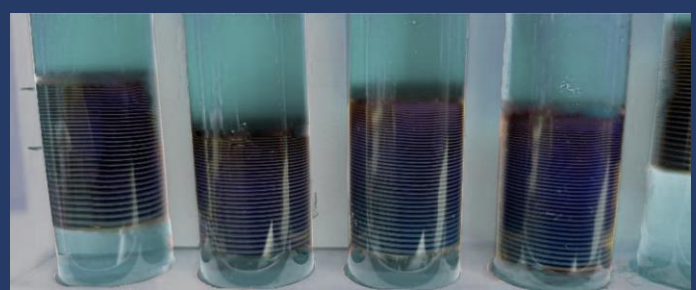


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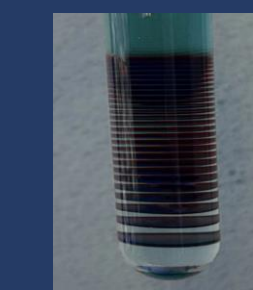


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Second step (RINGS): The second periodic precipitation was performed with Na_2HPO_4 in 3% agar gel. CaCl_2 was used as an external electrolyte. The reaction: $\text{CaCl}_2 + \text{Na}_2\text{HPO}_4 \rightarrow \text{CaHAP} \downarrow + 2\text{NaCl}$

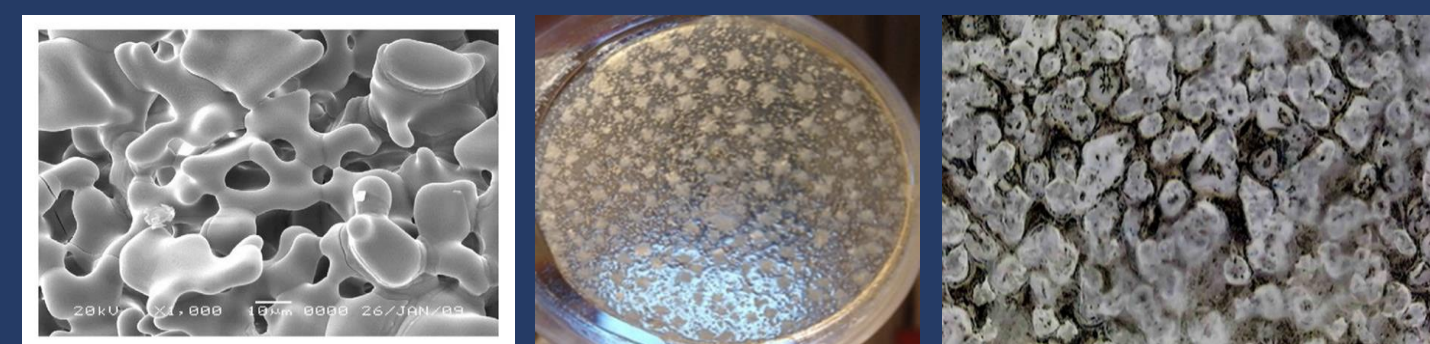


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- Third step (ISLANDS):** gelation of 0.1 M Na_2HPO_4 in 5% agar-agar at pH 7, subsequent addition of 1M CaCl_2 . The irregular light spots are islands of calcium hydroxyapatite $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$.



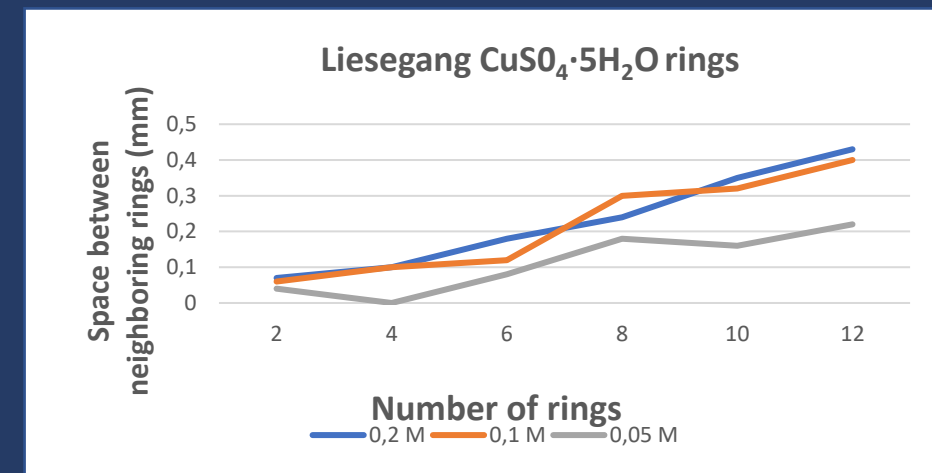
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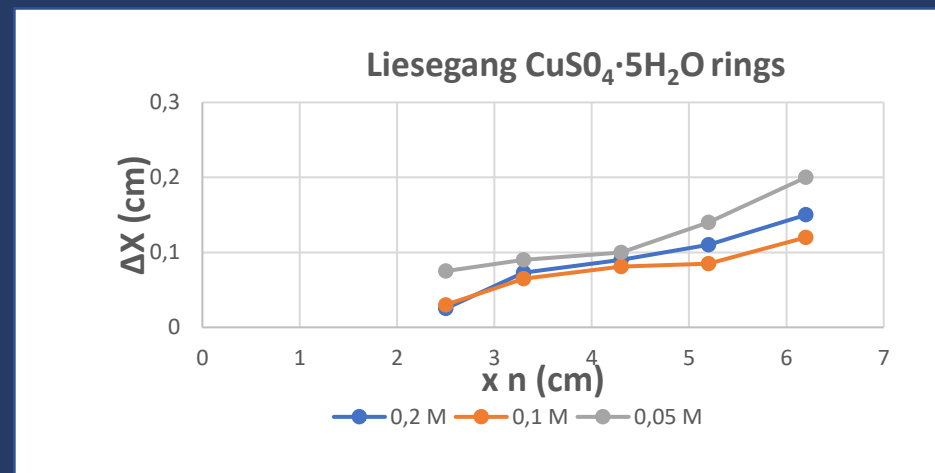
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Photo taken by Finalist using HiView20230724

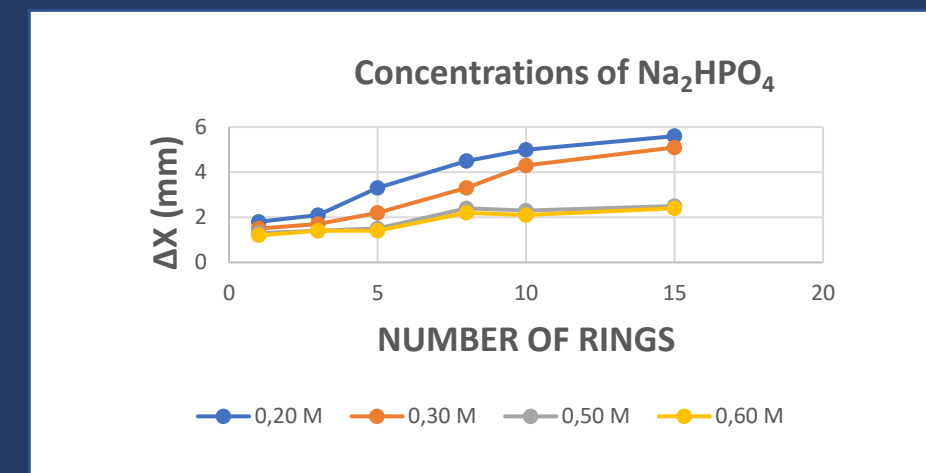
RESULTS (Liesegang Rings)



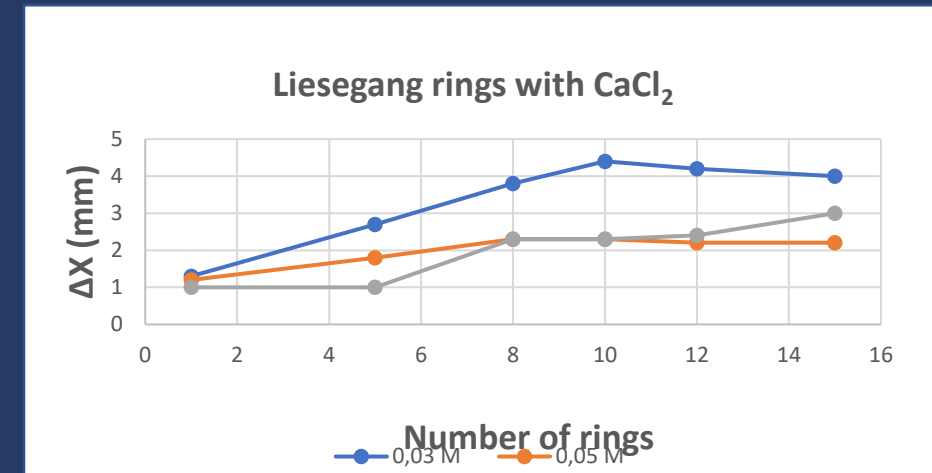
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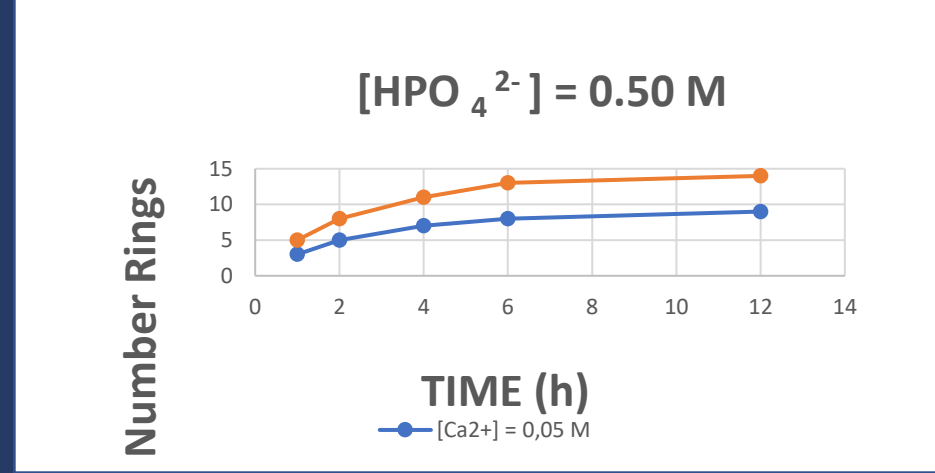
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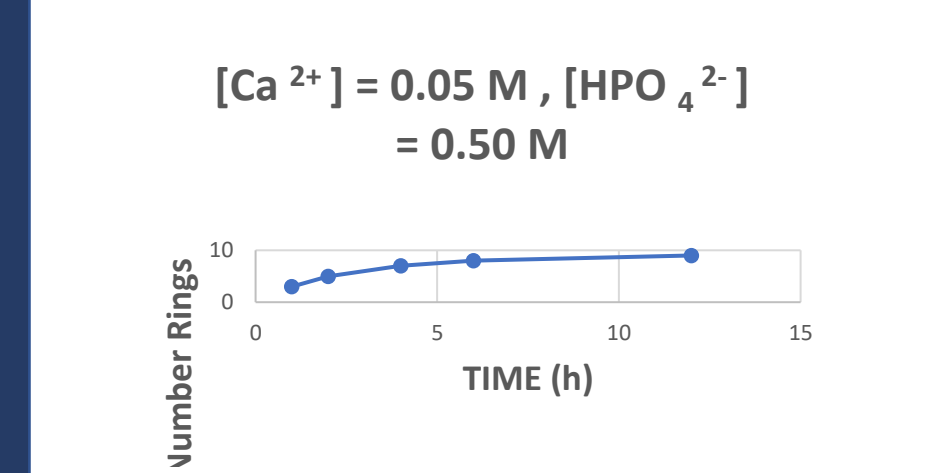
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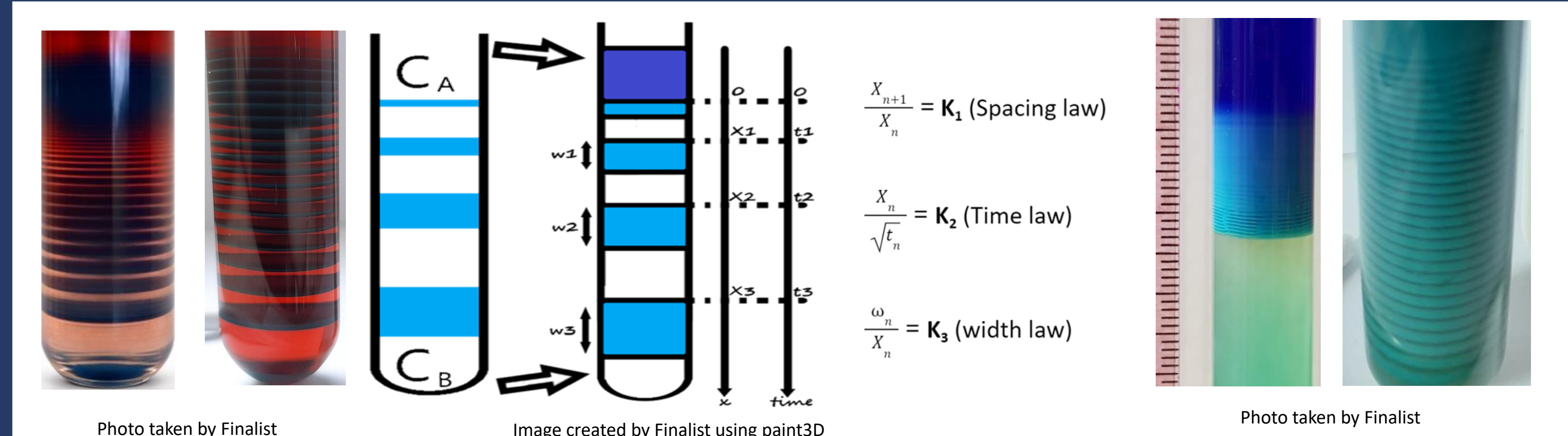


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x_n the distance of the n-th band from the spreading front; t_n the expected time of the n-th band; w_n the width of the n-th band; Liesegang rings have the following scaling properties: (constants k_1, k_2, k_3)

RESULTS (Liesegang Islands)

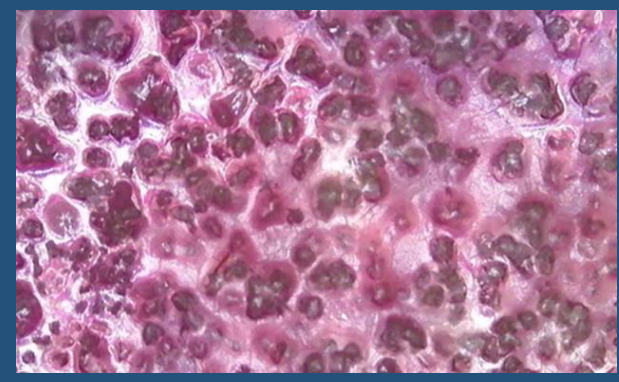
- It is not a completely random distribution
- Larger islands (85-110) tend to organize into zones or bands
- They have a radial or spotted near-periodicity
- Agar/gel works as a diffusive matrix
- The ΔC create zones where nucleation is favored and ones where it is inhibited

Typical indications of Liesegang are:

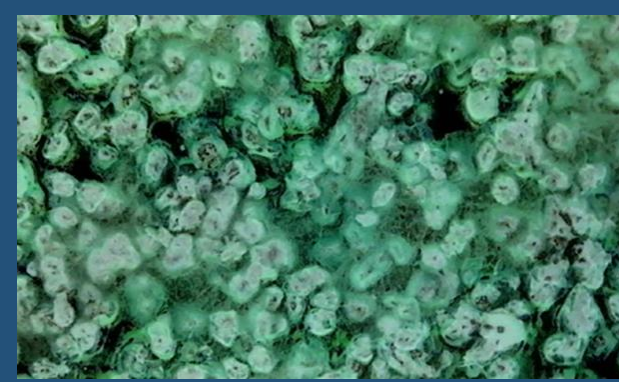
- Repeated clusters (non-uniform)
- Non-random distances between large colonies
- Hint of radial structure
- Coexistence of different scales (micro + macro)



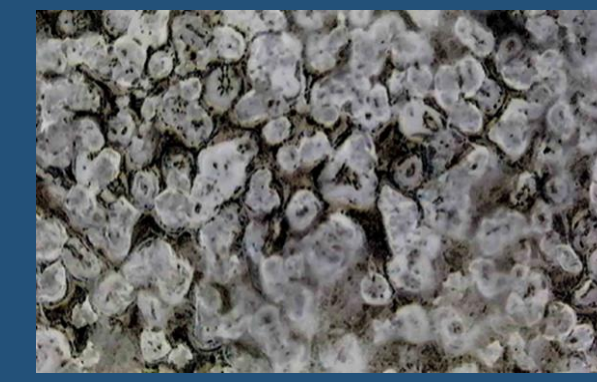
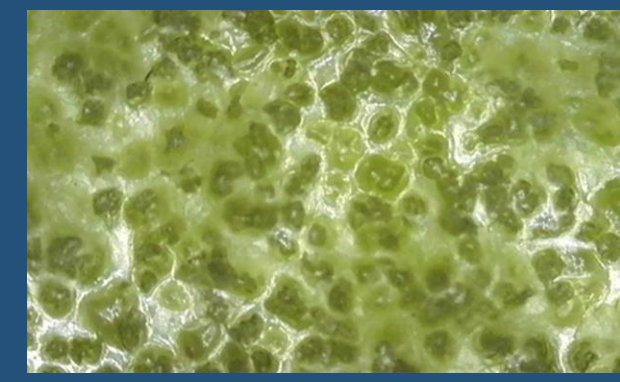
Photo taken by Finalist



Photos taken by the finalists using optical microscope with the software HiView20230724



Photos taken by the finalists using optical microscope with the software HiView20230724



Disturbed logarithmic spiral:

- arises from a nucleation center
- non-uniform radial growth disturbed by:
 - collisions between crystals
 - local variations in concentration

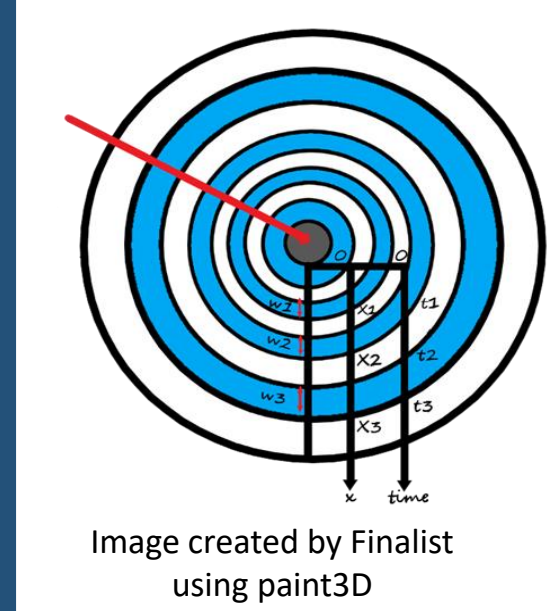


Image created by Finalist using paint3D



Photo taken by the finalist modified by GPT-5 by OpenAI on April 08, 2026

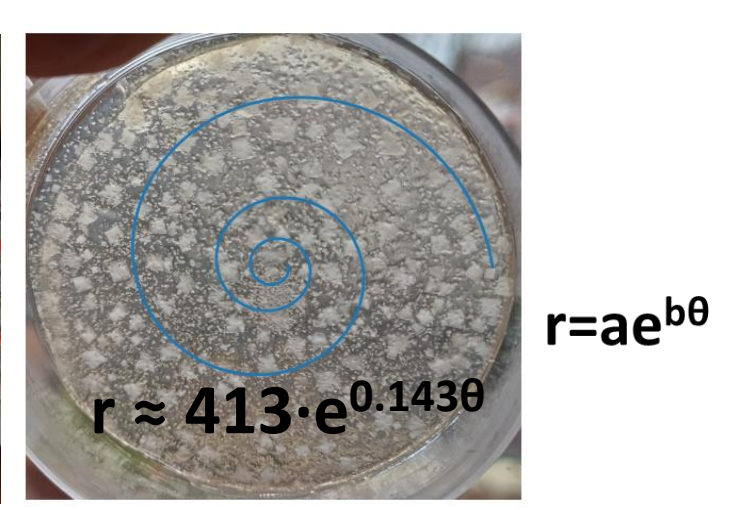
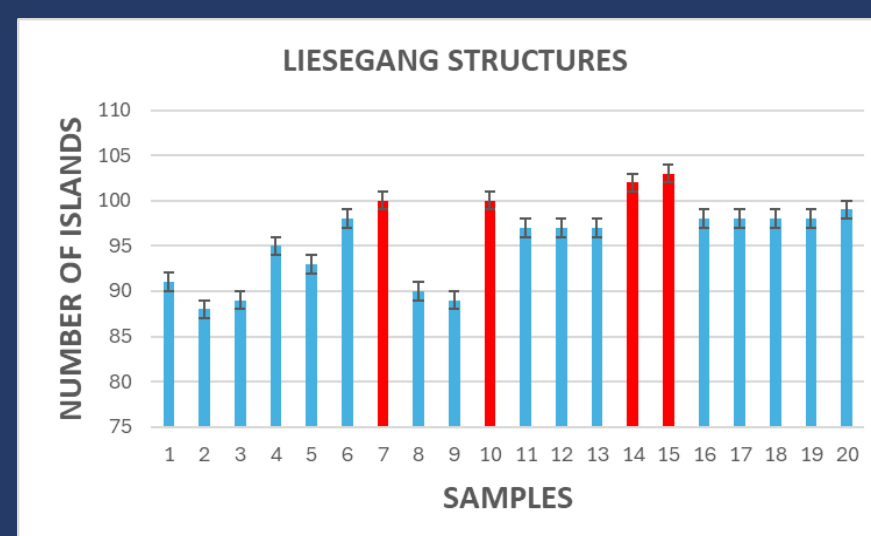


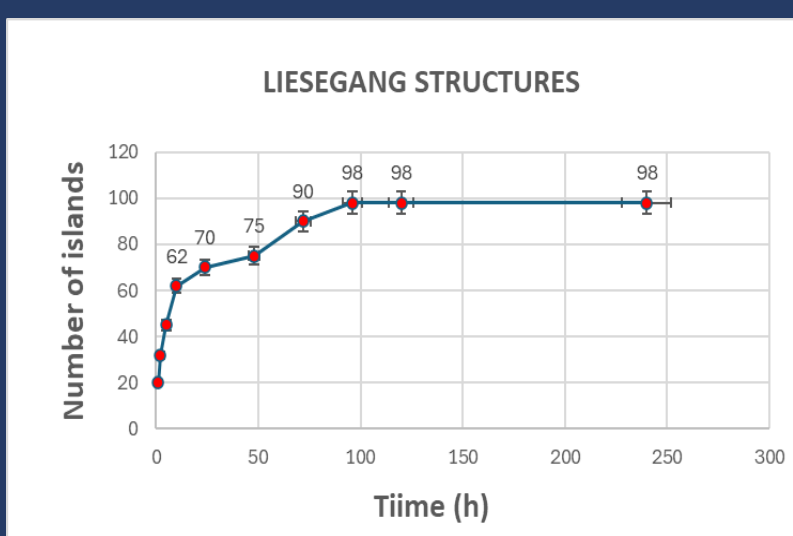
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REACTION PARAMETER EFFECT

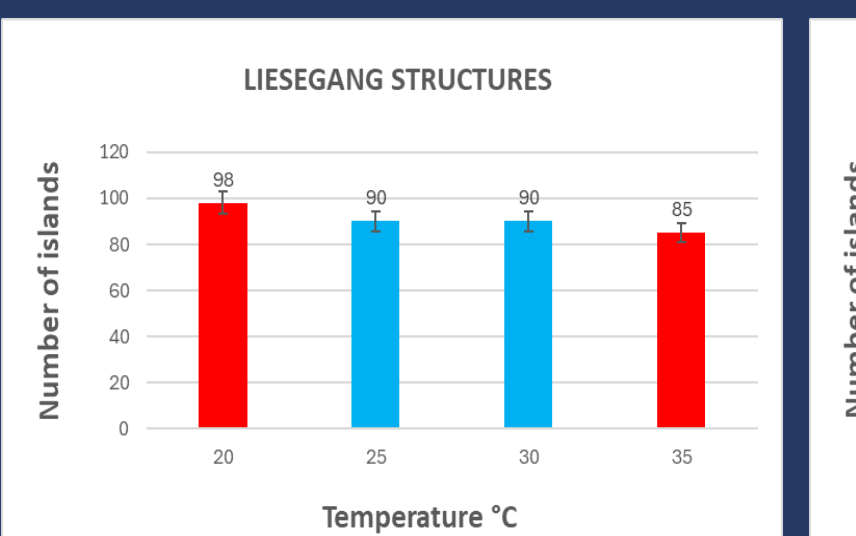
- The synthesis of Liesegang (rings or islands) for the pulsed release of ibuprofen has given excellent results.
- The number of Liesegang rings increases as the pH decreases, while the width decreases.
- pH 4.5 represents a point from which the spacing coefficient increases sharply.
- For the islands: the optimal pH is 7.4 and the optimal temperature 20°C, Na_2HPO_4 0.1 M and CaCl_2 1M.



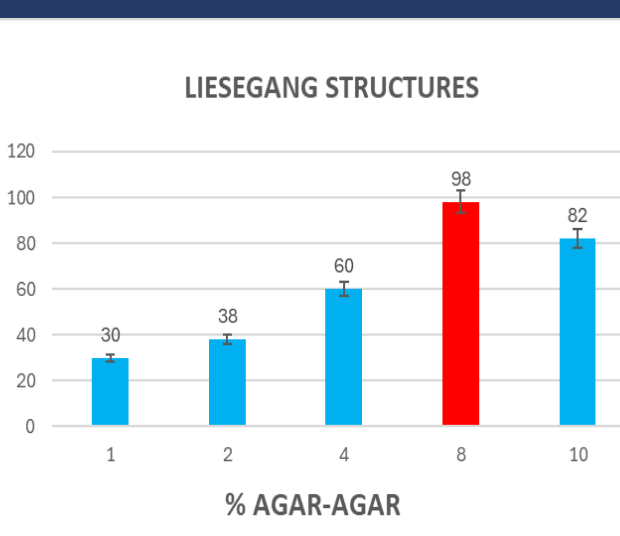
Graph created by finalist using Excel 365



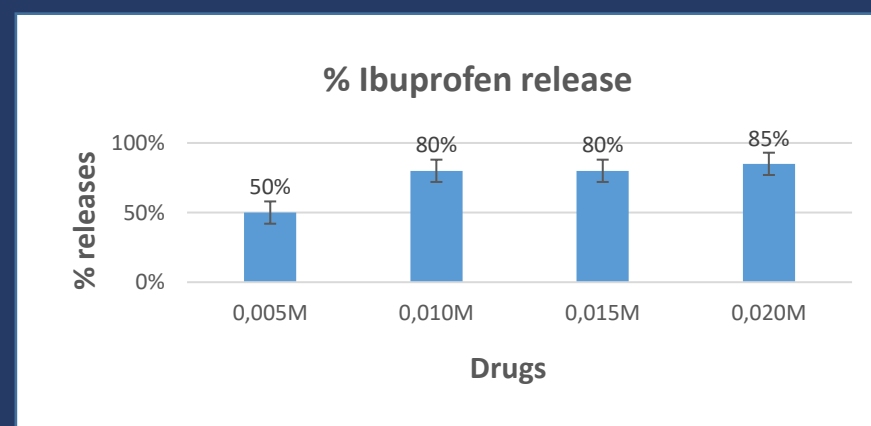
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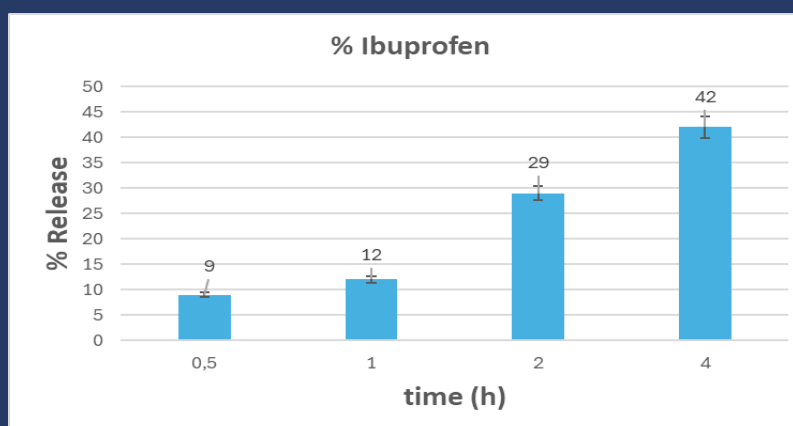
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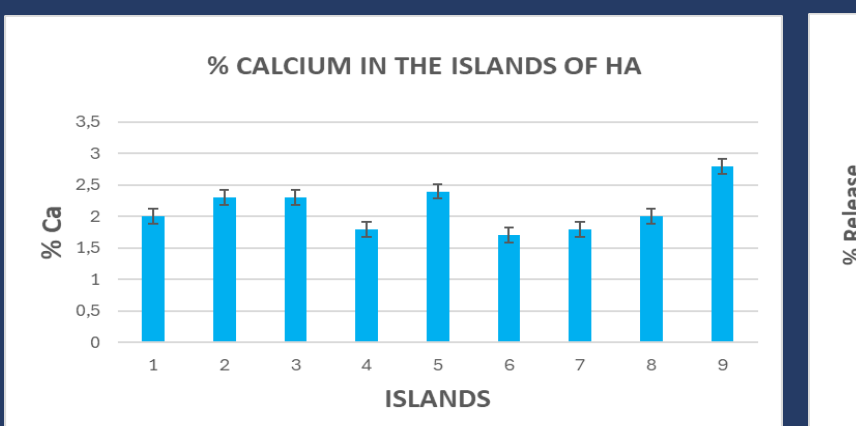
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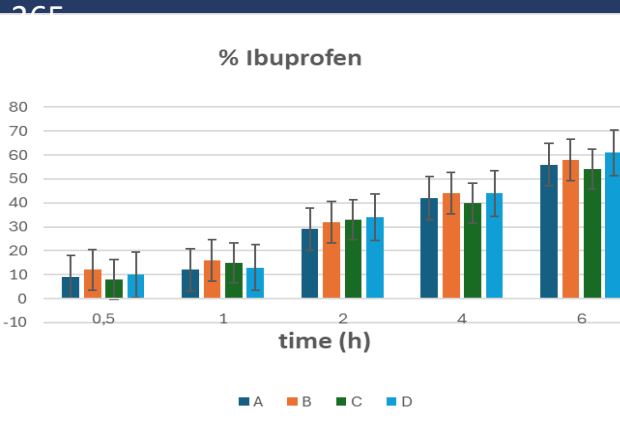
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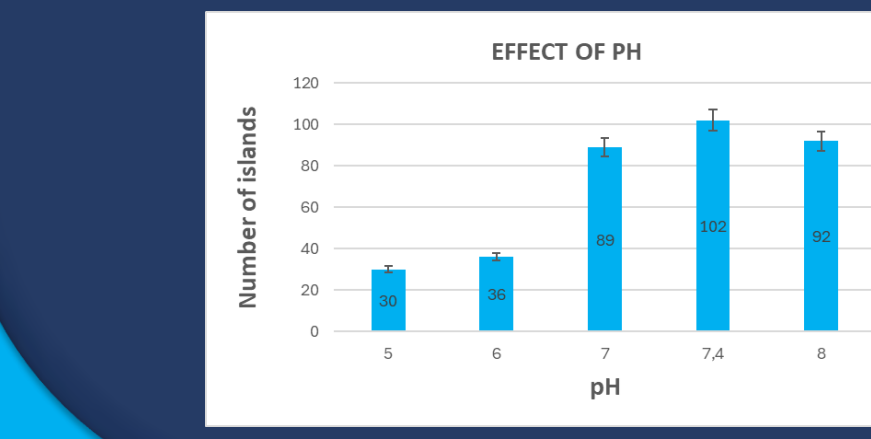
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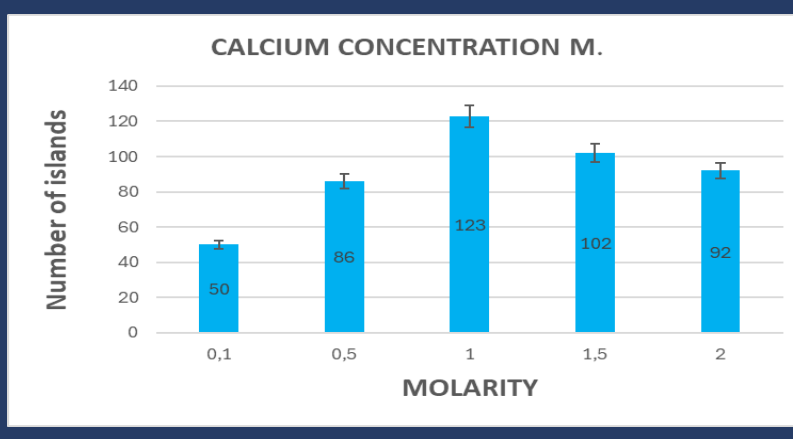
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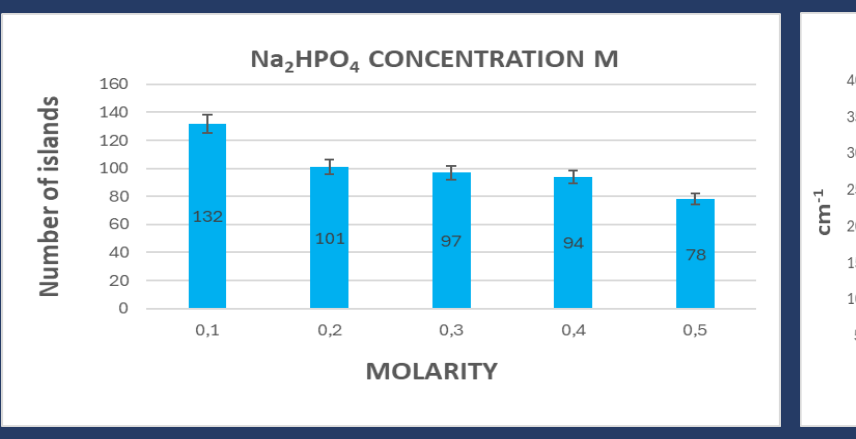
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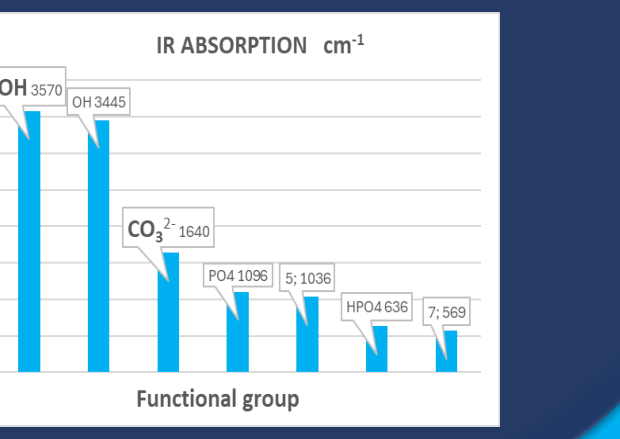
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DISCUSSION OF RESULTS

Based on the data obtained, it is possible to confirm the validity of the Liesegang periodic precipitation model as an alternative method for bone regeneration and controlled drug release.

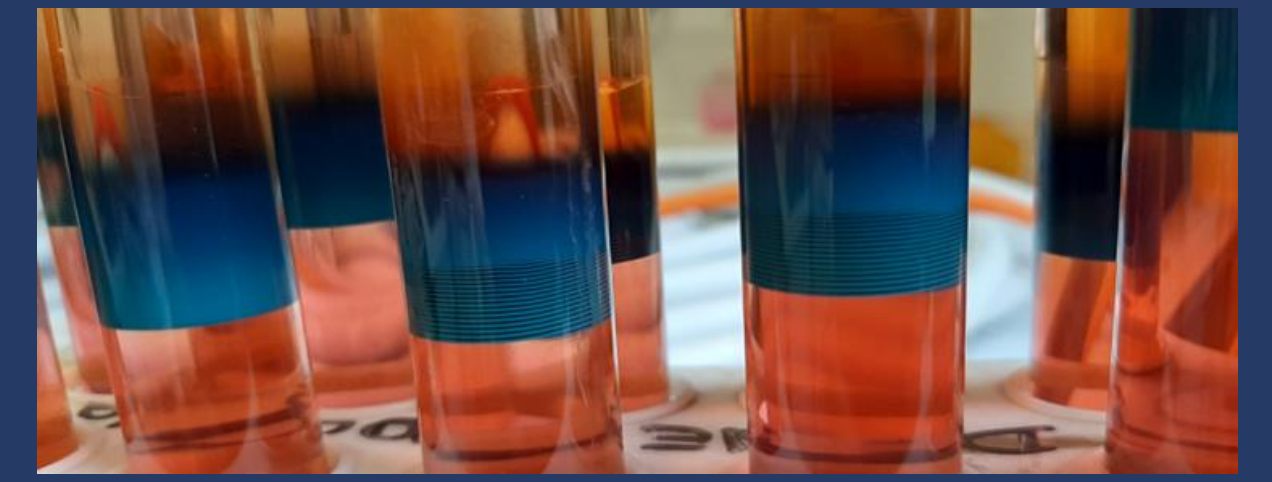


Photo taken by Finalist

By acting on the parameters involved in the synthesis process, such as the type of gelling agent, its concentration, the temperature and pH, it is possible to modulate the size, number and distance between the rings and the islands.

CONCLUSIONS

- The study demonstrates that Liesegang-type self-organization processes can be controlled to obtain ordered calcium phosphate-based mineralized structures.
- By changing the experimental conditions, it is possible to switch from periodic rings to discrete islands without altering the reaction-diffusion mechanism

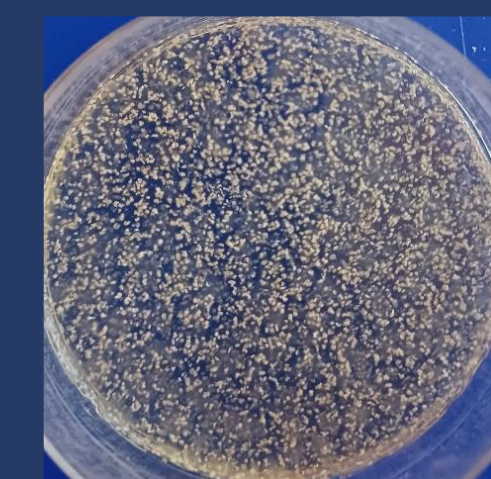


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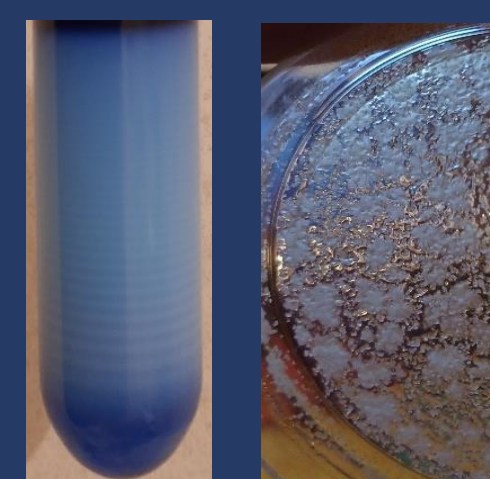


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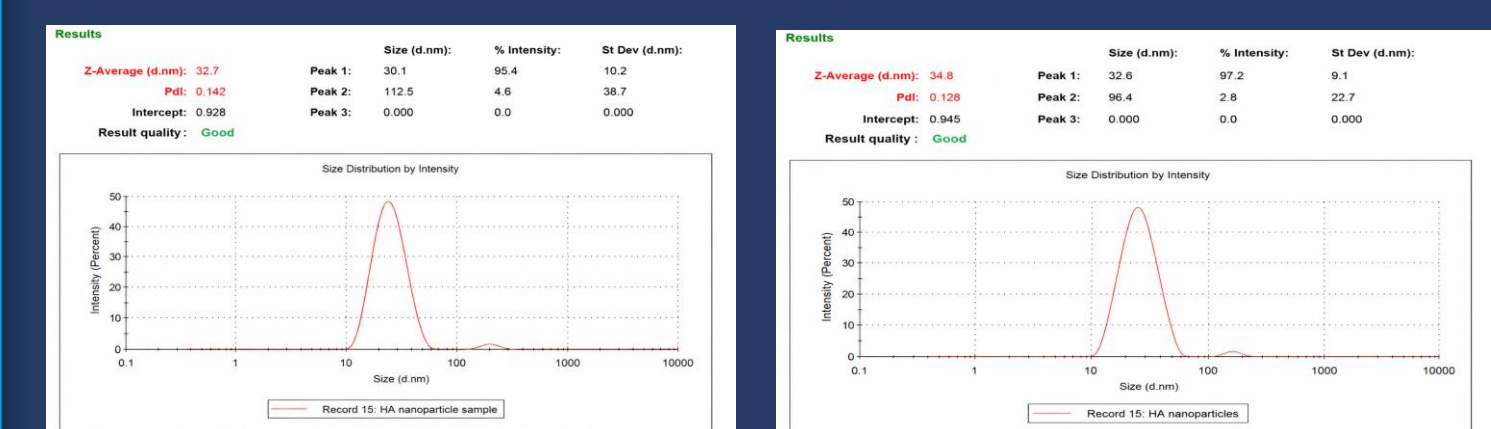
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The structures produced are chemically similar to natural calcium hydroxyapatite and useful for bone regeneration and controlled drug release

FUTURE WORK

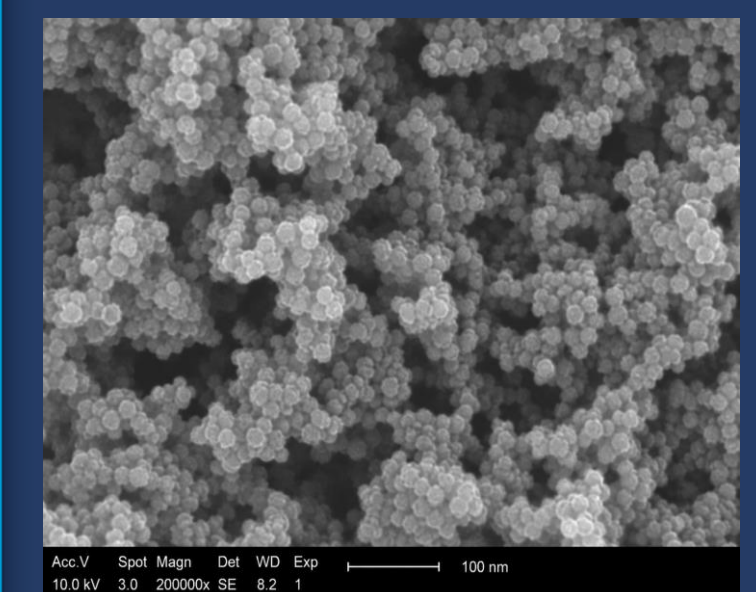
Hydroxyapatite structures exhibit biomimetic properties useful for bone regeneration and controlled drug release, with potential applications such as scaffolds, bioactive coatings, and multifunctional systems for therapeutic delivery.

DLS SEM XRF ANALYSIS



DLS Analysis

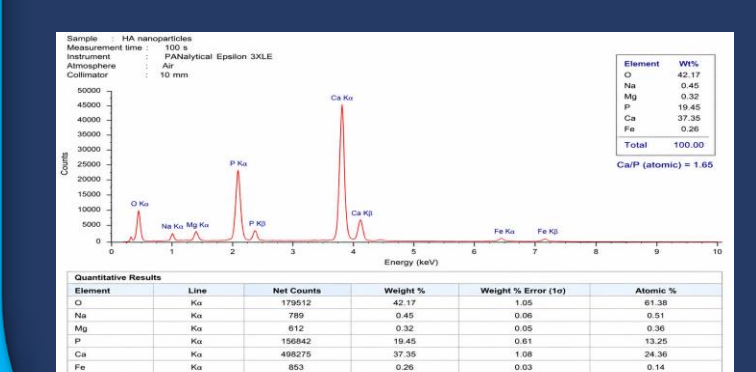
DLS Analysis



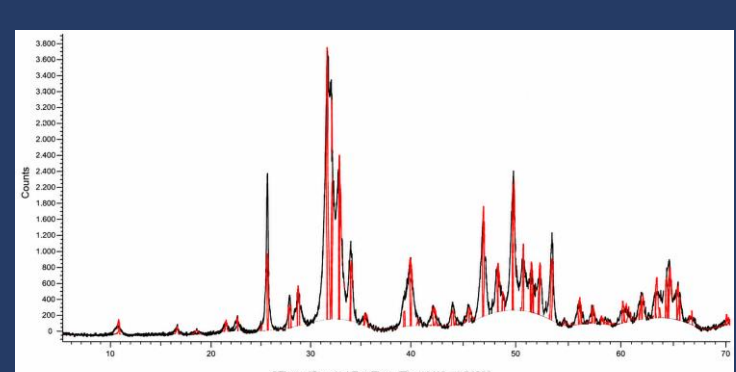
SEM Analysis



Optical Microscope



Elementary Analysis



XRF Analysis

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