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Phytochemical Profiling, Development, and Evaluation of *C. Cujete* Fruit Pulp as a Natural Disintegrant in Compressed Paracetamol Tablets

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Abstract: Synthetic excipients, especially disintegrants, are commonly used in tablet formulations but present challenges, including potential side effects, high costs, and environmental impact [14][29]. There is a need for safer, more sustainable alternatives, with plant-based excipients offering promising benefits [28][44]. *Crescentia cujete* (calabash tree) fruit pulp, rich in bioactive compounds and polysaccharides, has been traditionally used in ethnomedicine and could serve as a natural disintegrant [18][42]. This study aimed to assess the effectiveness of *C. cujete* as a natural disintegrant in compressed paracetamol tablet formulations, focusing on its ability to enable rapid disintegration while maintaining overall tablet quality. The fruit pulp was extracted, characterized, and incorporated into paracetamol tablets, which were then evaluated through standard pharmacopeial tests, including hardness, friability, disintegration time, and dissolution. Results showed that tablets containing *C. cujete* exhibited an acceptable value for the disintegration time parameter and maintained suitable physical characteristics within compendial limits. However, the dissolution profile did not meet the pharmacopeial standards, the same as the synthetic disintegrants that were used. In comparison, using one-way ANOVA, the *C. cujete* formulation did not show comparable or improved performance over that of the synthetic disintegrants, as indicated by a p-value of 0.4939 ($p > 0.05$). Thus, while *C. cujete* pulp is a potentially safer, more cost-effective, and environmentally friendly alternative, it does not demonstrate superior efficacy in dissolution behavior compared to synthetic disintegrants.

Keywords: *Crescentia Cujete, Tablet Formulation, Natural Disintegrant, Paracetamol, Compressed Tablets.*

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I. INTRODUCTION

Excipients, particularly disintegrants, are essential in tablet formulations, helping tablets break apart and release the active drug efficiently upon ingestion [14][37]. In drugs like paracetamol, choosing the right disintegrant is crucial to ensure consistent and effective treatment [17][19]. However, many synthetic disintegrants—such as croscarmellose sodium, sodium starch glycolate, and crospovidone—can cause side effects, increase production costs, and contribute to environmental harm [5][14]. This highlights the need for natural alternatives. One promising option is *Crescentia cujete*, or the calabash tree, whose fruit pulp contains antioxidant and anti-inflammatory compounds that may improve tablet formulations [7][42]. Its glycosides, iridoids, and polysaccharides suggest a significant carbohydrate content, which supports its potential as a natural disintegrant [13][18]. Carbohydrates, especially polysaccharides, help tablets disintegrate by absorbing water and swelling. In addition, compounds like 1-kestose and sucrose—found in its juice—further indicate its polysaccharide-rich composition [15][47]. Its traditional medicinal use and natural origin support both pharmaceutical relevance and sustainability [3]. Being biodegradable and derived from agricultural by-products, *C. cujete* also reduces waste and manufacturing costs [14][28][40]. This study aimed to develop and evaluate *C. cujete* as a natural disintegrant in paracetamol tablets by comparing its performance with synthetic disintegrants based on disintegration time, tablet hardness, and dissolution rate [29]. In addition, the phytochemical profile of the fruit pulp mucilage was also assessed.

II. MATERIALS AND METHODS

This section outlines the actions to investigate the potential of *Crescentia cujete* as a tablet binder and disintegrant in pharmaceutical formulations. It also rationalizes using specific procedures or techniques to identify, select, process, and analyze relevant information. By detailing the research process steps, this section provides a framework for understanding how the study addresses the research problem. It also enables the reader to critically assess

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the study's overall validity and reliability in evaluating *C. cujete's* effectiveness in tablet production.

➢ *Materials:*

- *Plant Material (C. cujete fruit):*

Fig 1 *Crescentia cujete* Fruit

Local ripe *C. cujete* fruit was collected from Buruun, Iligan City, Philippines (15° 9' 42.156" N, 120° 36' 27.6516" E) and authenticated at Mindanao State University-Iligan Institute of Technology (MSU-IIT) under the Department of Science and Mathematics.

- *Standards, Reagents, and Chemicals:*

The paracetamol USP working standard was used as the positive control, while the paracetamol API and the excipients—starch, croscarmellose sodium (CSC), sodium starch glycolate (SSG), sodium methylparaben, sodium propylparaben, magnesium stearate, and talc—were obtained from Shaanxi Dideu Medichem Co. Ltd, Changqing Industrial Park, Fengxiang District, Baoji City, Shaanxi, China 721400. The 95% ethanol and acetone were of analytical grade and were purchased from Medical Center Trading Corporation, Cagayan de Oro, Misamis Oriental, Philippines, and Merteflor Enterprises, Cagayan de Oro, Misamis Oriental, Philippines. The hydrochloric acid buffer was sourced from the AMCC Pharmacy Department Laboratory.

- *Instruments and Apparatus:*

A muslin cloth bag, sieve no. 12, and 20, desiccator, and glassware, including a graduated cylinder, beaker, mortar, and pestle, were used in the preparation of granulated paracetamol. An Electric Continuous Tablet Pressing Tablet Press Machine (Biobase), Tablet Hardness Tester (SaintyCo YD-1), Disintegration Basket, Paddle Rotator, Viscometer (NDJ-5S), Friabilator (Flight Pharmaceutical Machinery Co. Limited), and an electronic balance were also used and were obtained based on the availability of the AMCC Pharmacy Department laboratory. The following materials were used throughout the process.

➢ *Methods:*

- *Extraction of Mucilage from C. cujete:*

Fresh fruit of *C. cujete* was washed thoroughly with water, cut, and opened using a saw (Philippine standard hand saw), and the pulp was scooped out. Tweezers were used to remove the flat seeds from the pulp carefully, and the collected pulp was blended. The pulp was subjected to steam heating at 80 °C for 3 minutes to prevent enzymatic browning reaction [25][46]. The fruit pulp was homogenized by adding distilled water [26] three times the weight of the pulp, and then it was blended thoroughly to ensure complete homogenization. The solution was then immersed for 19–20 hours to facilitate mucilage release into the water. The solution was then strained and filtered through a muslin cloth bag.

- *Isolation of Mucilage:*

The filtrate was collected with slight modifications from the method of Sunitha et al. [45], and the mucilage was precipitated using a 3:5 ratio of mucilage volume to 95% ethanol [45]. As a result, a cream-colored precipitate was acquired and rinsed with acetone three times (10 mL each). The resulting solid was subjected to vacuum drying for 19-21 hours, to determine the amount in grams of mucilage per kilogram of the fruits. The separated mucilage was pulverized, sifted through a 60-mesh sieve, and kept in a desiccator for future experiments or subsequent testing [25].

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Percentage Yield (Yayehrad et al. [48]):

$$\%\ Yield = \left(\frac{Purified\ Weight}{Crude\ Weight}\right) 100$$

- *Qualitative Screening: Phytochemical Screening:*

The pulverized mucilage was then subjected to the following phytochemical screening as shown in Table 1:

Table 1 Phytochemical Screening for Dried Mucilage (Pant et al. [36]; Dubale et al. [16])

Test	Procedure	Observation	Inferences
Alkaloids	Add 10 mL acidified alcohol to 0.1 g extract, boil & filter. Add 0.4 mL dilute ammonia and 1 mL chloroform to 1 mL filtrate. Extract with 2 mL acetic acid. Divide into two; add Mayer's to one and Dragendorff's to another.	Cream ppt (Mayer's) or reddish-brown ppt (Dragendorff's)	Alkaloids are present
Carbohydrates (Molisch's Test)	Add Molisch's reagent (α-naphthol in ethanol) to extract, then add a few drops of conc. H_2SO_4 carefully.	Purple ring at interface	Carbohydrates are present
Flavonoids (Alkaline Reagent)	Add few drops of NaOH to extract, then dilute acid.	Yellow turns colorless	Flavonoids are present
Phenols	Dissolve 50 mg extract in 5 mL distilled water, add few drops of 5% neutral ferric chloride.	Dark green color	Phenolic compounds are present
Saponins	Add 0.1 g extract to 1 mL distilled water, shake to form froth, add 3 drops olive oil, shake vigorously.	Stable emulsion forms	Saponins are present
Tannins	Boil 0.1 g of extract in 2 mL water or DMSO, filter, add few drops of 0.1% ferric chloride.	Brownish green or blue-black color	Tannins are present
Steroids	Mix 1 mL crude extract with 10 mL chloroform and 10 mL sulfuric acid.	Formation of a red top layer and greenish bottom layer	Steroids are present
Terpenoids (Salkowski's Test)	Add 0.4 mL chloroform to 0.1 g extract, then carefully add conc. H_2SO_4.	Reddish brown layer at interface	Terpenoids are present

- *Quantitative Phytochemical Screening: Total Polyphenolic Content (TPC) and Total Flavonoid Content (TFC) Determination:*

Quantitative phytochemical screening was done by measuring the total phenolic content (TPC) and total flavonoid content (TFC) of the pulp extract. Results were expressed as milligrams of gallic acid equivalent per gram (mg GAE/g) of extract for TPC and milligrams of quercetin equivalent per gram (mg QE/g) of extract for TFC.

Table 2 Total Polyphenolic Content (TPC) and Total Flavonoid Content (TFC) Determination of the Extracted Fruit Pulp (Pant et al. [36])

Test	Procedure	Standard Used	Expression of Result
Total Phenolic Content (TPC)	Mix 0.5 mL extract (5 mg/mL) with 5 mL Folin–Ciocalteu reagent (1:10 v/v dilution) and 4 mL of 1 M sodium carbonate. Let stand in the dark for 15 min at room temperature. Determine phenolic content using a calibration curve.	Gallic acid (10–80 µg/mL)	mg gallic acid equivalent per gram of extract (mg GAE/g)
Total Flavonoid Content (TFC)	Mix 0.5 mL extract (50 mg/mL) with 1.5 mL methanol, 0.1 mL of 10% aluminum trichloride, 0.1 mL of 1 M potassium acetate, and 2.8 mL distilled water. Let stand in the dark for 30 min. Determine flavonoid content using a calibration curve.	Quercetin (10–50 µg/mL)	mg quercetin equivalent per gram of extract (mg QE/g)

- *Physicochemical Characterization of the Isolated Mucilage:*

The pulverized mucilage was then subjected to the following tests to determine its physicochemical and characterization properties:

✓ *Organoleptic Properties:*

In the study by Ilango et al. [25], taste, color, and odor were assessed through the sensory attributes of the mucilage. A panel of three members evaluated its organoleptic properties [20][25].

✓ *Solubility and Swelling Power:*

This parameter measured how well the mucilage dissolved in distilled water. The solubility index and swelling power were determined using a modified version of the method by Haile et al. [22].

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To conduct the test, 0.0625 g of the powdered sample was mixed with 5 mL of distilled water in a 10 mL test tube. The mixture was heated in a thermostatically controlled water bath (Biobase) at temperatures of 25°C, 40°C, 55°C, 65°C, 75°C, and 85°C for 10 minutes while being gently agitated. After heating, the test tubes were immediately placed in cold water for 5 minutes and then centrifuged (DigiSystem Laboratory Instruments Inc.) at 3000 rpm for 15 minutes.

The liquid portion (supernatant) was dried in a hot-air oven (Biobase) at 105°C until a constant weight was achieved. Both the dried supernatant and the remaining paste were weighed. Using these values, the water solubility index and swelling power of the mucilage were calculated.

$$Swelling\ Power = \frac{m_{sw}}{m_o - m_s}$$

$$Solubility\ (\%) = \left(\frac{m_s}{m_o}\right)100$$

Where:

m_{sw} = Weight of the swollen mucilage

m_o = The sample weight

m_s = The weight of the dried supernatant

✓ *Swelling Index:*

The swelling index was determined using a modified method by Sunitha et al. [45]. 0.5 grams of powdered mucilage was placed in a 100 mL stoppered measuring cylinder, and its initial volume was recorded. Distilled water was then added to make up 50 mL, and the cylinder was gently shaken before being left undisturbed for 24 hours. After this period, the final volume occupied by the swollen mucilage was noted, and the swelling index (SI) was calculated as a percentage. Triplicate analysis was done to evaluate the swelling index of the mucilage.

$$Swelling\ Index = \left(\frac{(Volume\ of\ Swollen\ Material\ (mL) - Original\ Volume\ of\ Liquid\ (mL))}{Original\ Volume\ of\ Liquid\ (mL)}\right)100$$

✓ *Viscosity:*

The mucilage was dissolved in distilled water at concentrations of 2%, 4%, and 6%. The procedure followed a slightly modified version of the method by Haile et al. [22]. Each concentration was mixed with 40 mL of distilled water while continuously stirring. The mixtures were then left to sit overnight at room temperature.

The viscosity of each dispersion was measured at 20 ± 0.5°C using a viscometer (NDJ-5S) equipped with spindle number 4, at shear rates of 12 and 30 rpm.

✓ *Loss on Drying:*

A modified version of the method by Haile et al. [22] was used. One gram of mucilage powder was placed in a hot-air oven at 105°C for 2 hours until a constant weight was achieved. The sample was then transferred to a desiccator for 30 minutes to prevent moisture absorption. After cooling, it was weighed again. This process was repeated until two consecutive weight measurements differed by no more than 0.01 g. The test was performed in triplicate, and the percentage weight loss was calculated to determine the loss on drying.

$$\%\ Loss\ on\ Drying = \left(\frac{Initial\ Weight - Final\ Weight}{Initial\ Weight}\right)100$$

✓ *FTIR (Fourier-Transform Infrared) Spectroscopy:*

To better understand the chemical structure of the extracted *C. cujete* fruit pulp mucilage, Fourier Transform Infrared (FTIR) spectroscopy was used. This technique helped identify the functional groups present in the mucilage, which are important in determining if it is suitable for pharmaceutical use. A small amount of the dried mucilage was mixed with potassium bromide (KBr), ground into a fine powder, and pressed into a thin, transparent pellet. The pellet was then scanned using an FTIR spectrometer, covering a range of 4000 to 400 cm^{-1}. The resulting spectrum showed specific peaks that correspond to common functional groups found in natural polysaccharides, such as hydroxyl, carbonyl, and carboxylic acid groups. These results were compared with the data reported by Hong et al. [23] to confirm the presence of these key structures. This comparison helped support the idea that the mucilage contains the necessary chemical features to function effectively as a natural disintegrant in tablet formulations [33].

- *Pre-compression Evaluation of the Disintegrants at Different Concentrations:*

The disintegrants — *C. cujete* mucilage, croscarmellose sodium, and sodium starch glycolate—were weighed based on their respective concentrations of 2% and 4%, corresponding to disintegrant weights of 672 mg and 1,344 mg, respectively, for the production of 187 tablets. The pre-compression parameters were evaluated, as shown in Table 4.

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Table 3 Pre-Compression Parameters (Hadi et al. [21])

Parameter	Description	Equation	Acceptable Values
Bulk Density	Weighed a known quantity of powder blend and measured it in a 10 ml cylinder. The volume in mL was recorded.	$Bulk\ Density\ (p_b) = \frac{Mass\ of\ Powder\ (m)}{Bulk\ Volume\ (V_b)}$	-
Tapped Density	Weighed a known quantity of powder blend, measured in a 10 ml cylinder. Tapping until volume no longer changes. The volume in mL was recorded.	$Tapped\ Density\ (p_t) = \frac{m}{Tapped\ Volume\ (V_t)}$	-
Angle of Repose (θ)	Measured by allowing powder blend to flow from a funnel onto a surface. Height and radius of the cone are used to calculate θ.	$\theta = \tan -1\left(\frac{h}{r}\right)$	**≤30°** indicates good flow; **>40°** suggests poor flow
Compressibility Index (Carr's Index)	Calculated from the difference between tapped and bulk densities.	$Compressibility\ Index\ (\%) = \left(\frac{p_t - p_b}{p_t}\right) 100$	**5–15%** = excellent to good flow; **>25%** = poor flow.
Hausner Ratio	Indirect measure of powder flowability. Calculated by the ratio of tapped density to bulk density.	$Hausner\ Ratio = \frac{p_t}{p_b}$	**≤1.25** indicates good flow; **>1.4** suggests poor flow.

Table 4 Composition of Paracetamol Tablet Formulations with Varying Concentrations of Disintegrating Agents: *C. cujete* Mucilage, CCS, and SSG, Modified from the study by Ilango et al. [25]

Ingredients	CD1 (mg)	CD2 (mg)	CD3 (mg)	CD4 (mg)	CD5 (mg)	CD6 (mg)
Paracetamol	111.75	111.75	111.75	111.75	111.75	111.75
Starch (diluent)	22.17	21.28	22.17	21.28	22.17	21.28
Starch (Binder)	6.71	6.71	6.71	6.71	6.71	6.71
Mucilage (Disintegrant)	3.58	7.15	-	-	-	-
Croscarmellose sodium (Disintegrant)	-	-	3.58	7.15	-	-
Sodium starch glycollate (Disintegrant)	-	-	-	-	3.58	7.15
Sodium methylparaben	0.179	0.179	0.179	0.179	0.179	0.179
Sodium propylparaben	0.09	0.09	0.09	0.09	0.09	0.09
Purified Water	q.s	q.s	q.s	q.s	q.s	q.s
Talc	1.79	1.79	1.79	1.79	1.79	1.79
Magnesium Stearate	0.89	0.89	0.89	0.89	0.89	0.89
Total Weight	178.8	178.8	178.8	178.8	178.8	178.8
Note: All ingredient quantities listed above are in **mg per tablet.**						

- *Preparation of Paracetamol Granules through Wet Granulation Process:*

The preparation of modified paracetamol tablet formulations, based on Ilango et al. [25], underwent slight modifications in this study and included key ingredients, each with a specific function. Paracetamol served as the active pharmaceutical ingredient for pain relief and fever reduction, while starch acted as both a diluent and binder, providing bulk and cohesiveness. Magnesium stearate and talc functioned as glidants to improve powder flow, with magnesium stearate also serving as a lubricant to reduce friction and ensure smooth tablet ejection. Sodium methylparaben and sodium propylparaben acted as preservatives to inhibit microbial growth and extend shelf life. Disintegrating agents, referred to by the formulation code "CD," such as mucilage (CD1 and CD2), croscarmellose sodium (CD3 and CD4), and sodium starch glycolate (CD5 and CD6), promoted tablet breakdown in the gastrointestinal tract for faster drug release. Purified water was used to adjust moisture content.

Granulation employed a wet granulation method, using purified water as the granulating liquid. It followed the bulk doubling technique based on Ilango et al. (2022), with modifications to the excipients by incorporating *C. cujete* mucilage as a disintegrant. The mucilage was used at concentrations of 2% w/w (CD1) and 4% w/w (CD2), while croscarmellose sodium (CD3 and CD4) and sodium starch glycolate (CD5 and CD6) at the same concentrations served as standard disintegrants. The formulation for granule preparation is summarized in Table 13, with quantities scaled up to yield approximately 178.8 mg per tablet, producing a total of 187 tablets. This adjustment was made to accommodate the capacity of the single-tablet compressor, which could only produce tablets weighing less than 200 mg [25].

The preparation process began with weighing and sieving the specified ingredients to ensure uniform particle size, followed by dry mixing to evenly distribute the active ingredient. The binder solution, along with the pre-diluted

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preservatives, was then prepared and gradually added to form damp granules. These were screened through sieve no. 12 for uniformity, dried at a controlled temperature of 50 °C in a hot-air oven for 2 hours, and rescreened using the same sieve to improve flow properties. Glidants and lubricants were subsequently added to enhance flowability and prevent sticking during compression. Finally, the granules were blended and compressed into tablets [9][10][24].

- *Paracetamol Tablet Formulation:*

Formulating paracetamol tablets involved combining the active pharmaceutical ingredient (API) with excipients to ensure proper tablet formation, stability, and bioavailability. Table 5 summarized the components of each tablet that were formulated, highlighting the precise selection of disintegrants, binders, and other additives to achieve optimal tablet performance and patient compliance.

The prepared granules were then subjected to tablet formulation, which involved mixing the granules with excipients such as glidants and lubricants to ensure optimal flow and prevent sticking during compression. These granules were subsequently compressed using a Biobase tablet press machine to produce approximately 187 tablets, each conforming to the specified requirements for weight, thickness, and hardness. After compression, the tablets underwent rigorous quality control tests to ensure compliance with regulatory standards [11]

Table 5 Formulation of Each Tablet Based on the Formulation Code (Mucilage as Disintegrant)

Formulation Code	Ingredients
CD1	111.75mg of Paracetamol (API) + 22.17 mg of starch (diluent) + 6.71 mg of starch (binder) + 3.58 mg of mucilage + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water
CD2	111.75 mg of Paracetamol (API) + 21.28 mg of starch (diluent) + 6.71 mg of starch (binder) + 7.15 mg of mucilage + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water
CD3	111.75 mg of Paracetamol (API) + 22.17 mg of starch (diluent) + 6.71 mg of starch (binder) + 3.58 mg of Croscarmellose Sodium + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water
CD4	111.75 mg of Paracetamol (API) + 21.28 mg of starch (diluent) + 6.71 mg of starch (binder) + 7.15 mg of Croscarmellose Sodium + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water
CD5	111.75 mg of Paracetamol (API) + 22.17 mg of starch (diluent) + 6.71 mg of starch (binder) + 3.58 mg of Sodium Starch Glycollate + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water
CD6	111.75mg of Paracetamol (API) + 21.28 mg of starch (diluent) + 6.71 mg of starch (binder) + 7.15 mg of Sodium Starch Glycollate + 0.179 mg of Sodium Methylparaben + 0.09 mg of Sodium Propylparaben + 1.79 mg of Talc + 0.89 mg of Magnesium Stearate + q.s. of Purified Water

- *Evaluation of C. cujete Tablets and Comparison with Paracetamol USP:*

✓ *Weight Variation:*

This test determined if the tablet weight fell within the acceptable range. For tablets with a nominal weight of 500 mg, the average weight was calculated from 20 tablets from each formulation, and the permissible weight variation was typically ±5%. The formula for weight variation was (Yayehrad et al. [48]):

$$Weight\ Variation = \left(\frac{Actual\ Weight - Average\ Weight}{Average\ Weight}\right)100$$

✓ *Uniformity of Dimensions (Thickness and Diameter) of Tablets:*

This involved measuring the dimensions (diameter and thickness) of twenty (20) tablets using a caliper to ensure they met specifications. Dimensional uniformity was visually assessed, and statistical methods were applied to analyze the data [48].

✓ *Tablet Hardness Test:*

The hardness of ten (10) tablets was determined individually by diametrically compressing each tablet using a VanKel tablet hardness tester. The average hardness was then calculated using the tensile strength (Ts) equation, based on the data obtained from the dimensional uniformity measurements [48]:

$$Tensile\ Strength\ (\sigma) = \frac{2F}{\pi DH}$$

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Where:
F (N) = Diametrical tablet break force
D (cm) = Tablet Diameter
T (cm) = Tablet Thickness

The hardness profile of the tablet, ranging from 4 kg/cm² to 10 kg/cm² [41], was a crucial indicator of product quality. This range ensured the tablet could withstand mechanical stress during handling and transportation, maintaining its integrity until consumption. A lower hardness could lead to crumbling, while a higher hardness indicated enhanced durability. Thus, achieving optimal hardness within this range was essential for the tablet's effectiveness and consumer satisfaction.

✓ *Friability Test:*

This test assessed the tablet's durability and was performed using the Friability test Apparatus (SaintyCo). Twenty tablets (20) were weighed and placed in the friabilator, then regulated at 25 revolutions per minute. The tablets were then subjected to one hundred (100) revolutions. Tablets were dedusted and reweighed to calculate the percentage of weight loss. The percentage friability was calculated as follows [48]:

$$\%\ Loss\ (Friability) = \left[\frac{(W_{Initial} - W_{Final})}{W_{Initial}}\right] 100$$

Where:
$W_{Initial}$ = Original Weight before the friability test
W_{Final} = Weight after the friability test

✓ *Disintegration Time Test:*

Six (6) tablets from each formulation were placed in a basket-type disintegration tester (SaintyCo) and immersed in 900 mL of distilled water, which was chosen to mimic the fluid environment of the stomach. The temperature was maintained at 37 ± 2°C to closely reflect human body temperature. Each tablet was placed in a cylindrical tube within the basket assembly of the tester, with a disc positioned above it to ensure proper placement during testing. The time required for each tablet to disintegrate completely—defined as breaking down into small particles and passing through the mesh at the bottom of the tube—was recorded. The mean disintegration time for each formulation was then calculated to evaluate its overall performance [35].

✓ *Dissolution Test:*

With slight modifications based on Kadhim et al. [27] and Bagyalakshmi [6] this dissolution test evaluated the rate at which the drug was released from the tablet. Five (5) tablets were used, and the test was carried out using USP Apparatus I (basket method), which involves placing the tablets in a rotating basket. The basket was rotated at a speed of 50 revolutions per minute (rpm). The dissolution medium used was simulated gastric fluid (SGF) prepared using hydrochloric acid to achieve a pH of 1.2, replicating the acidic environment of the human stomach. Each vessel contained 900 mL of this medium and was maintained at a constant temperature of 37 ± 0.5°C to simulate physiological conditions. At predetermined time intervals—5, 10, 20, 30, and 60 minutes—5 mL samples were withdrawn using a pipette. To maintain sink conditions, an equal volume of fresh, pre-warmed dissolution medium was added after each sampling. The samples were filtered to remove any undissolved particles, and the concentration of paracetamol in the solution was analyzed using a UV-visible spectrophotometer. The data gathered are then calculated using Beer-Lambert's Law [27].

$$\text{Absorbance } (A) = \varepsilon \cdot c \cdot l$$

where:
ε = Molar absorptivity
c = Concentration
l = Path length

Table 6 Ideal Quality Product Profile for Evaluation of Key Characteristics and Parameters

Characteristics / Parameters	Ideal Quality Range	Citation
Thickness and Diameter	It should be controlled within a ±5% variation from the average value of the tablets.	[38]
Weight Variation	It should fall within the acceptable weight variation range of ±5% of the average tablet weight.	[1]
Hardness	It ranges from 4 kg/cm² to 10 kg/cm².	[41]
Friability	Must not lose more than 1% of the total weight.	[1][30]
Disintegration Time	It should disintegrate within 15 minutes.	[1]
Dissolution	It should be ranging within >80% at 30 minutes.	[32]
Drug Content	The sample should be ranging 90% to 110%.	[1][48]

- *Data Analysis and Interpretation:* Data will be graphed and analyzed using quantitative

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research software. R programming and Microsoft Excel were used for analyzing the descriptive data, primarily presented in tabular form with mean and standard deviation. These tools were also used for deeper inferential analysis, including Analysis of Variance, Post-hoc tests, and Paired t-tests, to evaluate whether *C. cujete* fruit pulp, when used as a disintegrant in compressed paracetamol tablet formulations, provided disintegration properties and dissolution rates comparable to or improved over those of synthetic disintegrants (CSC and SSG).

III. RESULTS AND DISCUSSIONS

This presents the findings on the suitability of *C. cujete* fruit pulp as a pharmaceutical excipient. The results cover its phytochemical properties, physicochemical characterization, percentage yield, formulation performance, and comparative evaluation against synthetic excipients. Statistical analyses support these findings.

✓ *Descriptive Statistics:*

The data will be measured descriptively based on simple percentage, central tendency measures (mean), standard error, kurtosis, skewness, and standard deviation.

✓ *Inferential Statistics:*

The data will be analyzed inferentially by using a random sample taken from a population to describe and make inferences about the population. Inferential statistics utilized in this study include Analysis of variance, Post-hoc tests, and Paired t-tests.

➢ *Preparation of the Isolated Mucilage:*

The isolated mucilage from *C. cujete* fruit pulp is a dark brown to black solid (due to drying) with a smoky, charcoal-like odor (refer to fig. 2) The average percentage yield from 250 g of *C. cujete* fruit pulp, based on multiple replicates, was 0.474% ± 0.249%.

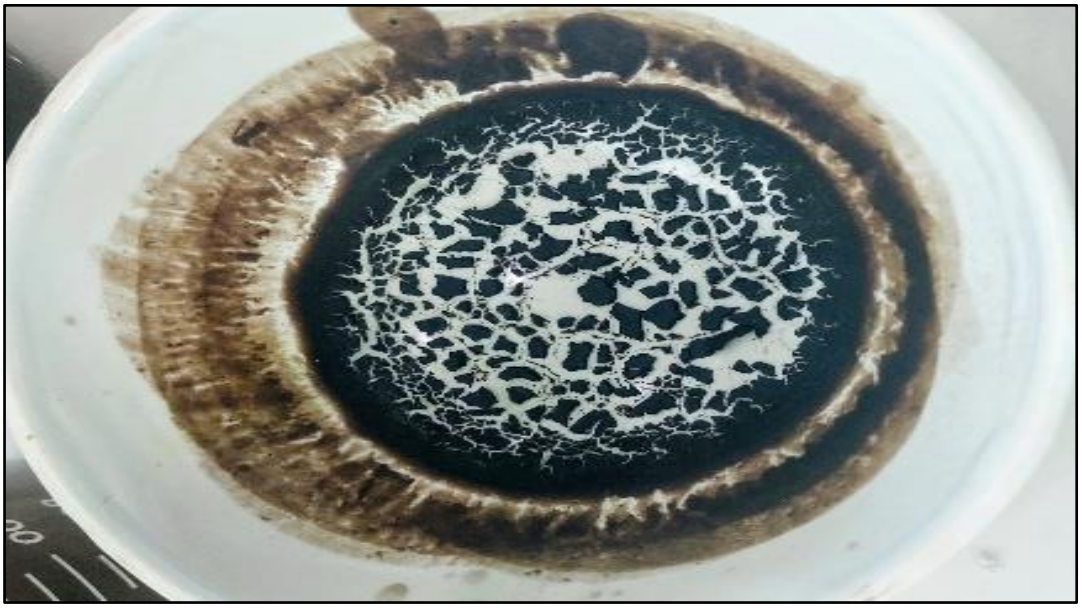

Fig 2 Isolated Mucilage of *C. cujete* Fruit Pulp

Table 7 Percentage Yield of the Isolated Mucilage from C. cujete Fruit Pulp

Replicant	Weight of the Fruit Pulp	Weight of the Mucilage	Percentage Yield
1	250 g	1.9 g	0.76%
2	250 g	0.911 g	0.364%
3	250 g	0.745 g	0.298%
Mean Value:		0.474133333% ± 0.249872	

The determination of percentage yield is essential in pharmaceutical formulation as it directly influences the efficiency, scalability, and economic viability of drug production. A high yield indicates minimal material loss and optimal process conditions, both of which are critical for maintaining consistent product quality and reducing manufacturing costs.

Although excipients are pharmacologically inactive, they significantly affect drug stability, bioavailability, and manufacturability, making their efficient production vital. From a cost-effectiveness perspective, Narang and Boddu [34] stated that yields above 90% are generally desirable, as lower yields may result in increased raw material consumption and processing costs. Moreover, the selection and performance of excipients are increasingly scrutinized due to their impact on drug delivery and patient outcomes.

In this study, the mean yield obtained was 0.4741%, which is substantially lower than the desirable threshold and does not even reach 10%, as referenced by Choudhary and

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Pawar [12]. Therefore, the *C. cujete* fruit pulp mucilage may not be considered cost-efficient for use as a natural excipient.

➢ *Qualitative and Quantitative Screening of the Secondary Metabolites of C. cujete Mucilage:*

- *Qualitative Screening: Phytochemical Screening:*

The phytochemical screening of secondary metabolites in *C. cujete* mucilage was conducted using the procedures and tests listed in Table 12 to identify potential compounds such as alkaloids, carbohydrates, flavonoids, tannins, saponins, phenols, steroids, and terpenoids [16][36]. The results of these tests are presented in Table 8.

Table 8 Results of the Preliminary Phytochemical Screening of C. cujete Mucilage

TEST	RESULT	IMPLICATION
Mayer's Test	++	Presence of Alkaloids
Molisch's Test	+++	Presence of Carbohydrates
Alkaline Reagent	+	Presence of Flavonoids
Ferric Chloride Test for Tannins	-	Absence of Tannins
Froth Test	++	Presence of Saponins
Ferric Chloride Test for Phenols	+++	Presence of Phenolic Compounds
Salkowski's Test for Steroids	-	Absence of Steroids
Salkowski's Test for Terpenoids	+	Presence of Terpenoids

The preliminary phytochemical screening of *C. cujete* mucilage revealed the presence of alkaloids, carbohydrates (notably detected despite the use of a Molisch reagent that was over four years expired), flavonoids, saponins, phenolic compounds, and terpenoids. However, steroids and tannins were not detected in the sample.

This result presents a discrepancy when compared to previous studies. For instance, Gonzales et al. [18] reported the presence of tannic acid, a specific type of tannin, in various extracts of *C. cujete* fruit. The absence of tannins in the present screening might be attributed to the limited quantity of sample submitted for testing.

Furthermore, Gonzales et al. [18], through UPLC-MS/MS analysis of the entire plant, identified flavonoids, phytosterols, glycosides, and terpenoids as the most abundant compounds. While the fruit extract specifically contained phytosterols, terpenoids, cardiac glycosides, and tannic acid, these compounds were not all detected in the mucilage used in this study.

Similarly, Abu et al. [2] found that the fruit pulp of *C. cujete* contains alkaloids, tannins, saponins, flavonoids, and glycosides. Again, the absence of certain compounds such as tannins in the current screening may be due to sample size limitations or extraction-specific differences.

Overall, these findings support the presence of several key phytochemical groups in *C. cujete* mucilage, aligning partially with the literature. However, inconsistencies such as the absence of tannins highlight the need for further screening with larger and fresher samples and potentially more sensitive analytical methods.

- *Quantitative Screening: Total Polyphenolic Content (TPC) and Total Flavonoid Content (TFC) Determination:*

The mucilage of *C. cujete* fruit pulp has further undergone TPC and TFC determination to ensure that the active compounds in the study tablet are present in consistent and effective amounts. A summary of the values is presented in Table 20 and Table 9.

Table 9 Total Phenolic Content (TPC) of *C. cujete* Fruit Pulp

Replicant	Total Phenolics (mg gallic acid per gram extract)	Mean Value
1	50.18	50.98 ± 1.17
2	52.33	
3	50.42	

Table 10 Total Flavonoid Content (TFC) of *C. cujete* Fruit Pulp

Replicant	Total Flavonoids (mg quercetin per gram extract)	Mean Value
1	3.11	3.12 ± 0.03
2	3.11	
3	3.16	

The data showed a mean TPC value of 50.98 mg gallic acid/g extract with a standard deviation of ±1.17, indicating low variability around the mean. The mean TFC value was 3.12 mg quercetin/g extract with a standard deviation of ±0.03, showing even higher consistency than the TPC. This suggests that both TPC and TFC results demonstrate good precision.

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The Total Phenolic Content (TPC) and Total Flavonoid Content (TFC) of a natural excipient are essential for evaluating its suitability and functional performance in pharmaceutical tablet formulations, particularly as a disintegrant. According to Sasidharan et al. [43], these compounds are known for their antioxidant properties, which can enhance the stability and shelf-life of active pharmaceutical ingredients (APIs) by preventing oxidative degradation. Additionally, TPC and TFC values provide insights into the excipient's potential to influence key disintegration mechanisms, such as swelling and moisture uptake.

Quantifying these contents also enables standardization and quality control of plant-based materials, ensuring consistency across batches. Moreover, a high phenolic and flavonoid content may correlate with improved bioavailability and therapeutic performance. Therefore, assessing TPC and TFC supports both the scientific validation and formulation effectiveness of natural excipients used in tablet manufacturing [43].

- *Physicochemical Characterization of the Isolated Mucilage:*

Physicochemical tests were conducted to determine the material's suitability for pharmaceutical use.

✓ *Organoleptic Properties of C. cujete Mucilage:*

A three-member panel (non-experts) assessed the parameters of color, odor, and taste of the *C. cujete* mucilage based on sensory properties. The assessment showed that the *C. cujete* mucilage is a black powder with a smoky, charcoal-like scent and is tasteless. Table 11 shows a summary of the panelists' assessment.

Table 11 Organoleptic Properties of the Powdered *C. cujete* Mucilage

Parameter	Observation
Color	Black
Odor	Smoky, Charcoal-like
Taste	Tasteless

The assessment was conducted because these characteristics directly influence patient acceptability and compliance, particularly in oral dosage forms. Therefore, organoleptic evaluation is essential in pharmaceutical development. Unpleasant sensory attributes may discourage use, especially among pediatric and geriatric populations. According to Kushwah et al. [31], organoleptic evaluation also serves as a preliminary quality control measure, helping to detect contamination, degradation, or inconsistencies in natural excipients. Furthermore, these properties contribute to the overall aesthetic appeal and marketability of the final product and may reveal potential incompatibilities with active pharmaceutical ingredients or other excipients. For plant-based excipients, organoleptic assessment is a practical and cost-effective tool to ensure identity and uniformity prior to further testing [31].

✓ *Solubility and Swelling Power of C. cujete Mucilage:*

The solubility and swelling power were determined using the procedure of Haile et al. [22]. A summary of the values is presented in Table 12 and Table 13.

Table 12 Swelling Power

Temperature	Swelling Power Value
25°C	3.5088
40°C	5
55°C	4.7368
65°C	5.56
75°C	4.6
85°C	1.8644

Table 13 Solubility

Temperature	Solubility (%)
25°C	8.0645%
40°C	6.4516%
55°C	8.0645%
65°C	12.9032%
75°C	19.3548%
85°C	4.8387%

The swelling power of the mucilage varied significantly with temperature, peaking at 65°C (5.56) and decreasing at 85°C (1.8644), indicating that the mucilage's ability to absorb water and swell is temperature-dependent. In contrast, its solubility increased with temperature, reaching a maximum at 75°C (19.35%), but showed a sharp decline at 85°C (4.84%).

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The determination of solubility and swelling power is essential when evaluating a tablet excipient, particularly a disintegrant, as these properties significantly influence its performance. Swelling power directly affects a disintegrant's ability to facilitate the breakup of a tablet upon contact with fluids. When a disintegrant absorbs water and swells, it generates internal pressure within the tablet matrix, thereby promoting disintegration and enhancing drug release [22].

On the other hand, solubility determines how much of the disintegrant dissolves in the surrounding fluid. Although disintegrants are generally designed to have low solubility, a certain level of hydration is necessary for them to function effectively. Excessive solubility may reduce disintegration efficiency, as the excipient may dissolve rather than swell and exert the mechanical force required for tablet rupture [22].

Therefore, assessing both swelling power and solubility during the preformulation stage is crucial for selecting appropriate disintegrants, optimizing their concentration, and ensuring the tablet's intended performance. This is supported by the findings of Haile et al. [22], who demonstrated that the swelling and solubility characteristics of *Grewia ferruginea* Hochst. mucilage significantly influenced the mechanical strength and disintegration behavior of paracetamol tablets.

✓ *Swelling Index of C. cujete Mucilage:*

Following the method of Sunitha et al. [45], the swelling index was calculated using the specified equation. Table 14 presents a summary of the replicate results.

Table 14 Swelling Index

Replicant	Initial Volume	Final Volume	Solubility Index
1	50 mL	50 mL	0%
2	51 mL	51 mL	0%
3	50 mL	50 mL	0%

The data showed that the mucilage did not accumulate (swell with) liquid after being stored for 24 hours at room temperature (approximately 27°C–32°C). This indicates that *C. cujete* mucilage is unable to absorb water and does not swell when exposed to an aqueous environment without the application of stress (such as centrifugation), as reflected in the solubility and swelling power data.

The Swelling Index is a vital parameter in evaluating the effectiveness of a disintegrant in tablet formulations, as it reflects the excipient's capacity to absorb water and expand. This property is directly related to a disintegrant's ability to facilitate the breakdown of a tablet upon ingestion, promoting faster drug release. In comparison, the study conducted by Sunitha et al. [45] reported a Swelling Index of 1100 for the mucilage derived from *Abroma augustum* leaves, highlighting its exceptional water absorption and expansion capacity. Such a high Swelling Index is desirable in disintegrants, as it contributes to internal pressure buildup that aids in tablet disintegration. Therefore, the lack of swelling behavior observed in *C. cujete* mucilage may indicate limited functionality as a disintegrant unless modified or used in combination with other excipients.

✓ *Viscosity of C. cujete Mucilage:*

Viscosity was evaluated using the method of Haile et al. [22] at three different concentrations, with the results summarized in Table 15.

Table 15 Viscosity

Concentration	Viscosity	
	Shear Rate: 12	Shear Rate: 30
2%	2 889 mPa	2 135 mPa
4%	2 700 mPa	2 224 mPa
6%	2 132 mPa	2 089 mPa

The viscosity values at 2% and 4% concentrations were relatively similar across both shear rates, while a noticeable decrease was observed at the 6% concentration. This indicates that the mucilage solution was more viscous at lower concentrations (2% and 4%), but exhibited reduced viscosity at higher concentration (6%), potentially due to molecular entanglement or structural changes that limit hydration.

Viscosity is an essential parameter in evaluating disintegrants because it directly affects hydration rate and swelling behavior—both of which are critical for tablet disintegration. According to Haile et al. [22], the viscosity of *Grewia ferruginea* mucilage showed pseudoplastic flow behavior, which enhances disintegration performance by allowing the excipient to become less viscous under mechanical stress, such as during mastication or gastrointestinal movement. Therefore, assessing viscosity not only aids in understanding the processing behavior of the excipient but also helps predict its functional performance in promoting tablet breakup and drug release.

✓ *Loss on Drying of C. cujete Mucilage*:

The average loss on drying of the *C. cujete* fruit pulp was determined through multiple replicates based on the procedure of Haile et al. [22]. The values were obtained after the fourth hour of drying in a hot oven, when the difference in weight from the previous measurement was less than 0.01 g. A summary of the replicates is presented in Table 16.

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Table 16 Loss on Drying

Replicant	Initial Weight (g)	Final Weight (g)	Loss on Drying (%)
1	1	0.959	4.1 %
2	1	0.896	10.4%
3	1	0.914	8.6%
		Mean Value: 7.7% ± 3.244996	

The triplicate determination of loss on drying (LOD) for the mucilage yielded a mean value of 7.7%, with a standard deviation of ±3.24. Loss on drying is an important parameter in characterizing tablet excipients, particularly disintegrants, as it reflects the moisture content of the material. Excess moisture may lead to microbial growth and reduced stability, while insufficient moisture can impair the disintegrant's hydration and swelling capacity. In comparison, Haile et al. [22] reported an LOD value of 10.85% for *Grewia ferruginea* mucilage, which falls within the acceptable moisture range for natural pharmaceutical excipients. The similar moisture content in *C. cujete* mucilage suggests it has adequate storage stability and functional potential as a disintegrant in tablet formulations.

✓ *Fourier Transform Infrared Spectroscopy (FTIR) Analysis of C. cujete Mucilage:*

The FTIR spectrum of the *C. cujete* pulp extract was recorded to characterize the major functional groups associated with carbohydrates, polysaccharides, and mucilage components. Several distinct absorption bands were observed as shown on the FTIR spectrum (Figure 3), providing key insights into the chemical composition of the sample.

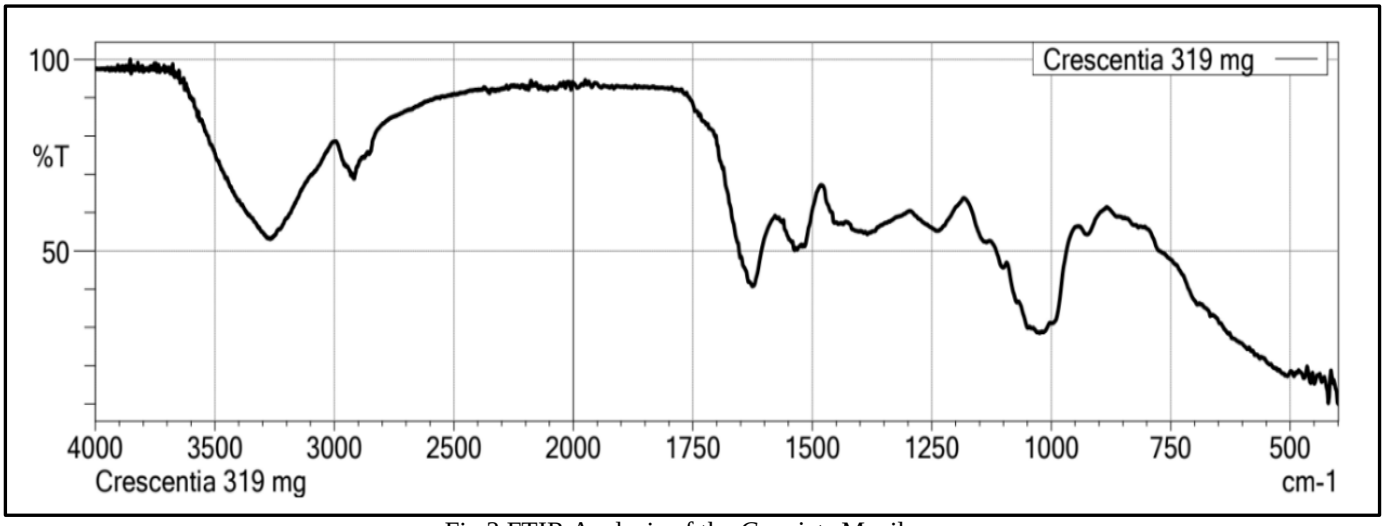

Fig 3 FTIR Analysis of the *C. cujete* Mucilage

The FTIR analysis of *C. cujete* pulp extract revealed key absorption bands, with a broad O–H stretching vibration centered around 3400 cm^{-1}, indicating the presence of hydroxyl (-OH) groups. These groups are commonly found in carbohydrates, polysaccharides, and mucilage-like substances, suggesting a strong hydrophilic nature that facilitates water binding and moisture retention. Additionally, a smaller absorption in the 2800–3000 cm^{-1} range corresponded to C–H stretching vibrations, pointing to sugar units –CH and $–CH_2$ groups typically present in polysaccharides.

A significant peak around 1700 cm^{-1} was observed, corresponding to C=O stretching vibrations, which are associated with uronic acids or other acidic sugar derivatives commonly found in plant-derived mucilage. This suggests that *C. cujete* mucilage contains these acidic sugars, contributing to the structural backbone of its polysaccharide matrix. Furthermore, sharp peaks in the fingerprint region (1000–1200 cm^{-1}) confirmed the presence of glycosidic linkages, with peaks below 900 cm^{-1} likely representing β-glycosidic bonds, typical of complex polysaccharides [23].

These findings are consistent with previous studies, including those by Hong et al. [23] and Ilango et al. [25], who reported similar FTIR features in other mucilage types. The presence of hydroxyl groups, C–H and C=O stretching vibrations, and glycosidic linkages supports the conclusion that *C. cujete* pulp extract is rich in carbohydrates, polysaccharides, and mucilage components. These results suggest its potential applicability as a natural pharmaceutical excipient, aligning with reported findings on other natural polymeric materials. Key FTIR results are summarized in Table 17.

An FTIR analysis was also conducted for paracetamol, as shown in Figure 4.

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Table 17 Interpretation of FTIR Spectra of *C. cujete*

Functional Group	Wavenumber (cm^{-1})	Interpretation in the Spectrum
O–H stretch	3200–3600	Strong broad peak indicating the presence of carbohydrates and mucilage.
C–H stretch	2800–3000	Weak peak attributed to sugar units.
C=O stretch	1700	Peak suggesting the presence of uronic acids (acidic polysaccharides).
C–O–C, C–O stretch	1000–1200	Multiple peaks confirming the presence of polysaccharides and mucilage.
Glycosidic bonds	~900	Peaks indicating β-glycosidic linkages typical in polysaccharides.

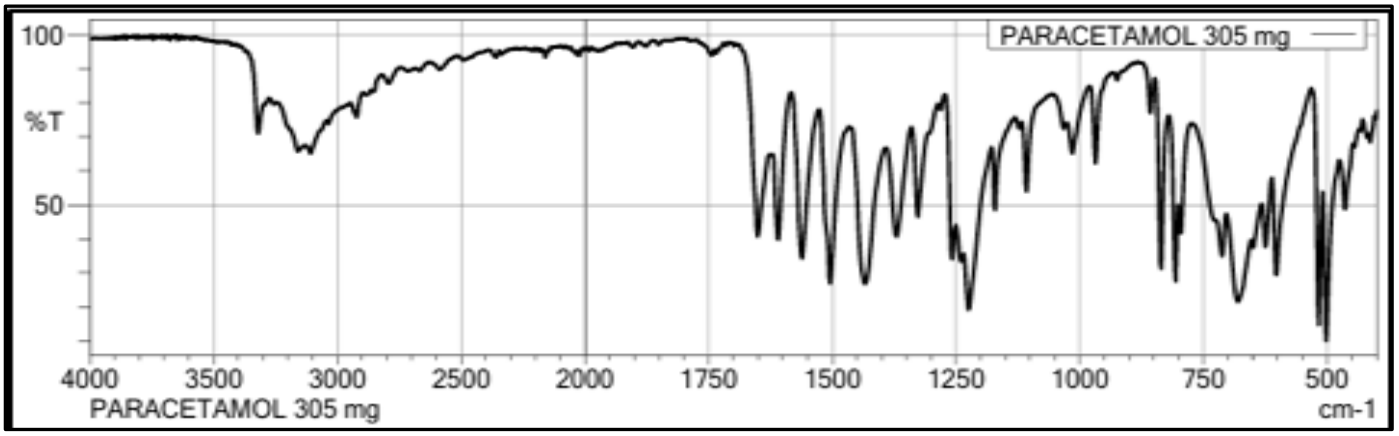

Fig 4 FTIR analysis of the Paracetamol

Although a physical mixture of *C. cujete* and paracetamol was not tested by FTIR in this study, the similar spectral profiles and absence of reactive groups suggest good chemical compatibility. This supports the potential of *C. cujete* mucilage as a stable, hydrophilic natural disintegrant for pharmaceutical use.

- *Pre-compression Evaluation of the Disintegrants at Different Concentrations:*

The pulverized mucilage, along with the standard disintegrants, underwent pre-compression evaluation, with the weight based on the total mass of each disintegrant in the formulation. The pre-compression parameters, shown in Table 18, assess how the powder will flow, compress, and behave during tablet production. Poor flowability or compressibility can result in issues such as tablet weight variation, poor hardness, or tablet breakage [21]

Table 18 Pre-Compression Evaluation

Disintegrant	Bulk Density (g/mL)	Tapped Density (g/mL)	Angle Repose (°)	Compressibility Index (%)	Hausner Ratio	
C. cujete Mucilage	**2%**	0.56	0.672	46.12330271°	16.66666667	1.2
	4%	0.672	0.84	45.80692946°	20	1.25
Croscarmellose Sodium	**2%**	0.448	0.56	47.48955292°	20	1.25
	4%	0.42	0.672	46.12330271°	37.5	1.6
Sodium Starch Glycolate	**2%**	0.395294118	0.610909091	53.13010235°	35.29411765	1.545454545
	4%	0.373333333	0.56	56.88865804°	33.33333333	1.5

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The evaluation began by weighing each disintegrant at a 2% concentration (approximately 672 mg of each powder), based on the formulation target of 187 tablets containing 111.75 mg of paracetamol each. This adjustment was necessary due to the limitations of the BioBase single-punch tablet press, which could only produce tablets weighing less than 200 mg. Bulk density was measured by pouring each powder into a 10 mL graduated cylinder and recording the initial volume. Tapped density was determined by tapping the cylinder after recording the initial volume and continuing until no further change in volume was observed; the final tapped volume was then noted. The angle of repose was measured by allowing the powder to flow through a funnel positioned 2 cm above the surface, and the height and diameter of the resulting conical pile were measured. Finally, the collected data were used to calculate the relevant parameters using the provided equations.

The *C. cujete* mucilage exhibited bulk and tapped densities that were similar to those of CCS and higher than those of SSG, which showed lower densities, especially at 4%. The angle of repose of the mucilage was also quite similar to the standards. At 2%, its value of 46.12° differed by approximately 1.37° from that of CCS, while it differed by about 7.01° from that of SSG. At 4%, the mucilage's angle of repose differed by around 0.31° from CCS and 11.08° from SSG. The mucilage's compressibility index was slightly lower than that of 4% CCS and SSG, and also lower than that of 2% CCS, yielding values in the range of 16–20%. In terms of the Hausner ratio, the mucilage exhibited the lowest values—1.20 and 1.25—compared to the synthetic disintegrants, which had values of 1.60, 1.55, and 1.50.

A previous review by Autade et al. [4] and Hadi et al. [21] described the flow characteristics based on the angle of repose, compressibility index, and Hausner ratio. According to this review, at a 2% concentration, the mucilage's angle of repose indicated poor flowability—comparable to that of CCS and SSG. At 4%, the mucilage demonstrated passable flowability, whereas the synthetic disintegrants still showed poor flowability. The compressibility index of the mucilage at 2% indicated fair flowability, comparable to CCS, while SSG exhibited very poor flowability. At 4%, the mucilage's compressibility index was more favorable than those of the synthetic disintegrants; according to the review, it demonstrated fair flowability, whereas both CCS and SSG exhibited very poor flow properties. Lastly, the Hausner ratio of the mucilage was also comparable to the synthetic disintegrants at both 2% and 4%. It showed fair flowability at both concentrations, while SSG had very poor flowability and CCS ranged from fair to extremely poor.

- *Evaluation of the C. cujete-based Compressed Paracetamol Tablets and Comparison with Synthetic Disintegrants (Paracetamol USP):*

Following the assessment of the disintegrants, tablet formulations were prepared using the procedure described by Ilango et al. [25]. After completing the granulation process through a series of steps, the granules were compressed into tablets using a Biobase single-punch tablet press. The resulting formulated tablets are shown in Figures 5, 6, and 7.

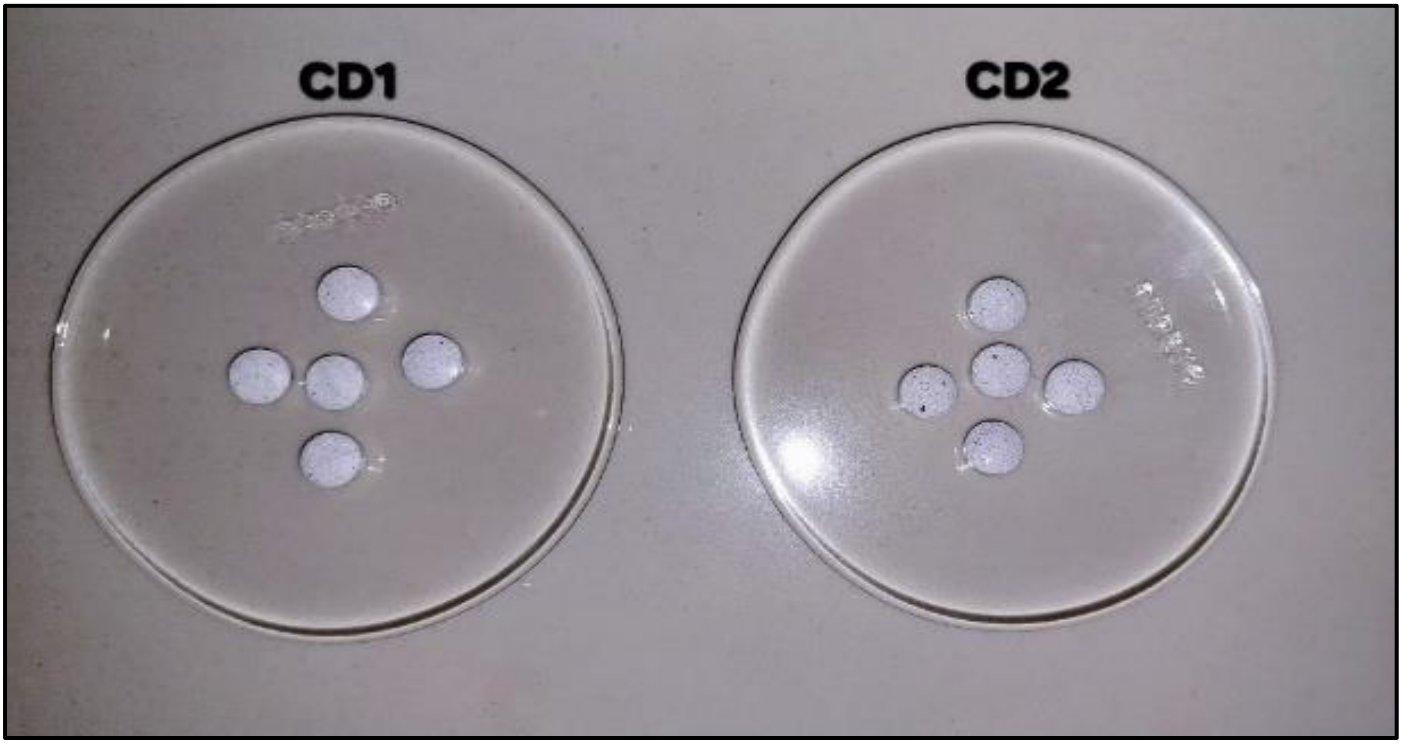

Fig 5 *C. cujete*-Based Paracetamol Tablets

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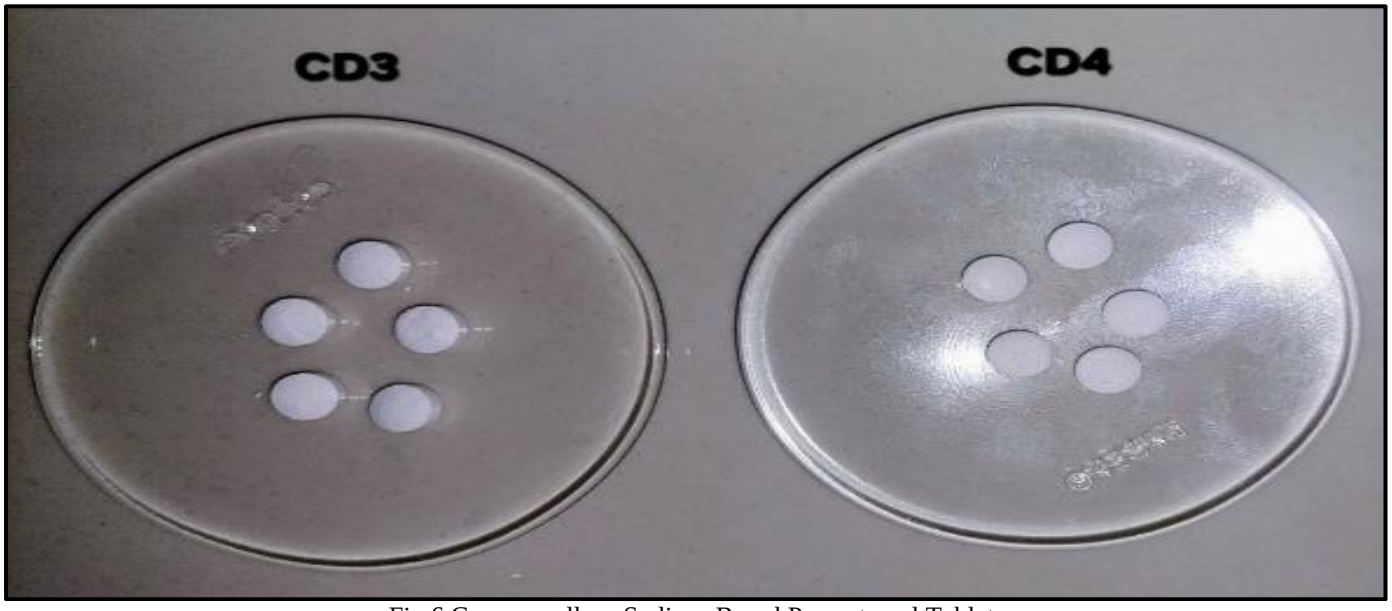

Fig 6 Croscarmellose Sodium-Based Paracetamol Tablets

Fig 7 Sodium Starch Glycollate-Based Paracetamol Tablets

- *Evaluation and Comparison Using Descriptive Statistics:*

✓ *Dimensions of the Tablet:*

The dimensional characteristics of compressed paracetamol tablets were assessed to evaluate the physical consistency of formulations containing *C. cujete* fruit pulp extract as a natural disintegrant at varying concentrations. Table 19 presents the average diameter and thickness, along with the corresponding standard deviations, for six different tablet formulations (coded CD1 to CD6). These formulations incorporated mucilage extracted from *C. cujete* fruit pulp at 2% and 4% concentrations, in addition to a positive control group.

Tablet diameters ranged from 0.812 cm (CD4) to 0.9055 cm (CD3), with CD3 exhibiting the most consistent size (SD = 0.0028), while CD1 showed the greatest variation (SD = 0.044). Thickness values varied from 0.362 cm (CD6) to 0.506 cm (CD5), with CD5 also presenting the highest variation (SD = 0.1909), suggesting inconsistencies in either the formulation or compression process. Overall, CD3 demonstrated the most uniform dimensions, whereas CD5 exhibited the least consistency.

According to Pharmapproach [38], acceptable tablet dimensions—specifically diameter and thickness—should fall within ±5% of the average value. Based on this criterion, all formulations exhibited acceptable diameter variation, as their standard deviations were within the ±5% range of their respective mean diameters. However, for thickness, CD1 and CD5 exceeded the acceptable ±5% threshold. CD1 recorded a standard deviation of 0.0428, surpassing the acceptable limit of 0.02065 (5% of its mean thickness), while CD5 demonstrated a significantly higher deviation of 0.1909, compared to the acceptable 0.0253.

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These findings indicate that both CD1 and CD5 formulations failed to meet the uniformity criteria for thickness, with CD5 showing particularly poor consistency. While *C. cujete* mucilage demonstrates potential as a natural excipient, these results highlight the need for further optimization in the formulation and compression processes to improve dimensional uniformity—particularly in terms of tablet thickness—to ensure compliance with pharmacopeial standards.

Table 19 Tablet Dimensions Mean and Standard Deviation of Diameter and Thickness

Formulation Code	Formulation Description	Diameter		Thickness	
		Mean	Standard Deviation (SD)	Mean	Standard Deviation (SD)
CD1	*C. cujete* Disintegrant at 2% concentration	0.8395	0.044	0.413	0.0428
CD2	*C. cujete* Disintegrant at 4% concentration	0.8995	0.0211	0.393	0.0073
CD3	Croscarmellose Sodium at 2% concentration	0.9055	0.0028	0.395	0.0109
CD4	Croscarmellose Sodium at 4% concentration	0.812	0.007	0.397	0.0066
CD5	Sodium Starch Glycolate at 2% concentration	0.824	0.0075	0.506	0.1909
CD6	Sodium Starch Glycolate at 4% concentration	0.9023	0.0041	0.362	0.007

✓ *Weight Variation:*

Table 20 presents the mean tablet weights and standard deviations for six paracetamol formulations using *C. cujete* fruit pulp as a natural disintegrant.

The mean tablet weights ranged from 166.85 mg (CD6) to 195 mg (CD2), showing slight variation among the formulations. CD2 exhibited the highest weight and variability (SD = 8.577 mg), suggesting less uniformity, whereas CD6 had the lowest weight and best consistency (SD = 3.7735 mg). These differences likely reflect the influence of varying concentrations of *C. cujete* mucilage and other excipients in the formulations.

According to the ±5% variation limit for weight uniformity outlined by [1], all formulations fell within the acceptable range, indicating overall good weight consistency. Consistent tablet weight is critical for ensuring accurate dosing. Despite some variability, these results support the potential use of *C. cujete* mucilage as a natural disintegrant capable of producing tablets with acceptable weight uniformity under the current formulation and manufacturing conditions.

✓ *Friability Testing:*

Table 21 presents the results of the friability test, which measures the mechanical strength of paracetamol tablets formulated with *C. cujete* fruit pulp as a natural disintegrant. Friability is determined by the weight loss after mechanical stress, with higher loss indicating lower resistance to abrasion.

Among the formulations, CD3 showed the highest percentage weight loss, with a mean friability of 40.77% and a large standard deviation of 35.22%, indicating very poor mechanical strength and inconsistent tablet integrity. CD2 and CD4 also exhibited notable friability values with high variability, suggesting moderate but still significant weight loss compared to CD3. In contrast, CD6 had the lowest percentage loss at 2.09% with a low standard deviation of 1.10%, demonstrating better tablet durability relative to the other batches.

Despite these differences, all formulations exceeded the ideal pharmacopeial friability limit of 1% weight loss set by Abebe et al. [1] and Khreit et al. [30], indicating generally poor mechanical strength across the tablets. The high friability values suggest that these tablets were prone to crumbling or breaking under mechanical stress, likely due to insufficient binder concentration, inadequate compression force, or poor granule cohesiveness.

While some *C. cujete*-based formulations exhibited particularly high friability, the relatively better performance of CD6 highlights the potential to improve tablet durability by optimizing excipient concentrations and processing parameters. These findings underscore the need for further formulation refinement to enhance tablet hardness and friability, ensuring reliable handling and stability for tablets formulated with *C. cujete* mucilage or synthetic disintegrants.

Table 20 Tablet Weight: Mean and Standard Deviation in Milligrams

Formulation Code	Formulation Description	Mean	Standard Deviation
CD1	*C. cujete* Disintegrant at 2% concentration	189.5	4.3468
CD2	*C. cujete* Disintegrant at 4% concentration	195	8.577
CD3	Croscarmellose Sodium at 2% concentration	178.3	6.626
CD4	Croscarmellose Sodium at 4% concentration	170.45	5.4337
CD5	Sodium Starch Glycolate at 2% concentration	173.75	4.241
CD6	Sodium Starch Glycolate at 4% concentration	166.85	3.7735

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Table 21 Friability Test Results: Mean and Standard Deviation in Percentage

Formulation Code	Formulation Description	Mean	Standard Deviation
CD1	*C. cujete* Disintegrant at 2% concentration	14.73061436	6.097211142
CD2	*C. cujete* Disintegrant at 4% concentration	22.41632428	18.82670614
CD3	Croscarmellose Sodium at 2% concentration	40.7769648	35.2181976
CD4	Croscarmellose Sodium at 4% concentration	22.52802903	18.33170887
CD5	Sodium Starch Glycolate at 2% concentration	15.70063525	6.70629863
CD6	Sodium Starch Glycolate at 4% concentration	2.089459869	1.102590699

✓ *Hardness Testing:*

Table 22 presents the results of the hardness test, specifically the tensile strength, for paracetamol tablets formulated with varying concentrations of *C. cujete* fruit pulp as a natural disintegrant. Tensile strength is a key indicator of a tablet's mechanical integrity—reflecting its ability to resist breaking under pressure during handling, packaging, and transport.

Among the six formulations, CD3 exhibited the highest tensile strength at 15.694 kg/cm² with a low standard deviation of 0.586, indicating strong and consistent tablet hardness. CD2 also performed well, showing high tensile strength (14.89 kg/cm²) and the lowest variability (SD = 0.469). In contrast, CD5 had the lowest tensile strength (13.64 kg/cm²) and the highest variability (SD = 0.94), suggesting relatively weaker mechanical properties.

Notably, all formulations produced tablets with tensile strengths exceeding the ideal range of 4 to 10 kg/cm² recommended by Pujari et al. [41], indicating tablets that are harder than pharmacopeial guidelines suggest. While this high hardness demonstrates excellent mechanical robustness, it may negatively affect disintegration and drug release if not properly controlled.

Overall, the results indicate that tablets containing *C. cujete* fruit pulp can achieve acceptable and even enhanced hardness, particularly in optimized formulations such as CD2 and CD3. This suggests that the natural disintegrant, when properly utilized, does not compromise tablet strength and may contribute positively to mechanical integrity.

✓ *Disintegration Testing:*

Table 23 presents the results of the disintegration test, which evaluates how quickly each paracetamol tablet formulation breaks down—a key factor in determining the onset of drug action. The formulations used varying concentrations of *C. cujete* fruit pulp as a natural disintegrant.

Table 22 Hardness Test (Tensile Strength) Results: Mean and Standard Deviation

Formulation Code	Formulation Description	Mean	Standard Deviation
CD1	*C. cujete* Disintegrant at 2% concentration	14.462	2.09
CD2	*C. cujete* Disintegrant at 4% concentration	14.88974	0.469
CD3	Croscarmellose Sodium at 2% concentration	15.694	0.586
CD4	Croscarmellose Sodium at 4% concentration	14.1	0.45
CD5	Sodium Starch Glycolate at 2% concentration	13.6381	0.94
CD6	Sodium Starch Glycolate at 4% concentration	13.9	0.61823

Table 23 Disintegration Test Results: Mean and Standard Deviation in Minutes

Formulation Code	Formulation Description	Mean	Standard Deviation
CD1	*C. cujete* Disintegrant at 2% concentration	7.833	1.94
CD2	*C. cujete* Disintegrant at 4% concentration	6.333	1.86
CD3	Croscarmellose Sodium at 2% concentration	5.833	0.7527
CD4	Croscarmellose Sodium at 4% concentration	4.5	0.8366
CD5	Sodium Starch Glycolate at 2% concentration	2.833	0.75277
CD6	Sodium Starch Glycolate at 4% concentration	2.6667	0.516

Among the formulations, CD6 exhibited the fastest disintegration time at 2.67 minutes with the lowest variability, indicating consistent and effective performance. CD5 followed closely with a disintegration time of 2.83 minutes. These results suggest that higher concentrations of *C. cujete* mucilage promote faster disintegration. In contrast, CD1 showed the longest disintegration time of 7.83 minutes and the highest variability, indicating lower disintegrant effectiveness.

Overall, all formulations disintegrated well within the acceptable 15-minute limit set by Abebe et al. [1]. These findings support the efficacy of *C. cujete* fruit pulp as a natural disintegrant, particularly in the CD5 and CD6

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formulations, and highlight its potential as a viable alternative to synthetic disintegrants

✓ *Dissolution Testing:*

Table 24 presents the dissolution test results, which assess the amount of drug released from the tablet into solution over time—a crucial factor in determining the drug's bioavailability. The results are expressed as percentage release, corresponding to the concentration of the dissolved drug.

The results of the dissolution test for paracetamol tablets formulated with *C. cujete* fruit pulp extract as a natural disintegrant indicate a consistent level of drug release across all test samples. The mean percentage release of paracetamol, representing the amount of drug dissolved, ranged narrowly from 42.6% (CD5) to 43.5% (CD4), with standard deviations between 0.31 and 0.98, confirming uniformity and reliability in dissolution performance. Statistically, these findings suggest that incorporating *C. cujete* fruit pulp at concentrations of 2% and 4% does not adversely affect the dissolution properties of compressed paracetamol tablets and may provide effective disintegration comparable to conventional synthetic disintegrants.

However, pharmacopeial standards require drug release greater than 80% within 30 minutes [32], which none of the formulations met—including those containing *C. cujete* mucilage and synthetic disintegrants. The highest observed release was approximately 44%, with minimal increase over time, indicating suboptimal drug release efficiency. This limited dissolution may result from factors such as excessive tablet hardness, insufficient disintegration dynamics, or excipient–drug interactions. Therefore, further formulation optimization is necessary, including potential adjustments to disintegrant concentration, binder levels, and compression force, to enhance drug release and ensure the therapeutic effectiveness of these tablets.

Table 24 Dissolution Test Results Mean and Standard Deviation of % Release (Paracetamol Concentration)

Formulation Code	Formulation Description	Mean	Standard Deviation
CD1	*C. cujete* Disintegrant at 2% concentration	43.049	0.98
CD2	*C. cujete* Disintegrant at 4% concentration	43.24	0.911
CD3	Croscarmellose Sodium at 2% concentration	42.79	0.708
CD4	Croscarmellose Sodium at 4% concentration	43.5	0.3108
CD5	Sodium Starch Glycolate at 2% concentration	42.6	0.946
CD6	Sodium Starch Glycolate at 4% concentration	42.98	0.361

- *Evaluation and Comparison Using Inferential Statistics:*

To assess the effectiveness of *C. cujete* fruit pulp as a natural disintegrant in compressed paracetamol tablet formulations, statistical analyses were conducted using ANOVA and paired t-tests. These tests evaluated whether the disintegration and dissolution performance of the natural disintegrant was comparable to or better than that of standard synthetic disintegrants such as croscarmellose sodium (CSC) and sodium starch glycolate (SSG), using a 0.05 level of significance.

✓ *ANOVA Comparison of Evaluation Parameters Between C. cujete Fruit Pulp Tablet Formulations and Paracetamol Tablets:*

Table 25 presents the ANOVA results comparing key evaluation parameters of *C. cujete* fruit pulp tablet formulations with paracetamol tablets. The analysis covers tablet dimensions (diameter and thickness), weight, friability, hardness, disintegration time, and dissolution.

Table 25 ANOVA Results Comparing Evaluation Parameters of *C. cujete* Tablets and Paracetamol: F-values and P-values

ANOVA Result	f-value	p-value
Tablet Dimension (Diameter)	88.6199	0.0001**
Tablet Dimension (Thickness)	7.5837	0.0001**
Tablet Weight	70.71844	0.0001**
Friability Test (Initial Weight)	41.4943	0.0001**
Friability Test (Final Weight)	8.718	0.0001**
Hardness Test (Tensile Strength)	5.275	0.000513**
Disintegration Test	16.114	0.0001**
Dissolution Test	0.9052	0.4939
Note: Significant if p-value < 0.05* and p-value < 0.01**		

The results show significant differences between the *C. cujete* formulations and the control group in tablet dimensions, weight, friability, and hardness, with p-values all below 0.05, indicating a meaningful impact. However, the p-value for the dissolution test was 0.4939, and the F-value was 0.9052 — both exceeding the 0.05 threshold for statistical significance — leading to a failure to reject the null hypothesis. This means that, at a 95% confidence level, there is no statistically significant difference in dissolution rates between the formulations and the control. Specifically, the dissolution results for CD1, CD2, CD3, CD4, CD5, and CD6 show no meaningful difference in how well the tablets dissolve, regardless of whether a natural or synthetic disintegrant was used, demonstrating similar performance across all formulations. This indicates that while *C. cujete* affects physical properties like hardness and disintegration, it

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does not significantly alter the dissolution rate. Overall, the ANOVA results support *C. cujete* as a promising natural disintegrant, improving tablet properties without compromising dissolution performance.

✓ *Tukey's HSD Post Hoc Test for Tablet Diameter Differences Among Paracetamol Formulations with C. cujete Fruit Pulp Following ANOVA Analysis:*

Table 26 presents the results of Tukey's HSD post hoc test, used to identify specific differences in tablet diameter among the various paracetamol tablet formulations containing *C. cujete* fruit pulp. While the ANOVA test confirmed overall significant differences, this analysis highlights the specific formulation pairs that differed.

Table 26 Post Hoc Test Results of Tablet Dimensions: Diameter

Post Hoc Test Result	p-value
CD1 vs CD2	0.0001**
CD1 vs CD3	0.0001**
CD1 vs CD4	0.009128317**
CD1 vs CD5	0.130530304
CD1 vs CD6	0.0001**
CD2 vs CD3	0.215957893
CD2 vs CD4	0.0001**
CD2 vs CD5	0.0001**
CD2 vs CD6	0.571462904
CD3 vs CD4	0.0001**
CD3 vs CD5	0.0001**
CD3 vs CD6	0.005763236**
CD4 vs CD5	0.0001**
CD4 vs CD6	0.0001**
CD5 vs CD6	0.0001**
Note: Significant if p-value < 0.05* and p-value < 0.01**	

The results show significant differences in tablet diameter between most formulations, especially CD1 vs. CD2, CD1 vs. CD3, CD2 vs. CD4, and CD4 vs. CD6, with p-values less than 0.01. This indicates noticeable diameter variation across most groups. However, pairs like CD1 vs. CD5 and CD2 vs. CD3 showed no significant differences, suggesting similar diameters. Overall, the findings emphasize that certain *C. cujete* concentrations influenced tablet diameter more than others, highlighting the role of formulation on tablet characteristics.

✓ *Tukey's HSD Post Hoc Results for Tablet Thickness:*

Table 27 presents the Tukey's HSD post hoc results for tablet thickness, highlighting specific differences between paracetamol formulations containing *C. cujete* as a natural disintegrant. While the ANOVA showed overall significant differences in thickness, the post hoc test clarifies which formulation pairs contributed to these variations.

Table 27 Post Hoc Test Results of Tablet Dimensions: Thickness

Post Hoc Test Result	p-value
CD1 vs CD2	0.046212364*
CD1 vs CD3	0.076074762
CD1 vs CD4	0.106512237
CD1 vs CD5	0.040098739*
CD1 vs CD6	0.0001**
CD2 vs CD3	0.499509055
CD2 vs CD4	0.076987484
CD2 vs CD5	0.011819853*
CD2 vs CD6	0.0001**
CD3 vs CD4	0.485944339
CD3 vs CD5	0.013347257*
CD3 vs CD6	0.0001**
CD4 vs CD5	0.014872805*
CD4 vs CD6	0.0001**
CD5 vs CD6	0.0017619**
Note: Significant if p-value < 0.05* and p-value < 0.01**	

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Several pairs showed significant differences in tablet thickness, particularly CD1 vs. CD2 ($p = 0.0462$), CD1 vs. CD5 ($p = 0.0401$), and CD1 vs. CD6 ($p < 0.0001$), indicating that different *C. cujete* concentrations affect tablet compactness. CD6 differed significantly from almost all other formulations, suggesting it had a unique thickness profile. Other significant differences were observed in CD2 vs. CD5, CD3 vs. CD5, and CD4 vs. CD6. However, some pairs like CD2 vs. CD3 and CD3 vs. CD4 showed no significant difference, implying similar thickness. Overall, these results suggest that the concentration and formulation of *C. cujete* mucilage impact tablet thickness, with certain formulations like CD6 leading to thinner tablets.

✓ *Tukey's HSD Post Hoc Results for Tablet Weight:*

Table 28 Post Hoc Test Results of Tablet Weight

Post Hoc Test Result	p-value
CD1 vs CD2	0.043101511*
CD1 vs CD3	0.0001**
CD1 vs CD4	0.0001**
CD1 vs CD5	0.0001**
CD1 vs CD6	0.0001**
CD2 vs CD3	0.0001**
CD2 vs CD4	0.0001**
CD2 vs CD5	0.0001**
CD2 vs CD6	0.0001**
CD3 vs CD4	0.000211629**
CD3 vs CD5	0.013651512*
CD3 vs CD6	0.0001**
CD4 vs CD5	0.038742935*
CD4 vs CD6	0.019758294*
CD5 vs CD6	0.0001**
Note: Significant if p-value < 0.05* and p-value < 0.01**	

Table 28 presents Tukey's HSD post hoc test results for tablet weight, following the ANOVA which revealed significant differences among formulations. The post hoc analysis highlights the specific formulation pairs with statistically significant differences in mean tablet weights.

The post hoc results show that most formulation pairs had statistically significant differences in tablet weight ($p < 0.05$), with CD1 differing notably from CD2 through CD6. Even the smallest p-value (CD1 vs. CD2 at 0.0431) was still significant. CD2 also showed highly significant differences when compared to CD3 through CD6 ($p = 0.0001$). These results suggest that changes in formulation, particularly the concentration of *C. cujete* mucilage, strongly influenced tablet mass. Overall, each formulation had a distinct weight profile, confirming the impact of the natural disintegrant on tablet weight.

✓ *Tukey's HSD Post Hoc Results for Friability Test:*

Table 29 shows the results of Tukey's HSD post hoc analysis, identifying significant differences in the initial tablet weights before the friability test among paracetamol formulations containing *C. cujete* fruit pulp.

Table 29 Post Hoc Test Results for Friability Test (Initial Tablet Weight)

Post Hoc Test Result	p-value
CD1 vs CD2	0.379695994
CD1 vs CD3	0.0001**
CD1 vs CD4	0.0001**
CD1 vs CD5	0.0001**
CD1 vs CD6	0.0001**
CD2 vs CD3	0.0001**
CD2 vs CD4	0.0001**
CD2 vs CD5	0.0001**
CD2 vs CD6	0.0001**
CD3 vs CD4	0.284913595
CD3 vs CD5	0.57119522
CD3 vs CD6	0.0001**
CD4 vs CD5	0.139904761
CD4 vs CD6	0.004831137**
CD5 vs CD6	0.0001**
Note: Significant if p-value < 0.05* and p-value < 0.01**	

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Among the lower-weight formulations (CD3, CD4, CD5, and CD6), most pairwise comparisons showed no significant differences, indicating similar initial weights—except for CD6. CD6 differed significantly from CD3, CD4, and CD5, confirming it had the lowest initial tablet weight.

Overall, CD1 and CD2 had consistently higher initial weights, while CD6 had the lowest. These results highlight how the type and concentration of *C. cujete* mucilage can influence tablet mass before friability testing.

Table 30 presents the results of Tukey's HSD post hoc analysis comparing the final tablet weights after the friability test among paracetamol formulations containing *C. cujete* fruit pulp and control disintegrants. This analysis identifies specific formulation pairs with significant differences in weight retention following mechanical stress.

Table 30 Post Hoc Test Results for Final Tablet Weight After Friability Test

Post Hoc Test Result	p-value
CD1 vs CD2	0.135455479
CD1 vs CD3	0.00020084**
CD1 vs CD4	0.000665396**
CD1 vs CD5	0.0001**
CD1 vs CD6	0.756105052
CD2 vs CD3	0.007703613**
CD2 vs CD4	0.168148832
CD2 vs CD5	0.80768475
CD2 vs CD6	0.156884256
CD3 vs CD4	0.061524268
CD3 vs CD5	0.003989672**
CD3 vs CD6	0.00022348**
CD4 vs CD5	0.088735687
CD4 vs CD6	0.00071541**
CD5 vs CD6	0.0001**
Note: Significant if p-value < 0.05* and p-value < 0.01**	

The post hoc results of the final tablet weight after the friability test revealed that CD1 retained significantly more weight than CD3, CD4, and CD5 ($p < 0.01$), indicating superior resistance to breakage. Notably, CD1 and CD6 showed no significant difference ($p = 0.7561$), suggesting both had strong structural integrity. CD3, on the other hand, experienced the most weight loss and differed significantly from several other formulations, indicating poor resistance to mechanical stress. CD2 showed consistent performance, with no significant differences compared to CD4, CD5, or CD6. However, a significant difference was observed between CD5 and CD6 ($p = 0.0001$), with CD6 retaining more of its original weight. Overall, CD6 and CD1 demonstrated the best friability resistance, while CD3 showed the weakest, highlighting how the concentration and formulation of *C. cujete* mucilage can influence the mechanical durability of paracetamol tablets.

✓ *Paired t-Test Comparing Initial and Final Tablet Weights Across Formulations:*

Table 31 presents the results of a paired t-test comparing the initial and final weights of tablets from formulations CD1 to CD6. This analysis aimed to determine whether the friability test caused statistically significant changes in tablet weight, indicating susceptibility to mechanical stress across the different formulations.

Table 31 Paired t-Test Analysis of Friability Test: Comparison Between Initial and Final Weights

Comparing Initial Weight and Final Weight	t-value	p-value
CD1	10.8213	0.0001**
CD2	5.1743	0.0001**
CD3	5.3262	0.0001**
CD4	6.8056	0.0001**
CD5	10.3186	0.0001**
CD6	9.2991	0.0001**
Note: Significant if p-value < 0.05* and p-value < 0.01**		

For all formulations, the t-values are high, showing a clear difference between initial and final weights. The p-values are all 0.0001, well below the 0.05 threshold, meaning the weight changes are statistically significant. This confirms that the friability test had a notable impact on tablet weight. The results suggest that all tablet formulations lost weight during the test, likely due to the disintegrant properties and the tablets' mechanical strength. In short, the paired t-test confirms that the tablets' disintegration and friability are significantly influenced by the natural disintegrant in the formulation.

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✓ *Tukey's HSD Post Hoc Results for Hardness Test:*

Table 32 shows the results of Tukey's HSD post hoc test for the hardness (tensile strength) of paracetamol tablets made with *C. cujete* fruit pulp. While the ANOVA indicated significant differences in hardness between the formulations, this table helps pinpoint which specific groups are responsible for those differences.

Table 32 Post Hoc Test Results for Hardness (Tensile Strength) of Paracetamol Tablets

Post Hoc Test Result	p-value
CD1 vs CD2	0.535999487
CD1 vs CD3	0.089619804
CD1 vs CD4	0.605391053
CD1 vs CD5	0.270793598
CD1 vs CD6	0.428596
CD2 vs CD3	0.003292276**
CD2 vs CD4	0.001319346**
CD2 vs CD5	0.001411844**
CD2 vs CD6	0.000807163**
CD3 vs CD4	0.0001**
CD3 vs CD5	0.0001**
CD3 vs CD6	0.0001**
CD4 vs CD5	0.173241236
CD4 vs CD6	0.414081936
CD5 vs CD6	0.465463124
Note: Significant if p-value < 0.05* and p-value < 0.01**	

The results show that CD3 stands out, with significant differences in hardness compared to CD2, CD4, CD5, and CD6, all with p-values below 0.01. This suggests that CD3 has a distinct hardness profile, likely due to the unique concentration or behavior of *C. cujete* as a disintegrant. On the other hand, CD1 showed no significant difference from the other formulations, indicating its tensile strength was relatively moderate. Similarly, no significant differences were found between CD4, CD5, and CD6, suggesting similar hardness levels in these three. Overall, CD3 has a noticeably different tensile strength, highlighting the impact of its specific *C. cujete* formulation on tablet compaction and integrity.

✓ *Tukey's HSD Post Hoc Results for Disintegration Test:*

Based on Table 33 and the formulation codes from Table 15, the disintegration times of various paracetamol tablet formulations with different disintegrants were compared. CD1 and CD2 contain *C. cujete* mucilage as a natural disintegrant at 2 mg and 4 mg, respectively. CD3 and CD4 use Croscarmellose Sodium, while CD5 and CD6 use Sodium Starch Glycolate, both at 2 mg and 4 mg.

Table 33 Post Hoc Test Results for Disintegration Test

Post Hoc Test Result	p-value
CD1 vs CD2	0.20182575
CD1 vs CD3	0.040406079*
CD1 vs CD4	0.003143106**
CD1 vs CD5	0.000154458**
CD1 vs CD6	0.0001**
CD2 vs CD3	0.555573075
CD2 vs CD4	0.052441068
CD2 vs CD5	0.001639952**
CD2 vs CD6	0.000910332**
CD3 vs CD4	0.015782019*
CD3 vs CD5	0.0001**
CD3 vs CD6	0.0001**
CD4 vs CD5	0.004632631**
CD4 vs CD6	0.001030204**
CD5 vs CD6	0.664251472
Note: Significant if p-value < 0.05* and p-value < 0.01**	

The post hoc analysis shows that increasing the concentration of *C. cujete* mucilage (CD1 vs. CD2) doesn't significantly change disintegration time ($p = 0.2018$). However, comparing natural disintegrants (CD1 and CD2) with synthetic ones (CD3 to CD6) reveals significant differences, especially at higher concentrations. For example, CD1 has highly significant differences with CD4, CD5, and CD6 ($p < 0.01$), suggesting that synthetic disintegrants affect disintegration time more than the natural one at lower doses. CD2 also shows significant differences with CD5 and CD6,

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highlighting that even at higher doses, *C. cujete* mucilage behaves differently from synthetic disintegrants. Among the synthetic disintegrants, higher concentrations generally improve disintegration times, as seen in the CD3 vs. CD4 and CD4 vs. CD6 comparisons. Overall, *C. cujete* mucilage influences disintegration time, particularly at higher concentrations, and shows promise as a natural alternative in tablet formulation.

IV. DISCUSSION

This study investigated the potential application of *C. cujete* fruit pulp mucilage as a natural disintegrant in paracetamol tablet formulations. The following discussion addresses the study's objectives and hypotheses while integrating key findings from both descriptive and inferential analyses.

The first objective involved determining the percentage yield of mucilage from *C. cujete* fruit pulp. The extraction process yielded a mean value of 0.4741% ± 0.2499, which is substantially lower than the 10% threshold generally considered pharmaceutically viable for natural excipients [12]. This low yield indicates that the current extraction method may require optimization to enhance efficiency and facilitate cost-effective large-scale production.

The second objective focused on phytochemical characterization. The qualitative screening confirmed the presence of several secondary metabolites—namely alkaloids, carbohydrates, flavonoids, saponins, phenols, and terpenoids—suggesting functional potential as a disintegrant. Notably, tannins—previously reported in other studies [18]—were not detected in the current analysis, possibly due to limited sample volume or reagent degradation. In contrast, steroids were entirely absent, consistent with findings from previous literature. Quantitative analyses further revealed a total phenolic content of 50.98 mg gallic acid equivalents per gram and a total flavonoid content of 3.12 mg quercetin equivalents per gram, indicating moderate antioxidant capacity. These properties may contribute to water-binding capacity and stability within the tablet matrix.

To evaluate functional performance, paracetamol tablets incorporating *C. cujete* mucilage were compared to those containing standard synthetic disintegrants—croscarmellose sodium (CSC) and sodium starch glycolate (SSG). Regarding mechanical strength, tablets containing 4% *C. cujete* mucilage exhibited tensile strength values (14.89 kg/cm²) comparable to CSC-based tablets. However, all formulations, including those with synthetic excipients, exceeded the pharmacopeial hardness range of 4–10 kg/cm². This excessive hardness is of concern, as it may hinder disintegration and subsequent drug dissolution [41].

Disintegration testing demonstrated that *C. cujete*-based tablets (CD1 and CD2) disintegrated within pharmacopeial limits, as defined by Abebe et al. [1], which specify a maximum disintegration time of 15 minutes. The observed disintegration times ranged from 6.33 to 7.83 minutes. These were notably longer than the disintegration times observed for SSG-based formulations (2.67–2.83 minutes). Although the results confirm functional disintegration, the prolonged disintegration time indicates that synthetic disintegrants remain superior in this regard. As highlighted by Berardi et al. [8], the evaluation of disintegrants should consider not only disintegration time but also the resultant effect on drug dissolution, which directly impacts bioavailability.

Dissolution testing further reinforced this point. Although no statistically significant differences were observed in dissolution profiles between *C. cujete*-based and synthetic formulations ($p = 0.4939$), none of the tested formulations—including those with synthetic disintegrants—achieved the pharmacopeial benchmark of ≥80% drug release within 30 minutes [32]. This suggests that disintegration alone was insufficient to facilitate adequate drug release, likely due to excessive hardness and limited porosity, which impair water penetration and tablet breakup. These findings underscore the need for simultaneous optimization of both disintegration and dissolution parameters.

From a statistical perspective, analysis of variance (ANOVA) followed by Tukey's post hoc test revealed significant differences among formulations in terms of tablet dimensions, friability, and weight. While *C. cujete* mucilage exhibited satisfactory compressibility and mechanical strength, some formulations showed elevated friability. Nonetheless, CD1 and CD6 demonstrated better structural integrity than other formulations, suggesting that specific concentrations and combinations may enhance performance.

The study's alternative hypothesis (H_1) posited that *C. cujete* mucilage would yield comparable or superior disintegration and dissolution performance relative to synthetic disintegrants. The null hypothesis (H_0) stated that there would be no such improvement. Based on the findings, the null hypothesis can only be partially rejected. Although *C. cujete* mucilage demonstrated comparable disintegration and mechanical behavior, dissolution performance remained statistically indistinct from that of synthetic disintegrants, and none of the formulations met USP dissolution standards. As emphasized by Berardi et al. [8], disintegration is a necessary but insufficient condition for optimal drug release if not accompanied by effective dissolution. Therefore, the study has failed to reject the null hypothesis.

V. CONCLUSIONS

The findings of the current study demonstrated that *C. cujete* fruit pulp mucilage contains notable phytochemical constituents—including alkaloids, carbohydrates, flavonoids, saponins, phenols, and terpenoids—that support its potential application as a natural disintegrant in pharmaceutical tablet formulations. Physicochemical characterization revealed acceptable properties in terms of viscosity, solubility, and moisture content, though limitations were observed in the swelling index and extraction yield, which may affect its scalability and efficiency. Pre-evaluation parameters showed fair to acceptable flowability and compressibility, contributing to consistent tablet formation in terms of weight and hardness. However, the high friability values across most

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formulations indicated a need for improved tablet integrity. While all *C. cujete*-based formulations met the pharmacopeial standards for disintegration time, their dissolution profiles were statistically comparable to those of tablets containing synthetic disintegrants, as indicated by an ANOVA p-value of 0.4939. Therefore, the study fails to reject the null hypothesis, concluding that *C. cujete* fruit pulp mucilage does not exhibit significantly superior dissolution or disintegration performance compared to standard disintegrants such as croscarmellose sodium and sodium starch glycolate. Nonetheless, its phytochemical richness, biocompatibility, and natural origin position it as a viable and sustainable alternative, meriting further optimization and investigation in future pharmaceutical research.

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