Electronic Supplementary Material (ESI) for Environmental Science: Nano.

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SI1. Synthesis and functionalization of nanoparticles

1.1 Synthesis of silica nanoparticles (SNPs)

The preparation of SNPs involved employing the modified Stober method. To begin, 500 mg of CTAB was added into 250 ml of DI water and stirred for 10 minutes. Following this, a base catalyst, NH_3, was added into the solution. Subsequently, TEOS was added drop by drop at a consistent flow rate of 50 ml/h. The solution was then left to stir at a temperature of 80°C for 2 hours. Afterwards, the solution was centrifuged at 8000 rpm and extensively washed with DI and ethanol. The subsequent step involved solvent extraction, which involved refluxing the as-prepared SNPs in 80 ml of methanol with the addition of 360 µL of concentrated HCL, a process conducted at 80ºC to remove the surfactant. Lastly, the resulting powders were re-suspended in 100 ml of DI water for a period of 12 hours, followed by centrifugation and lyophilization to obtain the final powdered samples.

1.2 Synthesis of Barium titanate nanoparticles (BTNPs)

Barium chloride and titanium tetrachloride of analytical grade were employed as the source materials to obtain barium and titanium. In addition, reagent-grade sodium hydroxide was used as a mineralizer. An aqueous solution containing titanium and barium precursors was prepared by gradually introducing 2.75 ml of $TiCl_4$ into cooled deionized water. Additionally, 7.75g $BaCl_2.2H_2O$ was dissolved in deionized water following a 15-minute boiling period to remove dissolved CO_2 gas. As formed $TiCl_4$ aqueous solution was then slowly added into the $BaCl_2$ aqueous solution while stirring. In a separate beaker, 14.4g of NaOH pellets were dissolved in 20ml of D.I. In addition, prepared NaOH was added to the solution to maintain a certain pH and to neutralise the HCl produced during $TiCl_4$ hydrolysis with stirring. White colloidal sol was formed as a result of the addition of NaOH. By using deionized water, the final volume was adjusted to 40 ml. The final solution was then transferred to a 50 mL Teflon lined stainless-steel vessel. After that, the vessel was sealed and heated in a muffle furnace for 24 hours to a temperature of 254^0C. Following a natural cooling process to room temperature, the precipitate containing BTNPs was centrifuged at 10,000 g, and repeatedly washed in water and then dried in a vacuum oven at 60^0C for 12 hours.(1)

1.3 Synthesis of core-shell BTNP@SiO_2 nanoparticles

Core shell BTNP@SiO_2 were synthesized by a two-step process.(2)(3) Initially, BTNPs were dispersed in ethanol and treated with oleic acid to provide a non-polar surface ligand. To achieve this, one mL of BTNPs in ethanol (20 mg/mL) was mixed with 4 mL of an oleic acid solution (5% v/v in cyclohexane) under stirring. The mixture was stirred for 12 hours to ensure complete coating of the NPs with oleic acids. Subsequently, the mixture was centrifuged for 20 minutes at 13,500 rpm to eliminate excess ethanol and oleic acids. To create a clear colloidal solution of BTNP@OA, the pellet was then redispersed in cyclohexane. The second step used for silica coating by employing the reverse microemulsion method, as per established literature procedures. In this step, 0.5 mL of Igepal CO-520 was mixed with 10 mL of a 0.2 mg/ml solution of BTNP@OA and stirred for 15 minutes. Following this, 0.1 mL of ammonia solution (28%) was added to the mixture. Lastly, various amount of TEOS was introduced using a fractionated drop-wise method, with 10 µL added every 30 minutes. The resulting BTNP@SiO_2 core/shell products were collected after centrifugation and washing, and subsequently redispersed in either water or ethanol. By adjusting the initial concentration of

BTNP@OA and the quantity of TEOS introduced in the final step (Table S1 & FigS1), it was possible to achieve single core BTNP@SiO_2 NPs with different shell thicknesses.

1.4 Preparation of amine functionalized SNPs and BTNP@SiO_2 NPs

A suspension of 100 mg of either SNPs or BTNP@SiO_2 has been prepared in 20 mL of toluene, to which 0.2 mL of APTES was added. This solution was subjected to stirring under reflux conditions for 8 hours at 60ºC.(4) Subsequently, the solution was allowed to cool, followed by centrifugation at 8000 rpm. The resulting pellet underwent two rounds of washing with toluene, two rounds with ethanol, and finally, it was washed and resuspended in water.

Table SI1. We have optimized the synthesis of core shell structure of piezoelectric Barium Titante nanoparticles (BTNPs) with Barium Titanate core and Silica shell and an average size of ~60 nm. Reverse microemulsion method for silica coating was used to prepare the silica shell coated BTNPs. For synthesis of single core BTNP@SiO_2 NPs and silica shell thickness is adjusted by the optimizing the initial concentration of BTNP@OA and the quantity of TEOS introduced in the final step.

Sample	BTNP@OA	TEOS Concentration
BTNP@SiO_2 1	0.2 mg/ml	120µL
BTNP@SiO_2 2	0.2 mg/ml	240µL
BTNP@SiO_2 3	0.2 mg/ml	480µL
BTNP@SiO_2 4	0.2 mg/ml	720µL

Figure SI1.

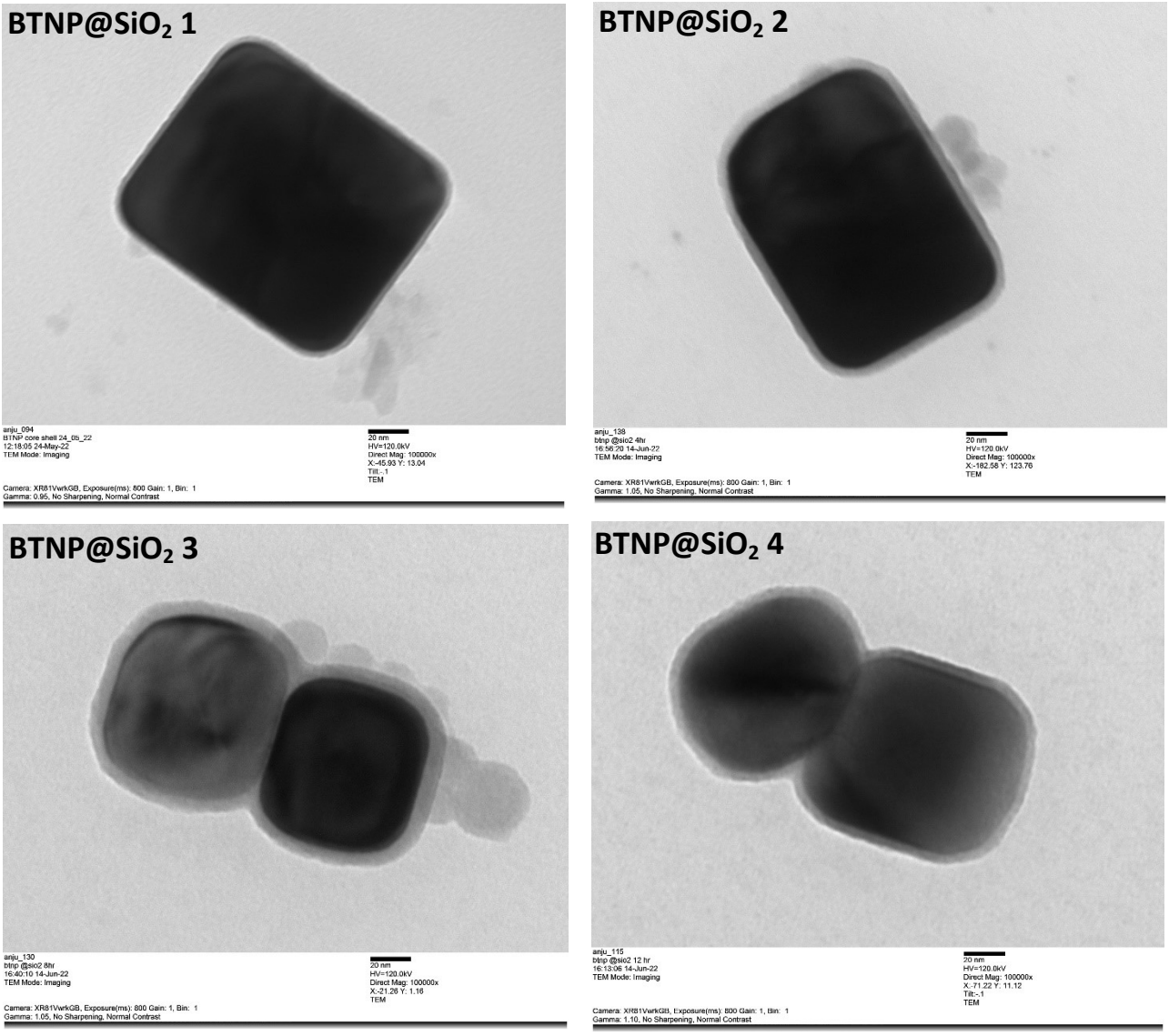
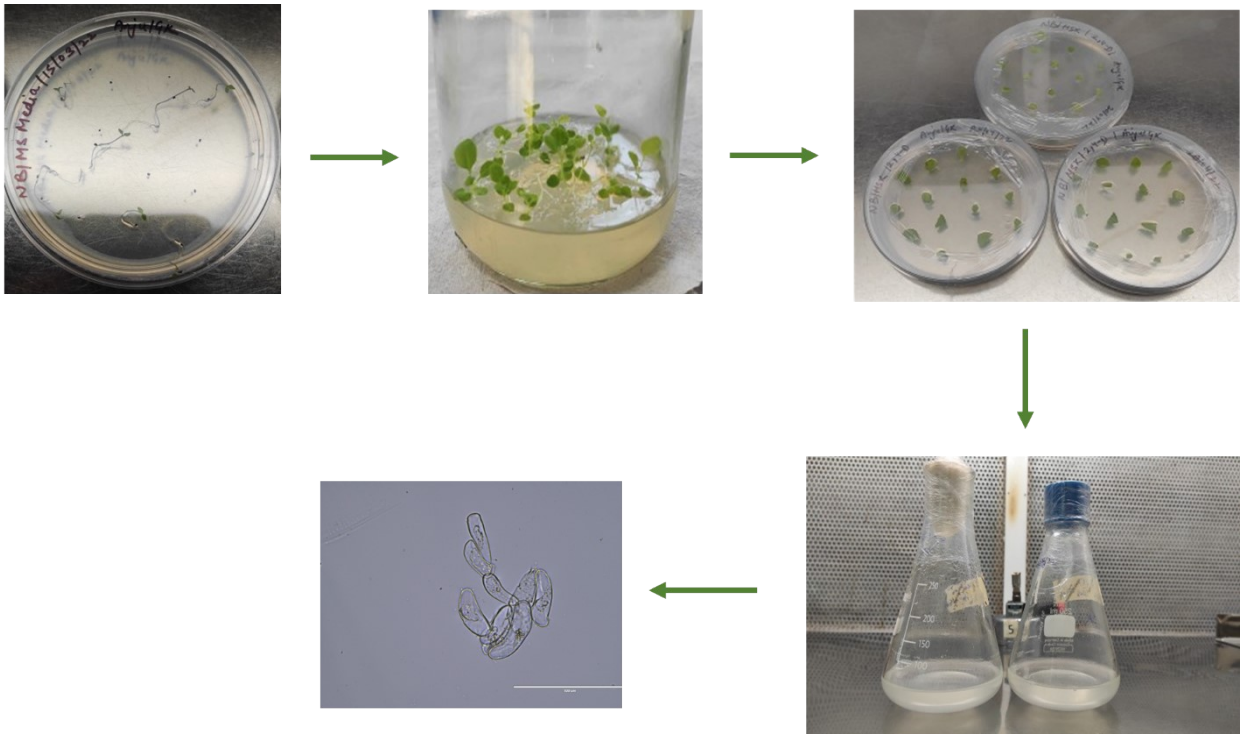


Fig SI1 . TEM images of BariumTitanate@SiO_2 core shell Nanoparticles

TableSI2 - Surface charge of nanoparticles – The zeta potential of the nanoparticles measured by Malvern Zetasizer Nano series and found that NPs suspended in water are of negative charge before functionalization. To make it conjugate with pDNA, nanoparticles are functionalized with 3-aminopropyltriethoxysilane (APTES) conferring positive charge.

Sample	Surface Charge of Nanoparticles before Functionalization	Surface Charge of Nanoparticles After Functionalization
SNP	-30mV	15mV
BTNP	-20.9mV	-
BTNP@SiO_2	-25.1mV	10mV

Figure SI2. *Nicotiana benthamiana* callus has been generated by taking leaf as explant and suspension cell culture has been generated by chopping off the developed callus into small



pieces and kept on shaking at 120rpm at 25°C.

Fig SI2 . Generation of *Nicotiana benthamiana* Suspension Cell culture

Figure SI3 *Oryza Sativa* callus has been generated by taking seeds as explant and suspension cell culture has been generated by chopping off the developed callus into small pieces and kept on shaking at 120rpm at 28^{o}C.

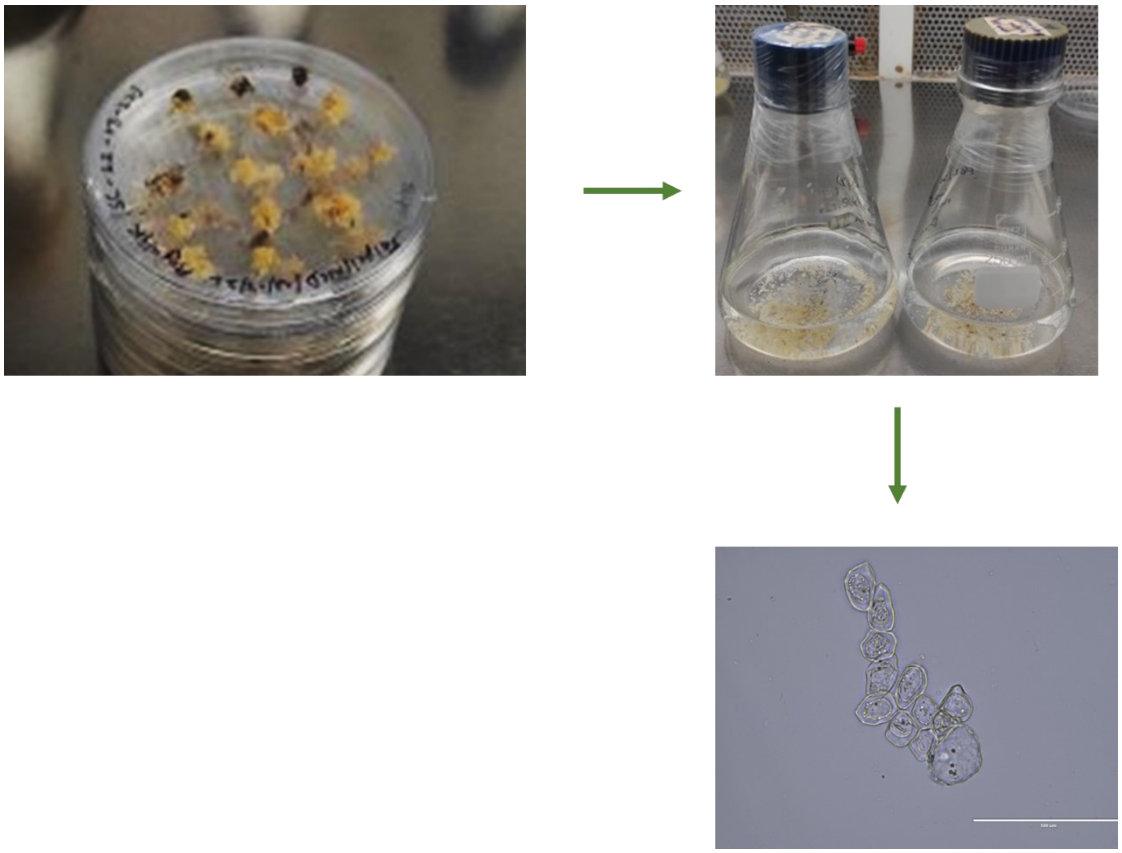


Fig SI3 . Generation of *Oryza sativa* Suspension Cell culture

Figure SI4 – Nanoparticle Stability studies - Stability and dispersibility studies have been performed via Differential light scattering (DLS) from day 1 to day 6. The data without sonication indicates that there is agglomeration of NPs from day 1 to day 6. However, following by brief sonication of 5 minutes, the size reduced similar to what was observed on the day 1 in both types of NPs, suggesting that the particles were no longer agglomerated together.

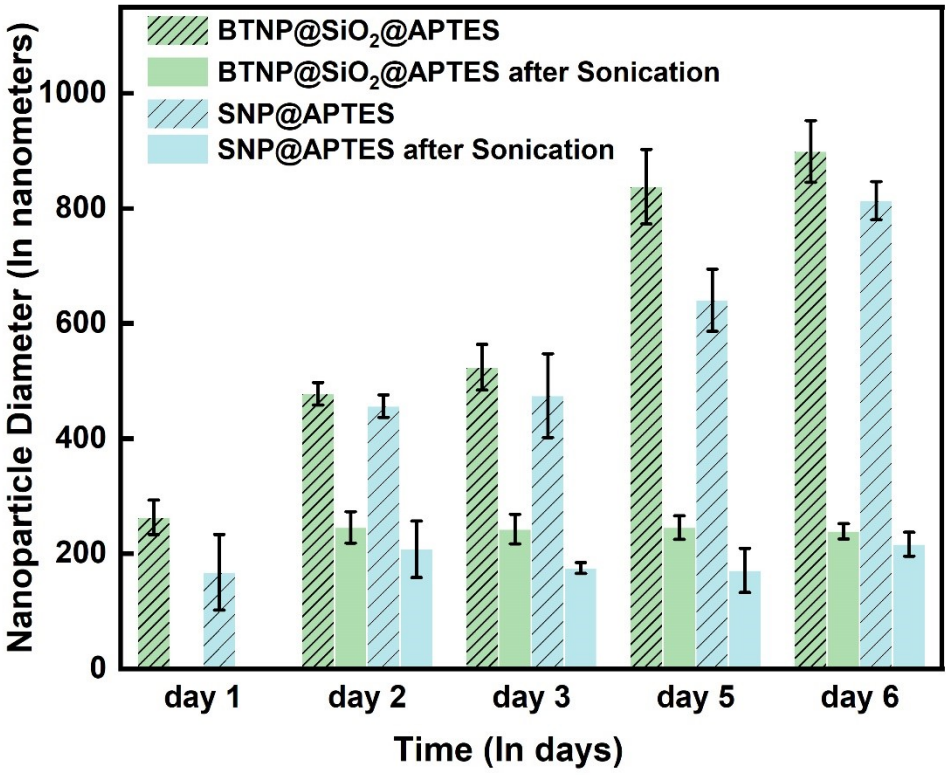


Figure SI4. Hydrodynamic sizes calculated at day 1 to day 6 in D.I. water. Data were attained from triplicates and presented as mean ± SD.

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