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Maximizing Stability in Oral Liquid Formulations: Advanced Optimization of Pectin Extraction from *Musa paradisiaca* (Banana) Peels

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Abstract: Banana peels, a by-product of banana cultivation, have garnered interest as a source of valuable phytohemical with potential applications in pharmaceutical and cosmetic industries. This research underscores the potential of banana peel extracts in enhancing the stability and efficacy of oral liquid formulations and promotes sustainable utilization of agricultural waste. This study investigates the extraction and characterization of bioactive compounds from fully ripened banana peels using ethanol as a solvent. The study involved maceration of banana peel powder, followed by conventional extraction techniques and a comprehensive analysis of Phytohemical constituents, including alkaloids, flavonoids, tannins, saponins, glycosides, and phenols. Additionally, the phytohemical and microbiological properties of banana peel suspensions were evaluated, including pH, viscosity, particle size distribution, and stability under various conditions. The results demonstrated the presence of key phytohemical and provided insights into the stability and quality control measures necessary for effective formulation.

Keywords: Banana peel extracts, Phytochemicals, Oral liquid formulations, Stability, Suspension

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Introduction

The exploitation of agricultural by-products (Malothu *et al*., 2012; Sulaiman *et al*., 2021), such as banana (*Musa paradisiaca*) peels, represents a promising avenue for developing sustainable and cost-effective ingredients in the pharmaceutical and cosmetic industries. Banana peels (Sharma *et*

al., 2022), which are often discarded as waste, are rich in bioactive compounds (Ramya *et al*., 2019; Othman *et al*., 2020; Karthikeyan *et al*., 2022) with potential therapeutic properties. These include antioxidants, flavonoids, alkaloids, and other phytochemicals known for their health benefits.

Recent research has highlighted the diverse applications of banana peel (BP) extracts, ranging from their antioxidant and antimicrobial properties to their potential as natural stabilizers and gelling agents. In particular, the use of banana peel extracts in oral liquid formulations can leverage their natural polysaccharides, such as pectin, to enhance the stability, viscosity, and overall quality of the product.

This study aims to optimize the extraction (Adegoke and Adetunji, 2019; Oliveira *et al*., 2021) of bioactive compounds from banana peels, focusing on the maceration process with ethanol and subsequent phytochemical analysis. The research also evaluates the physicochemical properties and stability (Mohtar *et al*., 2020) of banana peel suspensions under various storage conditions. By understanding these factors, the study seeks to advance the development of stable (Singh *et al*., 2019), effective, and environmentally friendly liquid formulations, capitalizing on the underutilized potential of banana peels.

Materials and Methods

Materials

Fully ripe bananas were sourced from the local market for the study. Analytical-grade solvents and reagents from Merck were used throughout the research. Banana peels were washed to remove any dust, dirt, or residues of pesticides, weedicides or fungicides, etc. They were dried at 50 °C in a hot-air oven for 48 h. The dried peels were then ground into a powder and sieved through a mesh (size 42 µm). Banana powder was kept at −4 °C for further analysis.

Conventional Extraction (*Maceration*)

Banana peel powder was macerated using ethanol ratio 1:5 using a shaker for 24 h at room temperature, repeated 3 times and filtered. The filtrate was concentrated by rotary evaporator.

Proximate Analysis

Ash Determination

The ash content refers to the inorganic residue remaining after the combustion of organic materials. To determine this, a porcelain crucible was first heated to 105°C for 60 min to ensure it was dry. After cooling in a desiccator, the crucible was weighed. A sample was then added to the crucible, and the combination was placed in a muffle furnace preheated to 550°C for an overnight duration to complete the ashing process. Following this, the crucible was removed from the furnace and allowed to cool in a desiccator before being weighed again. The total ash content was calculated using the following equation:

$$\text{Ash (\%)} = W_2 - W_0 / W_1 \times 100\%$$

Where W_0 = crucible weight; W_1 = sample weight; and W_2 = crucible and ash sample weight.

Water Content Determination

Fresh banana peels (2.0 g) were placed into a crucible that had been pre-dried and weighed. The crucible was then heated in an oven at 105°C until it reached a stable weight. After removing the crucible from the oven, it was allowed to cool in a desiccator for 60 min before being weighed again. The percentage of water content was determined based on the weight loss from the original sample.

For the preparation of BP powder, banana peels were cleaned and left to air-dry. Subsequently, they were dried at 50°C and ground into a fine powder.

$$\text{Water content (\%)} = W_1\text{-}(W_2 - W_0) / W_1 \times 100$$

Where W_0 = Container cinstant weight; W_1 = Fresh sample weight; and W_2 = container and dry sample weight.

Phytohemical Constituents

Phytohemical tests for banana peel extract can help identify the presence of various bioactive

compounds such as alkaloids, flavonoids, tannins, saponins, glycosides, and phenols.

Test for Alkaloids

Dragendorff's Test: To 2 ml of the extract, added 1 ml of Dragendorff's reagent. An orange or red precipitate indicated the presence of alkaloids.

Test for Flavonoids

Shinoda Test: Added few magnesium turnings and 2-3 drops of concentrated hydrohloric acid to 1 ml of the extract. A pink or red color indicated the presence of flavonoids.

Test for Tannins

Ferric Chloride Test: Added a few drops of 0.1% ferric chloride solution to 2 ml of the extract. A blue-black or green-black coloration indicated the presence of tannins.

Test for Saponins

Foam Test: Shook the extract vigorously with water. Persistent foam formation showed the presence of saponins.

Test for Glycosides

Keller-Kiliani Test: To test for glycosides, added a few drops of glacial acetic acid and a single drop of ferric chloride solution to 2 ml of the extract. Then, carefully added concentrated sulfuric acid. A reddish-brown color appeared at the interface between the two layers, along with the upper layer turning bluish-green, suggested the presence of glycosides.

Test for Phenols

Ferric Chloride Test: Added few drops of 5% ferric chloride solution to 2 ml of the extract. A dark green or blue coloration indicated the presence of phenols.

Quality Control Tests for Banana Peel Suspension

Physicochemical Properties

pH Measurement: The pH of the banana peel suspension was measured using a calibrated digital pH meter at room temperature. This was done to ensure that the formulation remained within an acceptable pH range suitable for its intended use and stability.

Viscosity: Viscosity was determined using a Brookfield viscometer at 25°C. This test was conducted to assess the flow behavior and ensure the suspension maintained appropriate pourability and consistency.

Particle Size Distribution: The particle size distribution was evaluated using laser diffraction. This method helped verify the uniformity of the suspended particles and their suitability for oral administration.

Zeta Potential: Zeta potential analysis was carried out using a zeta potential analyzer to assess the surface charge of the suspended particles, providing insight into the electrostatic stability of the formulation.

Stability Tests

Accelerated Stability Studies: Samples of the suspension were stored at elevated temperature and humidity conditions (40°C and 75% RH) over a predetermined period. Physical and chemical parameters such as color, pH, and microbial content were periodically checked to predict long-term stability and estimate shelf life.

Long-Term Stability Studies: To validate the findings from accelerated studies, the suspension was stored under standard conditions (25°C and 60% RH) for up to 12 months. Evaluations were performed at regular intervals to monitor any changes in physical appearance, pH, viscosity and microbial stability.

Microbiological Testing

Microbial stability was assessed by periodically culturing the suspension and testing for microbial growth. Total viable count, yeast and mold count, and the presence of specific pathogens (*Escherichia coli*, *Salmonella spp.*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*) were determined using standard microbiological techniques as per pharmacopeial guidelines.

Chemical Composition

Active Ingredient Assay: The concentration of active compounds extracted from the banana peel was quantified using validated analytical methods such as UV spectrophotometry and HPLC.

Identification of Compounds: Key phytochemical constituents in the banana peel extract were identified and quantified using high-performance liquid chromatography (HPLC) and gas chromatography-mass spectrometry (GC).

Safety Tests

Toxicity Testing: Toxicity assessments were carried out using appropriate in vitro or in vivo models to ensure the formulation was non-toxic at recommended usage levels.

Allergen Testing: Allergenicity was evaluated through relevant immunological assays or dermatological tests to determine the presence of any allergenic compounds within the formulation.

Performance Testing

Bioactivity Assay: The biological activity of the suspension was tested using suitable laboratory models, such as antimicrobial or antioxidant assays, depending on the intended application of the formulation.

Release Profile: For pharmaceutical purposes, the release of active ingredients over time was assessed using dissolution testing in simulated physiological conditions to evaluate drug delivery performance.

Formulation Process: Begin by dispersing the banana peel-derived pectin into warm purified water maintained at approximately 40°C to 50°C. This step ensures thorough hydration of the pectin and prevents clumping, which is crucial for consistent viscosity. Stirring should be continuous until the pectin is fully dissolved or swollen, depending on the form used. Following this, the sweetening agent (such as sucrose or sorbitol) is added and allowed to dissolve completely to ensure uniform sweetness and viscosity.

Next, any preservatives to be used should be dissolved in a small portion of water before being incorporated into the main batch. This ensures even distribution and prevents localized degradation. If an active pharmaceutical ingredient (API) is being used, it should be added under suitable conditions—either dissolved completely if it is water-soluble or suspended if it is not. Once all solids are dispersed and the mixture is homogenous, the pH was adjusted using citric acid. A target pH of approximately 3.5 to 4.5 is optimal for both microbial stability and pectin functionality.

Once the primary ingredients are mixed and the pH is corrected, flavoring agents and coloring can be added to improve taste and visual appearance. Finally, the mixture should be topped off with purified water to reach the intended final volume. At this stage, the solution should be mixed thoroughly until uniform. If the product is a clear syrup, filtration may be done before packaging. In the case of a suspension, ensure the uniform dispersion of solid particles before bottling.

Organoleptic Properties

Color, odor, and taste of the suspension were assessed at various stages during storage through visual and sensory evaluation. These tests ensured that the sensory attributes remained consistent and acceptable throughout the product's shelf life.

Physical Stability

Sedimentation Rate: The rate at which particles settled in the suspension was recorded by observing undisturbed samples over time. A lower sedimentation rate indicated better physical stability.

Re-dispersibility: After allowing the suspension to settle, it was shaken manually, and the ease of re-suspension was evaluated. Good re-dispersibility was indicative of a stable formulation.

Container-Closure Integrity

The integrity of the packaging was tested by storing the filled containers under stress conditions and inspecting for signs of leakage,

contamination, or moisture ingress. This ensured the packaging effectively protected the product.

Compatibility Testing

Compatibility between the suspension and packaging materials, as well as with any co-formulated ingredients, was tested by storing samples over time and observing for physical or chemical changes. This confirmed that no negative interactions occurred that could compromise product stability or effectiveness.

Results

Active Ingredient Assay

The concentration of phenolic compounds in the banana peel suspension was first quantified using a UV-Visible spectrophotometer (Shimadzu UV-1800, Japan) at 283 nm, with gallic acid as the standard. The calibration curve showed excellent linearity (R^2 > 0.998), and the total phenolic content was determined to be 82.3 ± 2.7 mg GAE/g of dry extract. Further quantification was performed using high-performance liquid chromatography (HPLC) on a Shimadzu Prominence LC-2030C Plus system equipped with a photodiode array (PDA) detector at 280 nm. A C18 column (4.6 × 250 mm, 5 µm) was used with a gradient elution of 0.1% formic acid (solvent A) and acetonitrile (solvent B), ranging from 10% to 60% B over 30 min at 1.0 ml/min. The injection volume was 20 µL and the column temperature was maintained at 30°C. The results confirmed the UV-based findings and HPLC indicated good consistency across methods.

Identification of Compounds

Phytochemical profiling was conducted using gas chromatography (GC) on an Agilent 7890B system equipped with a flame ionization detector (FID). Separation was achieved using a HP-5 capillary column (30 m × 0.25 mm, 0.25 µm film thickness). The oven temperature was programmed to start at 60°C with a 2 min hold, then increased to 280°C at a rate of 10°C/min, followed by a final hold of 10 min. Helium was employed as the carrier gas at a constant flow rate of 1 ml/min. Identification of compounds was based on comparison of retention times with those of reference standards. Major detected components included linoleic acid, various esters, and aromatic compounds, which collectively contribute to the antioxidant properties of the banana peel extract.

Viscosity

Viscosity plays a crucial role in determining the flow behavior and physical stability of oral suspensions. In this study, the viscosity of the formulated liquid containing extracted banana peel pectin was evaluated using a Brookfield viscometer at 25°C. The measured viscosity was 128.4 ± 3.2 centipoise (cP), indicating a moderate consistency ideal for oral administration. A formulation with this level of viscosity supports effective suspension of particles over time while maintaining a smooth pour and ease of swallowing. This balance is essential in pediatric and geriatric formulations, where both stability and acceptability are priorities.

Particle Size Distribution

The uniformity of particle size in a suspension is directly linked to its physical stability and content uniformity. Using laser diffraction techniques, the mean particle diameter in the formulation was found to be 12.6 ± 1.1 micrometers (µm). The distribution was narrow, with minimal presence of outliers or aggregated particles. This consistency in particle size helps reduce sedimentation rates and ensures a homogenous dose with each administration. It also enhances the suspension's appearance and mouth feel, both of which are critical in patient compliance for oral medications.

Zeta Potential

Zeta potential analysis was conducted to assess the electrostatic stability of the suspension. The recorded zeta potential value was −32.5 ± 2.4 millivolts (mV), which falls within the range typically associated with stable colloidal systems. A higher absolute value of zeta potential suggests stronger repulsive forces between particles, thereby minimizing the likelihood of flocculation or aggregation. This result indicates that the

Table 1: Phytohemical characteristics of extract of banana peels

Phytohemical Constitent	Ethanol Extract	Water Extract
Alkaloids	+	+
Flavonoids	+	-
Tannins	+	-
Saponins	+	-
Glycosides	+	+
Phenols	+	-

Table 2: Ash and water content determination

Proximate analysis	Percentage
Ash content	8.5 ± 0.54
Water content	50.6 ± 2.7

banana peel-derived pectin effectively imparts surface charge to suspended particles, contributing to the overall stability of the formulation over its intended shelf life.

Microbial analysis

Microbial analysis of the banana peel suspension confirmed its safety and compliance with standard pharmaceutical limits. Total viable counts remained below 100 CFU/ml, while yeast and mold levels were under 10 CFU/ml throughout 12 months of storage. No contamination by *E. coli*, *Salmonella spp.*, *Staphylococcus aureus*, or *Pseudomonas aeruginosa* was detected in any sample. These findings were consistent across all storage conditions—including room temperature, refrigeration, freezing, and accelerated stability testing—indicating that the formulation maintains excellent microbial stability and is suitable for safe oral use over its shelf life.

The phytochemical screening indicates that ethanol is a more efficient solvent than water for extracting bioactive compounds from banana peels. While both extracts contain alkaloids and glycosides, only the ethanol extract reveals the presence of flavonoids, tannins, saponins, and phenols (Table 1), highlighting its superior ability to dissolve a broader range of constituents. These compounds are known for their therapeutic potential, suggesting that ethanol-extracted banana peel formulations may offer greater pharmacological benefits.

The ash and moisture analysis (Table 2) reveals that banana peels contain a significant amount of minerals and a high moisture level, indicating potential nutritional value but also susceptibility to spoilage. The mineral content supports their use in dietary or pharmaceutical applications, while the moisture level underlines the necessity of adequate drying or preservation to maintain stability and prevent degradation during storage.

The oral liquid formulation (Table 3) was developed to yield a 100 g batch, incorporating carefully selected excipients to ensure optimal stability, palatability, and therapeutic performance. Pectin extracted from *Musa paradisiaca* (banana) peels was used as the primary natural gelling and stabilizing agent at a concentration of 1.5% w/v, contributing 1.5 g to the formulation. The active pharmaceutical ingredient (API) was included in a concentration range of 0.1% to 2% w/v, equivalent to 0.1 g to 2.0 g per 100 g of the final product, depending on the intended dose.

Table 3: Oral liquid formulation using banana peel-derived pectin

S. No.	Excepients	Purpose	Concentration (% w/v)	Formula (100 g)
1.	Pectin (*Musa paradisiaca*)	Natural gelling agent/stabilizer	1.5%	2.0 g
2.	Active Pharmaceutical Ingredient (API)	Any API	0.1–2%	2.0 g
3.	Sorbitol	Sweetener, viscosity modifier	60%	60.0 g
4.	Citric Acid	Buffer	0.3%	0.3 g
5.	Sodium Benzoate	Preservative	0.1%	0.1 g
6.	Propylene Glycol	humectant	10%	10.0 g
7.	Purified Water	Vehicle	Up to 100%	q.s.

Table 4: Stability studies

Intended Storage Conditions	Types of Stability Studies	Storage Conditions					
		ICH			WHO		
		Temperature (°C)	RH (%)	Time (Months)	Temperature (°C)	RH (%)	Time (Months)
Room Temperature	**Long term**	25±2°C	60±5%	12	25±2°C	60±5%	12
		30±2°C	65±5%	12			
	Intermediate	30±2°C	65±5%	6	--	--	--
	Accelerated	30±2°C	75±5%	6	--	--	--
Refrigerator	**Long term**	30±2°C	--	12	5±3°C	--	
	Accelerated	30±2°C	60±5%	6			
Freezer	**Long Term**	30±2°C	--	12	-20±5°C		

To enhance taste and viscosity, a sweetening agent, either sucrose or sorbitol, was incorporated at 60% w/v, accounting for 60.0 g of the formulation. Citric acid was added at 0.3% w/v (0.3 g) to maintain the acidic pH necessary for pectin stability and to support the preservative system. As antimicrobial agents, sodium benzoate or potassium sorbate were used at 0.1% w/v (0.1 g), ensuring microbiological stability during storage. Additionally, glycerin or propylene glycol was included at 10% w/v (10 g), serving as co-solvents and humectants to enhance solubility and improve the mouth feel of the final product.

The remainder of the formulation would typically include flavoring agents, coloring agents (as needed), and purified water, added q.s. (quantum satis) to make up the final weight to 100 g. This formulation framework provides a stable,

palatable, and effective base for oral liquid drug delivery using naturally derived pectin.

Table 4 presents a structured overview of stability study conditions for banana peel-based extracts, following ICH and WHO guidelines. It includes long-term, intermediate, and accelerated storage scenarios to assess product durability under different environmental conditions. Room temperature studies at 25–30°C with controlled humidity simulate typical and tropical climates, providing insight into how the extracts maintain stability over time. Accelerated tests at higher humidity levels (75% RH) are designed to reveal potential degradation under stress, while refrigerated (5°C) and frozen (-20°C) conditions help evaluate the preservation of heat-sensitive compounds. Together, these conditions offer a well-rounded approach to determining shelf life, guiding suitable storage practices for maintaining extract quality and efficacy.

Discussion

The phenolic content of the banana peel suspension, determined by both UV-Vis spectrophotometry and HPLC, confirmed that a high level of bioactive compounds are consistent with reported antioxidant activity. GC analysis identified additional bioactive constituents such as linoleic acid and esters, supporting the extract's therapeutic potential. The formulation showed favorable physicochemical properties, with moderate viscosity (128.4 ± 3.2 cP) ensuring good flow and stability, uniform particle size (12.6 ± 1.1 µm) minimizing sedimentation, and a zeta potential (−32.5 ± 2.4 mV) indicating strong electrostatic stability.

Microbial testing demonstrated that the suspension remained within safe microbial limits throughout 12 months under various storage conditions, despite the relatively high moisture content, highlighting effective preservation. Phytochemical screening indicated ethanol extraction was superior to water in recovering key bioactives, including flavonoids and tannins, which may enhance therapeutic effects. Ash content reflected a notable mineral presence, adding potential nutritional value.

Stability studies following ICH and WHO guidelines showed the suspension maintained its chemical, physical, and microbial integrity over long-term and accelerated conditions, supporting a stable shelf life of at least 12 months. These results collectively affirm the banana peel suspension's promise as a safe, stable, and effective natural formulation.

Conclusion

The extraction of pectin from *Musa paradisiaca* peels presents a promising, sustainable approach for enhancing the stability of oral liquid pharmaceutical formulations. Leveraging the natural gelling, thickening, and stabilizing properties of pectin, this method aligns with the increasing demand for plant-based, eco-friendly excipients in drug delivery systems. By carefully optimizing key extraction parameters—such as pH, temperature, and extraction duration—the yield and functional quality of the pectin can be significantly improved. When used in oral liquids, this refined pectin contributes to improved viscosity and uniform distribution, effectively minimizing problems like sedimentation and phase separation. These enhancements lead to better dosage consistency, improved patient compliance, and enhanced bioavailability.

In addition to its formulation benefits, pectin also offers therapeutic advantages. It has been associated with cholesterol-lowering effects, improved gastrointestinal health, and potential as a prebiotic, making it not just a functional excipient but also a contributor to overall patient well-being. Continued research and innovation in this area will likely expand the pharmaceutical applications of pectin and support the development of more natural, effective, and sustainable medicinal products.

Ethical Statement

The authors confirm that all ethical issues have been dealt with the research ethics guidelines

provided by the SVU College of Pharmaceutical Sciences Sri Venkateswara University, Tirupati, Andhra Pradesh, India.

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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