

Formulation and evaluation of *Solanum lycopersicum* seed mucilage loaded nanoparticles

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Abstract

The present study reports the formulation and evaluation of chitosan-based nanoparticles loaded with mucilage extracted from *Solanum lycopersicum* seeds. Nanoprecipitation was employed using chitosan as the carrier polymer and Tween 80 as stabilizer, yielding stable nanoparticles with sizes ranging from 80–114 nm and polydispersity indices between 0.217–0.321, indicating uniform distribution. UV-Visible spectrophotometry confirmed mucilage absorption maxima at 295 nm, and entrapment efficiency was found to be high (91–99%), demonstrating effective incorporation of mucilage within the nanocarrier system. The nanoformulation exhibited significant resistance to hydrolytic degradation, with 80.38% protection against artificial gastric juice and 98.23% resistance to α -amylase-mediated hydrolysis. These findings suggest that chitosan nanoparticles provide a protective matrix for mucilage, enhancing its stability and potential as a functional food ingredient or prebiotic delivery system. The study highlights the promise of mucilage-loaded nanoparticles in improving bioavailability and safeguarding bioactive compounds against gastrointestinal conditions

Keywords: Nanoparticle, chitosan, mucilage, *Solanum lycopersicum*, nanoprecipitation

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Introduction

Plants have been utilized as medicines for thousands of years (Samuelsson, 2004). Fruits and seeds are healthy diet, contains macro and minor nutrients (Lim, 2012). The specific nourishment demands of human beings are fulfilled through a combination of nutrients. Nutrients supply the energy needed for metabolic reactions in the body. The body gets its energy mainly from carbohydrates, proteins and lipids. The pulp of fleshy fruits is the primary food source for many people. The digestible carbohydrates are important in food as a major source of energy (Belitz et al., 2009). Worldwide, carbohydrates account for more than 70% of the caloric value of the human diet. Essentially all the carbohydrates in the food are absorbed in the form of monosaccharides; only a small fraction are absorbed as disaccharides and almost none as larger carbohydrate compounds (Adibi, 2003).

Prebiotics are selectively fermented ingredients that result in specific changes in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) upon host health” (Gibson et al, 2010; Falony et al, 2018). There has been a lot of research into new sources of prebiotics since more and more people around the world want functional foods and natural ingredients that are good for their health.

Mucilages and other extracts from plants are a very promising area of research (Punde and Tiwari, 2025). Nanomedicine is a subdivision of nanotechnology, which uses nanometric particles (Kasiramar, 2019). Nanoparticles (NPs) are capable of functioning as pharmaceutical carriers for a variety of delivery systems. Chitosan NPs have the benefit of slowing and controlling the release of drugs, improving their solubility and stability, and decreasing their toxicity (Zeng et al, 2011). In this work, our objective was to prepare nanoparticles containing mucilage of the seeds of *Solanum lycopersicum* and assess its ability to resist gastric hydrolysis.

Material and Methods

The seeds of *Solanum lycopersicum* were purchased from government authorized seed distribution center, Shivpuri, Madhya Pradesh, India. The mucilage was extracted using the aqueous macerate of the seeds and precipitation of mucilage with acetone as the organic solvent.

Formulation of mucilage loaded nanoparticles

The formulation of nanoparticles loaded with mucilage was accomplished by nanoprecipitation method using chitosan as the carrier polymer. Chitosan was dissolved in 50 mL of dilute acetic acid followed by addition and dissolution of the mucilage (Table 1). This solution was

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added dropwise under stirring to 40 mL of methanol containing Tween 80 and the mixture was centrifuged to collect the particles (Luque-Alcaraz et al, 2016). These particles were re dispersed in distilled water and sonicated for 5 min at 1 min interval with on-off pulse of 35 and 25 seconds. The particles were collected, dried by lyophilization and evaluated.

Table 1. Composition of mucilage loaded nanoparticles

| Formulation | Chitosan (mg/mL) | Mucilage (mg) | Tween 80 (g) |
|-------------|------------------|---------------|--------------|
| NM1 | 0.5 | 10 | 0.2 |
| NM2 | 0.5 | 20 | 0.2 |
| NM3 | 0.5 | 40 | 0.2 |
| NM4 | 1.0 | 10 | 0.2 |
| NM5 | 1.0 | 20 | 0.2 |
| NM6 | 1.0 | 40 | 0.2 |
| NM7 | 2.0 | 10 | 0.2 |
| NM8 | 2.0 | 20 | 0.2 |
| NM9 | 2.0 | 40 | 0.2 |

Evaluation of nanoparticles

Particle Size

The particle size of the formulated nanoparticles was observed by dynamic light scattering method using a particle size analyzer. The nanoparticles were dispersed in distilled water and placed in the path of laser source at 633nm. The scattering of the light was observed at 90° angle over time. The average diameter was calculated by the software of the instrument and result was displayed.

UV Spectrum of the formulation

Accurately weighed amount of mucilage (1 mg) was dissolved in 10 mL methanol and the sample was scanned in UV-Visible spectrophotometer from 800-200 nm. The absorption maximum was obtained from the UV Spectrum.

The working standards of concentration 5-25 µg/mL of mucilage was prepared using the above solution and appropriate dilutions. The calibration curve was prepared by measuring the absorbance of each dilution at the observed absorption maximum.

Entrapment Efficiency

The formulation was accurately weighed (1 mg) and added in 10 mL methanol to dissolve. The mixture was vortexed for 5 min using a vortex shaker and the absorbance of 0.5 mL of the solution was measured by suitable dilution with methanol using UV-Visible

spectrophotometer at 286 nm. The entrapment percentage was calculated by the formula:

$$\% EE = \frac{\text{Concentration of mucilage in solution}}{\text{Amount of mucilage used}}$$

Determination of gastric juice hydrolysis activity of nanoformulation

Acid resistance of nanoformulation was carried out using artificial gastric juice. The hydrochloric acid buffer (g/l) was mimicked as an artificial human gastric juice: NaH₂PO₄, 14.35; CaCl₂.2H₂O, 0.1; KCl, 0.2; NaCl, 8; Na₂HPO₄.2H₂O, 8.25; and MgCl₂.6H₂O, 0.18. The pH of the buffer was maintained at pH 1 using 5 M HCl (Korakli et al, 2002). The sample was prepared by dissolving the mucilage nanoformulation (1 % w/v) in water. Artificial gastric juice (5 ml) was added to the sample solution (5 ml) with further incubation for 6 h at 37±2°C in a water bath. The estimation of total and reducing sugar was done at both 0 and 6 h (Wichienchot et al, 2010). The percentage hydrolysis of the mucilage was estimated as the reducing sugar released and the total sugar content of the sample.

Determination of α-amylase hydrolysis activity of nanoformulation

For enzymatic hydrolysis α-amylase, 2 units mL⁻¹ was prepared in sodium phosphate buffer (20 mM) adjusted to pH 6.9 using 6.7 mM of sodium chloride (Lidiyawati et al, 2015). The sample was made as 1 % (w/v) of nanoformulation dissolved in the buffer. The sample solution 5 ml was further incubated with 5 ml of enzyme solution at pH 6.9 at 37± 2°C for 6 h. Enzymatic hydrolysis was estimated by the evaluation of total and reducing sugar in the sample. The percentage of hydrolysis was estimated.

Results and Discussion

The nanoprecipitation method successfully yielded mucilage-loaded chitosan nanoparticles. The dropwise addition of the aqueous chitosan–mucilage solution into methanol containing Tween 80 facilitated controlled precipitation, leading to uniform particle formation. Centrifugation and subsequent lyophilization produced stable, dry nanoparticles. Sonication improved the redispersion of lyophilized nanoparticles in distilled water, indicating good stability of the formulation. The on–off pulsed sonication prevented overheating and structural damage, maintaining particle integrity. The re-dispersed nanoparticles retained their size distribution, confirming that lyophilization did not cause irreversible aggregation.

Particle size and polydispersity

Particle size and polydispersity index (PDI) are critical parameters in nanotechnology, pharmaceuticals, and

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food science because they directly influence stability, bioavailability, and performance of colloidal systems. Smaller, uniform particles generally enhance stability and drug delivery efficiency, while a low PDI indicates a narrow size distribution and better reproducibility. The particle size of the formulation was measured using particle size analyzer (Table 2, Figure 1).

Table 2. Particle size and PDI of mucilage loaded nanoformulation

| Formulation | Particle size (nm) | PDI |
|-------------|--------------------|-------|
| NM1 | 91.47 | 0.321 |
| NM2 | 97.19 | 0.218 |
| NM3 | 80.04 | 0.301 |
| NM4 | 114.34 | 0.277 |
| NM5 | 80.04 | 0.294 |
| NM6 | 91.47 | 0.217 |
| NM7 | 104.81 | 0.317 |
| NM8 | 99.09 | 0.234 |
| NM9 | 80.04 | 0.255 |

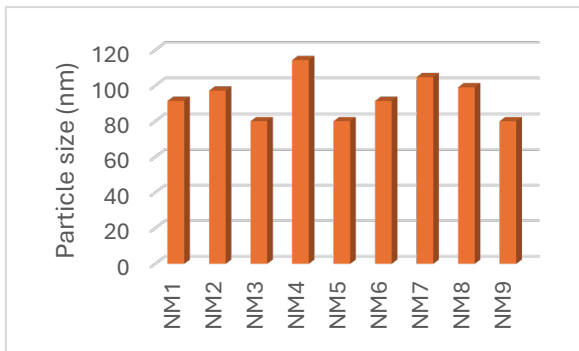


Figure 1. Particle size of formulations

Nanoparticles of less than 200 nm can cross biological barriers more effectively, improving absorption and bioavailability whereas larger particles (>500 nm) may be cleared rapidly or trigger immune responses. PDI measures the *uniformity of particle size distribution*. A value close to 0 indicates monodispersity (uniform particles), while values >0.5 suggest broad distribution. PDI of less than 0.2 means particles are consistent in size, reducing aggregation and phase separation whereas PDI >0.5 indicates instability of the formulation.

UV Spectra of mucilage

The absorption spectrum of the mucilage was obtained by scanning dilute solution of mucilage in the range of 1100 to 200 nm (Figure 2). The absorption maxima was found to be 295 nm.

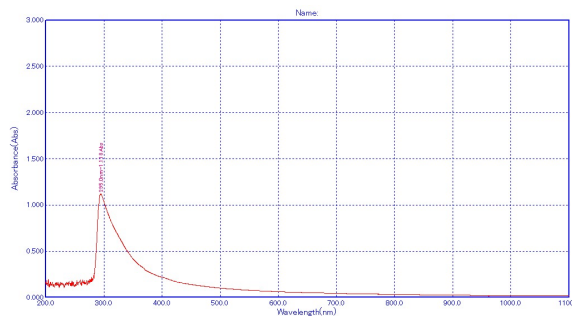


Figure 2. Absorption spectrum of mucilage by UV-Visible spectrophotometry

Entrapment Efficiency

Entrapment efficiency (EE%) is a key performance parameter in nanoparticle-based drug delivery systems. It reflects how effectively a drug or bioactive compound is encapsulated within the carrier. Calibration curve of mucilage was prepared at 295 nm by UV spectrophotometry (Table 3, Figure 3). The entrapment efficiency was determined by vortexing the nanoparticle to dissolve the contents and calculating amount of mucilage from the calibration curve (Table 4, Figure 4).

Table 5.21 Calibration data of mucilage

| Concentration (µg/mL) | Absorbance at 295 nm |
|-----------------------|----------------------|
| 5 | 0.443 |
| 10 | 0.887 |
| 15 | 1.241 |
| 20 | 1.612 |
| 25 | 2.009 |

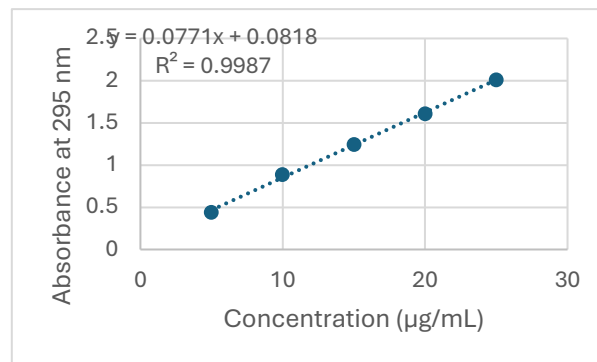


Figure 3. Calibration curve of mucilage

Table 4. Entrapment Efficiency of nanoparticles

| Formulation | Absorbance at 295 nm | Entrapment Efficiency (%) |
|-------------|----------------------|---------------------------|
| NM1 | 0.846 | 99.12 |
| NM2 | 0.798 | 92.89 |
| NM3 | 0.819 | 95.62 |

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| | | |
|-----|-------|-------|
| NM4 | 0.806 | 93.93 |
| NM5 | 0.821 | 95.88 |
| NM6 | 0.837 | 97.95 |
| NM7 | 0.787 | 91.47 |
| NM8 | 0.801 | 93.28 |
| NM9 | 0.832 | 80.04 |

High EE% means more drug is successfully incorporated into nanoparticles, maximizing therapeutic payload. It directly influences the dose delivered to the target site. Well-entrapped drugs are less prone to premature leakage or degradation and improves shelf-life and reduces variability during storage.

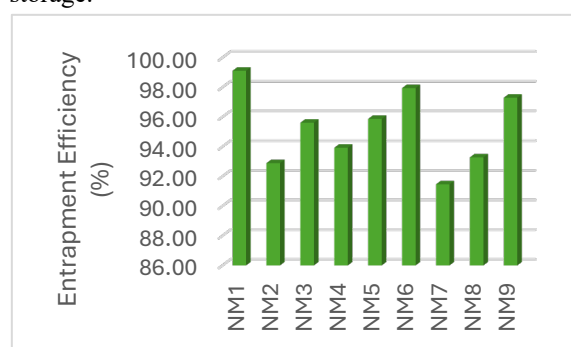


Figure 4. Mucilage entrapment in formulations

The resistance of the optimized nanoformulation to gastric juice and amylase mediated hydrolysis was assessed as per the previous method. The acidic hydrolysis of the nanoformulation was found to be 19.62% whereas 80.38% of the mucilage loaded nanoformulation was able to withstand hydrolysis in the artificial gastric juice. On the other hand, the hydrolysis by α -amylase was found to be 1.77% and the nanoformulation was able to resist 98.23% of enzymatic hydrolysis.

The nanoformulation was able to withstand hydrolysis better than crude mucilage because of the protective structural and physicochemical modifications introduced during formulation. The probable mechanisms (Figure 5) that would attribute to this protection may be that the mucilage was entrapped within a nano-sized matrix, which reduced its direct exposure to gastric acid and enzymes. This physical barrier slowed down hydrolytic attack. By converting mucilage into nanoparticles, the formulation minimized the accessible surface area for acid and enzyme interaction compared to the crude, unprocessed mucilage. Chitosan carries positive charges at acidic pH, which interact with negatively charged mucilage polysaccharides. This electrostatic interaction forms a compact matrix that is less

permeable to gastric acid. α -Amylase requires access to glycosidic linkages. Chitosan encapsulation creates steric hindrance and alters the surface chemistry, preventing enzyme binding and hydrolysis. In acidic gastric conditions, chitosan becomes protonated and swells minimally, which further restricts acid penetration. This explains the high resistance (80.38%) to gastric hydrolysis.

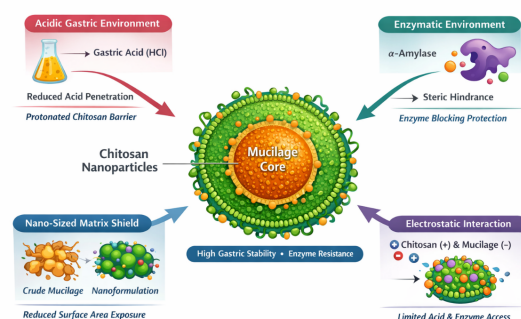


Figure 5. Mechanisms of prevention of hydrolysis of the mucilage nanoformulation

Conclusion

The successful formulation of *Solanum lycopersicum* seed mucilage-loaded chitosan nanoparticles demonstrates their potential as a robust delivery system for plant-derived bioactives. The nanoparticles exhibited desirable physicochemical properties, including small particle size, narrow distribution, and high entrapment efficiency. Importantly, the nanoformulation showed remarkable resistance to both gastric acid and enzymatic hydrolysis, underscoring the protective role of chitosan encapsulation. These results indicate that mucilage-loaded nanoparticles can serve as effective carriers for prebiotic compounds, ensuring stability and controlled release in gastrointestinal environments. Overall, this work contributes to the advancement of nanotechnology-based functional food formulations and supports the application of biopolymer nanoparticles in nutraceutical development.

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