RESEARCH PAPER

Development and Characterization of a Modified Aloe vera–Derived Powder as a Functional Pharmaceutical Excipient

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ABSTRACT

The increasing concerns associated with synthetic pharmaceutical excipients have encouraged the exploration of natural, biodegradable, and biocompatible alternatives from plant sources. In the present study, a modified polysaccharide-rich powdered excipient was successfully developed from Aloe vera (Aloe barbadensis Miller) gel and evaluated for its pharmaceutical applicability. The extracted gel was subjected to homogenization, alcohol precipitation, drying, pulverization, and sieving to obtain a stable powder form. The developed polymer was characterized using physicochemical, micromeritic, swelling, and structural evaluation techniques.

The prepared powder exhibited a percentage yield of 4.75% w/w with acceptable organoleptic properties, pH, moisture content, and ash values within pharmaceutically acceptable limits. Micromeritic analysis demonstrated favorable flow characteristics with bulk density and tapped density values of 0.414 g/mL and 0.489 g/mL, respectively. The Carr's index (15.4%), Hausner ratio (1.17), and angle of repose (28.74°) indicated good compressibility and flowability suitable for pharmaceutical processing. Hydration studies revealed significant water absorption capacity (7.57 g/g) and swelling index (2.765), showing superior hydration behavior compared with HPMC and MCC and comparable performance to guar gum. FTIR analysis confirmed the preservation of characteristic polysaccharide functional groups, while XRD studies demonstrated a semi-crystalline structure with enhanced amorphous characteristics. SEM analysis revealed porous and fibrous surface morphology with interconnected network-like structures.

The findings suggest that the modified Aloe vera powder possesses excellent functional and structural properties, indicating its strong potential as a natural multifunctional excipient for sustained-release and mucoadhesive drug delivery systems.

Keywords: Aloe vera powder, natural polymer, pharmaceutical excipient, swelling index, XRD, FTIR, SEM, controlled drug delivery.

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1. Introduction

In recent years, the pharmaceutical industry has increasingly shifted toward the use of natural polymers due to growing concerns regarding the toxicity, environmental impact, and regulatory limitations of synthetic excipients. Plant-derived polymers offer advantages such as biodegradability, biocompatibility, cost-effectiveness, and sustainable availability, making them attractive candidates for modern drug delivery systems.

Among natural sources, *Aloe vera (Aloe barbadensis Miller)* has gained considerable attention due to its rich content of bioactive polysaccharides, particularly Acemannan. Acemannan, an acetylated β-(1→4)-mannan, is primarily responsible for the functional properties of Aloe gel, including swelling, mucoadhesion, film formation, and matrix-forming ability. These characteristics make it highly suitable for pharmaceutical applications, especially in controlled and sustained drug delivery systems (Bai et al., 2023; Liu et al., 2019).

Despite its advantages, the direct use of Aloe vera gel presents several challenges, including high moisture content (90–95%), microbial susceptibility, enzymatic degradation, viscosity instability, and limited shelf life. These limitations restrict its direct incorporation into dosage forms and necessitate conversion into a stable, dry powder form. Processing techniques such as precipitation, drying, and structural modification can significantly improve stability while retaining functional properties (Minjares-Fuentes et al., 2017).

Furthermore, modification of natural polymers is often required to enhance their performance as pharmaceutical excipients. Structural modification can influence crystallinity, porosity, and intermolecular interactions, thereby improving swelling behavior, drug loading capacity, and release kinetics. However, such modifications must preserve the essential chemical integrity of the polymer to maintain its functional performance.

Although Aloe vera polysaccharides have been extensively investigated for biological applications, limited studies have systematically explored structurally modified Aloe-derived powder as a multifunctional pharmaceutical excipient with integrated physicochemical, micromeritic, and structural characterization. Therefore, the present study focuses on establishing a comprehensive excipient profile for modified Aloe vera powder intended for drug delivery applications.

2. Materials and Methods

2.1 Materials

Fresh mature leaves of *Aloe vera* (*Aloe barbadensis* Miller) were collected from authenticated sources. All chemicals and reagents used in the study were of analytical grade.

2.2 Preparation of *Aloe vera*–Derived Powder:

The collected *Aloe vera* leaves were thoroughly washed, and the outer rind was carefully removed to isolate the inner gel. The gel was homogenized and filtered to remove fibrous impurities. Alcohol precipitation was performed using ethanol in a 1:3 ratio (gel:alcohol), followed by cold storage for 24 h to facilitate polymer precipitation. The precipitated material was subsequently filtered, washed with acetone, and subjected to controlled drying.

The dried mass was pulverized and sieved through sieve No. 60 to obtain a uniform powder (see table no:1).

The percentage yield was calculated using the following equation:

% Yield = (Weight of dried powder / Weight of fresh gel) × 100

Table No:1 production and characterization of aloevera powder.

(phase I) Production of aloevera powder	**(phase II) Characterization of aloevera powder**

Collection of Aloe leaves (authentication certificate is required) ↓ Washing & Surface sterilization ↓ Rind removal ↓ Gel extraction ↓ Homogenization ↓ Filtration ↓ Alcohol precipitation (1:3 ratio) ↓ Cold storage (24 hrs) ↓ Filtration ↓ Acetone washing ↓ Drying (Oven / Freeze) ↓	Determination of % yield of aloevera powder. **Characterization of powder:** **1. Physicochemical evaluation** Physical examination (for report on excipient profile data): • Appearance, colour, odour • Particle size determination, • pH (1% solution), • Solubility profile, • Moisture content determination by LOD, • Ash values. **2. Powder flow property studies** (for report on its flow behaviour) Carried by: • Bulk density • Tapped density • Angle of repose • Carr's index • Hausner ratio For report on its

Pulverization ↓ Sieving (#60) ↓ **Packed in suitable air tight and moisture impermeable container until entered into**	flow behaviour. **3. Swelling properties(for** report on
phase II.	excipient behaviour): • Swelling index in water, • Water absorption capacity. (Importantfor binder/matrix role). **4. Structural & instrumental studies (**for report on polymer characterization) by: **(Mandatory tests have to performed)** • **FTIR→** functional

	groups • **XRD** → crystallinity • **SEM** → surface morphology.

2.3 Characterization of the Developed Powder (see table no:1)

2.3.1 Organoleptic and Physicochemical Evaluation:

The prepared powder was evaluated for appearance, color, odor, pH, moisture content, ash value, and particle size distribution (see table no:1. A) according to standard pharmacopeial procedures.

Table no: 1(A): Sieve-fractionated particle size classes and associated flow behavior of the powder sample.

Sieve number	**Nominal Aperture size (µm)**	**Particle size range**	**Pharmacopoeial description**	**Typical flow property**
20	850µm	>850µm	Very Coarse	Excellent
40	425µm	425-850µm	Coarse	Good
60	250µm	250-425µm	Moderately fine	Fair to good
80	180µm	180-250µm	Fine	Fair
100	150µm	150-180µm	Very fine	Poor
120	125µm	125-150µm	Very fine	Poor to very poor
200	75µm	<75µm	Extremely fine	Very poor /Cohesive

2.3.2 Micromeritic Properties:

Determination of Micromeritic properties refer to the study of the physical characteristics of powder particles, especially their size, shape, and flow behavior. These parameters are critical in pharmaceutical formulation, particularly for solid dosage forms like tablets and capsules. Key

micromeritic properties include in present studies are bulk density, tapped density, Carr's compressibility index, Hausner ratio and angle of repose.

2.3.3 Swelling and Hydration Studies:

Water absorption capacity (WAC) and swelling index (SI) were determined in triplicate using distilled water under controlled conditions. All experimental values were expressed as mean ± standard deviation (SD), and comparative studies were statistically evaluated using one-way ANOVA at a significance level of $p < 0.05$.

A. Determination of water absorption capacity (WAC)

Procedure (Perform in **triplicate (n=3)** for statistical reliability):

1. **Sample Preparation**
   - Accurately weigh **1.0 g** of polymer powder (W_1).
   - Transfer into a **pre-weighed centrifuge tube**.
2. **Hydration**
   - Add **10–20 mL distilled water** to the sample.
   - Mix thoroughly using lab mixer or manual shaking.
3. **Soaking**
   - Allow the sample to stand for **30 minutes to 1 hour** at room temperature(Maintain **constant temperature** (25 ± 2°C).
   - Ensure complete hydration.
4. **Centrifugation**
   - Centrifuge at **3000 rpm for 15 minutes**.
   - This separates unabsorbed water.
5. **Removal of Supernatant**
   - Carefully decant or pipette out the supernatant without disturbing the swollen mass.

6. **Final Weighing**
   - Weigh the centrifuge tube containing hydrated polymer (W_2).

Calculation

Water Absorption Capacity(WAC) = $\frac{(W2-W1)}{(W1)}$

Where:

- W_1 = *Initial weight of dry polymer (g)*
- W_2 = *Weight after water absorption (g)*

B. Determination of Swelling Index(S.I):

Procedure(Perform in **triplicate (n=3)** for statistical reliability):

1. **Sample Weighing**
   - Accurately weigh **1.0 g** of polymer powder.
2. **Initial Volume Measurement**
   - Transfer the powder into a **graduated measuring cylinder**.
   - Note the **initial volume (V_1)** occupied by the powder.
3. **Hydration**
   - Add **distilled water up to 10 (or) 25ml mark**.
   - Shake gently to disperse the powder uniformly.
4. **Standing Period**
   - Allow the mixture to stand for **24 hours at room temperature**.
   - Ensure the cylinder is properly stoppered to prevent evaporation.
5. **Final Volume Measurement**
   - After 24

hours(**Temperature (25 ± 2°C)**, record the **final swollen volume (V_2)**. **Calculation**

Swelling Index S.I (%) = $(\frac{(V2-V1)}{V1})\%$

Where:

- V_1 = Initial volume of polymer (mL)
- V_2 = Final volume after swelling (mL)

2.3.4 Instrumental Characterization

FTIR Analysis

FTIR spectra were recorded in the range of 4000–400 cm^{-1} using the KBr pellet method to identify functional groups and evaluate structural integrity.

XRD Analysis

X-ray diffraction studies were performed using Cu-Kα radiation (λ = 1.5418 Å) over a 2θ range of 10°–90° to evaluate crystallinity characteristics.

SEM Analysis

Surface morphology and microstructural characteristics were analyzed using scanning electron microscopy at different magnification levels.

3. Results and Discussion:

3.1 percentage yield:

The processing of 2 kg of fresh Aloe vera gel yielded 95 g of dried powder. The percentage yield was calculated to be 4.75% (w/w). The Aloe vera powder obtained in this study showed a yield of (%Yield = (95/2000) = 4.75%w/w. The slightly lower yield compared to theoretical expectations is primarily due to the natural composition of Aloe vera, which contains a very high proportion of water (above 95%). During drying, most of this water is removed, leaving behind only solid components such as polysaccharides, minerals, and other bioactive compounds. This indicates that the drying process used in the present work was effective in removing moisture while retaining a substantial portion of the solid bioactive material, making it suitable for further pharmaceutical or nutraceutical applications.

3.2. Organo leptic Properties:

Organoleptic characteristics refer to the sensory properties of a substance that can be evaluated using human senses include color, odor, taste, texture, appearance (physical state) (see table no: 2).

Table no:2 evaluation of organo leptic properties of aloe vera powder.

Parameter	**Result**	**Acceptable range**
Physical appearance	Fine powder with flakes and irregular particles	Characteristic
Colour	Pale cream to off-white	Pale cream to off-white
Odour	Mild, Characteristic	Characteristic
Taste	Slightly bitter to bland	No excessive bitterness
pH 1%(w/v)	5.2	4.0-6.5
Moisture content % (w/w)	8.7 %	8-10%
Ash value %(w/w)	4.9 %	3-8% (WHO) 15% (IP)

These parameters are crucial for:

- Preliminary identification of raw materials,
- Detecting impurities or degradation,
- Ensuring batch-to-batch consistency.

Particle size determination by Sieve Analysis Method:

The particle size analysis revealed that the powdered sample successfully passed through sieve No. 60, indicating that the particles possessed a size ≤ 250 µm. The predominance of particles within this size range confirms the production of a moderately fine powder, suitable for pharmaceutical and nutraceutical applications. Uniform passage through sieve No. 60 also suggests effective size reduction and minimal agglomeration during the milling process.

3.2.2 Micromeritic Properties:

Table no 3: powder flow characteristics of Aloevera.

Trail	**Bulkdensity mg/ml**	**Tapped density mg/ml**	**Carr'sindex (%)**	**Hausner's ratio(%)**

1	0.41	0.48	14.6	1.17
2	0.41	0.49	16.3	1.19
3	0.42	0.495	15.15	0.85
Average	0.414	0.489	15.4	1.07

3.3 Micromeritic Properties

The powder exhibited average bulk density and tapped density values of 0.414 ± 0.006 g/mL and 0.489 ± 0.008 g/mL, respectively (n = 3). The calculated Carr's index (15.35 ± 0.87%) and Hausner ratio (1.18 ± 0.01) (see table no:3) suggested acceptable compressibility and good flow behavior. Similarly, the average angle of repose (28.74 ± 1.41°) (see table no:4) confirmed good-to-excellent flow characteristics.

The favorable micromeritic properties may be attributed to uniform particle size distribution and reduced cohesive interactions among particles. Such characteristics are highly advantageous during large-scale manufacturing processes, including blending, granulation, and tablet compression.

Table no 4: Angle of Repose of Aloe vera powder.

Trail	**Height of the pile(h) in cm**	**Radius of the pile(r) in cm**	**Angleof Repose(θ)=tan^{-1}(h/r)**
1	2.4	4.8	26.78
2	3.0	5.3	29.51
3	2.7	5.0	28.74
Average	2.7	5.0	28.74

3.4 Swelling and water absorption capacity Studies:

The average water absorption capacity of the developed *Aloe vera* powder was found to be 7.57 ± 0.15 g/g (n = 3), which was substantially higher than HPMC (4.8 g/g) and MCC (1.9 g/g), and slightly higher than guar gum (7.2 g/g). These findings indicate excellent hydrophilic behavior and strong water retention ability due to the presence of hydroxyl-rich polysaccharides and mucilaginous components (see table no:5).

Table no: 5 comparative study of water absorption capacity of sample and standard polymers.

Trial	**(W_1)** Initial weight of dry aloevera powder (g)	**(W_2)**Weight after water absorption (g)	WAC (g/g) = $\frac{(W2-W1)}{(W1)}$
I(aloe vera powder)	1.0	8.6	7.6
II(aloe vera powder)	1.0	8.4	7.4
III(aloe vera powder)	1.0	8.7	7.7
Average	1.0	8.57	7.57
Average (HPMC)	1.0	5.8	4.8
Average (MCC)	1.0	2.9	1.9
Average (Guargum)	1.0	8.2	7.2

Similarly, the swelling index of the developed powder (2.76 ± 0.08, n = 3) was higher than HPMC (2.64) and MCC (2.25), although slightly lower than guar gum (3.2). The enhanced swelling behavior supports the suitability of the developed polymer as a binder, matrix-forming agent, and controlled-release excipient (see table no:6). The hydration and swelling behavior observed in the present study may significantly contribute to drug diffusion control, matrix integrity, and sustained drug release performance in oral dosage forms.

The higher swelling property compared to synthetic and semi-synthetic polymers demonstrates the potential of aloe vera powder as an effective natural polymer in pharmaceutical formulations.

Table no: 6 comparative study of swelling index of sample and standard polymers.

Trial	weight of dry aloevera powder (g)	(V_1) Initial volume of polymer (mL).	(V_2) Final volume after swelling (mL)	Swelling Index (S.I)= $(\frac{V2-V1}{V1})$%.
I	1.0	2.6	9.6	2.69
II	1.0	2.5	9.4	2.76
III	1.0	2.5	9.6	2.84
Average	1.0	2.534	9.54	2.765
Average (HPMC)	1.0	2.2	8.0	2.64
Average (MCC)	1.0	2.4	7.8	2.25
Average (Guargum)	1.0	2.5	10.5	3.2

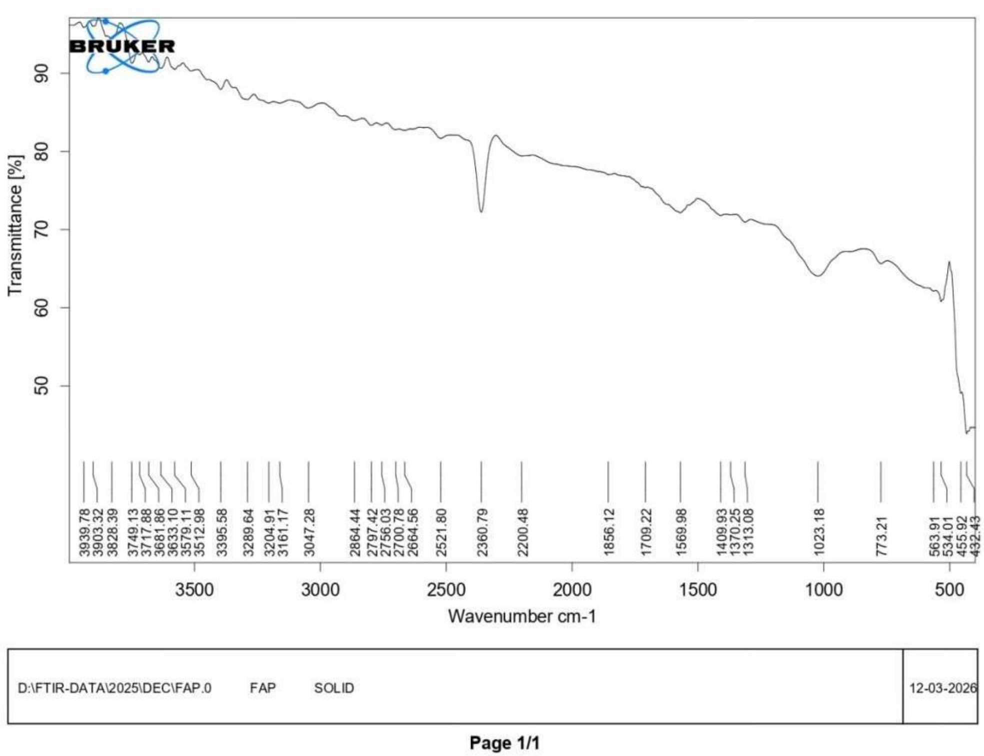
3.5 FTIR Analysis:

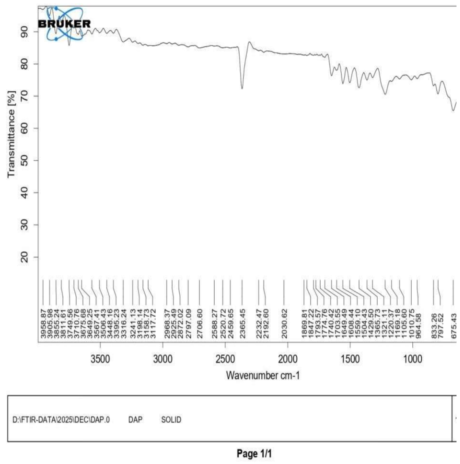
FTIR spectral analysis confirmed the presence of characteristic polysaccharide functional groups in both fluid aloe polymer (FAP) and dried aloe powder (DAP). Broad absorption bands observed around 3200–3400 cm^{-1} corresponded to O–H stretching vibrations associated with hydroxyl-rich polymeric structures and hydrogen bonding interactions.

The peaks observed near 2920–2850 cm^{-1} were attributed to aliphatic C–H stretching vibrations, confirming the organic nature of the polymeric matrix. Absorption bands around 1630–1650 cm^{-1} were associated with bound water and carbonyl-related vibrations of acetylated polysaccharides.

The strong peaks within the fingerprint region (1200–1000 cm^{-1}) confirmed the presence of glycosidic linkages characteristic of carbohydrate-rich polymers (see graph no:1&2). **Comparative analysis demonstrated that the drying and modification processes did not significantly alter the core chemical structure of the polymer.**

Graph no: 1 FTIR results of FLUID FORM ALOE VERA POLYMER (FAP)



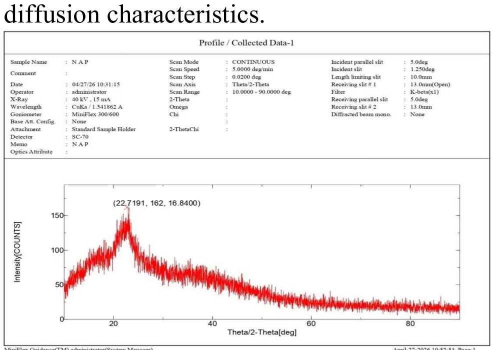


Graph no: 2 FTIR results of DRY POWDER FORM ALOE VERA(DAP)

3.6 XRD Analysis

XRD analysis revealed a semi-crystalline structure characterized by a broad amorphous halo and a distinct diffraction peak at approximately 2θ = 22.9°. The calculated crystallinity index (CI ≈ 43.2%) confirmed partial disruption of crystalline domains and increased amorphous character (see graph no:3).

Reduction in crystallinity suggests decreased intermolecular hydrogen bonding and lower chain-packing efficiency, thereby enhancing polymer chain mobility and water penetration. Increased amorphous nature is considered beneficial for pharmaceutical excipients because it improves hydration, swelling behavior, and drug diffusion characteristics.



Graph no:3 XRD analysis of aloe vera powder.

The observed decrease in crystallinity is a strong indicator of successful structural modification. Such transformation is highly desirable in pharmaceutical excipients, as increased amorphous regions improve drug diffusion and release kinetics without compromising structural integrity.

3.7 SEM Analysis:

SEM analysis demonstrated substantial morphological transformation in the modified polymeric system. At lower magnifications, the particles exhibited irregular flakes, porous structures, and loosely packed aggregates with inter-particulate voids (see table no:7).

At higher magnifications, rough, wrinkled, fibrous, and rod-like structures were observed within the polymeric matrix. The interconnected porous network indicates significant structural reorganization during processing and modification.

The observed increase in surface roughness and porosity is expected to enhance solvent penetration, swelling efficiency, drug entrapment, and diffusion-controlled release behavior. Therefore, the SEM analysis strongly support the pharmaceutical applicability of the developed excipient. Overall, the SEM findings confirm successful modification of the polymer and demonstrate substantial alteration in surface morphology and microstructural organization.

table no: 7SEM images of aloe vera powder at different magnification levels.

Image no:1

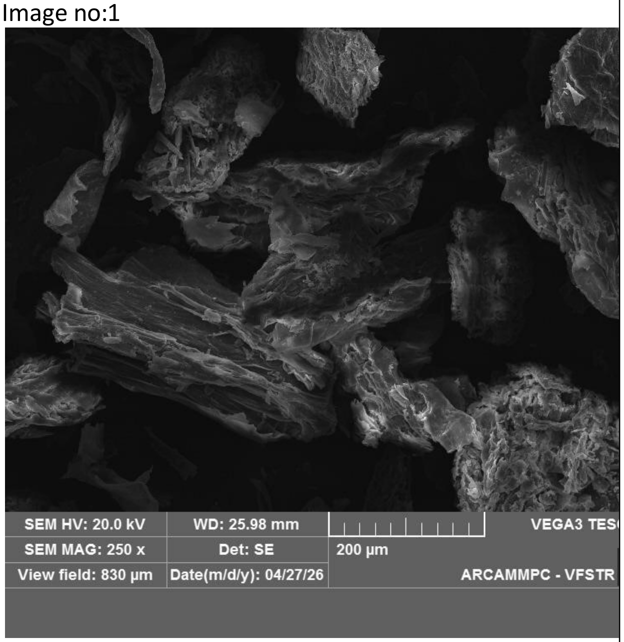
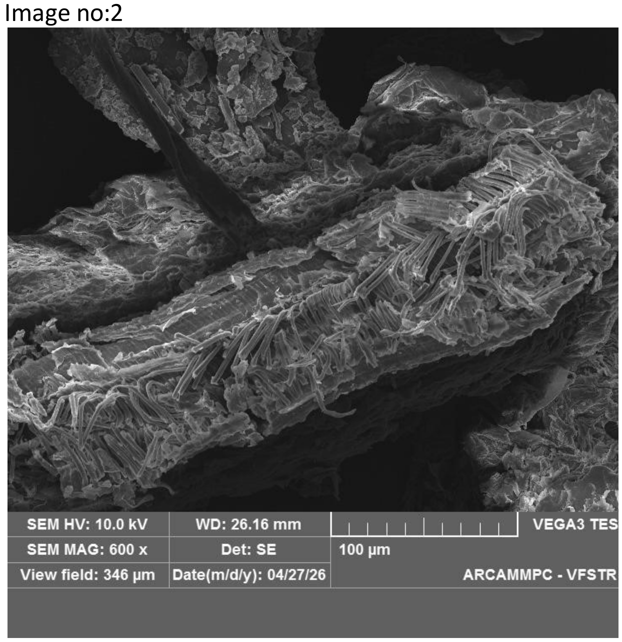


Image no:2



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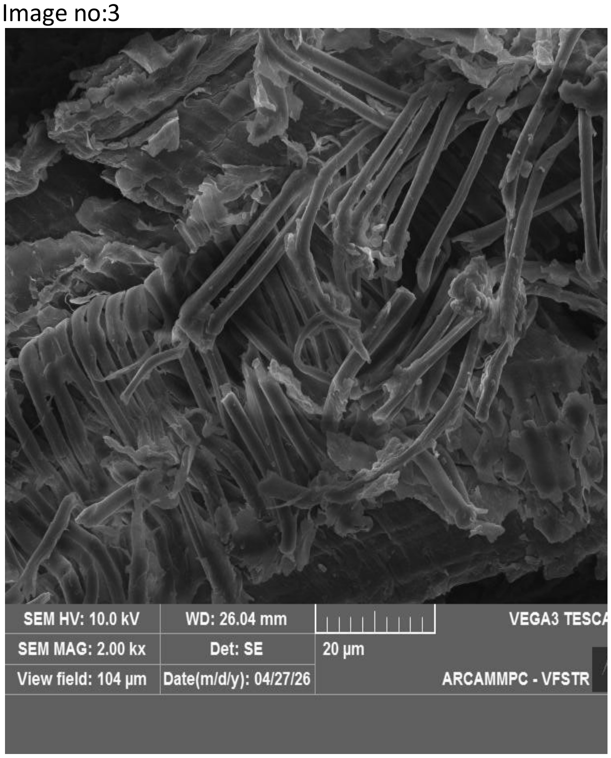

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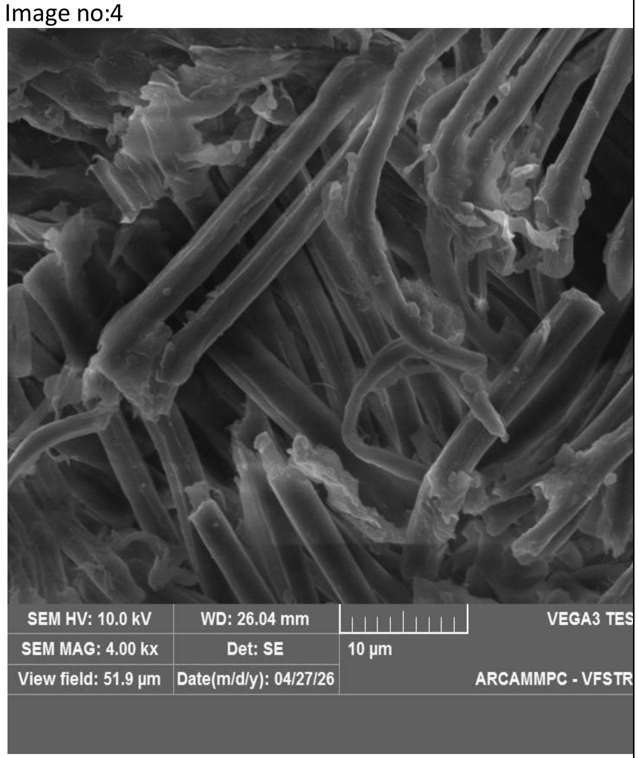
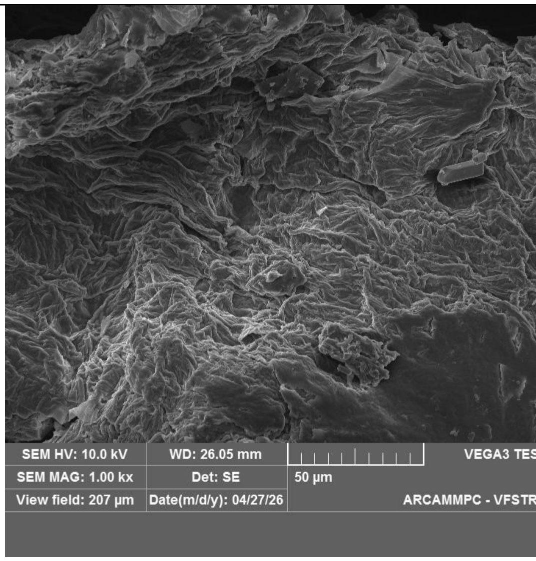
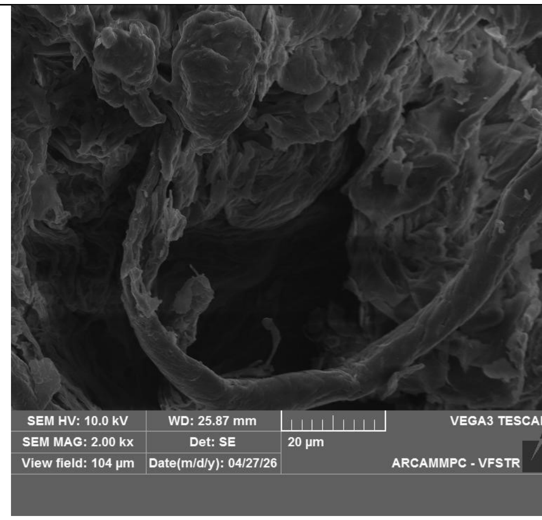


Image no:5

Image no:6





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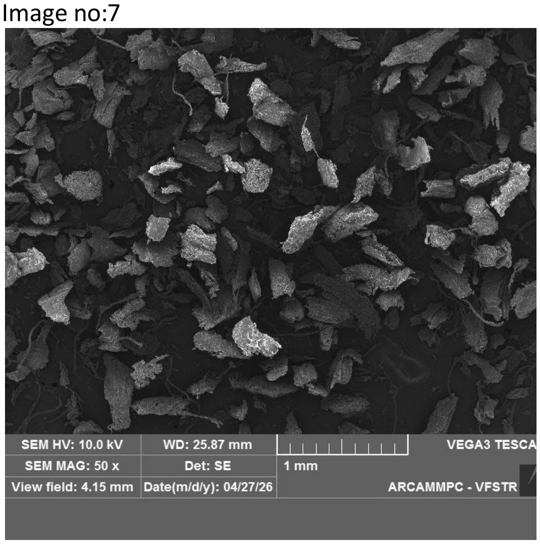
- Enhanced porous morphology,
- Semi-amorphous structural characteristics,
- Potential for controlled drug release,

Image no:7



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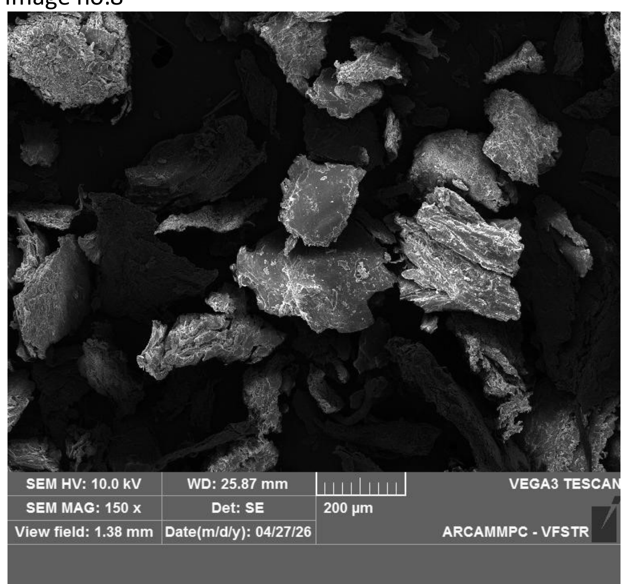

development.

3.8 Integrated Structural Correlation studies:

A strong correlation among FTIR, XRD, and SEM findings confirmed successful structural modification of the developed polymer.

- FTIR analysis confirmed preservation of the core polysaccharide chemical structure.
- XRD analysis demonstrated reduced crystallinity and increased amorphous characteristics.
- SEM analysis revealed enhanced porosity and surface roughness.

Collectively, these structural transformations

The developed powder exhibited acceptable organoleptic characteristics, good flowability, favorable compressibility, and significant hydration behavior. The high water absorption capacity and swelling index confirmed the strong hydrophilic nature of the polymeric matrix, supporting its potential application as a binder, matrix-forming agent, and controlled-release excipient.

FTIR analysis confirmed preservation of characteristic polysaccharide functional groups following processing, while XRD studies demonstrated increased amorphous characteristics favorable for hydration and drug diffusion. SEM analysis further revealed porous, rough, and fibrous surface morphology capable of enhancing solvent penetration and drug entrapment.

Overall, the integrated characterization findings establish the developed *Aloe vera* powder as a promising natural pharmaceutical excipient with potential applications in sustained-release systems, matrix tablets, and advanced drug delivery platforms. The study also provides a strong foundation for future formulation development and industrial exploration of *Aloe vera*–based biomaterials.

Future work:

The present study primarily focused on physicochemical and structural characterization of the developed polymer. Further investigations like thermal analysis, rheological evaluation Drug–polymer compatibility and formulation studies drug-polymer compatibility, formulation development, in vitro dissolution studies, and long-term stability evaluation are required to fully establish its industrial applicability as a pharmaceutical excipient." will be conducted in future investigations.

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