

Formulation and Evaluation of Tablets Using Orange and Banana Peels as Natural Excipients: A Comprehensive Review

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Abstract-- The growing demand for eco-friendly and biocompatible pharmaceutical excipients has encouraged researchers to explore natural waste-derived materials for tablet formulation. Among various agricultural by-products, orange peels and banana peels have emerged as promising natural excipients because of their rich content of pectin, starch, cellulose, hemicellulose, lignin, and other polysaccharides. These materials possess excellent binding, disintegrating, suspending, and release-retarding properties, making them suitable alternatives to synthetic excipients. The utilization of fruit peel waste in pharmaceutical formulation not only reduces environmental burden but also supports sustainable pharmaceutical development. This review discusses the extraction methods, physicochemical characterization, formulation approaches, and evaluation parameters of tablets prepared using orange and banana peel derivatives. The review also summarizes recent advances in natural polymer-based tablet systems, including orally disintegrating tablets, sustained-release tablets, and conventional compressed tablets. Comparative studies between synthetic excipients and peel-derived polymers demonstrate the significant pharmaceutical potential of these natural materials. Furthermore, challenges related to standardization, microbial stability, regulatory acceptance, and industrial scalability are critically discussed. The review concludes that orange and banana peel-derived excipients represent a sustainable and cost-effective strategy for modern pharmaceutical formulations and could play an important role in green pharmaceuticals in the future.

Keywords-- Orange peel, Banana peel, Natural excipients, Pectin, Tablet formulation, Sustainable pharmaceuticals, Natural polymers, Pharmaceutical technology.

I. INTRODUCTION

Pharmaceutical excipients are pharmacologically inactive substances incorporated into dosage forms to improve product stability, manufacturability, appearance, patient acceptability, and therapeutic performance [1,2]. Although active pharmaceutical ingredients (APIs) are primarily responsible for pharmacological activity, excipients play a critical role in ensuring the successful delivery and release of drugs from dosage forms [3].

In tablet formulations, excipients are essential for providing bulk to formulations, improving compressibility, enhancing flowability, promoting disintegration, controlling drug release, and maintaining tablet integrity during manufacturing, transportation, and storage [4]. Synthetic excipients such as sodium starch glycolate, croscarmellose sodium, hydroxypropyl methylcellulose (HPMC), polyvinylpyrrolidone (PVP), and microcrystalline cellulose (MCC) are widely used in pharmaceutical industries due to their reproducibility and functionality [5]. However, several concerns are associated with synthetic excipients, including high manufacturing costs, environmental hazards, poor biodegradability, toxicity concerns, and dependence on petrochemical resources [6]. In recent years, the pharmaceutical industry has increasingly shifted toward the exploration of naturally derived excipients because of their biocompatibility, biodegradability, low toxicity, economic feasibility, and eco-friendly nature [7]. Natural excipients obtained from plant sources have attracted significant interest owing to their renewability and wide range of pharmaceutical applications [8]. Various natural polymers such as gums, starches, mucilage, pectin, cellulose, alginate, and carrageenan have demonstrated excellent utility in pharmaceutical formulations [9]. Among plant-based materials, fruit-processing waste has become an important area of research because of the increasing global emphasis on sustainable development and waste valorization [10]. Fruit peels constitute a substantial proportion of agricultural waste generated by food processing industries worldwide [11]. Disposal of fruit waste creates serious environmental and economic challenges. However, fruit peels are rich in polysaccharides, dietary fibers, antioxidants, minerals, flavonoids, and bioactive compounds that possess remarkable pharmaceutical properties [12]. Orange peels contain significant amounts of pectin, cellulose, hemicellulose, flavonoids, and essential oils, whereas banana peels contain starch, pectin, mucilage, cellulose, and phenolic compounds [13, 14]. These natural constituents exhibit excellent binding, swelling, disintegrating, and release-retarding properties suitable for oral tablet formulations [15].

Several researchers have successfully utilized orange peel pectin and banana peel starch in conventional tablets, sustained-release tablets, floating tablets, and orally disintegrating tablets [16]. Comparative studies indicate that peel-derived excipients may perform similarly or even superiorly to synthetic excipients in terms of tablet hardness, friability, dissolution profile, and drug release kinetics [17]. Furthermore, the utilization of fruit waste supports green pharmaceutical technology and circular bioeconomy by

converting waste materials into value-added pharmaceutical products [18]. The present review aims to provide a detailed and comprehensive overview of the formulation and evaluation of tablets using orange and banana peels as natural excipients. The review discusses extraction methods, physicochemical characterization, formulation technologies, evaluation parameters, pharmaceutical applications, advantages, limitations, and future perspectives associated with peel-derived natural excipients.



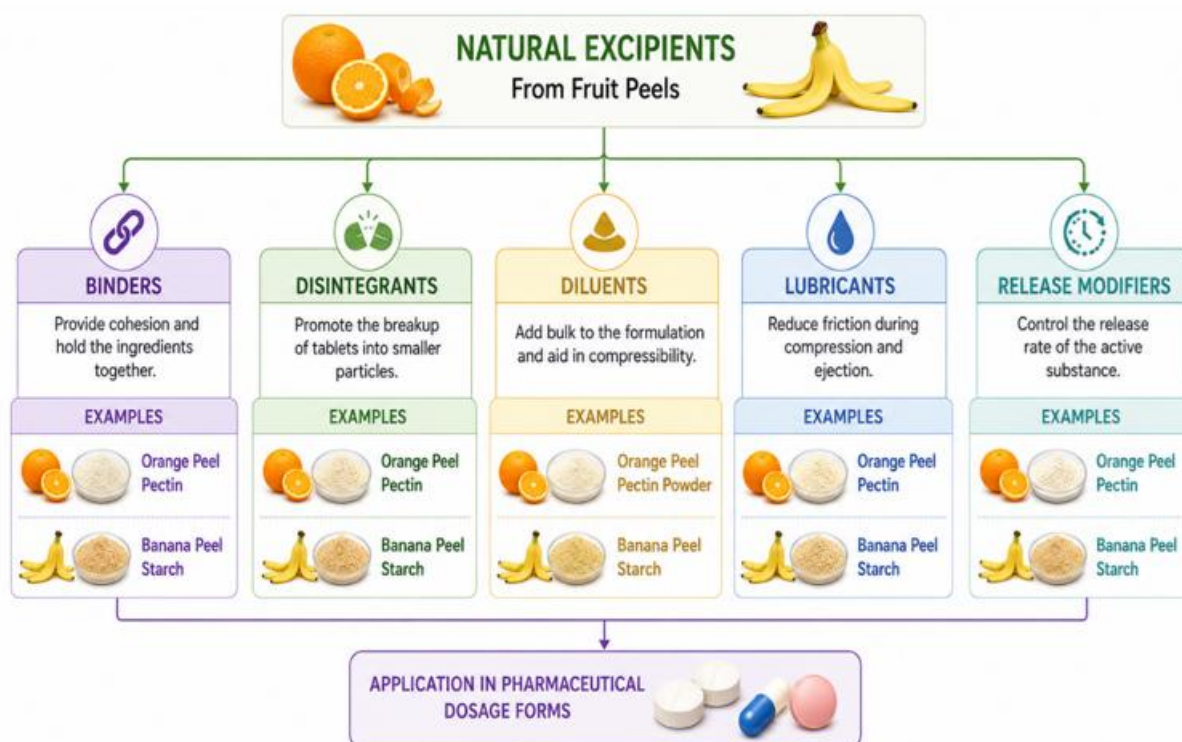
II. NATURAL EXCIPIENTS IN PHARMACEUTICAL FORMULATION

Natural excipients are substances obtained from biological sources such as plants, animals, microorganisms, and minerals and are incorporated into pharmaceutical formulations to improve dosage form characteristics [19]. The use of natural polymers in pharmaceutical technology has increased significantly due to rising concerns regarding environmental sustainability, toxicity, and patient safety associated with synthetic excipients [20]. Plant-derived excipients possess several advantages over synthetic materials because they are biodegradable, biocompatible, non-toxic, renewable, and relatively inexpensive [21]. Additionally, natural polymers often exhibit multifunctional properties that allow them to perform multiple pharmaceutical roles simultaneously [22].

For example, starch can function as a binder, disintegrant, and filler, whereas pectin may act as a binder, gelling agent, and controlled-release polymer [23]. The increasing popularity of herbal medicines and natural products has also influenced the demand for naturally derived excipients [24]. Regulatory agencies and pharmaceutical industries are actively encouraging research on sustainable and eco-friendly excipient systems [25]. Consequently, researchers are exploring agricultural waste materials as alternative sources of pharmaceutical polymers. Orange and banana peels represent promising natural excipient sources because they are abundantly available and rich in functional polysaccharides [26]. Orange peel pectin possesses excellent swelling and gel-forming characteristics that are useful for sustained-release formulations [27]. Banana peel starch and mucilage exhibit good hydration capacity and compressibility, making them suitable for direct compression tablets and fast-disintegrating systems [28].

Natural excipients derived from fruit peels have been investigated for various pharmaceutical applications including matrix tablets, orally disintegrating tablets, gastro-retentive systems, colon-targeted drug delivery, and mucoadhesive formulations [29].

Studies have shown that peel-derived excipients can improve tablet mechanical strength, disintegration behavior, and dissolution profile while reducing formulation costs [30].



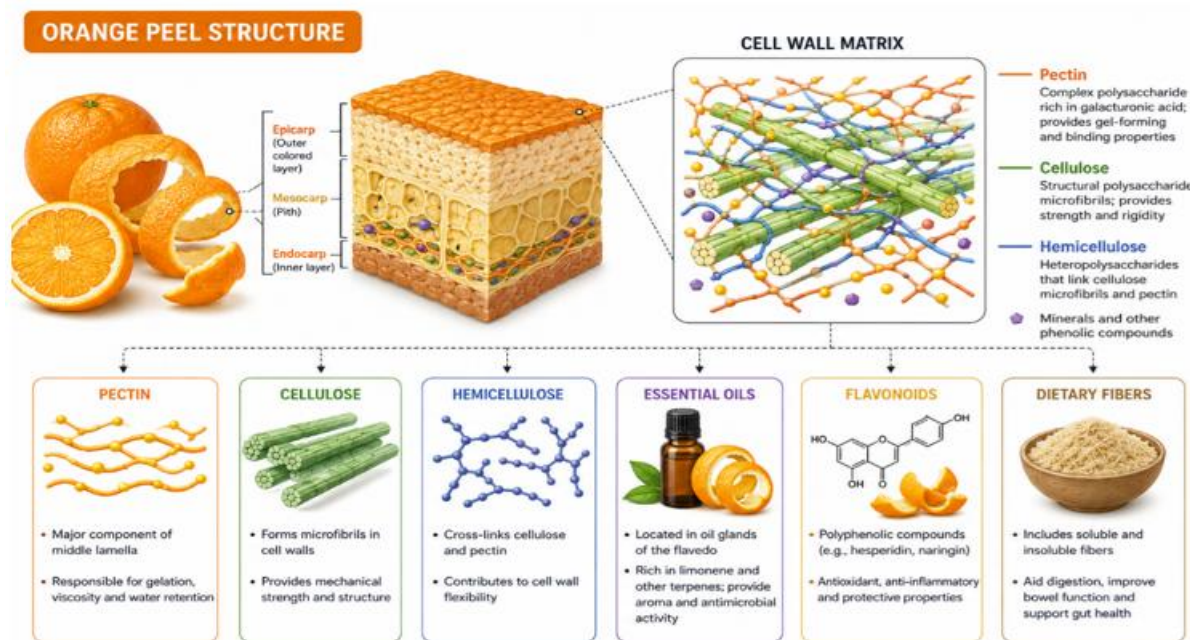
III. ORANGE PEEL AS A PHARMACEUTICAL EXCIPIENT

Orange peel is one of the major agro-industrial wastes generated by citrus juice industries worldwide [31]. Nearly half of the orange fruit weight becomes waste after juice extraction [32]. Traditionally, orange peels were discarded or used as animal feed, resulting in underutilization of valuable bioactive compounds [33]. However, recent studies have demonstrated that orange peels are rich sources of pectin, cellulose, hemicellulose, flavonoids, essential oils, and dietary fibers possessing significant pharmaceutical potential [34]. Pectin is considered the most important pharmaceutical constituent present in orange peel. It is a natural polysaccharide primarily composed of galacturonic acid residues linked through α -(1→4) glycosidic bonds [35]. The pharmaceutical importance of pectin arises from its excellent swelling, gelling, film-forming, and mucoadhesive properties [36]. Orange peel pectin has been widely investigated as a tablet binder, release-retarding agent, suspending agent, and controlled-release polymer [37].

The swelling behavior of orange peel pectin significantly influences tablet disintegration and drug release kinetics [38]. At lower concentrations, pectin promotes rapid hydration and tablet disintegration, whereas at higher concentrations it forms a viscous gel matrix capable of sustaining drug release over prolonged periods [39]. This dual functionality makes orange peel pectin highly suitable for both immediate-release and sustained-release formulations. Several studies have reported successful formulation of tablets using orange peel pectin as a natural binder and disintegrant [40]. Tablets formulated with orange peel pectin exhibited satisfactory hardness, friability, drug content uniformity, and dissolution characteristics comparable to conventional formulations containing synthetic excipients [41]. Orange peel pectin has also demonstrated significant utility in orally disintegrating tablets due to its rapid swelling and hydration properties [42].

In addition to pectin, orange peel contains cellulose and flavonoids that may contribute to tablet stability and antioxidant activity [43].

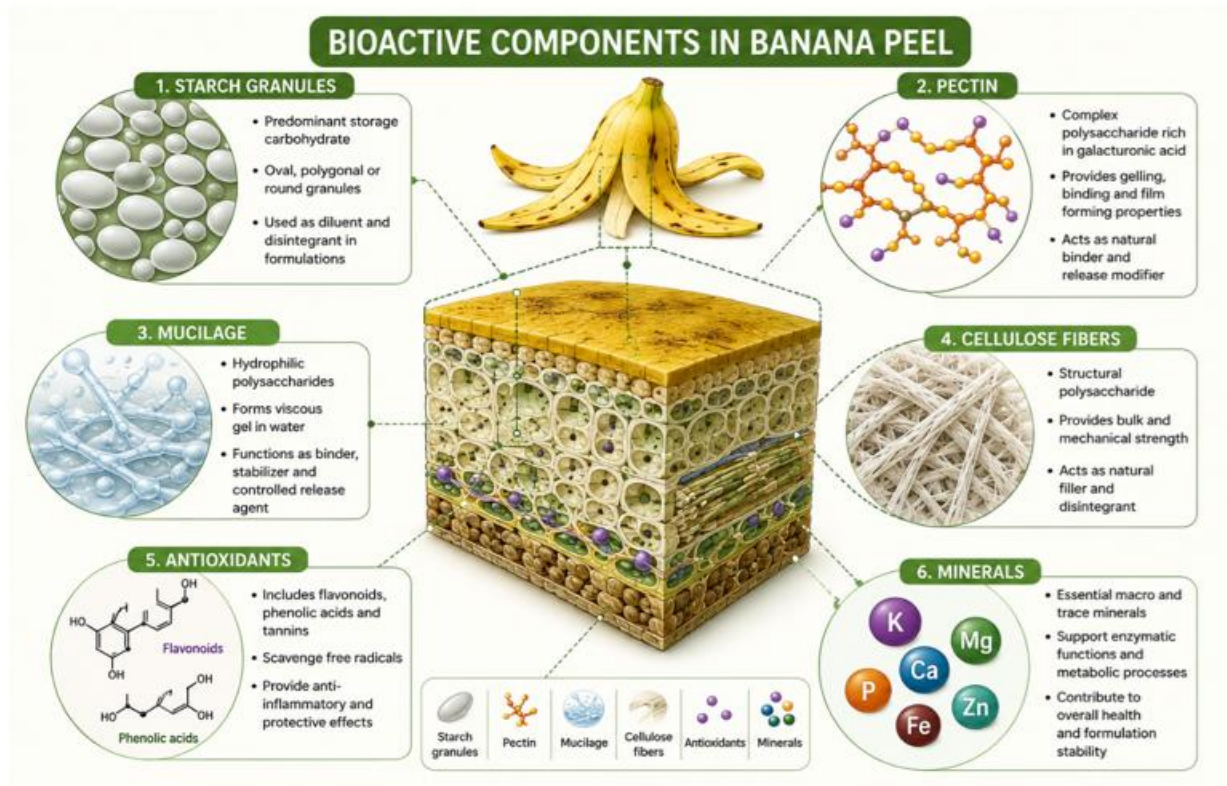
The presence of natural antioxidants in orange peel-derived excipients may enhance the stability of oxidation-sensitive drugs [44].



IV. BANANA PEEL AS A PHARMACEUTICAL EXCIPIENT

Banana peel is another abundant agricultural waste material generated in large quantities throughout the world [45]. Banana processing industries and domestic consumption produce enormous quantities of peel waste that often contribute to environmental pollution [46]. Banana peels contain substantial amounts of starch, cellulose, pectin, lignin, mucilage, proteins, minerals, and polyphenolic compounds [47]. Banana peel starch has attracted considerable attention as a pharmaceutical excipient because of its excellent compressibility, swelling behavior, and water absorption capacity [48]. Starch derived from banana peel has been investigated as a binder, filler, and disintegrant in tablet formulations [49]. Studies have shown that banana starch can successfully replace maize starch and sodium starch glycolate in conventional tablet formulations [50].

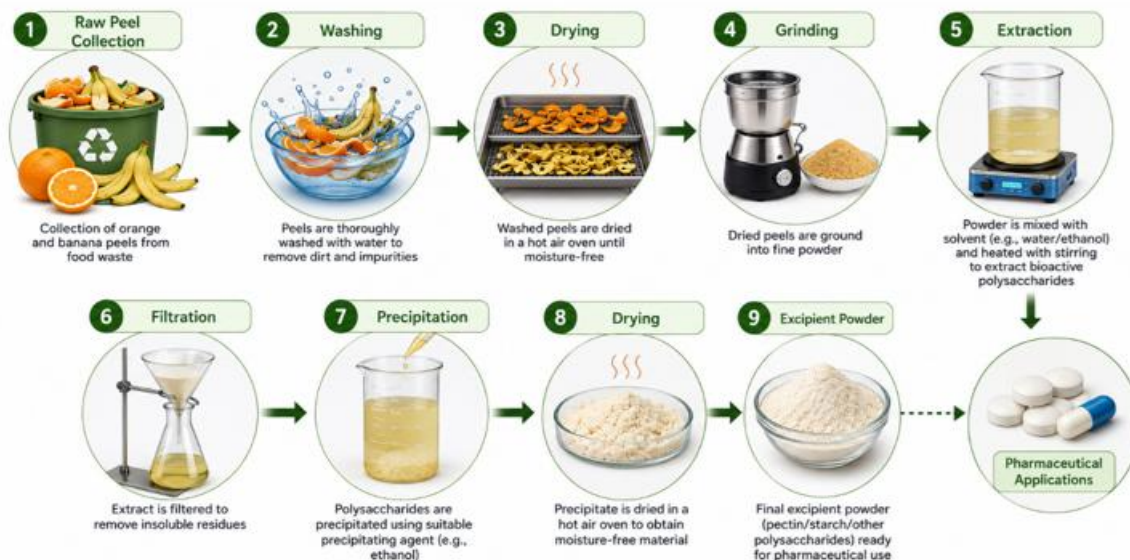
Banana peel mucilage is another important natural polymer exhibiting excellent bioadhesive and swelling properties [51]. The mucilage forms a viscous hydrated layer around tablets, thereby influencing drug release kinetics and gastrointestinal residence time [52]. Consequently, banana peel-derived polymers have been investigated for sustained-release and gastro-retentive drug delivery systems. Researchers have reported that tablets prepared using banana peel starch exhibit satisfactory hardness, friability, disintegration time, and dissolution characteristics [53]. Banana peel-derived excipients have also demonstrated good compatibility with various active pharmaceutical ingredients [54]. The natural abundance and low cost of banana peels make them attractive candidates for sustainable pharmaceutical applications. Furthermore, their utilization contributes to waste reduction and supports environmentally friendly pharmaceutical manufacturing practices [55]. starch in direct compression tablet formulations [34].



V. EXTRACTION AND CHARACTERIZATION OF PEEL-DERIVED EXCIPIENTS

The extraction process plays a crucial role in determining the physicochemical properties and pharmaceutical functionality of natural excipients [56]. Extraction of pectin from orange peel generally involves washing, drying, grinding, acid extraction, filtration, precipitation, purification, and drying [57]. Acid extraction is the most commonly employed method for pectin isolation. During extraction, orange peel powder is heated in acidic medium using hydrochloric acid, citric acid, nitric acid, or sulfuric acid at controlled temperatures [58]. The extracted pectin is filtered and precipitated using ethanol or acetone, followed by washing and drying [59].

Similarly, banana peel starch extraction involves crushing, filtration, sedimentation, washing, and drying processes [60]. Mucilage extraction is generally carried out by soaking peel powder in water followed by heating, filtration, and alcohol precipitation [61]. The extracted polymers are characterized using various physicochemical and analytical techniques including swelling index, viscosity measurement, moisture content determination, Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), and X-ray diffraction analysis [62]. These characterization studies help determine polymer purity, compatibility, thermal stability, crystallinity, and pharmaceutical suitability [63].



VI. FORMULATION APPROACHES FOR TABLETS USING ORANGE AND BANANA PEEL EXCIPIENTS

The formulation of tablets using natural excipients derived from orange and banana peels has become an important area of pharmaceutical research because of the increasing demand for sustainable and biodegradable dosage forms. Tablet formulation involves the proper selection and optimization of active pharmaceutical ingredients and excipients in order to achieve desired physicochemical properties, mechanical strength, drug release characteristics, and patient acceptability [64]. Natural excipients derived from fruit peels possess multifunctional properties that enable their utilization in several types of tablet formulations including conventional tablets, sustained-release tablets, orally disintegrating tablets, chewable tablets, and gastro-retentive systems. Orange peel pectin and banana peel starch are mainly employed as binders, disintegrants, fillers, and release-retarding agents during tablet preparation. The concentration of these polymers significantly affects tablet hardness, friability, disintegration time, and dissolution behavior [65].

At lower concentrations, orange peel pectin promotes rapid disintegration because of its swelling and hydration capacity, whereas at higher concentrations it forms a gel-like matrix that retards drug release [66]. Similarly, banana peel starch improves powder compressibility and tablet mechanical strength due to its granular structure and high water absorption capacity [67]. Tablet formulations using peel-derived excipients are commonly prepared by wet granulation and direct compression techniques. Wet granulation is widely preferred because natural polymers often exhibit poor flowability and irregular particle size distribution [68]. In this method, the active drug and excipients are blended uniformly, followed by addition of binder solution to produce a wet mass. The wet mass is converted into granules using sieving or granulation equipment, dried at controlled temperature, lubricated, and finally compressed into tablets [69]. Wet granulation improves powder flow characteristics, compressibility, and content uniformity, thereby producing tablets with enhanced mechanical properties [70].



Direct compression is another important technique used for tablet preparation when the excipients possess good compressibility and flowability [71]. Banana peel starch has demonstrated promising performance in direct compression formulations because of its excellent compactibility [72]. Direct compression offers several advantages including reduced processing steps, lower production cost, minimal heat exposure, and improved stability of moisture-sensitive drugs [73]. However, successful direct compression requires excipients with excellent flow and compressibility properties. Several researchers have formulated paracetamol tablets using banana peel starch as a natural disintegrant and binder [74]. The formulations exhibited acceptable hardness, friability, and disintegration characteristics comparable to formulations containing conventional starch. Similarly, diclofenac sodium tablets formulated with orange peel pectin demonstrated controlled drug release and satisfactory mechanical strength [75]. Studies involving metformin hydrochloride matrix tablets prepared using orange peel pectin reported prolonged drug release profiles due to formation of hydrated gel matrices [76]. The compatibility between active pharmaceutical ingredients and natural excipients is another critical aspect of formulation

development. Compatibility studies are generally performed using Fourier-transform infrared spectroscopy, differential scanning calorimetry, and X-ray diffraction analysis [77]. These studies help determine the presence of possible chemical interactions between drugs and natural polymers. Most studies indicate that orange peel pectin and banana peel starch exhibit excellent compatibility with commonly used pharmaceutical drugs [78]. Natural excipients derived from fruit peels may also influence tablet porosity and moisture uptake behavior. Tablets containing high concentrations of peel-derived polymers often exhibit increased swelling and hydration, which significantly affect drug release kinetics [79]. Therefore, optimization of polymer concentration is essential to achieve desired therapeutic performance. The pharmaceutical functionality of peel-derived excipients may further be improved through polymer modification techniques such as cross-linking, co-processing, and blending with other natural or synthetic polymers [80]. Modified orange peel pectin and banana starch have demonstrated enhanced stability, controlled swelling behavior, and improved mechanical properties suitable for advanced drug delivery systems [81].




VII. EVALUATION PARAMETERS OF TABLETS PREPARED USING PEEL-DERIVED EXCIPIENTS

Evaluation of pharmaceutical tablets is essential to ensure quality, safety, efficacy, and patient acceptability of the final dosage form [82]. Tablets prepared using orange and banana peel-derived excipients are subjected to several pre-compression and post-compression evaluation tests according to pharmacopeial standards. Pre-compression parameters are primarily used to assess powder flowability and compressibility before tablet compression. These parameters include angle of repose, bulk density, tapped density, Hausner ratio, and Carr's compressibility index [83].

Good flow properties are essential for uniform die filling and consistent tablet weight during compression. Banana peel starch and orange peel pectin have demonstrated acceptable pre-compression characteristics after appropriate processing and granulation [84]. Angle of repose is used to evaluate powder flowability. Lower angle of repose values indicate better flow characteristics [85]. Bulk density and tapped density help determine powder packing behavior and compressibility [86]. Carr's index and Hausner ratio are indicators of interparticle friction and flow properties [87].

1. ANGLE OF REPOSE (FUNNEL METHOD)



PROCEDURE

- Fix the funnel at a certain height (h).
- Allow the powder to flow through the funnel freely onto a flat surface.
- Measure the height (h) of the funnel from the top of the heap.
- Measure the radius (r) of the base of the heap.
- Calculate the angle of repose (θ).


FORMULA

$$\tan \theta = \frac{h}{r}$$

$$\theta = \tan^{-1} \left(\frac{h}{r} \right)$$

Where, h = height of heap
r = radius of heap

2. BULK DENSITY



PROCEDURE


- Accurately weigh a known mass (W) of powder.
- Transfer gently into a graduated cylinder.
- Note the unsettled volume (V₀).

FORMULA

$$\text{Bulk Density } (\rho_b) = \frac{W}{V_0}$$

Where, W = mass of powder (g)
V₀ = initial (bulk) volume (mL)

3. TAPPED DENSITY



PROCEDURE

- The same cylinder containing the powder is placed on the tapping apparatus.
- Tap the cylinder for a fixed number of taps (e.g., 500 taps) or until constant volume is obtained.
- Note the final tapped volume (V_t).

FORMULA

$$\text{Tapped Density } (\rho_t) = \frac{W}{V_t}$$

Where, W = mass of powder (g)
V_t = tapped volume (mL)

Note: Tap until the difference between two successive readings is ≤ 2%.

4. APPARATUS SUMMARY

- Funnel**: Metal or glass funnel with a fixed orifice.
- Measuring Cylinder**: Graduated cylinder (e.g., 100 mL).
- Tapping Apparatus**: Mechanical or digital tapping device.
- Balance**: Digital balance for accurate weighing.

5. CALCULATION CHARTS

A. ANGLE OF REPOSE

$$\tan \theta = \frac{h}{r}$$

$$\theta = \tan^{-1} \left(\frac{h}{r} \right)$$

Where, h = height of heap (cm)
r = radius of heap (cm)
θ = angle of repose (degrees)

B. BULK DENSITY

$$\rho_b = \frac{W}{V_0}$$

Where, W = mass of powder (g)
V₀ = initial volume (mL)

C. TAPPED DENSITY

$$\rho_t = \frac{W}{V_t}$$

D. COMPRESSIBILITY INDEX (CARR'S INDEX)

$$CI (\%) = \frac{\rho_t - \rho_b}{\rho_t} \times 100$$

Where, ρ_t = tapped density
ρ_b = bulk density

E. HAUSSNER RATIO

$$HR = \frac{\rho_t}{\rho_b}$$

Where, ρ_t = tapped density
ρ_b = bulk density

6. INTERPRETATION GUIDE

A. ANGLE OF REPOSE (θ)	
Angle (degrees)	Flow Property
≤ 25	Excellent
25 – 30	Good
30 – 40	Possible
40 – 45	Poor
> 45	Very Poor

B. FLOW PROPERTY (BASED ON CI AND HR)		
Carr's Index (%)	Hausner Ratio	Flow Property
5 – 15	1.00 – 1.11	Excellent
12 – 16	1.12 – 1.18	Good
18 – 21	1.19 – 1.25	Fair
23 – 35	1.26 – 1.34	Poor
33 – 38	1.35 – 1.45	Very Poor
> 40	> 1.45	Extremely Poor

Note: The values are indicative and may vary with material.

7. SUMMARY FLOW CHART

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    graph TD
      A[Weigh known mass (W) of powder] --> B[Measure bulk volume (V0) in cylinder]
      B --> C[Calculate Bulk Density (ρb) = W/V0]
      C --> D[Tap the cylinder (500 taps or until constant volume)]
      D --> E[Measure tapped volume (Vt)]
      E --> F[Calculate Tapped Density (ρt) = W/Vt]
      F --> G[Calculate: CI (%), HR, Angle of Repose (θ)]
      G --> H[Evaluate Flow Property]
    
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Post-compression evaluation parameters are critical for determining the quality and performance of compressed tablets. These tests include hardness, friability, thickness, weight variation, drug content uniformity, disintegration time, dissolution profile, and stability studies [88]. Tablet hardness determines the ability of tablets to withstand mechanical stress during handling, packaging, and transportation [89]. Natural excipients such as orange peel pectin and banana peel starch contribute significantly to tablet hardness due to their binding properties [90]. Studies have shown that increasing polymer concentration generally increases tablet hardness. Friability testing evaluates the resistance of tablets to abrasion and mechanical shock [91]. Tablets formulated using peel-derived excipients usually demonstrate friability values within acceptable pharmacopeial limits. Excessive friability may indicate insufficient binding or poor compressibility [92]. Disintegration time is a crucial parameter for immediate-release tablets.

Banana peel starch exhibits rapid swelling upon contact with water, thereby facilitating tablet disintegration [93]. In contrast, higher concentrations of orange peel pectin may prolong disintegration because of gel layer formation [94]. Dissolution testing is one of the most important evaluation methods because it determines drug release behavior from tablets [95]. Drug release profiles are influenced by polymer concentration, tablet porosity, swelling behavior, and gel formation characteristics [96]. Sustained-release tablets formulated using orange peel pectin have shown prolonged drug release over several hours due to formation of hydrated polymeric matrices [97]. Stability studies are conducted to evaluate the effect of temperature, humidity, and storage conditions on tablet quality [98]. Natural excipients may absorb moisture because of their hydrophilic nature, which can influence tablet hardness, friability, and drug release characteristics [99]. Therefore, proper packaging and storage conditions are essential for maintaining product stability.



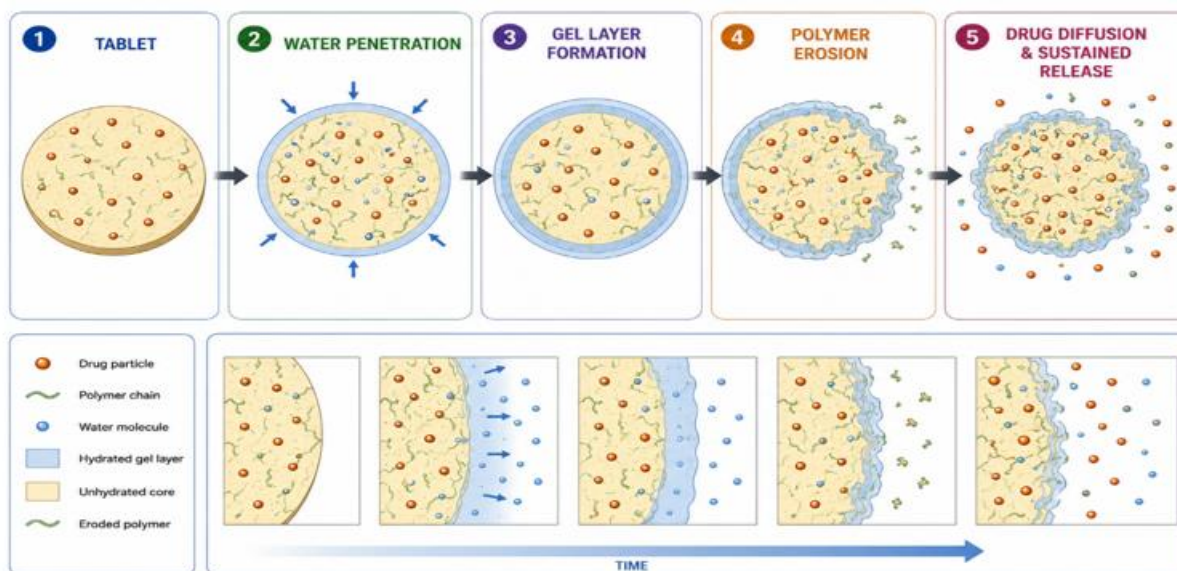
VIII. DRUG RELEASE MECHANISM FROM PEEL-DERIVED POLYMER TABLETS

Drug release from tablets formulated using natural polymers depends upon several physicochemical mechanisms including diffusion, swelling, erosion, and polymer relaxation [100]. Orange peel pectin forms a hydrated gel barrier around tablets upon contact with dissolution media, thereby controlling drug diffusion and release rate [101].

The thickness and viscosity of the gel layer influence sustained-release behavior. Banana peel starch absorbs water rapidly and undergoes swelling, which facilitates tablet disintegration and drug release [102]. In immediate-release formulations, rapid water penetration into the tablet matrix promotes breakup of the tablet into smaller particles, thereby increasing drug dissolution rate [103]. The concentration of peel-derived polymers significantly affects drug release kinetics.

Low polymer concentrations generally produce rapid drug release, whereas higher concentrations prolong release because of increased gel strength and matrix density [104]. Researchers have applied various kinetic models such as zero-order, first-order, Higuchi, and Korsmeyer–Peppas models to analyze drug release mechanisms from natural polymer-based tablets [105]. Studies suggest that tablets containing orange peel pectin often follow anomalous non-Fickian diffusion due to combined effects of polymer swelling and erosion [106].

The release behavior may also be influenced by environmental pH, polymer molecular weight, and degree of esterification [107]. Natural excipients have demonstrated significant potential for colon-targeted drug delivery because pectin undergoes enzymatic degradation by colonic microflora [108]. This property makes orange peel pectin particularly useful for site-specific delivery of drugs intended for treatment of inflammatory bowel diseases and colorectal disorders [109].



IX. ADVANTAGES OF ORANGE AND BANANA PEEL-DERIVED EXCIPIENTS IN PHARMACEUTICAL FORMULATIONS

Orange and banana peel-derived excipients possess significant pharmaceutical, environmental, and economic advantages that make them promising alternatives to synthetic excipients in tablet formulations. These fruit peels are abundantly available as agricultural waste from food processing industries and domestic consumption. Their utilization in pharmaceutical formulations helps in waste valorization and reduces environmental pollution caused by improper disposal of fruit waste [110]. This approach supports sustainable pharmaceutical development and green chemistry principles. One of the major advantages of peel-derived excipients is their biodegradability and biocompatibility. Natural polymers such as pectin, starch, cellulose, and mucilage obtained from orange and banana peels are non-toxic, eco-friendly, and safe for oral administration [111].

Unlike synthetic excipients, they do not accumulate in the environment and therefore reduce ecological hazards. Orange peel pectin exhibits excellent swelling and gel-forming properties, making it useful in sustained-release and controlled-release tablet formulations [112]. Banana peel starch demonstrates good compressibility and water absorption capacity, which improve tablet hardness and disintegration characteristics [113]. Another important advantage is cost-effectiveness. Since fruit peels are inexpensive waste materials, the extraction of pharmaceutical polymers from these sources significantly lowers production costs [114]. This is especially beneficial for developing countries where affordable medicines are required. Peel-derived excipients also possess multifunctional properties and may act as binders, disintegrants, fillers, and release retardants depending on formulation requirements [115].



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