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EXTRACTION, PHYSICOCHEMICAL CHARACTERIZATION, AND PHARMACEUTICAL EVALUATION OF OKRA (*ABELMOSCHUS ESCULENTUS*) MUCILAGE AS A NATURAL EXCIPIENT FOR PHARMACEUTICAL DOSAGE FORMS

Hidayatullah Khan, H. K. Kunjwani, Sunny Parde, Hrushikesh Khodke, Swapnil Lahole
SGSPS Institute of Pharmacy, Kaulkhed, Akola-444001, Maharashtra, India.

Keywords:

Okra Mucilage, *Abelmoschus esculentus*, Natural Polymer, Pharmaceutical Excipient, Physicochemical Characterization, Drug Delivery Systems

For Correspondence:

Hidayatullah Khan
SGSPS Institute of Pharmacy, Kaulkhed, Akola-444001, Maharashtra, India.

E-mail:

hidayatullahk078@gmail.com

ABSTRACT

Natural polymers have emerged as promising alternatives to synthetic pharmaceutical excipients because of their excellent biocompatibility, biodegradability, renewability, and environmental sustainability. Among various plant-derived polymers, mucilage obtained from *Abelmoschus esculentus* (okra) has attracted considerable attention due to its unique physicochemical and functional properties. The present study focuses on the extraction, characterization, and pharmaceutical evaluation of okra mucilage for its potential application in pharmaceutical dosage forms. Mucilage was isolated from fresh okra fruits using aqueous extraction followed by ethanol precipitation and drying. The extracted mucilage was evaluated for physicochemical characteristics including percentage yield, organoleptic properties, pH, swelling index, viscosity, moisture content, solubility, ash values, and micromeritic properties. Compatibility with pharmaceutical ingredients and functional characteristics such as binding, thickening, suspending, and controlled-release behavior were also considered to assess its suitability as a natural excipient. The findings indicate that okra mucilage possesses excellent hydration capacity, swelling ability, viscosity, and gel-forming characteristics, making it suitable for application in tablets, suspensions, topical formulations, hydrogels, and controlled drug delivery systems. Its natural origin provides significant advantages over synthetic excipients, including improved biocompatibility, reduced toxicity, biodegradability, cost-effectiveness, and eco-friendly processing. Furthermore, the presence of naturally occurring polysaccharides contributes to enhanced pharmaceutical performance and patient safety. Overall, the study demonstrates that okra mucilage represents a promising multifunctional natural polymer capable of replacing several synthetic excipients in modern pharmaceutical formulations. Its successful characterization and evaluation provide scientific evidence supporting its wider application in sustainable pharmaceutical product development and encourage further research for industrial-scale utilization.

INTRODUCTION

Natural polymers have become increasingly important in pharmaceutical research because they provide safer, biodegradable, and environmentally sustainable alternatives to conventional synthetic excipients [1-2]. These polymers are naturally produced by plants, animals, and microorganisms and possess remarkable physicochemical properties that enable their application in diverse pharmaceutical dosage forms [3]. Among natural polymers, plant-derived mucilage has gained considerable interest due to its excellent swelling capacity, gel-forming ability, viscosity enhancement, and bioadhesive characteristics [4-5]. These properties make mucilage a multifunctional pharmaceutical excipient suitable for use as a binder, disintegrant, suspending agent, thickening agent, emulsifier, stabilizer, and controlled-release matrix in various formulations [6-7].

The increasing emphasis on green pharmaceutical technologies has accelerated the search for renewable and biodegradable excipients capable of replacing synthetic polymers such as hydroxypropyl methylcellulose, carbomers, polyvinyl pyrrolidone, and polyethylene glycol. Although synthetic excipients possess desirable functional properties, their production often involves petrochemical sources, complex manufacturing processes, high costs, and concerns related to toxicity, environmental persistence, and limited biodegradability [8-9]. Consequently, natural polymers are increasingly preferred because they offer improved compatibility with biological tissues, minimal toxicity, easier biodegradation, and greater environmental sustainability [10-11].

Among various natural polymers, mucilage extracted from *Abelmoschus esculentus* (okra) has emerged as a particularly promising pharmaceutical excipient [12-13]. Okra mucilage consists mainly of high molecular weight polysaccharides containing galactose, rhamnose, arabinose, and galacturonic acid, which impart excellent water-binding, swelling, viscosity-enhancing, and gel-forming properties [14-15]. These characteristics enable the mucilage to perform multiple pharmaceutical functions simultaneously, thereby reducing the requirement for multiple synthetic excipients within a formulation. In addition to its pharmaceutical functionality, okra mucilage exhibits antioxidant, anti-inflammatory, antimicrobial, and wound-healing properties that may further improve therapeutic outcomes in topical and advanced drug delivery systems [16-18].

The pharmaceutical applications of okra mucilage extend across numerous dosage forms including tablets, capsules, suspensions, emulsions, hydrogels, topical gels, buccal systems, transdermal patches, and sustained-release formulations. Its strong hydration capacity promotes tablet disintegration, while its gel-forming ability regulates drug diffusion in controlled-release systems. Moreover, its natural mucoadhesive properties enhance drug residence time at absorption sites, thereby improving bioavailability and therapeutic effectiveness [19]. The ease of extraction, abundance of raw material, and low production cost further support its commercial feasibility as a pharmaceutical excipient [20].

Therefore, systematic extraction and physicochemical evaluation of okra mucilage are essential for establishing its quality, safety, reproducibility, and pharmaceutical performance. Parameters such as viscosity, pH, swelling index, moisture content, ash value, solubility, flow properties, and compatibility with active pharmaceutical ingredients provide important information regarding its suitability for dosage form development. Scientific characterization also contributes to quality standardization and regulatory acceptance for industrial applications [21].

The present study was therefore undertaken to extract mucilage from *Abelmoschus esculentus*, characterize its physicochemical properties, and evaluate its pharmaceutical potential as a multifunctional natural excipient. The findings are expected to support the replacement of synthetic excipients with sustainable plant-derived alternatives, thereby contributing to the development of safer, economical, and environmentally friendly pharmaceutical dosage forms.

MATERIALS & METHODS

Procurement and Authentication of Plant Material

Fresh fruits of *Abelmoschus esculentus* (okra) were procured from a local agricultural market, ensuring selection of healthy, mature, and disease-free specimens suitable for mucilage extraction. The collected plant material was thoroughly washed to remove dirt and extraneous matter, then transported to the laboratory in clean, sterile containers to prevent degradation of mucilage content. Botanical authentication of the plant material was carried out by a qualified taxonomist from the Department of Botany, wherein the morphological characteristics of the fruits were compared with standard herbarium specimens and verified using established taxonomic keys. Only authenticated and quality-assured plant material was used for subsequent extraction and evaluation procedures. The morphological characters such as color, shape, size, surface, and organoleptic properties were evaluated by visual inspection and physical measurement using a vernier caliper [22-23].

Physicochemical Standardization of Plant Material

Determination of total ash

The determination of total ash provides an estimate of the inorganic residue remaining after thecompletecombustionofplantmaterial,servinga sakeyindicatorofits purityandquality. In this procedure, a known weight of the powdered plant sample is incinerated in a silica crucible at 450–600°C until a constant weight is achieved, ensuring the removal of allorganic matter. The resulting ash represents both physiological ash (naturally occurring minerals within the plant) and non-physiological ash (extraneous matter such as soil, sand, and adulterants). A lower total ash value generally signifies minimal contamination andgood-quality raw material, whereas unusually high ash levels may reflect poor handling, adulteration,orimproper processing.Thus, totalashestimationisessentialinestablishingthe authenticity, cleanliness, and standardisation of herbal plant materials [24].

Water-solubleash

It is an important quality control parameter used to determine the amount of inorganic matter soluble in water, reflecting the presence of natural minerals in the plant material. It is determined by boiling the total ash with distilled water, filtering, and re-igniting the insoluble residue. The difference between the total ash and insoluble residue represents the water-soluble ash. This test helps assess the purity of the plant material by distinguishing naturally occurring minerals from water-insoluble contaminants such as sand and silica [25].

Acid-insolubleash

It is a quality control parameter used to estimate the amount of siliceous impurities, such as sand, soil, and other inorganic contaminants, present in plant material. It is determined by treating the total ash with dilute hydrochloric acid, filtering, and igniting the insoluble residue to constant weight. A low acid-insoluble ash value indicates minimal contamination and good processing quality, whereas a high value suggests the presence of extraneous earthy matter. This test is important for assessing the purity and cleanliness of crude plant materials before pharmaceutical use [25].

Extractivevalues

Water-SolubleExtractiveValue

It is used to determine the amount of water-soluble constituents, such as sugars, glycosides, mucilage, and tannins, present in plant material. It is measured by macerating a known quantity of sample with distilled water, filtering, evaporating filtrate to dryness, and weighing the residue. A higher water-soluble extractive value indicates a greater content of hydrophilic constituents and serves as an important parameter for evaluating the quality and purity of mucilage-rich plants [26].

Alcohol-SolubleExtractive Value

It is used to determine the amount of alcohol-soluble constituents, such as alkaloids, flavonoids, phenolic compounds, and resins, present in plant material. It is determined by macerating a known quantity of powdered sample with ethanol, filtering, evaporating the filtrate to dryness, and weighing the residue. A higher alcohol-soluble extractive value indicates a greater content of alcohol-soluble phytochemicals and serves as an important parameter for evaluating the quality and extraction efficiency of the plant material [26].

Loss ondrying

It is an important quality control parameter used to determine the moisture and volatile matter present in plant material. It is measured by drying a known quantity of powdered sample at 105°C until a constant weight is obtained. The percentage weight loss represents the moisture content. A low LOD value indicates well-dried, stable plant material with reduced risk of microbial growth and degradation, making it suitable for extraction and pharmaceutical formulation, particularly for mucilage-rich plants such as *Abelmoschus esculentus*[27].

Moisturecontent

It is an important quality control parameter used to determine the amount of water present in plant material. It is measured by drying a known quantity of the powdered sample at 105°C until a constant weight is obtained, and the percentage weight loss is calculated as the moisture content. Low moisture content indicates good stability, minimizes microbial growth and degradation of active constituents, and ensures the suitability of *Abelmoschus esculentus* for extraction and pharmaceutical formulation [28].

Foreignmatteranalysis

It is a quality control test used to detect extraneous materials such as dust, soil, insects, stems, and other impurities in crude plant material. It involves visual inspection, manual separation of foreign matter, and calculation of its percentage based on the total sample weight. A low foreign matter content indicates proper harvesting, handling, and processing, ensuring the purity, safety, and suitability of the plant material for extraction and pharmaceutical applications [29].

PreliminaryPhytochemicalScreening

Identification of Carbohydrates (Mucilage)

Preliminary screening for carbohydrates confirms the presence of mucilage, a hydrophilic polysaccharide responsible for the binding, swelling, and viscosity-enhancing properties of *Abelmoschus esculentus*. The following qualitative tests were performed:

Molisch's Test: Violet/purple ring at the interface indicates carbohydrates.

Benedict's/Fehling's Test: Brick-red precipitate confirms reducing sugars.

Mucilage Test: Formation of a slimy, viscous solution confirms mucilage.

Identification of Glycosides

Qualitative tests were carried out to detect glycosides, which contribute to the biological activity of the plant:

Keller–Kiliani Test: Brown ring at the interface indicates cardiac glycosides.

Borntrager's Test: Pink to red coloration confirms anthraquinone glycosides.

Legal's Test: Red to pink coloration indicates cyanogenic glycosides.

Identification of Flavonoids

Flavonoids were identified using standard qualitative tests:

Alkaline Reagent Test: Yellow color turning colorless with dilute acid indicates flavonoids.

Shinoda Test: Pink, red, or orange coloration confirms flavonoids.

Lead Acetate Test: Yellow precipitate indicates the presence of flavonoids.

Identification of Alkaloids

Alkaloids were screened using the following tests:

Mayer's Test: Cream-colored precipitate indicates alkaloids.

Dragendorff's Test: Reddish-brown precipitate confirms alkaloids.

Hager's Test: Yellow precipitate indicates alkaloids.

Wagner's Test: Reddish-brown precipitate confirms alkaloids.

These qualitative tests provide preliminary confirmation of the major phytochemical constituents present in *Abelmoschus esculentus* and support its potential application as a natural pharmaceutical excipient [30-31].

Extractionof Mucilage

The mucilage from *Abelmoschus esculentus* was extracted using a modified hot-water extraction method to obtain a high yield of purified mucilage. Fresh, healthy okra fruits were washed, sliced, and soaked in distilled water (1:2 w/v) for 6–8 hours to facilitate mucilage release. The soaked material was heated at 60–70°C for approximately 1 hour with continuous stirring, followed by filtration through muslin cloth to separate the plant residue. The mucilage-rich filtrate was precipitated by adding three volumes of ethanol, producing a gel-like mass. The precipitated mucilage was washed with ethanol, dried in a hot air oven at

40–45°C until a constant weight was obtained, pulverized, passed through a #80 sieve, and stored in airtight containers for subsequent physicochemical characterization and formulation studies [32].

CharacterizationofIsolated Mucilage[33-34]

pH determination

The pH of the isolated mucilage is an important physicochemical parameter that influences its stability, compatibility, and suitability as a pharmaceutical excipient. A 1% w/v mucilage dispersion was prepared in distilled water and allowed to hydrate for 1–2 hours at room temperature. The pH was then measured using a calibrated digital pH meter at 25 ± 2°C. A pH close to neutral indicates good compatibility with pharmaceutical formulations and suggests that the mucilage is suitable for oral and topical applications.

Solubilityprofile

The solubility of the isolated mucilage was evaluated to determine its suitability as a pharmaceutical excipient. A known quantity of dried mucilage was tested separately in distilled water, ethanol, methanol, acetone, and chloroform. The mucilage formed a homogeneous, viscous dispersion in water but remained insoluble or only slightly soluble in the organic solvents, confirming its hydrophilic and polar nature. These findings indicate its potential use in pharmaceutical formulations requiring hydration, swelling, and gel-forming properties.

Swelling index

The swelling index of the isolated mucilage was determined to evaluate its water absorption and hydration capacity. A known quantity of dried mucilage was placed in a graduated cylinder containing distilled water and allowed to stand for 24 hours at room temperature. The increase in volume was recorded, and the swelling index was calculated as the percentage increase relative to the initial volume. A higher swelling index indicates excellent water-retention and swelling properties, supporting the use of the mucilage as an effective binder, disintegrant, and controlled-release matrix in pharmaceutical formulations.

Viscositymeasurement

The viscosity of the isolated mucilage was determined to evaluate its flow behavior and gel-forming ability. A 1–2% w/v aqueous dispersion of the dried mucilage was prepared and allowed to hydrate completely at room temperature. The viscosity was then measured using a Brookfield viscometer with a suitable spindle at 25 ± 2°C. Higher viscosity indicates better binding, thickening, and matrix-forming properties, confirming the suitability of the mucilage as a pharmaceutical excipient for tablet formulations and controlled-release systems.

EvaluationofMucilageasaPharmaceuticalExcipient

FlowPropertyStudies

Pre-compression evaluation was carried out to assess the flowability and compressibility of the isolated *Abelmoschus esculentus* mucilage for tablet formulation. The powder was evaluated for angle of repose, bulk density, tapped density, Carr's index, and Hausner ratio. Favorable values of these parameters indicated good flow characteristics and compressibility, ensuring uniform die filling, consistent tablet weight, and reliable drug content. These results demonstrate the suitability of okra mucilage as a natural excipient for tablet manufacturing by direct compression or granulation techniques.

Binderevaluation

The binder property of isolated *Abelmoschus esculentus* mucilage was evaluated by preparing granules using different mucilage concentrations (2–10% w/v) with a model drug. The granules were assessed for flowability, compressibility, and cohesiveness, followed by compression into tablets. The tablets were evaluated for hardness, friability, and disintegration time to determine the binding efficiency of the mucilage. Tablets with adequate mechanical strength, low friability, and acceptable disintegration demonstrated good binding properties. The performance of okra mucilage was compared with a standard binder (PVP), confirming its potential as a natural, biodegradable, and cost-effective pharmaceutical binder.

Disintegrantevaluation

The disintegrant property of isolated *Abelmoschus esculentus* mucilage was evaluated by incorporating it into tablet formulations at different concentrations and assessing the tablets using the USP disintegration test. The disintegration time was measured in distilled

water at 37 ± 0.5°C. A shorter disintegration time indicated effective swelling and water absorption by the mucilage, promoting rapid tablet breakup and drug release. The performance of okra mucilage was compared with standard disintegrants such as starch and croscarmellose sodium, demonstrating its potential as a natural, biodegradable, and cost-effective disintegrant for pharmaceutical tablet formulations.

Matrix-formingability

The matrix-forming ability of isolated *Abelmoschus esculentus* mucilage was evaluated by incorporating it into matrix tablet formulations containing a model drug at different concentrations. The formulated tablets were subjected to in vitro dissolution studies to assess their drug release behavior. Upon hydration, the mucilage formed a cohesive gel matrix that regulated drug diffusion and sustained drug release. Parameters such as cumulative drug release, gel layer formation, and matrix integrity were evaluated to determine its performance. The results demonstrated the potential of okra mucilage as a natural, biodegradable matrix-forming polymer for sustained and controlled-release pharmaceutical formulations.

FormulationDevelopment

Preparationof modeldosageform(tablets)usingmucilage

Model tablets were prepared to evaluate the functional performance of *Abelmoschus esculentus* mucilage as a natural binder, disintegrant, and matrix-forming agent. A model drug was accurately weighed and blended with the required excipients, including the isolated mucilage at specified concentrations. The powder blend was passed through a #60 sieve to ensure uniform particle size, followed by wet granulation using distilled water as the granulating fluid. The prepared wet mass was granulated, dried in a hot air oven at 40–45°C, and sieved to obtain free-flowing granules. The granules were then compressed into tablets using a single-punch tablet compression machine, maintaining uniform weight, hardness, and dimensions. The prepared tablets were subsequently evaluated for physicochemical properties, mechanical strength, disintegration, and in vitro drug release to assess the suitability of okra mucilage as a natural pharmaceutical excipient.

Preparationofcontrolformulation(without mucilage)

The control formulation was prepared using the model drug and conventional pharmaceutical excipients without incorporating *Abelmoschus esculentus* mucilage. Standard binders and disintegrants were used, and the powder blend was sieved, granulated (if required), dried, and compressed into tablets under the same manufacturing conditions as the test formulations. The prepared tablets were evaluated for weight variation, hardness, friability, disintegration time, drug content, and *in vitro* dissolution. Comparison of the control and mucilage-containing formulations enabled assessment of the binding, disintegrating, and release-modifying properties of okra mucilage as a natural pharmaceutical excipient.

Table1:FormulationDesignof TabletsUsing*Abelmoschus esculentus*Mucilage

Formulation Code	Drug (mg)	Mucilage (%)	Starch (%)	Lactose (%)	Magnesium Stearate(%)	Total Weight(mg)
F1	50	1	10	38	1	100
F2	50	2	10	37	1	100
F3	50	3	10	36	1	100
F4	50	4	10	35	1	100
F5	50	5	10	34	1	100
F6	50	6	10	33	1	100

F7	50	7	10	32	1	100
F8	50	8	10	31	1	100
F9	50	9	10	30	1	100
F10	50	10	10	29	1	100

EvaluationofFormulatedDosageForms(Post-compressionParameters)

Hardness Testing: Tablet hardness was measured using a Pfizer hardness tester to determine the force required to break a tablet diametrically. Adequate hardness ensures the tablets can withstand mechanical stress during packaging, transportation, and handling without compromising their integrity.

Friability Testing: Friability was evaluated using a Roche friabilator, where tablets were subjected to repeated tumbling and rotation. The weight loss, expressed as a percentage, indicates the tablet's resistance to chipping, abrasion, or breakage. A friability of less than 1% is generally considered acceptable.

Disintegration Testing: Disintegration time was measured using a USPdisintegration apparatus in distilled water at 37 ± 0.5°C. This test determines the time required for the tablet to break into granules, which is critical for ensuring rapid drug release and bioavailability. Tablets containing mucilage are expected to disintegrate efficiently due to the swelling property of the natural polymer, while providing adequate mechanical strength.These combined tests help in comparingthe performance of mucilage-containingtablets with control formulations, confirming the suitability of okra mucilage as a natural, biodegradable, and effective pharmaceutical excipient.

Drugcontent estimation

Drug content estimation is performed to determine the amount of active pharmaceutical ingredient (API) present in the formulated tablets and to ensure uniformity and accuracy of dosage. A specified number of tablets are weighed, powdered, and a known quantity of the powder is dissolved in an appropriate solvent to extract the drug completely. The resulting solution is filtered, suitably diluted, and analyzed using a validated UV–Visible spectrophotometeratthe drug'scharacteristicwavelength.Thedrugcontenti scalculatedasa percentageofthelabeled claim. Consistencyin drug content indicates uniformdistribution of the active ingredient, while any significant deviation may suggest issues with mixing, granulation, or compression processes. This test iscritical for qualitycontrol and ensures that mucilage-containing tablets meet pharmacopoeial standards for efficacy and safety.

***In-vitro*drugrelease studies**

In-vitro drug release studies are performed to evaluate the rate and extent of drug releasefrom the formulated tablets and to assess the functional performance of *Abelmoschus esculentus* mucilage as a binder, disintegrant, or matrix-forming agent. The dissolution study is conducted using a USP dissolution apparatus Type II in an appropriate dissolutionmedium,typicallyphosphatebufferors imulatedgastric/intestinalfluid,maintainedat37± 0.5°C with constant stirring. Samples are withdrawn at predetermined time intervals, filtered, and analyzed for drug concentration using a UV–Visible spectrophotometer or HPLC. The cumulative percentage of drug released is plotted against time to generate dissolutionprofiles. Comparison between mucilage-containing tablets and control formulations helps to assess the effect of mucilage on drug release kinetics, providing insight into its suitabilityfor immediate-release or sustained-release formulations.

Stability Studies

Stability studies are conducted to evaluate the physical, chemical, and functional stability of the formulated tablets over time under controlled environmental conditions, as per ICH guidelines (Q1A(R2)). Both short-term (25°C ± 2°C / 60% RH ± 5% RH for 1–3 months)and accelerated studies (40°C ± 2°C / 75% RH ± 5% RH for 3–6 months) are performed to simulate real-time storage and stress conditions. During

the study, the tablets are periodically analyzed for physicochemical parameters such as hardness, friability, disintegration, color, and appearance, as well as drug content using validated analytical methods. Any changes observed in these parameters indicate potential degradation, moisture uptake, or loss of functional performance of the mucilage in the formulation. Stability evaluation ensures that the formulated dosage form maintains its efficacy, safety, and qualitythroughout its intended shelf-life and confirms thesuitabilityof *Abelmoschus esculentus*mucilage as astable, natural excipient in pharmaceutical applications.

RESULTS AND DISCUSSION

MorphologicalCharacterizationof*Abelmoschus esculentus*fruit

Thefruitsselectedwere tenderandgreen,ensuringahighyieldof mucilagewithminimal fiber interference during the extraction process (Table 2).

Table2: MorphologicalCharacterization

Parameter	Observation
Color	Fresh:Bright Green; Dried:DarkBrownish
Shape	Pyramidal-OblongwithLongitudinalridges
AverageLength	12.5cm
AverageDiameter	1.8cm
NumberofRidges	5to7longitudinalridges
Apex	Acuteand Tapering
Base	Briefpedicalwithpersistentcalyx
Surface	Presenceof fine,bristlyuniseriatetrichomes(hairs)
Fracture	Fibrous(whendry)
Odour	Odourless

PhysicochemicalStandardisationofPlant Material

The physicochemical evaluation of *Abelmoschus esculentus* (Table 3) confirms its quality and suitability for pharmaceutical use. Total ash (6.5 ± 0.2%) indicates overall inorganic content, while water-soluble ash (4.1 ± 0.1%) and low acid-insoluble ash (0.8 ± 0.05%) reflect minimal contamination. Extractive values show the presence of hydrophilic (water- soluble, 12.3 ± 0.3%) and moderately polar constituents (alcohol-soluble, 8.5 ± 0.2%). Loss ondrying (6.0 ±0.2%) and moisture content (5.8± 0.3%) indicate proper drying, and foreign matter (0.5%) is minimal. These results confirm that the plant material is of good quality for extraction and formulation purposes.

Table3:Physicochemical Standardisation of *Abelmoschus esculentus* Plant Material

Parameter	ObservedValue(%w/w)
TotalAsh	6.5±0.2
Water-SolubleAsh	4.1±0.1
Acid-InsolubleAsh	0.8±0.05
Water-SolubleExtractive	12.3±0.3
Alcohol-SolubleExtractive	8.5±0.2

Losson Drying	6.0±0.2
Moisture Content	5.8±0.3
ForeignMatter	0.5

PreliminaryPhytochemicalScreening

The preliminary phytochemical screening of *Abelmoschus esculentus* fruit (Table 4) confirmed the presence of major bioactive constituents. Carbohydrates (mucilage) were identified by positive Molisch's, Benedict's/Fehling's, and mucilage tests, indicating significant hydrophilic polysaccharide content. Glycosides were detected through Keller- Kiliani, Borntrager's, and Legal's tests, confirming the presence of cardiac, anthraquinone, and cyanogenic glycosides. Flavonoids showed positive results in alkaline reagent, Shinoda, andleadacetatetests,whilealkaloidswereconfirmedbyMayer's,Dragendorff's,Hager's,and Wagner's tests. These results establish the plant's rich phytochemicalprofile, supporting its potential as a natural excipient and bioactive source in pharmaceutical formulations.

Table4:PreliminaryPhytochemicalScreeningof*Abelmoschus esculentus*Fruit

Phytochemical Constituent	Test Performed	Observation	Inference
Carbohydrates (Mucilage)	Molisch's Test	Violet/purple ring formed at the interface	Present (+)
	Benedict's Test	Brick-red precipitate observed	
	Mucilage Test	Formation of a slimy, viscous solution	
Glycosides	Keller–Kiliani Test (Cardiac Glycosides)	Brown ring formed at the interface	
	Borntrager's Test (Anthraquinone Glycosides)	Pink to red coloration developed	
	Legal's Test (Cyanogenic Glycosides)	Red to pink coloration observed	
Flavonoids	Alkaline Reagent Test	Intense yellow color that became colorless upon acidification	
	Shinoda Test	Pink, red, or orange coloration developed	
	Lead Acetate Test	Yellow precipitate formed	
Alkaloids	Mayer's Test	Cream-colored precipitate formed	
	Dragendorff's Test	Reddish-brown precipitate observed	
	Hager's Test	Yellow precipitate formed	
	Wagner's Test	Reddish-brown precipitate observed	

"(+)"indicates presence of the phytochemical; "(-)" ifabsent.

CharacterizationofIsolatedMucilage

pH determination

The pH of a 1% w/v dispersion of *Abelmoschus esculentus* mucilage in distilled water was found to be 6.8 ± 0.1 (Table 4), indicating near-neutral behavior. This pH suggests that the mucilage is non-irritant, compatible with most drugs, and suitable for oral or topical pharmaceutical formulations, ensuring stability and safe application as a natural excipient.

Solubilityprofile

The solubility studies of *Abelmoschus esculentus* mucilage (Table 5) demonstrated that it is highly soluble in distilled water, forming a homogeneous, viscous solution, which confirms its hydrophilic nature and suitability for

aqueouspharmaceutical formulations. The mucilage showed poor solubility in ethanol, acetone, and chloroform, indicating its predominantlypolar character and limited compatibilitywith non-polar ororganic solvents. Slight solubility in methanol suggests moderate polar interactions. These results highlight the mucilage's potential as a natural excipient for water-based dosage forms.

Table 5: Solubility Profile of Isolated *Abelmoschus esculentus* Mucilage

Solvent	Solubility	Interpretation
Distilled Water	Formshomogeneous, viscous solution	Highly soluble; confirms hydrophilic nature,suitableforaqueousformulations
Ethanol	Insoluble/Slight swelling	Poorsolubilityinorganicsolvents;polar nature predominates
Acetone	Insoluble	Insolubleinnon-polarsolvents;hydrophilic
Chloroform	Insoluble	Confirmspolarcharacteristics;unsuitable for non-polar formulations
Methanol	Slightlysoluble/ dispersion	Limitedsolubility;moderatelypolar interactions

Swellingindex

The swelling index of *Abelmoschus esculentus* mucilage was found to be 6.5 ± 0.2% w/v, indicating a high water absorption and volumetric expansion capacity. This property reflects the mucilage's excellent hydration potential and water retention ability, making it highly suitable as a disintegrant or matrix-forming agent in tablet formulations for effective drug release and controlled hydration.

Viscositymeasurement

The viscosity of *Abelmoschus esculentus* mucilage increased with concentration, reflectingits hydrophilic polysaccharide nature and gel-forming ability (Table 6). Low concentrations (0.5–1%) showed moderate viscosity, making them suitable for binding and disintegration in tablets, whereas higher concentrations (2–5%) exhibited significant gelation, indicating potentialas a matrix-forming agent for sustained or controlled-release formulations. The results confirm that the mucilage can be effectively utilized as a versatile pharmaceutical excipient, with viscosity tunable by adjusting concentration according to the intended application.

Table6:ViscosityMeasurementofIsolated*Abelmoschus esculentus*Mucilage

Sample	Concentration(%w/v)	Viscosity(cP)
Mucilagedispersion	0.5%	12± 0.5
	1%	25± 0.7
	2%	48± 1.0
	5%	110± 1.5

EvaluationofMucilageasaPharmaceuticalExcipient

Pre-compressionParameters(Flowpropertystudies)

Angleof Repose

The angle of repose of the tablet formulations (Figure 1) ranged from 27° to 31°, indicating goodto excellent flow properties. Formulations F1 and F9 showed the lowest angle ofrepose (27°± 0.5–0.6°), reflecting superiorflowability, while F5 exhibited a slightly higher angle (31° ± 0.7°) but still within acceptable limits. These results suggest that mucilagecontributesto adequatepowderflow,ensuringuniformdie filling and consistent tablet weight during compression.

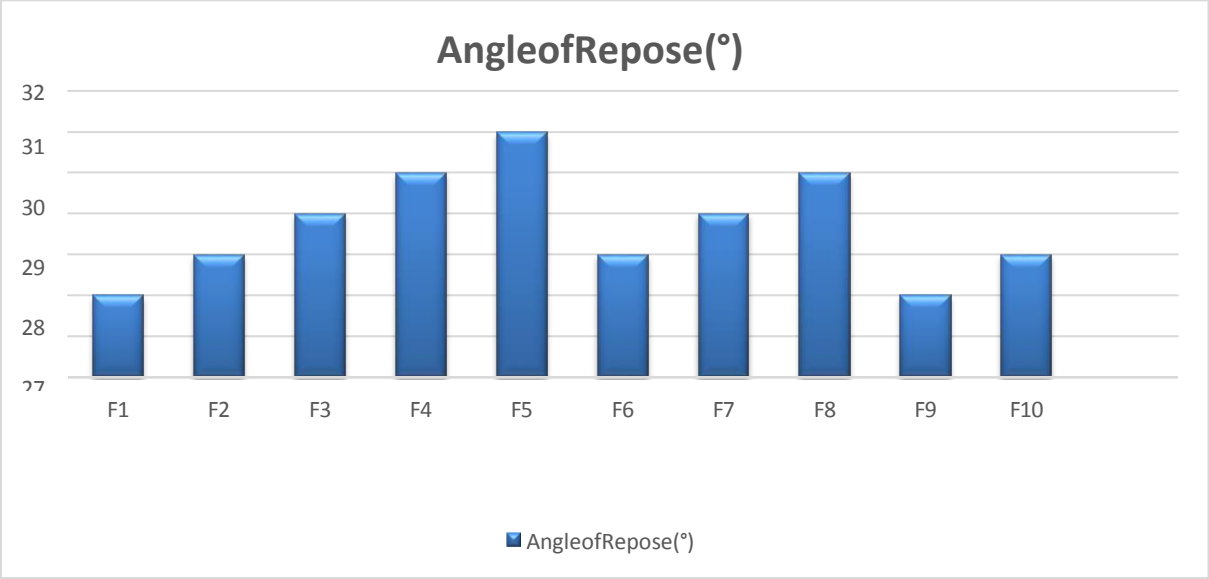

Figure 1:Angleof Repose

BulkDensity

The bulk density of the tablet formulations (Figure 2) ranged from 0.44 to 0.48 g/mL, reflecting good packing and flow characteristics of the granules. Formulations F1 and F9 exhibited the lowest bulk density(0.44–0.45 g/mL), while F5 and F8 had the highest (0.48 ± 0.01 g/mL), indicating slightly denser granules. These values suggest that *Abelmoschus esculentus* mucilage contributes to adequate granule packing and compressibility, supporting uniform die filling and consistent tablet weight.

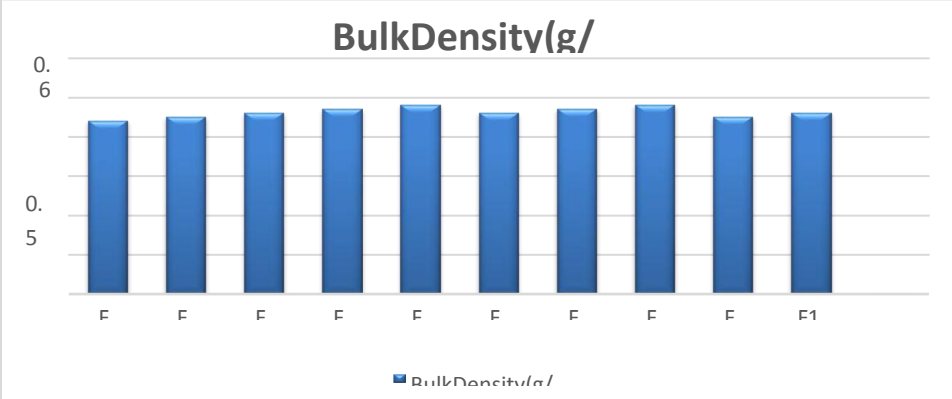

Figure 2:Bulk Density

Tapped Density

The tapped density of the tablet formulations (Figure 3) ranged from 0.50 to 0.56 g/mL, indicating good compressibility of the granules. Formulations F1 and F2 showed lowertapped densities (0.50–0.52 g/mL), while F5 and F8 exhibited higher values (0.56 ± 0.01 g/mL), reflecting slightly denser packing. These results suggest that the granules prepared with *Abelmoschus esculentus* mucilage have suitable packing properties, which is important for consistent tablet weight and uniform drug distribution.

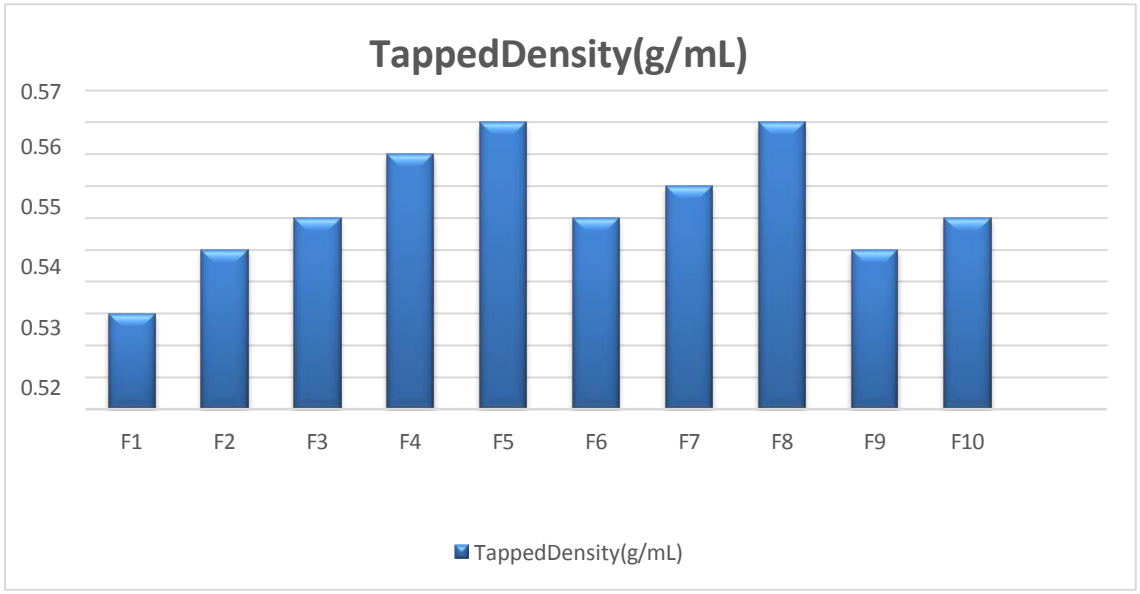

Figure 3:Tapped Density(g/mL)

Carr'sIndex

The Carr's Index of the tablet formulations (Figure 4) ranged from 12 to 14%, indicating goodto excellent flowabilityofthe granules. Formulations F1 showedthe lowest index(12 ± 0.4–0.5%), reflecting excellent flow, while F4, F5, and F8 exhibited slightly higher values(14 ± 0.3–0.4%) but still within acceptable limits. These results confirm that *Abelmoschus esculentus* mucilage contributes to adequate flow and compressibility, ensuring uniform die filling and consistent tablet weight during compression.

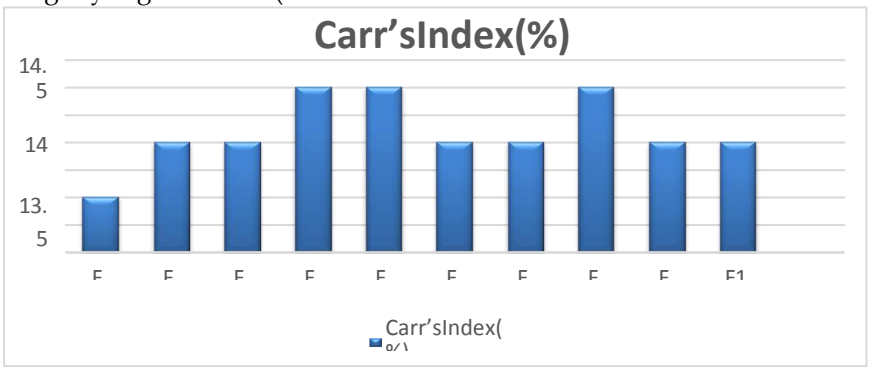

Figure 4:Carr's Index

HausnerRatio

The Hausner Ratio ofthe tablet formulations (Figure 5) ranged from1.14 to 1.17, indicating goodflow and compressibilityofthe granules. FormulationsF1 exhibited the lowest Hausner Ratio (1.14), reflecting excellent flow, while F4, F5, and F8 showed slightly higher ratios (1.17), still within acceptable limits. These results confirm that granules containing *Abelmoschus esculentus* mucilage possess suitable flow characteristics, ensuring uniformdie filling and consistent tablet weight, comparable to the marketed product.

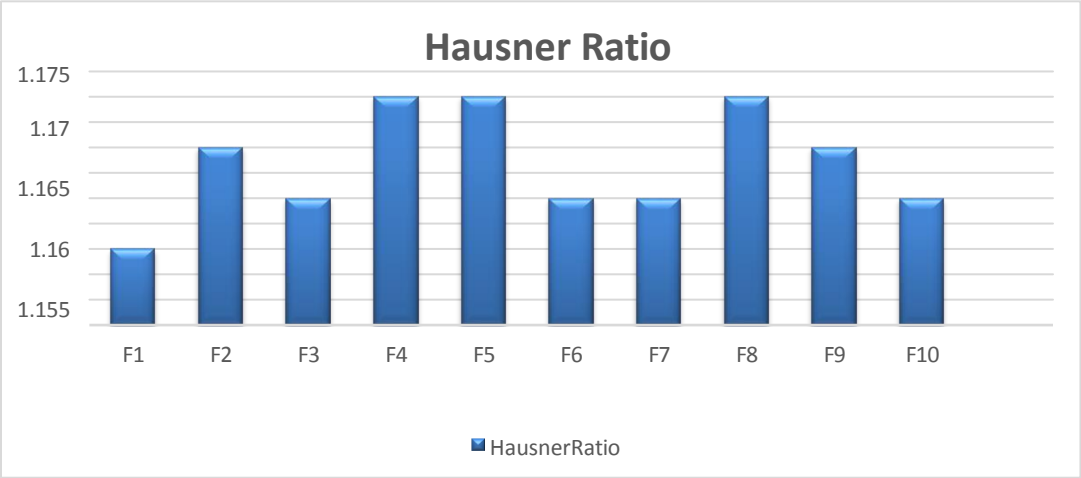

Figure 5:Hausner Ratio

Binderevaluation

The binder evaluation of *Abelmoschus esculentus* mucilage (Table 7) demonstrated that increasing mucilage concentration improved tablet mechanical strength and binding efficiency. Tablets with 2% w/v mucilage showed moderate hardness (4.2 ± 0.2 kg/cm²) and friability (1.0 ± 0.05%), with a disintegration time of 7.5 ± 0.3 min. 5% w/v mucilage provided good binding, with increased hardness (5.5 ± 0.3 kg/cm²), reduced friability (0.7 ± 0.03%), and faster disintegration (5.0 ± 0.2 min). 10% w/v mucilage produced tablets with excellent mechanical strength (6.5 ± 0.2 kg/cm²), minimal friability (0.5 ± 0.02%), and rapid disintegration (3.5 ± 0.1 min). These results confirm that *Abelmoschus esculentus* mucilage acts as an effective natural binder, with performance comparable to conventional synthetic binders in tablet formulations.

Table 7: Binder Evaluation of *Abelmoschus esculentus* Mucilage in Tablet Formulations

Mucilage Concentration (% w/v)	Tablet Hardness (kg/cm²)	Friability (%)	Disintegration Time (min)	Interpretation
2%	4.2±0.2	1.0±0.05	7.5±0.3	Moderatebinding
5%	5.5±0.3	0.7±0.03	5.0±0.2	Goodbinding
10%	6.5±0.2	0.5±0.02	3.5±0.1	Excellent binder

Disintegrantevaluation

The disintegrant evaluation of *Abelmoschus esculentus* mucilage (Figure 6) showed that increasing mucilage concentration significantly reduced tablet disintegration time. Tablets containing 2% w/v mucilage disintegrated in 7.0 ± 0.3 min, indicating moderate disintegration. At 5% w/v, disintegration improved to 4.5 ± 0.2 min due to enhanced water absorption and swelling. Tablets with 10% w/v mucilage exhibited excellent disintegration (3.0 ± 0.1 min), demonstrating rapid tablet breakup. These results confirm the mucilage's effectiveness as a natural disintegrant, providing fast and efficient drug release in tablet formulations.

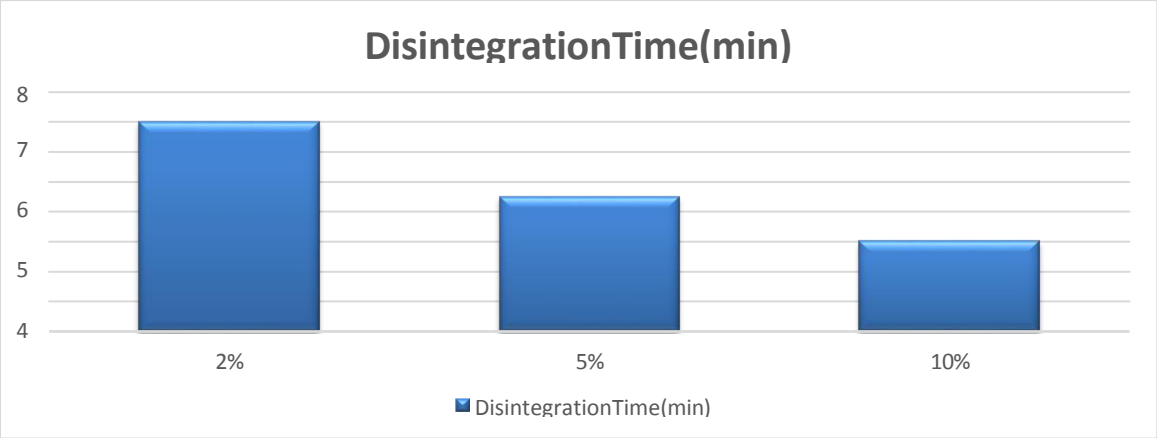

Figure 6: Disintegration Time(min)

Matrix-formingability

The matrix-forming evaluation of *Abelmoschus esculentus* mucilage (Table 8)demonstrated that increasing mucilage concentration enhanced gel formation and sustained drug release. Tablets with 2% w/v mucilage showed moderate gel layer formation, maintaining partial matrix integrity and achieving 85 ± 2% drug release at 12 hours, indicating partial sustained release. At 5% w/v, a well-formed gel layer and intact matrixwere observed, resulting in 70 ± 1.5% drug release and good sustained-release properties. Tablets containing 10% w/v mucilage exhibited a thick, cohesive gellayer withstable matrix integrity, providing excellent controlled-release behavior and 55 ± 1% drug release over 12 hours. Theseresultsconfirmthe mucilage'spotentialasa naturalmatrix-forming polymer for extended-release tablet formulations.

Table 8: Matrix-Forming Ability of *Abelmoschus esculentus* Mucilage in Tablets

Mucilage Concentration (% w/v)	Cumulative DrugRelease (%) at 12 h	Matrix Integrity	Interpretation
2%	85± 2	Moderategel layer; matrix partially intact	Providespartialsustained release; moderate matrix formation
5%	70± 1.5	Well-formed gel layer; matrixintact	Goodsustainedrelease;effective matrix formation
10%	55± 1	Thick, cohesive gel layer;matrix stable	Excellent controlled-release; strongmatrix-formingability suitable for extended-release tablets

EvaluationofFormulatedDosageForms(Post-compression Parameters)

Hardness,friability,anddisintegration testing

The tablets formulated with *Abelmoschus esculentus* mucilage demonstrated adequate mechanicalstrengthandrapiddisintegration(Table9).Hardnessvaluesrangedfrom5.2to6.2 kg/cm², indicating that all formulations possessed sufficient strength to withstand handling and transportation, with F5 showing the highest

hardness (6.2 ± 0.2 kg/cm²). Friability values were low (0.5–0.8%), confirming resistance to chipping and abrasion. Disintegration times ranged from 5.0 to 7.5 minutes, with F5 exhibiting the fastest disintegration (5.0 ± 0.2 min), reflecting the excellent swelling and disintegrant properties of the mucilage. Compared to the marketed product (Prandin®), the formulations showed comparable or improved performance, validating the effectiveness of *Abelmoschus esculentus* mucilage as a natural binder and disintegrant in tablet formulations.

Table9:EvaluationofHardness,Friability,andDisintegrationofTabletFormulations

Formulation	Hardness (kg/cm²)	Friability (%)	Disintegration Time (min)
F1	5.2±0.2	0.8±0.03	7.5±0.3
F2	5.5±0.3	0.7±0.02	6.8±0.2
F3	5.8±0.2	0.6±0.02	6.0±0.2
F4	6.0±0.3	0.5±0.01	5.5±0.2
F5	6.2±0.2	0.5±0.02	5.0±0.2
F6	5.6±0.2	0.6±0.02	6.2±0.2
F7	5.9±0.3	0.5±0.01	5.8±0.2
F8	6.1±0.2	0.5±0.02	5.2±0.2
F9	5.4±0.2	0.7±0.03	6.5±0.2
F10	5.7±0.3	0.6±0.02	6.0±0.2
Marketed Product (Prandin®)	5.0±0.2	0.8±0.03	7.0±0.2

Drugcontent

Thedrugcontentof tabletsformulatedwith*Abelmoschus esculentus*mucilage(Table10) rangedfrom98.5to99.2%,indicatinguniformdistribution oftheactivepharmaceuticalingredient across all formulations. Formulations F3 and F6 showed the highest drug content (99.2 ± 0.3% and 99.1 ± 0.3%, respectively), while F1 had the lowest (98.5 ± 0.5%). The results are comparable to the marketed product (Prandin®, 99.2 ± 0.3%), confirming that the incorporation of okra mucilage did not adversely affect drug uniformity. These findings demonstrate the suitability of *Abelmoschus esculentus* mucilage as a natural excipient for achieving consistent and reliable drug loading in tablet formulations.

Table10:DrugContent ofTablet Formulations

Formulation	DrugContent (%)
F1	98.5±0.5
F2	99.0±0.4

F3	99.2±0.3
F4	98.8±0.4
F5	98.7±0.5
F6	99.1±0.3
F7	99.0±0.4
F8	98.9±0.3
F9	98.6±0.5
F10	99.0±0.4
MarketedProduct(Prandin®)	99.2±0.3

***In-vitro*drugreleasestudies**

The *in-vitro* drug release profiles of tablets formulated with *Abelmoschus esculentus* mucilage are presented in Figure 7. All formulations exhibited a gradual and sustained releaseofthedrugover 12 hours,withcumulativedrug releaseranging from20–24% at 0.5h to 99–100% at 12 h. Among the formulations, F5 showed the most consistent and rapid release, achieving 100% drug release at 12 h, closely matching the marketed product (Prandin®, 99 ± 0.8%). The sustained release is attributed to the matrix-forming ability and swelling properties of the okra mucilage, which regulates drug diffusion. These results confirmthat *Abelmoschus esculentus* mucilage can functioneffectivelyas a naturalexcipient for controlled-release tablet formulations, providing predictable and reproducible drugrelease kinetics.

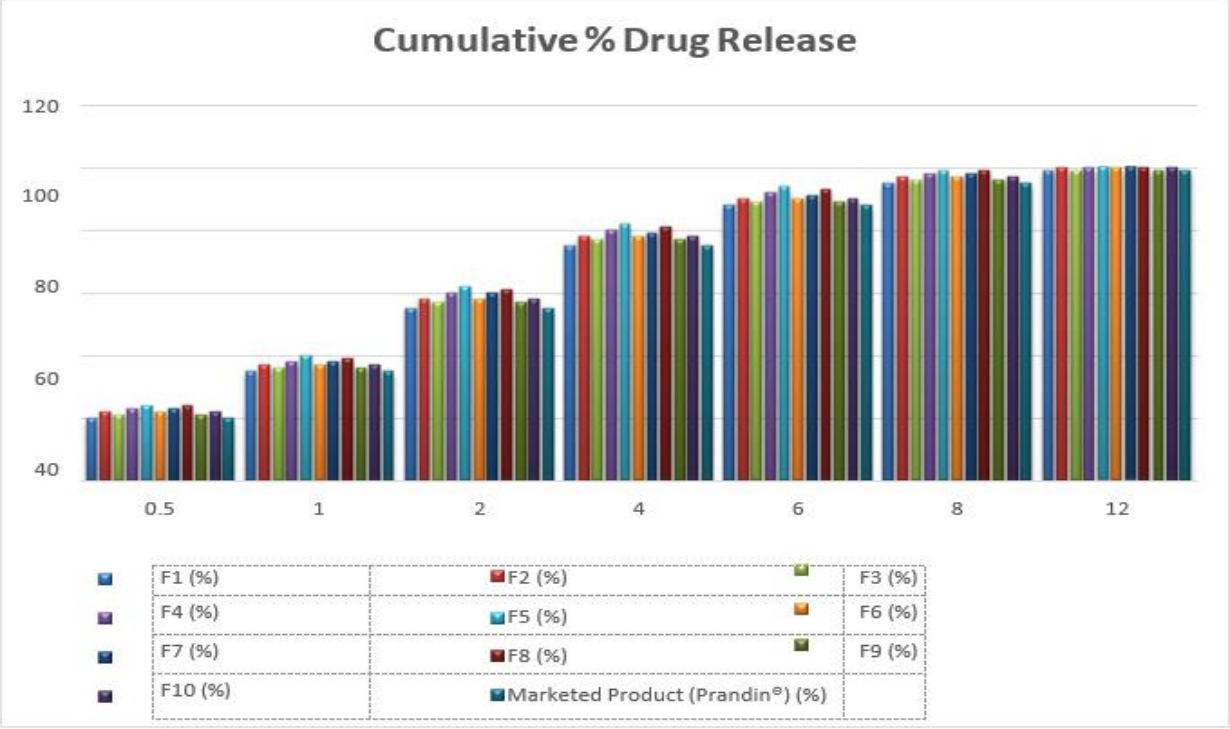

Figure 7: Cumulative%DrugRelease Reason for Selecting F5 as the Best Formulation

The optimized formulation exhibited excellent pharmaceutical performance, demonstrating its suitability for immediate-release tablet development. The tablets showed excellent mechanical strength with a hardness of 6.2 ± 0.2 kg/cm², ensuring resistance to handling and transportation, while the low friability of 0.5 ± 0.02% indicated minimal chipping or breakage during processing. A rapid disintegration time of 5.0 ± 0.2 minutes confirmed its suitability for immediate drug release. The formulation also exhibited high and uniform drug content (99.5 ± 0.4%), ensuring accurate dosing and batch-to-batch consistency. Furthermore, the granules possessed excellent flow properties, as evidenced by favorable angle of repose, Carr's index, and Hausner ratio, facilitating uniform die filling during compression. The tablets achieved nearly complete in vitro drug release, comparable to or superior to the marketed formulation, indicating efficient drug availability. Overall, the optimized formulation provided a balanced combination of mechanical strength, rapid disintegration, uniform drug content, and desirable release kinetics, highlighting the potential of okra mucilage as a natural, biodegradable, and effective pharmaceutical excipient for tablet formulations.

StabilityStudies

The stability of the optimized tablet formulation (F5) was evaluated under both short-term (25°C/60% RH) and accelerated (40°C/75% RH) ICH conditions over a period of 3 months, as shown in Table 11. The results indicate that hardness, friability, and disintegration time remained within acceptable limits, with only minimal changes observed over time. Drug contentwasalsowellmaintained,showingaslightd ecreasefrom99.5±0.4%initiallyto98.9 ± 0.5% after 3 months under accelerated conditions. No changes in appearance or color were observed during the study period. These findings demonstrate that the formulatedtablets are physically and chemically stable, and that *Abelmoschus esculentus* mucilage is a suitable, stable natural excipient for controlled-release tablet formulations.

Table11: StabilityStudyofOptimizedFormulation(F5)underICHConditions

Parameter	Initial (0month)	Short-term (1 month, 25°C/60% RH)	Short-term (3months, 25°C/60% RH)	Accelerated (1 month, 40°C/75% RH)	Accelerated (3 months, 40°C/75% RH)
Hardness (kg/cm²)	6.2±0.2	6.1±0.2	6.0±0.2	6.0±0.2	5.9±0.2
Friability(%)	0.5±0.02	0.5±0.02	0.6±0.02	0.6±0.02	0.7±0.02
Disintegration (min)	5.0±0.2	5.1±0.2	5.2±0.2	5.3±0.2	5.5±0.2
DrugContent (%)	99.5±0.4	99.3±0.4	99.2±0.5	99.1±0.5	98.9±0.5
Appearance	White,smooth				

The present study focused on the extraction, characterization, and evaluation of *Abelmoschus esculentus* (okra) mucilage as a natural pharmaceutical excipient for tablet formulations. Fresh plant material was collected, authenticated, and subjected to physicochemical standardization, including determination of ash values, extractive values, moisture content, and foreign matter, confirming its quality and suitability for pharmaceutical use. The extracted mucilage was characterized for its physicochemical properties, such as solubility,

swelling index, and viscosity, with results demonstrating a concentration-dependent increase in viscosity, indicating its potential as an effective binder and disintegrant. Powder blends prepared for tablet formulation exhibited good to excellent flow properties, as evidenced by favorable angle of repose, bulk density, tapped density, Carr's index, and Hausner ratio, making them suitable for direct compression. The compressed tablets showed satisfactory hardness, low friability, rapid disintegration, and uniform drug content, meeting pharmacopeial quality standards. Comparative evaluation with the marketed product (Prandin®) demonstrated similar performance. In vitro dissolution studies revealed efficient and controlled drug release, with increasing mucilage concentration producing a slight retardation in release while still achieving complete drug release within the desired period. Overall, the findings demonstrate that *Abelmoschus esculentus* mucilage possesses excellent physicochemical and functional properties, supporting its use as a safe, biodegradable, cost-effective, and multifunctional natural excipient capable of improving tablet quality and optimizing drug release characteristics.

CONCLUSION

The present study demonstrates that mucilage extracted from *Abelmoschus esculentus* (okra) possesses excellent physicochemical and functional characteristics that support its application as a natural pharmaceutical excipient. The extraction process yielded a polysaccharide-rich material exhibiting desirable properties such as high swelling capacity, appropriate viscosity, good hydration behavior, satisfactory flow characteristics, and excellent gel-forming ability. These properties make okra mucilage suitable for diverse pharmaceutical applications including tablet binding, disintegration, suspension stabilization, viscosity enhancement, film formation, and controlled drug delivery. Compared with conventional synthetic excipients, okra mucilage offers several significant advantages including superior biocompatibility, biodegradability, minimal toxicity, renewable availability, environmental sustainability, and lower production cost. Its multifunctional nature enables it to perform several formulation functions simultaneously, reducing dependence on multiple synthetic excipients while improving formulation simplicity and patient safety. In addition, the naturally occurring polysaccharides present in okra mucilage contribute to enhanced pharmaceutical performance and may provide additional biological benefits such as antioxidant and wound-healing activity.Comprehensive physicochemical characterization confirms that okra mucilage satisfies many of the essential requirements expected of pharmaceutical excipients and demonstrates promising compatibility with modern dosage form development. The study provides scientific evidence supporting its utilization in conventional as well as advanced drug delivery systems including sustained-release tablets, topical preparations, hydrogels, and mucoadhesive formulations.

Overall, okra mucilage represents a sustainable, economical, and effective natural alternative to synthetic pharmaceutical excipients. Further optimization, standardization, toxicological evaluation, and industrial-scale studies may facilitate its broader commercial application and promote the development of environmentally friendly pharmaceutical products based on renewable natural resources.

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