Formulation Development and Evaluation of Fast Dissolving Tablets of Pantoprazole for Enhanced Dissolution Rate and Bioavailability

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Abstract

The present study aimed to formulate and evaluate fast-dissolving tablets of pantoprazole to achieve rapid drug release and improve patient convenience. Ten formulations (F1–F10) were prepared and evaluated for pre-compression and post-compression parameters, including flow properties, hardness, friability, wetting time, water absorption ratio, and drug content. Formulation F10 showed satisfactory physical characteristics, a wetting time of 32.8 ± 0.6 seconds, a water absorption ratio of 87.6%, and drug content of 99.6 ± 0.2%. In-vitro dissolution studies demonstrated 99.8% drug release within 10 minutes. Accelerated stability studies conducted for three months showed no significant changes in the evaluated formulation characteristics. In conclusion, F10 demonstrated promising performance as a fast-dissolving pantoprazole tablet formulation. Further studies are required to establish its in-vivo performance and clinical applicability.

Keywords: Pantoprazole, fast-dissolving tablets, formulation development, drug release, stability studies.

Introduction:

1.1.1 Overview of Oral Drug Delivery Systems

Oral drug delivery involves administering medications through the gastrointestinal tract, where absorption mostly takes place in various medicine. Solubility, absorption, overall bioavailability are all significantly influenced by the gastrointestinal system, which includes the mouth, esophagus, human stomach, and intestines (Lou et al., 2023).

Because of their stability, convenience of production, and precise dosing, forms are frequently utilized. Furthermore, oral delivery improves patient adherence by avoiding issues related to invasive approaches such injections (Zhang et al., 2025).

Despite these benefits, the complicated physiological environment of the gastrointestinal tract presents a number of difficulties for oral medication administration systems. Drug bioavailability and therapeutic efficacy can be considerably decreased by elements such acidic pH, enzymatic degradation, poor permeability, and first-pass metabolism (Mehrdadi, 2024; Lou et al., 2023).

Because of their affordability, ease of use, and patient compliance, oral drug delivery systems (ODDS) (Patel et al., 2023). By delivering therapeutic substances through the gastrointestinal tract, these systems enable medications to be absorbed into the systemic circulation for either local or systemic effects. ODDS can be broadly divided into two categories: innovative or advanced systems like fast dissolving tablets (FDTs), oral disintegrating films (ODFs), controlled-release tablets, and mucoadhesive formulations, and conventional systems like tablets, capsules, syrups, and powders.

Inconsistent drug absorption can also result from variations in gastrointestinal circumstances, such as motility and pH shifts. In order to improve drug stability, absorption, and patient compliance, these constraints have prompted methods, fast-dissolving tablets and sophisticated nanocarrier-based systems (Acta Pharmaceutica Sinica B, 2025).

Table 1.1: Types of Oral Drug Delivery Systems

Category	Type / Examples	Dosage Form	Mechanism / Notes	Advantages	References
Conventional	Tablets	Solid	Compressed mixture of drug and excipients; immediate release	Easy to manufacture, precise dose, stable	Patel et al., 2023

	Capsules	Solid (gelatin shell)	Drug enclosed in capsule; dissolves in GI tract	Mask taste, flexible formulation	Rathod et al., 2023
	Syrups / Solutions	Liquid	Drug in aqueous or non-aqueous solvent	Easy to swallow, suitable for pediatrics	Sharma & Gupta, 2024
	Suspensions / Emulsions	Liquid	Drug particles dispersed in liquid; requires shaking	Suitable for insoluble drugs	Singh & Sharma, 2022
Novel / Advanced	Fast Dissolving Tablets (FDTs)	Solid	Disintegrates rapidly in saliva; partial buccal absorption possible	Rapid onset, good for dysphagia, no water needed	Rathod et al., 2023
	Orally Disintegrating Films (ODFs)	Thin film	Dissolves quickly in oral cavity; can carry low-dose drugs	Rapid action, portable, convenient	Sharma & Gupta, 2024
	Controlled Release Tablets / Capsules	Solid	Drug released slowly over time	Reduces dosing frequency, steady plasma level	Patel et al., 2023

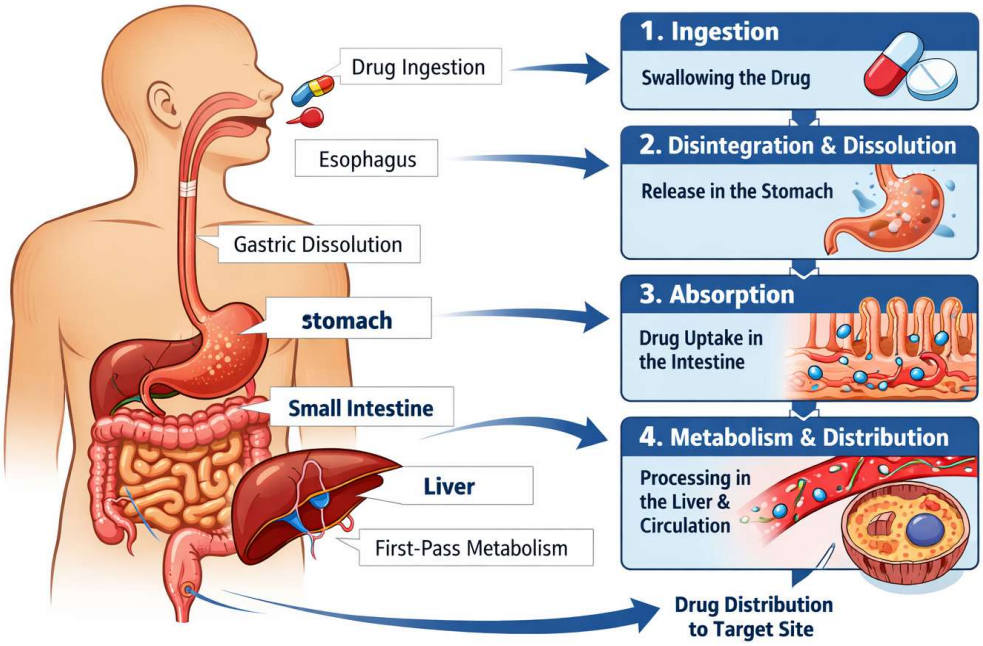

Fig 1.1: Schematic of Oral Drug Delivery Pathway

1.1.2 Concept of Fast Dissolving Tablets (FDTs)

The idea of FDTs was created to get around the drawbacks of traditional oral dosage forms, especially mental, and pediatric patients. In circumstances where water is not easily accessible, FDTs facilitate administration and enhance patient compliance (Kaur et al., 2023).

Specialized excipients like superdisintegrants, which promote quick tablet disintegration by processes like swelling, wicking, and capillary action, are used in the formulation of FDTs. The drug's surface area is increased by the quick disintegration, which speeds up solubility and may enhance bioavailability (Deshmukh et al., 2024).

These pills are especially helpful for medications that need to start working quickly, like analgesics, antiemetics, and antiulcer medications like pantoprazole. The medication's rapid release from the dose form improves therapeutic efficacy and speeds up symptom alleviation.

All things considered, development systems that combine the benefits of liquid and solid dosage forms while enhancing therapeutic efficacy, convenience, and compliance.

1.1.3 Advantages of FDTs

Orally disintegrating tablets (ODTs), sometimes known as (FDTs), novel the need for. Compared traditional pills capsules, this feature offers a number of benefits.

- **Patient Convenience and Compliance:** FDTs are perfect bedridden trouble traditional pills (dysphagia) because they do not require water. This improves acceptability and patient adherence (Sen & Rathore, 2025; Zhang et al., 2024).
- **Rapid Onset of Action:** FDTs swiftly dissolve and disintegrate, allowing for fast medication absorption through the oral mucosa or after swallowing. take effect quickly, including antiulcer medications like pantoprazole (Fu et al., 2022).
- **Improved Bioavailability:** Fast disintegration increases the drug's surface area, which improves the rate of solubility and, for some medicines, may lower first-pass metabolism, improving bioavailability (Sharma et al., 2025).
- **Ease of Administration in Special Situations:** FDTs are easy to administer when traveling, in an emergency, or without access to water. Patient acceptability is also enhanced by their pleasing mouthfeel and flavor (Zhang et al., 2024).
- **Reduced Risk of Choking:** FDTs reduce the possibility of suffocating or choking that comes with traditional tablets, especially in young patients and the elderly (Sen & Rathore, 2025).

1.1.4 Limitations of Conventional Dosage Forms

Because of their stability, precise dosing, and convenience of production, conventional oral dosage forms including tablets and capsules are frequently utilized. They do, however, have a number of drawbacks that may have an impact on overall medication performance, therapeutic efficacy, and patient compliance.

1. **Difficulty in Swallowing:** Many patients, especially those who are bedridden, elderly, or children, have trouble swallowing traditional pills or capsules (dysphagia), which can result in missed doses or non-compliance (Sen & Rathore, 2025).
2. **Delayed Onset of Action:** Conventional dosage forms frequently need to dissolve and disintegrate in the gastrointestinal system prior to drug absorption, which causes therapeutic benefits to be delayed. This is crucial for medications that need to start working quickly (Zhang et al., 2024).
3. **First-Pass Metabolism:** Hepatic first-pass metabolism of drugs absorbed via the gastrointestinal tract can decrease therapeutic efficacy and lower bioavailability (Fu et al., 2022).
4. **Dependence on Water:** Conventional tablets and capsules typically need water to be administered, which can be problematic when traveling or in an emergency (Sharma et al., 2025).

5. **Reduced Patient Compliance:** Treatment outcomes are impacted by factors that limit patient adherence, including big tablet size, poor flavor, and difficulty swallowing (Bagde et al., 2026).
6. **Risk of Choking or Aspiration:** There is a possibility of aspiration or choking, which raises safety issues, especially in young and elderly patients (Sen & Rathore, 2025).

Fast dissolving tablets (FDTs), which offer developed novel improve convenience, and therapeutic efficacy in response to these restrictions (Fu et al., 2022; Zhang et al., 2024).

1.1.5 Need for Fast Dissolving Tablets

Even while traditional oral dose, there are still a number of issues with patient care. Many patients, particularly those who are bedridden, elderly, or children, have trouble swallowing traditional tablets, which results in irregular drug consumption and poor compliance (Patel et al., 2023).

FDTs were created to get around these restrictions by quickly dissolving administration easier, and improving patient compliance (Rani & Sharma, 2024). Compared to traditional tablets, they enable quicker therapeutic effects for medications that need a quick onset of action, such as analgesics, antiemetic, and antiulcer medicines (Verma et al., 2022).

Additionally, by permitting partial absorption via the oral mucosa, FDTs can increase the bioavailability of medications that are vulnerable to first-pass metabolism. Because of their simplicity of usage, they are also perfect for patients with restricted access to water, during travel, or in emergency situations, guaranteeing continuous drug delivery (Singh et al., 2023).

FDTs are development contemporary because of combination of patient-centric needs, quicker therapeutic action, better compliance, and increased bioavailability (Kumar et al., 2024).

Table 1.2: Comparison of Conventional Tablets and FDTs

Feature	Conventional Tablets	Fast Dissolving Tablets (FDTs)	References
Disintegration Time	2–10 minutes or more in GI tract	Less than 60 seconds in oral cavity	Patel et al., 2023
Onset of Action	Relatively slower	Rapid onset due to quick dissolution and partial	Rathod et al., 2023

		buccal absorption	
Patient Compliance	Moderate, difficult for pediatrics/geriatrics	High, especially for children, elderly, and dysphagic patients	Sharma & Gupta, 2024
Administration	Requires water	No water needed	Singh & Sharma, 2022
Taste Masking	Usually not required	Essential, as the tablet dissolves in mouth	Rathod et al., 2023
Moisture Sensitivity	Generally stable	Sensitive, requires special packaging	Sharma & Gupta, 2024
Manufacturing Cost	Low to moderate	Higher due to specialized excipients and techniques	Patel et al., 2023
Drug Dose Limitations	Can handle high doses	Generally suitable for low to moderate doses	Rathod et al., 2023
Mechanical Strength	High	Moderate, requires optimization	Sharma & Gupta, 2024
Bioavailability	Standard, may be affected by first-pass metabolism	Often enhanced due to rapid absorption and partial buccal uptake	Singh & Sharma, 2022

1.2 Anatomy and Physiology of the Human stomach

1.2.1 Structure of the Human Stomach

A key organ in the digestive system that breaks down food both chemically and mechanically (Guyton & Hall, 2021). The stomach is anatomically separated into four main regions: the body (corpus), which is the central mixing region; the fundus, a the cardia, which surrounds the esophageal opening and receives ingested food; and the pylorus, which connects to the duodenum through the pyloric sphincter and controls the passage of gastric contents (Standring, 2021).

Each of the four separate layers that make up the stomach wall has a specific purpose. Hydrochloric acid (HCl), pepsinogen, and protective mucus are secreted by stomach

glands located in the innermost mucosa. that supports and is rich in blood arteries, lymphatics, and nerves, is located beneath it that make up muscularis externa help with mechanical digestion by mixing and churning. In addition to offering structural support and lowering friction with nearby organs, the outermost serosa is a protective layer that is continuous with the peritoneum (Martini et al., 2022).

The mucosa's specialized cells are essential to stomach function. HCl and digestion and the is produced and transformed digestion proteins. G cells release gastrin, a hormone that controls acid secretion and motility, while mucous cells secrete a protective layer of mucus to prevent autodigestion of the stomach lining (Guyton & Hall, 2021). The stomach's complex structure, with its distinct areas and cell types, guarantees effective digestion and shields the digestive system against self-destruction.

1.2.2 Functions of the Stomach

In order to prepare food for nutritional absorption, the stomach combines mechanical, chemical, and hormonal processes. Food is broken up into a semi-liquid combination known as chyme by the mechanical churning and mixing of ingested food with gastric secretions by the stomach's muscular walls. This peristaltic mixing guarantees progressive emptying into the duodenum and improves surface contact for enzymatic action (Furness, 2023).

Chemically, the stomach's that denatures food proteins, converts pepsinogen into pepsin, and aids in the removal of ingested pathogens (Goyal et al., 2022). Chief cells create pepsin, which breaks down big protein molecules into smaller peptides to start the digestion process (Lai et al., 2024).

Food is also momentarily stored in the stomach, where the pyloric sphincter controls its flow into the small intestine. This regulated release permits effective enzymatic digestion and keeps the duodenum from being overloaded (Kumar & Sharma, 2023). The gastric lining is shielded against autodigestion by acidic gastric secretions by mucus secreted by epithelial cells, preserving mucosal integrity (Wang et al., 2023).

In addition, the stomach has an endocrine function. G cells in the antrum secrete gastrin, which stimulates acid secretion and gastric motility, coordinating the digestive process. The stomach protects the gastrointestinal system, guarantees effective digestion, and controls the flow of nutrients to the intestines through these combined functions.

1.3 Acid-Related Disorders of the Stomach

1.3.1 Gastroesophageal reflux disease (GERD)

GERD happens when esophageal clearance is compromised or when the lower esophageal sphincter (LES) is unable to maintain sufficient closure, allowing reflux to occur (Vakil et al., 2022). Obesity, hiatal hernias, delayed stomach emptying, and specific eating habits are among the physiological and lifestyle aspects linked to the condition (El-Serag, 2023).

Inflammation, erosive esophagitis, and, in extreme situations, Barrett's esophagus, a precancerous condition, can result from esophageal (Savarino et al., 2024). Proton pump inhibitors (PPIs) like pantoprazole, lifestyle changes, and H2 receptor antagonists to reduce stomach acid production and encourage mucosal repair are common management techniques (Moayyedi & Talley, 2022). efficient fast-dissolving formulations that offer quick symptom alleviation, requires an understanding of the pathophysiology of GERD.

1.3.2 Peptic ulcer disease (PUD)

Protective (mucus, bicarbonate, prostaglandins) aggressive forces (gastric acid, pepsin) leads to the formation of open sores in the gastric or duodenal mucosa, which is known as peptic ulcer disease (PUD) (Malfertheiner et al., 2023). Lifestyle choices such drinking alcohol and smoking are the most frequent causes (Chey & Leontiadis, 2022). Epigastric discomfort, nausea, vomiting, bloating, and in extreme situations, bleeding or perforation are clinical signs. Proton pump inhibitors (PPIs) like pantoprazole, eradication therapy for H. pylori, and lifestyle changes to encourage mucosal healing are the mainstays of management (Katz et al., 2022).

1.3.3 Zollinger–Ellison Syndrome

Caused by gastrinoma, typically located that secrete excessive amounts of gastrin, resulting in hypersecretion of gastric acid, which causes recurrent peptic ulcers, diarrhea, and malabsorption (Ito et al., 2023). ZES is frequently linked to Multiple Endocrine Neoplasia type 1 (MEN1). Treatment options include high-dose proton pump inhibitors for acid suppression and, when feasible, surgical resection of gastrinomas (Jensen et al., 2022). Malabsorption, diarrhea, and recurring peptic ulcers are brought on by the excess acid. Multiple Endocrine Neoplasia type 1 (MEN1) is frequently linked to ZES. Serum gastrin levels, stomach acid measurements, and imaging tests to identify tumors are used in the diagnosis process. When possible, gastrinomas are surgically removed, and high-dose (Jensen et al., 2022).

1.3.4 Erosive Esophagitis

Heartburn, dysphagia, chest pain, and in severe cases, bleeding, are the symptoms of erosive esophagitis, a condition that frequently develops in patients with GERD.

Recurrent acid exposure damages the mucosa, increasing strictures. Endoscopy confirms the diagnosis, and treatment includes proton pump inhibitors, lifestyle changes, and addressing underlying causes like obesity and hiatal hernia (Patti & Vela, 2023). Heartburn, dysphagia, chest pain, and in extreme situations, bleeding are among the symptoms that frequently appear in GERD patients (Spechler & Souza, 2022). Frequent exposure to acid destroys the mucosa, raising the risk strictures. Endoscopy confirms diagnosis, and proton pump inhibitors, lifestyle changes, and addressing underlying problems like obesity and hiatal hernia are all part of the treatment (Patti & Vela, 2023).

1.3.5 Causes and Pathophysiology of Acid-Related Disorders

Excessive acid secretion, impaired LES function, delayed gastric emptying, or defects in the mucosal barrier; NSAID use inhibits prostaglandin synthesis, weakens mucosal defenses; hypergastrinemia, as seen in ZES, increases acid output and predisposes patients to recurrent ulcers (Wallace & Blackwell, 2022). Tissue damage may result from excessive acid secretion, compromised LES function, delayed stomach emptying, or mucosal barrier abnormalities. NSAID use weakens mucosal defenses by inhibiting prostaglandin synthesis, whereas Helicobacter pylori infection leads to ulcer development and persistent inflammation. As shown in ZES, hypergastrinemia raises acid production and puts patients at risk for recurrent ulcers (Wallace & Blackwell, 2022). Developing successful treatments, such as fast-dissolving PPI formulations that target rapid acid suppression, requires an understanding of these pathways.

1.4 Fast Dissolving Tablets (FDTs)

1.4.1 Definition and Characteristics

Fast disintegration in the oral cavity, adequate mechanical strength for handling, a pleasant taste and mouthfeel, and sufficient stability during storage are among the key characteristics of FDTs (Rathod et al., 2023). Additionally, FDTs frequently contain superdisintegrants, flavoring agents, and fillers to facilitate rapid dispersion and improve palatability. Their rapid disintegration allows partial enhance bioavailability for some drugs, making them especially appropriate for drugs with poor solubility or extensive hepatic metabolism (Sharma & Gupta, 2024). In order to promote quick dispersion and enhance palatability, FDTs frequently include superdisintegrants, flavoring agents, and fillers. They are especially appropriate for medications with poor solubility or substantial hepatic metabolism since their quick breakdown permits partial absorption through the

oral mucosa, which can improve bioavailability and avoid first-pass metabolism for some pharmaceuticals (Sharma & Gupta, 2024).

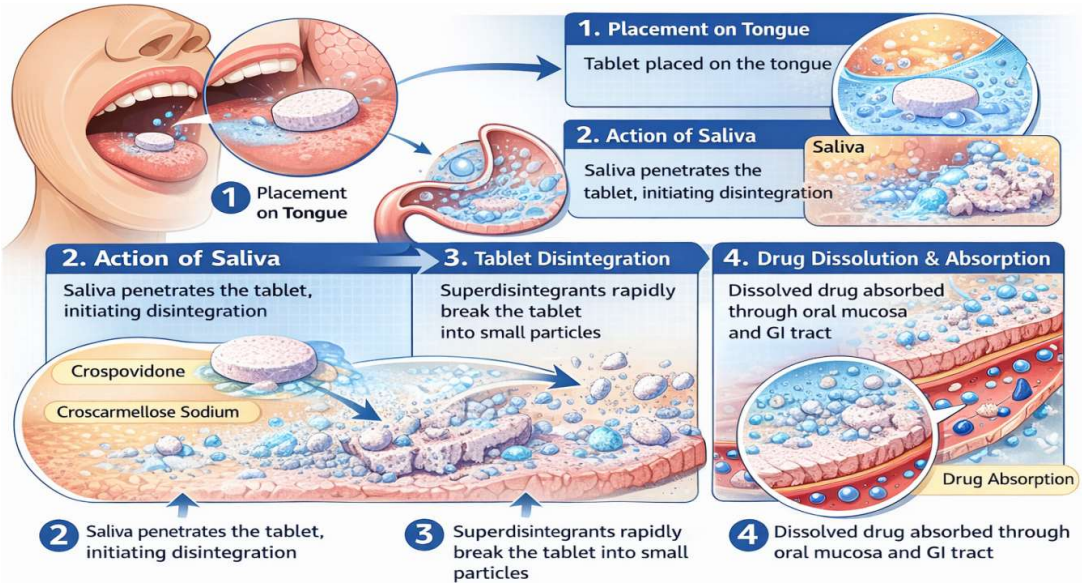

Fig 1.2: Mechanism of Fast Dissolving Tablets

1.4.2 Ideal Properties

To guarantee effectiveness, patient compliance, and stability, an ideal fast dissolving tablet (FDT) should have a number of essential qualities. Firstly, FDTs should dissolve quickly usually in 60 seconds— resulting in a prompt onset of action (Patel et al., 2023). Secondly, should mechanical endure, packaging, transportation while remaining soft enough to facilitate rapid disintegration (Rathod et al., 2023). First, in order to provide a rapid beginning of action, FDTs must dissolve quickly, usually in 60 seconds, requirement (Patel et al., 2023). Additionally, the tablets should be soft enough to allow for quick disintegration while having enough mechanical strength to endure handling, packing, and shipping (Rathod et al., 2023).

In order to maintain drug potency during storage, FDTs should have good chemical and physical stability (Kumar & Gupta, 2024). Lastly, for drugs susceptible to first-pass metabolism, FDTs may enable partial absorption through the oral mucosa, enhancing bioavailability and therapeutic effect. Together, these characteristics ensure that FDTs are a patient-friendly, effective, and dependable oral drug delivery system. To increase acceptability, FDTs frequently contain sweeteners, flavorings, and taste-masking agents (Singh & Sharma, 2022). To preserve medication efficacy while being stored, desirable FDTs should also show strong chemical and physical stability under a range of environmental factors, including temperature and humidity (Kumar & Gupta, 2024).

Finally, FDTs may facilitate partial absorption via the oral mucosa for medications that are vulnerable to first-pass metabolism, improving bioavailability and therapeutic impact. When taken as a whole, these characteristics guarantee that FDTs are a dependable, efficient, and patient-friendly oral medication administration method.

Table 1.3: Ideal Characteristics of FDTs

Characteristic	Description / Requirement	Reason / Importance	References
Rapid Disintegration	Should disintegrate within seconds (usually <60 sec)	Ensures quick onset of action and patient convenience	Rathod et al., 2023
Mechanical Strength / Hardness	Sufficient to withstand handling, packaging, and transport	Prevents breakage while maintaining fast disintegration	Sharma & Gupta, 2024
Good Taste / Palatability	Should mask bitter or unpleasant drug taste	Enhances patient compliance, especially for pediatrics and geriatrics	Singh & Sharma, 2022
Mouth Feel / Smooth Texture	Pleasant, non-gritty, and smooth	Improves acceptance and comfort in oral cavity	Patel et al., 2023
Low Moisture Sensitivity	Resistant to humidity	Prevents premature disintegration or degradation	Rathod et al., 2023
Adequate Flow Properties	Powder blend should flow easily for uniform die filling	Ensures uniform weight and drug content	Sharma & Gupta, 2024
Uniform Drug Content	Consistent drug distribution in tablets	Ensures accurate dosing and therapeutic effect	Singh & Sharma, 2022
Rapid Wetting and Dissolution	High porosity and water absorption	Facilitates immediate release and absorption	Patel et al., 2023
Acceptable Tablet Size	Small and easy to handle	Improves patient compliance and ease of administration	Rathod et al., 2023

Stability	Chemically and physically stable over shelf life	Ensures drug efficacy and quality	Sharma & Gupta, 2024

1.4.3 Advantages and Disadvantages

Additionally, FDTs may improve bioavailability for drugs with significant allowing (Patel et al., 2022). Finally, FDTs are more stable than liquid formulations, which makes them appropriate for medications with bitter or unpleasant flavors (Rathod et al., 2023). The benefits include better patient compliance for pediatric, elderly, and dysphagic patients, immediate beginning of action due to rapid breakdown in the oral cavity, and easy administration without water (Kumar & Singh, 2023). By permitting absorption via the oral mucosa, FDTs may also improve bioavailability for medications with substantial first-pass metabolism (Patel et al., 2022). Additionally, FDTs are more stable than liquid formulations, enhance taste masking, and lower the chance of choking, making them appropriate for medications with bitter or disagreeable flavors (Rathod et al., 2023).

FDTs have limitations, though, such as being moisture-sensitive and needing specialized packaging to maintain stability (Sharma & Gupta, 2024). It can be difficult to formulate drugs with high doses or poor solubility as FDTs, and taste-masking processes can increase manufacturing complexity and cost (Singh & Sharma, 2022). Despite the fact that FDTs offer significant clinical and patient-centered advantages, careful formulation strategies are necessary to overcome these issues. Because of their sensitivity to moisture, they need specific packaging to stay stable (Sharma & Gupta, 2024). It is difficult to maintain fast disintegration while achieving sufficient mechanical strength. Taste-masking techniques can raise manufacturing complexity and cost, and drugs with high dosages or low solubility are challenging to develop as FDTs (Singh & Sharma, 2022). Therefore, rigorous formulation strategies are necessary to address these problems, even though FDTs offer important clinical and patient-centered advantages.

1.4.4 Challenges in Formulation

(FDTs) poses a number technical and pharmaceutical challenges. One of the main challenges is striking a must be both soft enough to dissolve quickly in the oral cavity and strong enough to withstand handling, packaging, and transportation (Rathod et al., 2023). Another major concern is moisture sensitivity, since FDTs frequently contain hygroscopic excipients and superdisintegrants, which can cause degradation or premature disintegration if improperly packaged (Sharma & Gupta, 2024). Achieving a speedy is

one the main challenges; need to be both soft enough to dissolve rapidly in the oral cavity and sturdy enough to endure handling, packing, and transportation (Rathod et al., 2023). Because FDTs frequently contain hygroscopic excipients and superdisintegrants, which make them vulnerable to deterioration or early disintegration if improperly packaged, moisture sensitivity is another major concern (Sharma & Gupta, 2024).

It is challenging to formulate medications with high dosages or poor water solubility because the tablet size may get excessively big or disintegration may take longer, which lowers patient acceptability also difficult hide taste of bitter or disagreeable medications; this calls for complex techniques such coating, complexation, or adding tastes and sweets without compromising stability or disintegration (Singh & Sharma, 2022). Large-scale production may also be constrained by the high production costs of cutting-edge technologies like lyophilization or spray drying. Careful excipient selection, manufacturing procedure optimization, and appropriate packaging are necessary to overcome these formulation difficulties and guarantee stability and patient compliance.

1.5 Methods of Preparation of FDTs

1.5.1 Direct Compression

Due to its ease of use, affordability, and minimal processing steps, direct compression is a popular method for making fast dissolving tablets (FDTs) (Patel et al., 2023). The drug key excipients, such as superdisintegrants, fillers, and binders, are carefully chosen to ensure rapid disintegration, sufficient mechanical strength, and uniform drug content (Rathod et al., 2023). This approach eliminates the requirement for granulation by blending the medicine and excipients evenly and compressing them straight into tablets. Because the method doesn't require heat or solvents, it appropriate moisture or heat. To guarantee quick disintegration, sufficient mechanical strength, and consistent drug content, key excipients such superdisintegrants, fillers, and binders are carefully chosen (Rathod et al., 2023).

Reduced manufacturing time, fewer processing steps, and lower production costs are benefits of direct compression; nevertheless, poor powder flowability, problems with content uniformity, and possible component segregation are drawbacks. For many FDT formulations, direct compression is the ideal method since it is necessary to optimize powder properties and choose the right excipients to create tablets that are robust but quickly disintegrate (Sharma & Gupta, 2024).

1.5.2 Sublimation

Fast dissolving tablets (FDTs) are made using the sublimation technique, which produces a highly porous structure that speeds up disintegration (Patel et al., 2023). This process involves adding volatile ingredients to the tablet formulation during compression, such as urea, ammonium bicarbonate, or camphor. The volatile component is eliminated by sublimation under vacuum or heat after tablet manufacture, leaving pores in the matrix. The pill dissolves and disintegrates more quickly in the oral cavity due to these pores' increased water penetration (Rathod et al., 2023).

Sublimation is especially useful for individuals who have trouble swallowing traditional tablets and for medications that need to function quickly. However, the method has drawbacks, including increased production costs, longer processing times, and the possibility of heat-sensitive medications degrading if improperly managed. To produce volatile agent must be chosen carefully and the sublimation conditions must be optimized (Sharma & Gupta, 2024).

1.5.3 Freeze Drying (Lyophilization)

A popular method for creating fast dissolving tablets (FDTs) with extremely porous architectures (Patel et al., 2023). This process involves dissolving or suspending the medicine and excipients in an appropriate solvent, followed by a quick freezing. A lightweight, porous tablet matrix is left behind after the frozen material is vacuum-dried, which sublimates the solvent. The resulting pills dissolve and disintegrate quickly in the mouth, which makes them appropriate for medications that need to start working right away (Rathod et al., 2023).

For medications that are susceptible to heat, freeze drying is especially beneficial because it keeps the substance stable and active by avoiding the use of high temperatures. Additionally, it enables improved bioavailability and consistent drug distribution. Nevertheless, there are drawbacks to this method, such as the need for specialized equipment, lengthy processing periods, and expensive manufacturing prices (Sharma & Gupta, 2024). To preserve tablet integrity and mechanical strength while guaranteeing quick disintegration, careful selection of stabilizers and cryoprotectants is required.

1.5.4 Spray Drying

Fast dissolving tablets (FDTs) with fine, porous particles that improve rapid disintegration and dissolution can be made using (Patel 2023). This process involves dissolving or suspending the drug and excipients in an appropriate solvent before atomizing them drying quickly leaving behind uniform, and highly. The porosity and

surface area generated by spray drying allow for rapid water penetration and faster tablet disintegration in the oral cavity (Rathod et al., 2023).

Optimizing process parameters, such as inlet/outlet temperatures, atomization pressure, and solvent selection, is crucial to achieving mechanically robust tablets with rapid disintegration and acceptable taste. Spray drying is particularly helpful for thermally stable drugs and can improve flow properties and content uniformity of FDTs. However, the method has limitations, such as high equipment cost, energy consumption, and potential degradation of heat-sensitive drugs (Sharma & Gupta, 2024).

1.5.5 Melt Granulation

A thermoplastic binder is melted and combined with the medication and excipients to create granules, which are subsequently cooled and compressed into tablets. This solvent-free method is used to formulate fast dissolving tablets (FDTs) (Patel et al., 2023). Require water or approach especially beneficial for medications that are sensitive to moisture. Because superdisintegrants and porous fillers were carefully incorporated, the resulting granules are homogeneous, cohesive, and able to disintegrate quickly (Rathod et al., 2023).

Improved flowability, consistent medication distribution, and shorter processing times are some advantages of melt granulation. However, it has drawbacks, such as the need for exact temperature control, specialized equipment, and thermal degradation of heat-sensitive medications. Melt granulation is a feasible alternative for some FDT formulations because careful selection of the binder type and melting point is necessary to produce tablets that retain mechanical strength while guaranteeing quick disintegration and dissolution (Sharma & Gupta, 2024).

Table 1.4: Comparison of FDT Preparation Methods

Method	Principle / Process	Advantages	Limitations	Suitable Drug Types	References
Direct Compression	Blend of drug and excipients compressed into tablets without granulation	Simple, cost-effective, minimal processing, suitable for heat/moisture-sensitive	Poor flowability, content uniformity issues, segregation of powders	Drugs stable under compression, non-hygroscopic powders	Patel et al., 2023; Rathod et al., 2023

		drugs			
Sublimation	Incorporation of volatile substances (e.g., camphor) that are removed post-compression to create pores	Rapid disintegration due to porous structure, good for immediate action	High cost, heat may affect sensitive drugs, longer processing	Low-dose, heat-stable drugs	Rathod et al., 2023; Sharma & Gupta, 2024
Freeze Drying (Lyophilization)	Drug solution or suspension frozen, solvent removed by sublimation	Highly porous tablets, rapid disintegration, preserves thermolabile drugs	Expensive, long processing time, fragile tablets	Thermolabile and moisture-sensitive drugs, low-dose	Patel et al., 2023; Sharma & Gupta, 2024
Spray Drying	Atomization of drug solution/suspension into hot air; solvent evaporates	Produces uniform, porous particles; improves flow and dissolution	High equipment cost, energy-intensive, unsuitable for heat-sensitive drugs	Water-soluble, thermally stable drugs	Rathod et al., 2023; Patel et al., 2023

Melt Granulation	Thermoplastic binder melted and mixed with drug/excipients to form granules	Solvent-free, good for moisture-sensitive drugs, uniform granules	Thermal degradation risk, precise temperature control required, specialized equipment	Drugs stable at melting temperature of binder	Sharma & Gupta, 2024; Patel et al., 2023

Literature review;

Lou et al.,(2023) reported that "For both local and systemic medication distribution, the oral route is seen to be the best option. The gastrointestinal tract's harsh physiological and physicochemical characteristics, which frequently restrict medication bioavailability and impede efficient targeted administration design, must be overcome by oral drug delivery systems. Numerous cutting-edge pharmaceutical techniques, order to solve these issues. The anatomical, biochemical, and physiological aspects of oral medication delivery are covered in this study, along with new developments in both traditional and cutting-edge oral delivery strategies meant to enhance drug absorption and targeting

effectiveness. It also describes the main obstacles to and prospects for the advancement of oral medication administration methods."

Zhang et al.,(2022) reported that "Topical medication administration in drawbacks. Success medicine application in this open and extremely complicated environment depends on a number of elements. Therapeutic effect free greatly the dynamic physical chemical circumstances of the oral cavity, including food intake and saliva flow. Therefore, in order to improve regulated drug diffusion, promote tissue regeneration, and increase antibacterial activity, drug delivery systems are used as supporting matrices or carriers for active agents like growth factors (GFs) and antimicrobial chemicals. These devices are frequently used for local anesthetic delivery, periodontal and periapical disorders, and dental caries carrier materials, design approach, have been created for clinical usage, including films, scaffolds, hydrogels, nanoparticles, and nanofibers. This analysis offers fresh perspectives for the creation of by outlining benefits and drawbacks of different carrier systems as well as their preparation techniques and application areas."

Kaur et al.,(2019) reported that "Modern drug delivery systems typically make it easier to reformulate drugs and change how they are administered, which together enhance and patient compliance, especially for chronic illnesses like pain, which is a symptom rather than a disease, even if the medicine and disease features are the key factors that influence the choice of administration method. In order to improve the risk-benefit profile of current oral therapies, support early-stage drug discovery efforts to lower attrition rates, and facilitate the conversion of injectable drugs to oral formulations, this review attempts to provide an overview of recent developments in oral drug delivery technologies."

Yu et al.,(2026) reported that "Therefore, the intestinal permeability barrier and significant individual variation in absorption are the primary factors controlling their restricted oral bioavailability rather than dissolving issues. The main factors influencing medications examined this study using the primary. It also offers a critical and comparative evaluation of current approaches to increasing bioavailability. It also assesses these methods' mechanisms of action, degree of improvement attainable, acceptability under various physicochemical and physiological settings, and translational applicability, identifying their inherent limitations and usage bounds. The paper concludes by emphasizing that there is no one universal solution to the absorption problems of BCS III medications, underscoring the necessity of systems. The end, this encourages the creation of customized delivery methods made especially for BCS III medications."

Ren et al.,(2023) reported that "Attempted due to its high safety profile, good patient compliance, and a number of other noteworthy benefits. The gastrointestinal tract's hostile biochemical environment and immune exclusion mechanisms, which restrict absorption and bloodstream entrance, make oral administration of particle systems for systemic circulation extremely difficult. Furthermore, it is currently unclear if oral administration of targeted drugs may reach distant regions outside of the gastrointestinal tract. This review offers a targeted analysis of the viability and promise of oral targeting techniques in this particular situation."

Homayun et al.,(2019) stated that "Biological effects, therapeutic efficacy, are significantly influenced by drug delivery routes and the physicochemical characteristics that go along with them. Every delivery route has benefits and drawbacks that call for the creation of unique delivery systems. Oral delivery is seen to be the most advantageous of these methods because it may be used with solid potential for sustained release, is simple to administer, and improves patient compliance. However, there are a number of difficulties with oral delivery that have recently drawn a lot of attention from researchers. This analysis highlights why oral delivery is still one of the most promising methods by quickly examining several routes of administration and their corresponding benefits and drawbacks. It goes on to address the main obstacles to oral medication delivery systems and shows new approaches that have been created to get over these restrictions."

Hilal et al.,(2013) reported that "Because the digestive system is built to break down proteins and peptides into smaller components before absorption, oral administration of medicines is still quite difficult. Intact medication molecules must endure and navigate the challenging gastrointestinal environment in order to be absorbed systemically. Non-peptide medications have been effectively shielded from the stomach's acidic environment by formulation techniques including enteric coating. These methods, however, have not shown to be very successful in protecting therapeutic proteins and peptides. Significantly, during the past few decades, the intrinsic permeability of pharmacological molecules has remained a significant unsolved problem. This study provides an overview of methods that have been developed to improve intestinal permeability, either by changing the drug molecules themselves or by modifying the intestinal epithelium. These strategies employ functional compounds that can be co-administered to temporarily alter epithelial barrier function or conjugated with

medications to increase cellular permeability, hence facilitating efficient drug absorption."

Siow et al.,(2016) stated that "Freeze-drying has become increasingly important due to the increased focus on oral drug delivery systems (ODDS) freeze-dried are directly impacted by formulation and process parameters, which is why they are so important. Therefore, creating novel ODDS products requires an understanding of the fundamentals and effects basic concepts are covered in this overview, along with important formulation and processing factors. It delves deeper into its applications in three main areas: creating new freeze-dried excipients, modifying active pharmaceutical substances, and creating final freeze-dried dosage forms. According to experts, freeze-drying opportunities for oral drug delivery by allowing for the change of final solid dose parameters, excipients, and drug properties. Freeze-drying technology continues to be a pertinent and viable strategy in ODDS development due to its growing applications."

Graham et al.,(2018) stated that "Frequently recommended; nevertheless, there is still uncertainty regarding their relative potency and ideal dosage schedules. Intragastric pH monitoring was used to compare the efficacy of in randomized clinical studies. Patients were treated for at least five days. The efficacy of various (pH4time). The pH4time increased linearly from roughly 10.0 to 15.6 hours when was but no additional improvement was seen after that. While three-times-daily regimens shown comparable efficacy to twice-daily dosage, of dose further in a linear fashion from roughly 15.8 to 21.0 hours. PPI prices varied significantly, but there was no correlation between medicine potency and this heterogeneity. Overall, the results indicate that twice-daily dosing is more beneficial than just increasing once-daily doses."

Plan of work :

1. Literature Review

- Study of proton pump inhibitors and fast dissolving tablet technology
- Review of Pantoprazole pharmacology, pharmacokinetics, and clinical relevance
- Review of superdisintegrants, excipients, and direct compression methods
- Analysis of previous studies on FDTs and bioavailability enhancement

2. Collection and Authenticationof Materials

- Collection of Pantoprazole drug samples from authorized pharmaceutical suppliers
- Verification of drug identity and quality via pharmacopoeial tests

3. Preformulation Studies

3.1. Drug Characterization

- Physical properties: color, odor, taste, and appearance
- Determination of melting point
- Solubility studies in different solvents
- Determination of partition coefficient (Log P)
- pH solubility profile

4. Formulation Development

4.1. Selection of Excipients

- Superdisintegrants (crospovidone)
- Fillers, binders, lubricants, sweeteners, and flavoring agents

4.2. Preparation of Fast Dissolving Tablets

- Direct compression method
- Formulation of multiple batches with varying concentrations of superdisintegrants

5. Pre-compression Evaluation

- Bulk density
- Tapped density
- Carr’s index
- Hausner ratio
- Angle of repose

6. Post-compression Evaluation

6.1. Physical Evaluation

- Weight variation, thickness, and diameter

- Hardness
- Friability

6.2. Functional Evaluation

- Wetting time
- Water absorption ratio

6.3. Drug Content Determination

- Uniformity of drug content across tablet batches

7. In Vitro Drug Release

- Dissolution studies in simulated intestinal fluids
- Comparative study with conventional Pantoprazole tablets
- Calculation of % drug release and dissolution efficiency

8. Stability Studies as per ICH Guidelines

MATERIAL & METHOD

4.1 Materials

The drug as well as different excipients and reagents utilized in this investigation are given below.

Table 4.1: Materials used

S. No.	Material	Category	Source/Supplier
1	Pantoprazole	Active Pharmaceutical Ingredient	Authorized supplier
2	Crospovidone	Superdisintegrant	Pharmaceutical grade supplier
3	Microcrystalline Cellulose (MCC)	Filler/Diluent	Pharmaceutical grade supplier
4	Mannitol	Filler/Sweetening agent	Pharmaceutical grade supplier
5	Aspartame	Sweetening agent	Pharmaceutical grade supplier
6	Flavor	Flavoring agent	Pharmaceutical grade supplier

7	Magnesium Stearate	Lubricant	Pharmaceutical grade supplier
8	Talc	Glidant	Pharmaceutical grade supplier
9	Methanol	Solvent	Analytical grade supplier
10	Ethanol	Solvent	Analytical grade supplier
11	Distilled Water	Solvent	Laboratory supply
12	Phosphate Buffer (pH 6.8)	Dissolution medium	Prepared as per standard procedure

4.2 List of Instrument used

The following Table lists the instrument and several additional tools utilised in this experiment.

Table 4.2: Instruments used

S. No.	Instrument/Equipment	Model/Specification	Purpose/Use
1	Digital Weighing Balance	Analytical balance	Weighing of drug and excipients
2	UV–Visible Spectrophotometer	Double beam	Estimation of drug content and dissolution studies
3	Tablet Compression Machine	Single rotary/punch machine	Preparation of tablets
4	Vernier Caliper (Digital)	Digital	Measurement of tablet thickness and diameter
5	Hardness Tester	Monsanto/Pfizer	Determination of tablet hardness
6	Friabilator (Roche type)	Standard model	Determination of friability
7	Dissolution Apparatus	USP Type II (Paddle)	In vitro drug release study

8	Melting Point Apparatus	Capillary method	Determination of melting point
9	pH Meter	Digital	Preparation of buffer solutions
10	Mechanical Shaker	Orbital shaker	Solubility and partition studies
11	Sonicator	Ultrasonic bath	Sample dissolution and dispersion
12	Stability Chamber	ICH compliant	Stability studies

4.3 Drug Profile

Table 4.3 Drug Profile of Pantoprazole

Parameter	Details
Generic Name	Pantoprazole
Chemical Name	5-(Difluoromethoxy)-2-[(3,4-dimethoxypyridin-2-yl)methylsulfinyl]-1H-benzimidazole
Molecular Formula	C16H15F2N3O4S
Molecular Weight	383.36 g/mol
Class	Proton Pump Inhibitor (PPI)
Mechanism of Action	Irreversibly inhibits H^+/K^+-ATPase enzyme in gastric parietal cells, reducing gastric acid secretion
Therapeutic Uses	GERD, Zollinger-Ellison syndrome, Peptic ulcers, Erosive esophagitis
Dosage Form	Conventional tablets, capsules, injectable solution, fast-dissolving tablets (experimental)
Recommended Adult Dose	40 mg once daily (varies by indication)
Bioavailability	~77% after oral administration
Protein Binding	~98%
Half-Life (t½)	~1 hour (plasma); effect lasts up to 24 hours
Metabolism	Hepatic (CYP2C19 and CYP3A4)
Excretion	Urine (~80% as metabolites), feces (~20%)

Solubility	Practically insoluble in water, soluble in basic solutions
Stability Considerations	Acid-labile; sensitive to acidic environment; enteric coating usually required for oral tablets
Side Effects	Headache, diarrhea, nausea, abdominal pain, dizziness, rare hypersensitivity reactions
Pregnancy Category	B (Animal studies show no risk; limited human data)

4.4 Collection and Authenticationof Materials

To guarantee adherence to regulatory quality standards, pantoprazole was purchased from approved and accredited pharmaceutical vendors. A certificate of analysis was included with the drug sample that was received, and it was kept in suitable storage until it was needed again. Pantoprazole's authenticity, purity, and quality were verified through authentication conducted in compliance with pharmacopoeial criteria (IP/USP). The medication was assessed for its organoleptic characteristics and put through routine identification procedures, such as spectroscopic examination like UV-visible spectrophotometry and melting point testing. The validity and acceptability of the medicine for formulation development were confirmed by comparing the observed features and analytical results with approved pharmacopoeial limitations.

4.5 Preformulation Studies

4.5.1 Drug Characterization

4.5.1.1 Physical properties

- **Color**

Pantoprazole's color was assessed as part of the initial medication identification. To create a thin layer, a tiny amount of the sample was put evenly over a dry, clean watch glass. To ensure accurate observation, the material was then visually inspected on a white background in daylight. This evaluation's objectives were to evaluate the drug's appearance and look for any obvious indications of contamination or foreign objects. To verify conformity, the observed hue was compared to the description found in official pharmacopoeial standards.

- **Odor**

Pantoprazole's smell was assessed as part of the initial medication identification. To evaluate the odor, a small amount of the sample was put in a dry, clean container. The air above the sample was gently wafted toward the nose to prevent direct inhalation. The purpose of this assessment was to look for any distinctive smells or the presence of

strange or off-odors that would point to contamination or deterioration. To verify conformity, the odor was compared to the description found in official pharmacopoeial standards.

- **Taste**

In order to determine the drug's distinctive taste, which is a crucial factor in the creation of fast-dissolving tablets, a very small amount of the sample was carefully placed on the tongue, allowed to briefly interact with saliva, and then immediately rinsed the mouth with water. The taste was noted and taken into consideration for the selection of appropriate sweetening and flavoring agents during formulation development. After carefully placing a very small amount of the sample on the tongue and letting it momentarily contact with saliva, the mouth was immediately rinsed with water. The purpose of this review was to determine the drug's distinctive flavor, which is a crucial factor in the creation of tablets that dissolve quickly. During the formulation development process, the observed taste was noted and taken into consideration for choosing appropriate flavoring and sweetening ingredients.

- **Appearance**

Pantoprazole's appearance was assessed as part of the preliminary characterization of the drug. A small amount of the sample was placed on a clean, dry watch glass and visually inspected under suitable lighting conditions. The sample was examined for its physical nature, including texture and crystalline characteristics, to assess the drug's overall physical form and to detect any foreign matter, aggregates, or irregularities. The observed appearance was compared with the description given in official pharmacopoeial standards to ensure compliance and suitability for additional formulation studies. A tiny amount of the material was put on a dry, clean watch glass and visually inspected in well-lit surroundings. The physical properties of the sample, such as its texture and crystalline features, were examined. The purpose of this assessment was to evaluate the drug's general physical shape and look for any abnormalities, aggregates, or foreign objects. To verify conformity and suitability for additional formulation research, the observed look was compared with the description found in official pharmacopoeial standards.

4.5.1.2 Determination of melting point

Principle:

The temperature at which a substance turns from a solid to a liquid under standard atmospheric pressure is known as its melting point. It is a crucial physical characteristic that is used to identify and evaluate a drug's purity. The melting point of a pure substance is sharp, but the melting range can be changed or expanded by the presence of impurities.

Procedure:

1. A small quantity of Pantoprazole was finely powdered using a mortar and pestle.
2. The powdered drug was filled into a clean, dry capillary tube sealed at one end.
3. The capillary tube was gently tapped to ensure uniform packing of the sample.
4. The filled capillary tube was placed in the melting point apparatus.
5. The temperature of the apparatus was gradually increased at a controlled rate.
6. The sample was continuously observed during heating.
7. The temperature at which the drug started melting and the temperature at which it completely melted were noted.
8. The melting point range was recorded and compared with pharmacopoeial standards.

4.5.1.3 Solubility studies in different solvents

Principle:

A crucial preformulation factor that affects medication absorption, formulation development, and the choice of appropriate excipients is solubility, which is defined as a substance's capacity to dissolve in a particular solvent at a specific temperature and pressure. It is a crucial preformulation factor that affects formulation development, medication absorption, and the choice of appropriate excipients.

Procedure:

1. An excess amount of Pantoprazole was added to a series of test tubes containing different solvents such as distilled water, methanol, ethanol, and phosphate buffer of varying pH.
2. The test tubes were sealed and shaken intermittently to facilitate dissolution of the drug.

3. The mixtures were allowed to stand at room temperature for a specified period to attain equilibrium.
4. The solutions were then observed visually for solubility.
5. If necessary, the samples were filtered to remove any undissolved particles.
6. The solubility of Pantoprazole in each solvent was qualitatively assessed and categorized (e.g., freely soluble, soluble, sparingly soluble, or insoluble) based on pharmacopoeial guidelines.

4.5.1.4 Determination of partition coefficient (Log P)

Principle:

A crucial metric that shows a medication's lipophilicity and capacity to cross biological membranes is the partition coefficient (Log P), which is defined as the ratio of the concentration of a drug dispersed between two immiscible phases, usually n-octanol and water. It is a crucial metric that shows how lipophilic the medication is and how well it can cross cellular membranes.

Procedure:

1. Equal volumes of n-octanol and distilled water were taken in a separating funnel and shaken thoroughly to achieve mutual saturation of the solvents.
2. An accurately weighed quantity of Pantoprazole was added to the separating funnel containing the pre-saturated solvent system.
3. The mixture was shaken vigorously for a fixed period to allow the drug to partition between the two phases.
4. The separating funnel was then allowed to stand undisturbed until complete separation of the aqueous and organic layers was achieved.
5. The aqueous layer was carefully collected and filtered if necessary.
6. The concentration of Pantoprazole in the aqueous phase was determined using UV–Visible spectrophotometry at its λmax.
7. The concentration of drug in the organic phase was calculated by subtracting the amount present in the aqueous phase from the initial amount of drug added.

8. The partition coefficient (P) was calculated as the ratio of the concentration of drug in n-octanol to that in water, and Log P was determined using the logarithmic value of the partition coefficient.

4.5.1.5 pH solubility profile

A drug's solubility at various pH levels is determined by its pH solubility profile. Understanding how pH affects medication solubility, stability, and dissolution behavior is crucial for formulation development.

Procedure:

1. Buffer solutions of different pH values (e.g., pH 1.2, 4.5, 6.8, and 7.4) were prepared using standard buffer systems.
2. An excess amount of Pantoprazole was added separately to each buffer solution in clean, dry containers.
3. The mixtures were shaken continuously using a mechanical shaker to facilitate dissolution.
4. The samples were maintained at a constant temperature until equilibrium was achieved.
5. The solutions were then filtered to remove any undissolved drug particles.
6. An appropriate dilution of each filtrate was prepared using the respective buffer.
7. The concentration of dissolved drug was determined using UV–Visible spectrophotometry at its λmax.
8. The solubility of Pantoprazole at different pH values was determined and used to construct the pH solubility profile.

4.6 Formulation Development

4.6.1 Selection of Excipients

Excipients were chosen for the formulation of fast-dissolving pantoprazole tablets based on their functional role in attaining rapid disintegration, sufficient mechanical strength, and enhanced patient acceptability, as well as their physicochemical compatibility with the medication. Excipients were carefully selected to guarantee that they are appropriate for the direct compression method and do not interact with the medication.

Crospovidone, a superdisintegrant, was chosen because of its strong capillary activity and swelling capacity, which enable speedy tablet disintegration and water absorption. Since the medicine is present in a relatively modest dose, fillers or diluents were added to improve compressibility and provide the formulation enough bulk. In order to give the tablets the required mechanical strength without appreciably slowing down disintegration, binders were added in small amounts.

In order to ensure smooth manufacture, lubricants were used to decrease friction between the tablet and the die wall during compression and ejection. Furthermore, glidants were included to enhance the powder blend's flow characteristics. In order to cover up the drug's disagreeable taste and improve patient compliance—which is crucial for fast-dissolving tablets meant for oral cavity disintegration—sweetening and flavoring ingredients were added.

Every excipient that was chosen was of pharmaceutical grade and adhered to official pharmacopoeial requirements; their concentrations were adjusted to strike a compromise between acceptable tablet hardness, quick disintegration, and overall formulation stability. In order to strike a compromise between acceptable tablet hardness, quick disintegration, and overall formulation stability, their concentrations were tuned.

4.6.2 Preparation of Fast Dissolving Tablets

Principle:

By compressing powders directly into tablets without the need for granulation, direct compression is a straightforward and effective method of making tablets. It is especially useful for fast-dissolving tablets because it reduces exposure to heat and moisture, maintaining drug stability. The addition of superdisintegrants speeds up saliva absorption, which results in rapid disintegration and drug release in the oral cavity. Because it reduces exposure to heat and moisture and maintains drug stability, it is especially appropriate for fast-dissolving tablets. Superdisintegrants make it easier for saliva to be absorbed quickly, which speeds up medication release and breakdown in the oral cavity.

Procedure:

1. All the ingredients, including Pantoprazole and selected excipients, were accurately weighed according to the formulation design.
2. The drug and excipients were passed through a suitable sieve to ensure uniform particle size distribution.

3. The sieved ingredients, except lubricants and glidants, were mixed thoroughly using a mortar and pestle or blender to obtain a homogeneous mixture.
4. Lubricants and glidants were added to the blend and mixed gently to ensure uniform distribution.
5. The prepared powder blend was evaluated for pre-compression parameters.
6. The blend was then compressed into tablets using a tablet compression machine fitted with appropriate punches and dies.
7. Multiple batches were prepared by varying the concentration of the superdisintegrant (crospovidone) while keeping other excipients constant.
8. All batches were compressed under similar conditions to maintain uniformity in tablet characteristics.

Table 4.4: Composition of Fast Dissolving Tablets of Pantoprazol

Ingredients	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
Pantoprazole (mg)	40	40	40	40	40	40	40	40	40	40
Crospovidone (mg)	2	4	6	8	10	12	14	16	18	20
Microcrystalline Cellulose (mg)	120	118	116	114	112	110	108	106	104	102
Mannitol (mg)	30	30	30	30	30	30	30	30	30	30
Aspartame (mg)	5	5	5	5	5	5	5	5	5	5
Flavor (mg)	3	3	3	3	3	3	3	3	3	3
Magnesium Stearate (mg)	2	2	2	2	2	2	2	2	2	2
Talc (mg)	3	3	3	3	3	3	3	3	3	3
Total Weight (mg)	**205**	**205**	**205**	**205**	**205**	**205**	**205**	**205**	**205**	**205**

4.7 Pre-compression Evaluation

4.7.1 Bulk density

Principle:

The mass of a powder divided by its bulk volume, which includes the volume of interparticulate gaps, is known as bulk density. This ratio gives information about the powder blend's packing capacity and flow characteristics, which are crucial for consistent die filling during tablet compression. It offers details on the powder blend's

flow characteristics and packing capacity, which are crucial for consistent die filling during tablet compression.

Procedure:

1. A known quantity of the powder blend was accurately weighed.
2. The weighed powder was carefully transferred into a clean, dry graduated measuring cylinder.
3. The powder was poured without compacting, and the initial volume (bulk volume) was noted.
4. Care was taken to avoid any vibration or tapping during the measurement.
5. The bulk density was calculated by dividing the mass of the powder by its bulk volume.

Bulk Density = Mass of Powder / Bulk Volume

Interpretation:

Bulk density is a useful parameter for evaluating flow behavior and guaranteeing uniformity during tablet compression. A higher bulk density indicates better packing ability, while a lower bulk density suggests a more porous and less dense powder. While a lower bulk density implies a less dense and more porous powder, a greater bulk density indicates superior packing ability. When evaluating flow behavior and guaranteeing homogeneity during tablet compression, this metric is helpful.

4.7.2 Tapped density

Principle:

The ratio of a powder's mass to its volume following a predetermined number of taps or mechanical tapping is known as tapped density, and it gives information about the powder's compressibility and packing capacity under external forces. It gives details regarding the powder's compressibility and packing capacity when exposed to outside forces.

Procedure:

1. A known quantity of the powder blend was accurately weighed.
2. The weighed powder was transferred into a clean, dry graduated measuring cylinder.
3. The initial volume of the powder was noted.

4. The cylinder was then subjected to mechanical tapping using a tapped density apparatus for a fixed number of taps (usually 100–500 taps) until a constant volume was achieved.

5. The final tapped volume was recorded after tapping.

6. The tapped density was calculated by dividing the mass of the powder by the tapped volume.

Tapped Density = Mass of Powder / Tapped Volume

Interpretation:

The degree to which a powder can be compacted is indicated by its tapped density. While a lower difference indicates better flow characteristics and packing behavior of the powder mix, a large gap between bulk density and tapped density indicates poor flow properties and higher compressibility.

4.7.3 Carr's index

Principle:

An indirect indicator of a powder blend's compressibility and flow characteristics is Carr's index. It is computed using the bulk density and tapped density measurements. The degree of volume loss after tapping reveals the powder's capacity for consolidation, which in turn reveals its flow characteristics.

Procedure:

1. The bulk density of the powder blend was determined using a graduated measuring cylinder.

2. The tapped density of the same powder sample was determined using a tapped density apparatus.

3. The values obtained for bulk density and tapped density were recorded.

4. Carr's index was calculated using the standard formula.

Carr's Index (%) = [(Tapped Density – Bulk Density) / Tapped Density] × 100

Interpretation:

The Carr's index gives an indication of the powder blend's flowability; values below 15% indicate good flow, values between 15% and 25% indicate fair to passable flow, and values above 25% indicate poor flow characteristics. Better flow qualities are

indicated by lower numbers, whereas poor flow characteristics are suggested by higher values. Good flow is often indicated by a Carr's index below 15%, fair to passable flow is indicated by values between 15% and 25%, and poor flow attributes are indicated by values above 25%.

4.7.4 Hausner ratio

Principle:

The Hausner ratio, which is defined as the ratio of tapped density to bulk density and indicates interparticle friction and powder cohesiveness, is an indirect indicator of a powder blend's flow characteristics. It gives an indication of the cohesiveness and interparticle friction of the powder and is defined as the ratio of tapped density to bulk density.

Procedure:

1. The bulk density of the powder blend was determined using a graduated measuring cylinder.
2. The tapped density of the same sample was determined using a tapped density apparatus after a fixed number of taps.
3. The values of bulk density and tapped density were recorded.
4. The Hausner ratio was calculated using the standard formula.

Hausner Ratio = Tapped Density / Bulk Density

Interpretation:

The flowability of the powder blend is indicated by the Hausner ratio. Good flow characteristics are indicated by a value near 1, while poor flow and greater cohesion are indicated by higher values. In general, good flow is indicated by a Hausner ratio of less than 1.25, and poor flow characteristics are suggested by values greater than 1.25.

4.7.5 Angle of repose

Principle:

The greatest angle that forms between the surface of a powder pile and the horizontal plane is known as the angle of repose. It is a crucial metric for assessing a powder blend's flow characteristics. The frictional forces between particles determine the angle; better flowability is indicated by smaller angles.

Procedure:

1. A clean, dry funnel was fixed at a suitable height above a flat surface.

2. A sheet of paper was placed on the surface to collect the powder.
3. The powder blend was allowed to flow freely through the funnel to form a conical heap.
4. Care was taken to ensure that the funnel tip remained at a constant height and that the powder flowed without interruption.
5. The height (h) of the powder heap was measured using a scale.
6. The radius (r) of the base of the heap was measured.
7. The angle of repose (θ) was calculated using the formula.

Formula:

$\tan \theta = h / r$

Interpretation:

The powder blend's flowability is indicated by the angle of repose; a smaller angle (usually less than 30°) denotes good flow characteristics, a number between 30 and 40° implies passable flow, and a value larger than 40° suggests poor flow behavior. Good flow characteristics are indicated by smaller angles (usually less than 30°), acceptable flow is indicated by angles between 30 and 40°, and bad flow behavior is suggested by angles larger than 40°.

4.8 Post-compression Evaluation

4.8.1 Physical Evaluation

4.8.1.1 Weight variation

Principle:

The purpose of the weight variation test is to verify that the weight of the tablets is consistent, which in turn indicates that the medicine is distributed uniformly throughout each tablet. Maintaining dosage accuracy and therapeutic efficacy requires consistent tablet weight.

Procedure:

1. A total of 20 tablets were selected randomly from each batch.
2. Each tablet was individually weighed using a calibrated digital weighing balance.
3. The average weight of the tablets was calculated.

4. The individual weights of tablets were compared with the average weight.
5. The percentage deviation of each tablet from the average weight was calculated.
6. The results were evaluated according to pharmacopoeial limits for weight variation.

% Deviation = [(Individual Weight – Average Weight) / Average Weight] × 100

Interpretation:

The test guarantees consistency in tablet weight within a batch. Tablets that fall within the designated pharmacopoeial limits demonstrate consistent die filling and manufacturing process uniformity.

4.8.1.2 Thickness and Diameter

Principle:

Two crucial physical metrics for assessing the consistency of tablet size and shape are thickness and diameter. For consistency in tablet appearance, packaging, and mechanical strength, these characteristics are crucial.

Procedure:

1. A sample of 10 tablets was selected randomly from each batch.
2. The thickness of each tablet was measured using a calibrated digital Vernier caliper.
3. The diameter of each tablet was measured using the same instrument.
4. All measurements were recorded in millimeters.
5. The average thickness and diameter were calculated for each batch.

Interpretation:

Consistent die fill and compression force during tablet manufacturing are indicated by uniformity in thickness and diameter; significant variation could point to problems with the compression process or inconsistent formulation. Significant variation could be a sign of inconsistent formulation or problems with the compression process.

4.8.1.3 Hardness

Principle:

The force needed to shatter a tablet diametrically is known as its hardness, and it's a crucial indicator of the tablet's mechanical strength and resistance to handling, packing, and shipping. It is a crucial metric that shows the tablet's mechanical strength and resilience to handling, packing, and shipping.

Procedure:

1. A sample of 6 tablets was selected randomly from each batch.
2. Each tablet was placed individually in the hardness tester (e.g., Monsanto or Pfizer hardness tester).
3. The force required to break the tablet was applied gradually by operating the instrument.
4. The reading at which the tablet fractured was recorded in kg/cm² or Newton (N).
5. The hardness values of all tablets were noted, and the average hardness was calculated.

Interpretation:

The mechanical integrity of the formulation is indicated by the hardness of the tablet; a sufficiently high hardness may impact drug release and disintegration, while a sufficient hardness guarantees resistance to breaking during handling. While too high hardness may impact medication release and disintegration, adequate hardness guarantees resistance to fracture during handling.

4.8.1.4 Friability

Principle:

The mechanical strength of tablets and their capacity to tolerate abrasion and mechanical stress during handling, packing, and transportation are measured by their friability. The weight loss % of tablets following a standardized tumbling action is used to express it.

Procedure:

1. A sample of tablets (usually 10–20 tablets) was accurately weighed and the initial weight (W_0) was recorded.
2. The tablets were placed in the friabilator (Roche friabilator).
3. The apparatus was operated at 25 rpm for 4 minutes (equivalent to 100 revolutions).
4. After completion, the tablets were removed, dedusted, and reweighed to obtain the final weight (W_1).
5. The percentage friability was calculated using the standard formula.

$$\% \text{ Friability} = [(W_0 - W_1) / W_0] \times 100$$

Interpretation:

The ability of tablets to withstand abrasion is indicated by their friability. A percentage friability of less than 1% is usually regarded as acceptable, suggesting that the tablets have sufficient mechanical strength.

4.8.2 Functional Evaluation

4.8.2.1 Wetting time

Principle:

Wetting time is a crucial metric for fast dissolving tablets since it indicates the tablet's capacity to absorb saliva and start rapid disintegration. Wetting time is the amount of time needed for a tablet to get totally wet when placed in an appropriate medium. It is a crucial metric for fast-dissolving tablets since it shows how well the tablet absorbs saliva and starts to dissolve quickly.

Procedure:

1. A piece of tissue paper was folded twice and placed in a Petri dish containing a measured volume of distilled water.
2. The tissue paper was allowed to absorb the water completely to create a moist surface.
3. A tablet was carefully placed on the surface of the wetted tissue paper.
4. The time required for the tablet to become completely wet was recorded using a stopwatch.
5. The experiment was repeated for multiple tablets, and the average wetting time was calculated.

Interpretation:

A shorter wetting time implies quicker medium penetration into the tablet matrix, which is ideal for quick disintegration in fast-dissolving tablets. Wetting time also shows how well the tablet absorbs water. For fast-dissolving tablets, a shorter wetting time indicates quicker medium penetration into the tablet matrix, which is desirable.

4.8.2.2 Water absorption ratio

Principle:

The water absorption ratio is a crucial metric for fast dissolving tablets because it shows the tablet's ability to absorb water, which promotes quick disintegration. It measures the quantity of water absorbed by a tablet when placed in an appropriate medium. It is a

crucial factor for tablets that dissolve quickly since it shows how well the tablet absorbs water, which speeds up disintegration.

Procedure:

1. A piece of tissue paper was folded twice and placed in a Petri dish containing a known volume of distilled water.
2. The tissue paper was allowed to absorb the water completely to create a uniformly moist surface.
3. A tablet was weighed accurately (W_0) and placed on the wetted tissue paper.
4. The tablet was allowed to absorb water completely.
5. The wet tablet was then carefully removed and reweighed (W_1).
6. The water absorption ratio was calculated using the standard formula.

$$\textbf{Water Absorption Ratio (R)} = [(W_1 - W_0) / W_0] \times 100$$

Interpretation:

The tablet's capacity to absorb water is reflected in the water absorption ratio; a larger number denotes increased water uptake, which accelerates the tablet's swelling and disintegration. Greater water absorption is indicated by a higher value, which accelerates the tablet's swelling and disintegration.

4.8.3 Drug Content Determination

Principle:

Drug content uniformity guarantees that, within predetermined bounds, each tablet contains the desired quantity of active medicinal ingredient. It is crucial for preserving therapeutic efficacy and dose precision. UV-visible spectrophotometry is frequently used for the assay, which is based on the drug's absorbance at its characteristic wavelength (λmax).

Procedure:

1. A sample of 10 tablets was selected randomly from each batch.
2. The tablets were individually weighed and finely powdered using a mortar and pestle.
3. An accurately weighed quantity of powder equivalent to the dose of Pantoprazole was transferred into a volumetric flask.
4. A suitable solvent (e.g., phosphate buffer) was added, and the mixture was sonicated or shaken to ensure complete dissolution of the drug.

5. The solution was filtered to remove any insoluble excipients.
6. An appropriate dilution of the filtrate was prepared using the same solvent.
7. The absorbance of the resulting solution was measured using a UV–Visible spectrophotometer at the λmax of Pantoprazole.
8. The drug content was calculated using a previously prepared calibration curve.

Interpretation:

The test verifies that the medication is distributed uniformly throughout the tablets. Each drug content value should be within the permissible pharmacopoeial limits, demonstrating the formulation's consistency and dependability. The formulation's consistency and dependability should be demonstrated by the individual drug content values falling within the permissible pharmacopoeial limits.

4.9 In Vitro Drug Release

Principle:

In vitro dissolution experiments, which mimic the in vivo drug release behavior and are crucial for evaluating the effectiveness of fast dissolving tablets, are carried out to measure the rate and degree of drug release from the formed tablets under controlled settings. This test is crucial for evaluating the effectiveness of fast-dissolving tablets because it replicates the in vivo drug release behavior.

Procedure:

1. The dissolution study was performed using a USP dissolution apparatus (Type II – paddle method).
2. A specified volume of dissolution medium (phosphate buffer pH 6.8) was taken in the dissolution vessel and maintained at 37 ± 0.5°C.
3. The paddle rotation speed was adjusted to a constant value (50 rpm).
4. One tablet from each formulation batch was placed in the dissolution medium.
5. At predetermined time intervals, a fixed volume of sample was withdrawn and replaced with an equal volume of fresh dissolution medium to maintain sink conditions.
6. The withdrawn samples were filtered and appropriately diluted.
7. The absorbance of the samples was measured using a UV–Visible spectrophotometer at the λmax of Pantoprazole.
8. The amount of drug released at each time interval was calculated using a calibration curve.

9. The percentage cumulative drug release was calculated and plotted against time to obtain the dissolution profile.

% Drug Release = (Amount of drug released / Total drug content) × 100

Interpretation:

Information about the formulation's release properties is provided by the dissolving study. The medication release profile aids in assessing how well the formulation achieves quick drug release.

4.10 Stability Studies as per ICH Guidelines

Principle:

Stability studies are carried out to assess how environmental elements like humidity and temperature affect the pharmaceutical formulation's quality, safety, and effectiveness over time. These investigations aid in establishing the created formulation's stability and storage conditions in compliance with ICH criteria.

Procedure:

1. The optimized formulation of fast dissolving tablets was selected for stability studies.
2. The tablets were packed in suitable packaging materials (e.g., aluminum foil or blister packs).
3. The packed samples were stored under accelerated stability conditions at 40 ± 2°C and 75 ± 5% relative humidity in a stability chamber.
4. Samples were withdrawn at predetermined time intervals (e.g., 0, 1, 2, and 3 months).
5. At each interval, the tablets were evaluated for physical parameters such as appearance, hardness, friability, and drug content.
6. In vitro dissolution studies were also performed to assess any changes in drug release profile.
7. The obtained results were compared with initial values to assess stability of the formulation.

Interpretation:

Stability studies give information about the formulation's integrity and performance over time. The formulation is said to be stable under the given conditions if there are no appreciable changes in the evaluated parameters. The formulation is stable under the given conditions if there are no notable changes in the evaluated parameters.

RESULT & DISCUSSIONS

5.1 Preformulation Studies

5.1.1 Drug Characterization

5.1.1.1 Physical properties of Pantoprazole

As part of the initial identification and characterization of pantoprazole, a physical assessment was conducted. The drug's hue was found to be white to off-white, which is consistent for its typical description. When evaluated under controlled circumstances, it was discovered to be odorless, indicating the lack of any volatile contaminants or degradation products. Pantoprazole's taste was found to be rather bitter, which is a property of the medication and is important when developing fast-dissolving tablet formulations to guarantee patient acceptability through the use of suitable flavoring agents. The drug's consistent physical nature and appropriateness for additional preformulation and formulation investigations were confirmed by its appearance as a crystalline powder with a uniform texture. Overall, the observed physical characteristics verified the identification and purity of the drug sample used in the investigation and were in line with official criteria.

Table 5.1: Physical properties

Parameter	Observation
Color	White to off-white crystalline powder
Odor	Odorless
Taste	Slightly bitter taste
Appearance	Crystalline powder with uniform texture

5.1.1.2 Determination of melting point

The capillary method was used to estimate the melting point of pantoprazole in order to verify its identity and evaluate its purity prior to formulation. A digital melting point device was used to gradually heat the medication sample, and it was found that it melted between 140 and 144°C. Since pure compounds usually have sharp melting points with little variance, the narrow melting range suggests good drug purity. The drug sample's legitimacy was confirmed by the observed value, which was in line with published literature. In order to determine whether pantoprazole was suitable for further

preformulation and the creation of fast-dissolving tablets, this parameter was employed as an initial characterisation step.

Table 5.2: Melting Point of Pantoprazole

Parameter	Observation
Melting point range	140–144°C

5.1.1.3 Solubility studies in different solvents

Pantoprazole's solubility was assessed using the excess saturation method in a variety of solvents and buffer media. The substance was most soluble in methanol (8.65 ± 0.21 mg/mL), with ethanol coming in second (5.48 ± 0.18 mg/mL). Distilled water showed 0.42 ± 0.03 mg/mL and phosphate buffer pH 7.4 showed 0.61 ± 0.03 mg/mL, indicating relatively reduced solubility in aqueous and buffer systems. In buffer systems, it was discovered that the solubility decreased as the pH increased. The selection of appropriate media for additional formulation and assessment research was supported by these findings.

Table 5.3: Solubility Profile of Pantoprazole in Different Solvents

S. No.	Solvent / Medium	Solubility (mg/mL)
1	Distilled water	0.42 ± 0.03
2	Methanol	8.65 ± 0.21
3	Ethanol	5.48 ± 0.18
4	Phosphate buffer (pH 1.2)	1.25 ± 0.05
5	Phosphate buffer (pH 4.5)	0.96 ± 0.04
6	Phosphate buffer (pH 6.8)	0.73 ± 0.02
7	Phosphate buffer (pH 7.4)	0.61 ± 0.03

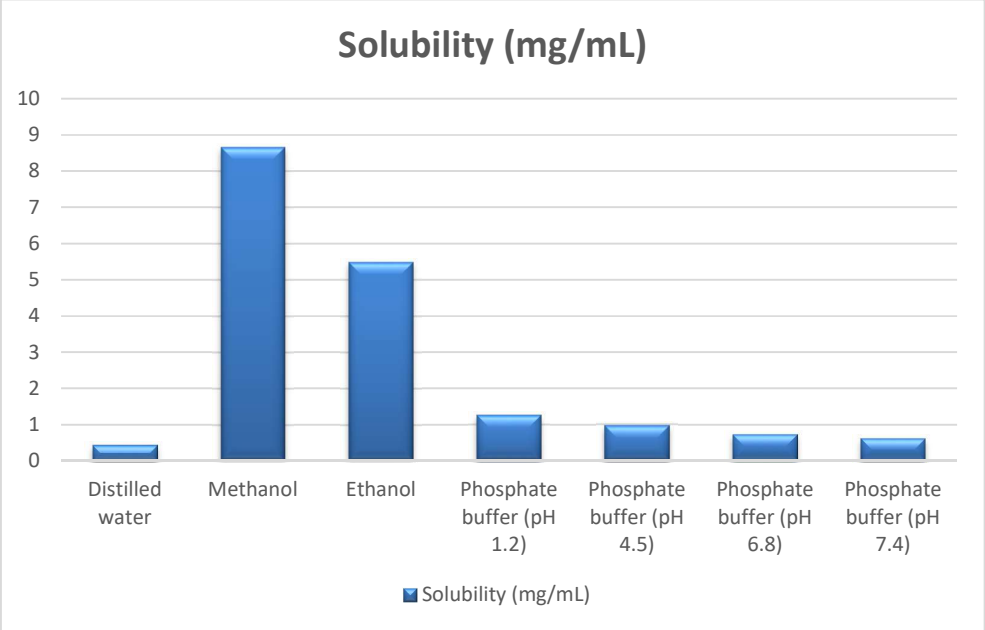

Fig 5.1: Solubility (mg/mL)

5.1.1.4 Determination of partition coefficient (Log P)

Pantoprazole's lipophilicity and distribution behavior between aqueous and organic phases were assessed utilizing the n-octanol–water system to calculate its partition coefficient (Log P). The drug's moderate lipophilic nature was indicated by its higher affinity for the organic phase (n-octanol) than for the aqueous phase. 5.83 ± 0.18 was the computed partition coefficient (P), and the related Log P value was 0.76 ± 0.02. These findings point to a hydrophilic-lipophilic balance that is advantageous for oral absorption. Pantoprazole's suitability for the creation of fast-dissolving tablets was supported by this parameter, which was utilized as a crucial preformulation feature.

Table 5.4: Partition Coefficient (Log P) of Pantoprazole

Parameter	Observation
Concentration in n-octanol phase	7.82 ± 0.25 mg/mL
Concentration in aqueous phase	1.34 ± 0.06 mg/mL
Partition coefficient (P)	5.83 ± 0.18
Log P	0.76 ± 0.02

5.1.1.5 pH solubility profile

To comprehend the solubility behavior of pantoprazole in physiological conditions, the pH-dependent solubility profile of the drug was assessed using buffer solutions with varying pH values. The drug's solubility varied significantly over the pH range that was examined. The highest solubility was found in an acidic medium (pH 1.2), and as the pH

rose toward neutral and alkaline conditions, solubility gradually decreased. According to its physicochemical makeup, this behavior suggests that pantoprazole is more soluble in acidic environments. The obtained solubility data were utilized to assist the selection of suitable dissolve media for additional in vitro testing of the designed fast dissolving tablets and to evaluate the impact of gastrointestinal pH on medication performance.

Table 5.5: pH Solubility Profile of Pantoprazole

S. No.	pH of Buffer	Solubility (mg/mL)
1	1.2	1.85 ± 0.05
2	4.5	1.10 ± 0.04
3	6.8	0.78 ± 0.03
4	7.4	0.62 ± 0.02

5.2 Pre-compression Evaluation

5.2.1 Bulk density

To assess the packing properties of the powder before compression, the bulk densities of the marketed formulation and the powder blends (F1–F10) were calculated. The generated formulations' bulk density values ranged from 0.41 ± 0.02 g/mL to 0.52 ± 0.01 g/mL, while the commercial formulation's bulk density was 0.55 ± 0.02 g/mL. From F1 to F10, a progressive rise in bulk density was noted, suggesting greater particle arrangement and packing capacity inside the powder blend with formulation modification. The marketed formulation's relatively larger bulk density indicated a more densely packed powder system. Overall, the findings showed that the prepared blends had adequate bulk properties that made them suitable for additional tablet compression.

Table 5.6: Bulk Density of Powder Blends

Formulation	Bulk Density (g/mL)
F1	0.41 ± 0.02
F2	0.42 ± 0.01
F3	0.44 ± 0.02
F4	0.45 ± 0.01
F5	0.47 ± 0.02
F6	0.48 ± 0.01
F7	0.49 ± 0.02
F8	0.50 ± 0.01

F9	0.51 ± 0.02
F10	0.52 ± 0.01
Marketed tablet blend	0.55 ± 0.02

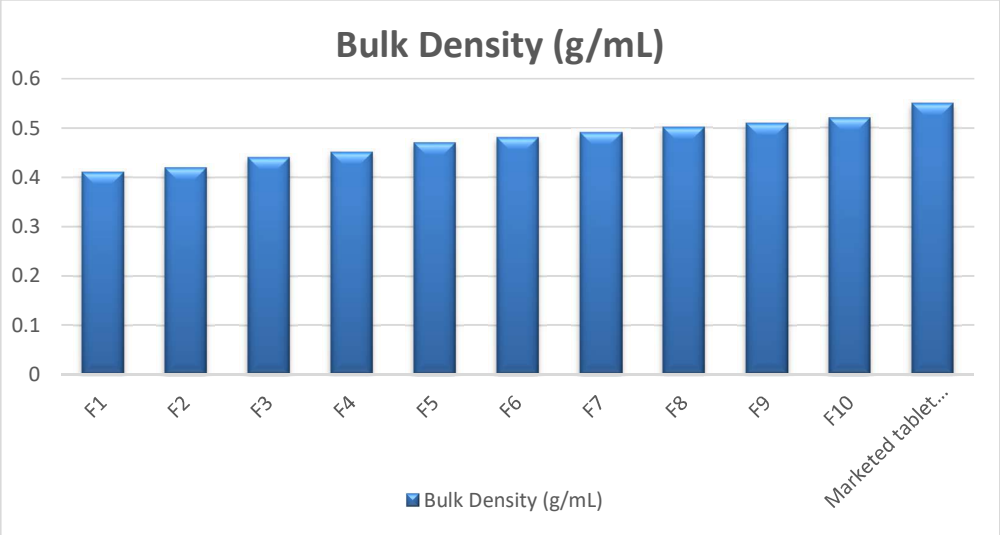

Fig 5.2: Bulk Density (g/mL)

5.2.2 Tapped density

To determine the packing efficiency of the powders following standardized tapping, the tapped density of the powder blends (F1–F10) and the commercial formulation were assessed. The produced formulations' tapped density values varied from 0.52 ± 0.02 g/mL (F1) to 0.63 ± 0.01 g/mL (F10), whereas the commercial tablet blend's tapped density was 0.66 ± 0.02 g/mL. From F1 to F10, a steady rise in tapped density was seen in all formulations, suggesting better particle packing and less interparticulate void space with formulation modification. Due to its enhanced packing structure, the marketed formulation's increased tapped density indicated improved consolidation behavior under external stress. All formulations had adequate packing qualities that were appropriate for direct compression into tablets, according to the overall results.

Table 5.7: Tapped Density of Powder Blends

Formulation	Tapped Density (g/mL)
F1	0.52 ± 0.02
F2	0.53 ± 0.01
F3	0.55 ± 0.02
F4	0.56 ± 0.01
F5	0.58 ± 0.02

F6	0.59 ± 0.01
F7	0.60 ± 0.02
F8	0.61 ± 0.01
F9	0.62 ± 0.02
F10	0.63 ± 0.01
Marketed tablet blend	0.66 ± 0.02

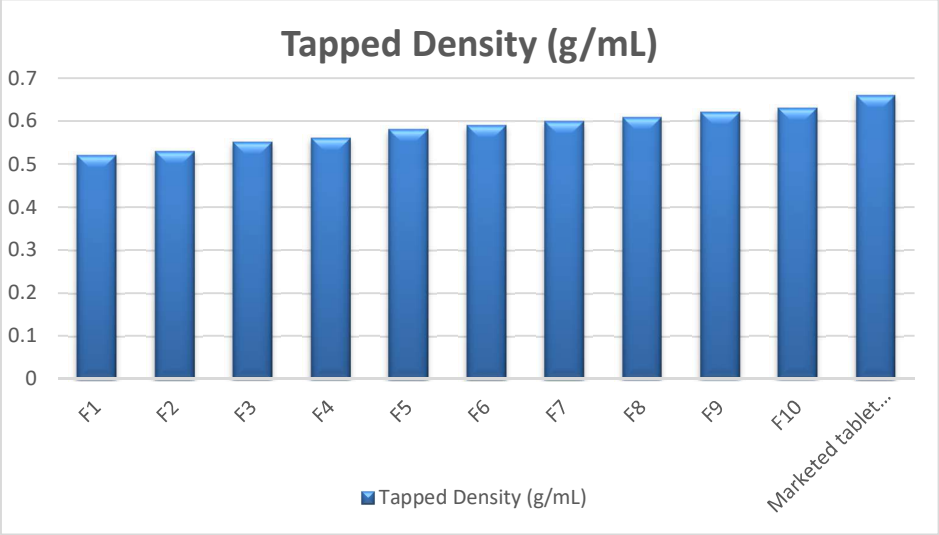

Fig 5.3: Tapped Density (g/mL)

5.2.3 Carr's index

In order to assess the flow characteristics and compressibility behavior of the powder blends (F1–F10) and the marketed formulation, Carr's Index was calculated. The values obtained for the prepared formulations ranged from 20.19 ± 0.81% (F1) to 17.46 ± 0.68% (F10), while the marketed tablet blend showed a lower Carr's Index of 16.67 ± 0.62%. Overall, all formulations showed Carr's Index values within an acceptable range, suggesting better flow characteristics and superior compressibility behavior. The created formulations had values ranging from 20.19 ± 0.81% (F1) to 17.46 ± 0.68% (F10), but the marketed tablet blend had a lower Carr's Index of 16.67 ± 0.62%. From F1 to F10, a progressive decline in Carr's Index was noted, suggesting that the powder blends' flowability and packing efficiency improved with formulation optimization. Better flow properties and superior compressibility behavior were suggested by the marketed formulation's relatively lower value. All formulations showed good to fair flow characteristics appropriate for direct compression, with Carr's Index values generally falling within an acceptable range.

Table 5.8: Carr's Index of Powder Blends

Formulation	Carr's Index (%)
F1	20.19 ± 0.81
F2	20.75 ± 0.69
F3	20.00 ± 0.72
F4	19.64 ± 0.65
F5	18.97 ± 0.74
F6	18.64 ± 0.63
F7	18.33 ± 0.70
F8	18.03 ± 0.66
F9	17.74 ± 0.71
F10	17.46 ± 0.68
Marketed tablet blend	16.67 ± 0.62

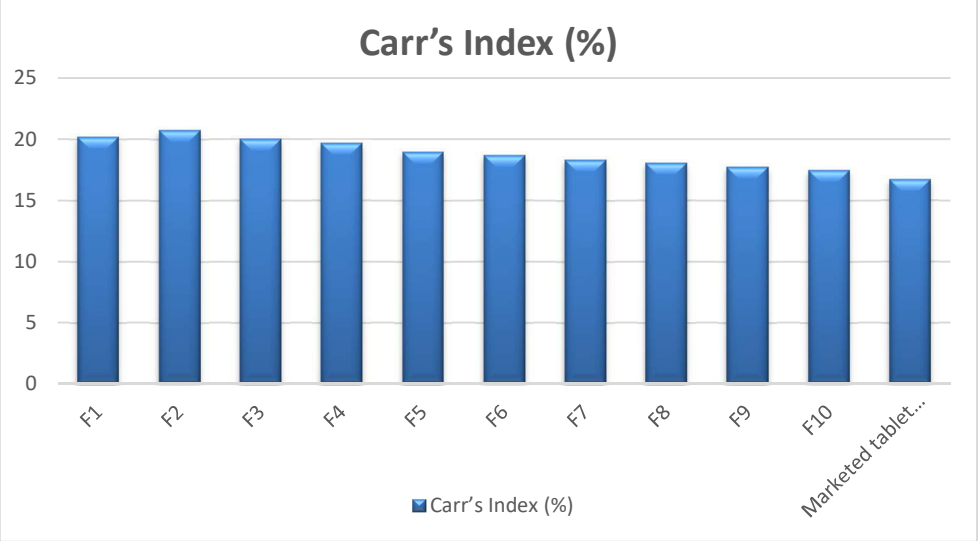

Fig 5.4: Carr's Index (%)

5.2.4 Hausner ratio

To assess the flow characteristics and interparticle friction of the powder blends (F1–F10) and the commercial formulation, the Hausner ratio was calculated. The developed formulations' Hausner ratio values varied from 1.27 ± 0.02 (F1) to 1.21 ± 0.01 (F10), whereas the commercial tablet blend's value was 1.19 ± 0.01. From F1 to F10, the Hausner ratio gradually decreased, suggesting that formulation modification improved flowability and decreased interparticle cohesion over time. When compared to the prepared batches, the marketed formulation's lower Hausner ratio indicated better packing behavior and flow characteristics. All formulations showed respectable Hausner ratio

values overall, suggesting adequate flow characteristics appropriate for consistent die filling during compression.

Table 5.9: Hausner Ratio of Powder Blends

Formulation	Hausner Ratio
F1	1.27 ± 0.02
F2	1.28 ± 0.01
F3	1.27 ± 0.02
F4	1.25 ± 0.01
F5	1.23 ± 0.02
F6	1.23 ± 0.01
F7	1.22 ± 0.02
F8	1.22 ± 0.01
F9	1.21 ± 0.02
F10	1.21 ± 0.01
Marketed tablet blend	1.19 ± 0.01

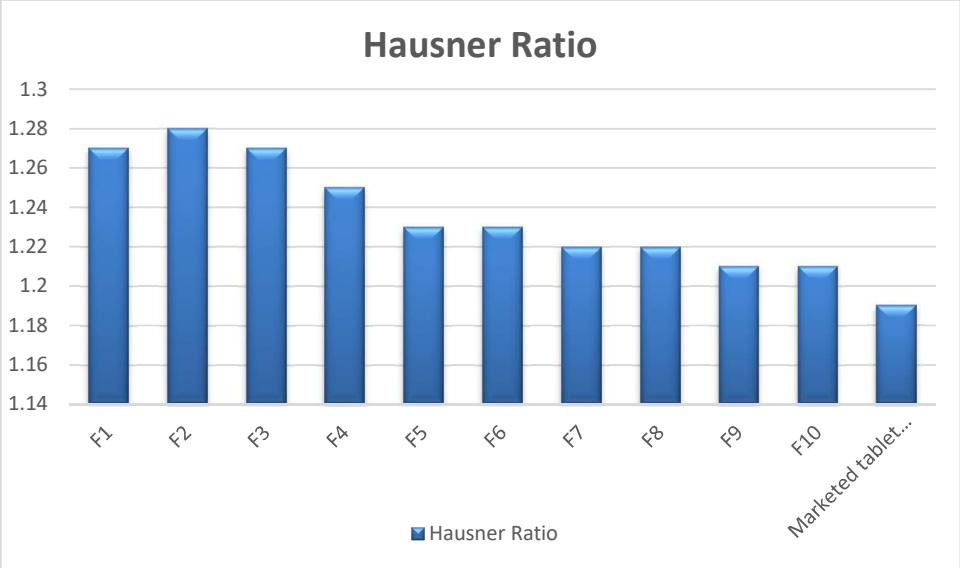

Fig 5.5: Hausner Ratio

5.2.5 Angle of repose

In order to assess the flow behavior of the powder blends (F1–F10) and the marketed formulation, the angle of repose was measured. The values obtained for the prepared

formulations ranged from 32.45 ± 0.85° (F1) to 27.50 ± 0.52°, while the marketed tablet blend showed a lower angle of repose of 26.80 ± 0.50°. The marketed formulation demonstrated the best flow characteristics among all samples, as evidenced by its lowest angle of repose. While the marketed tablet mix showed a lower angle of repose of 26.80 ± 0.50°, the values obtained for the produced formulations ranged from 32.45 ± 0.85° (F1) to 27.50 ± 0.52°. The angle of repose gradually decreased between F1 and F10, suggesting that formulation adjustment improved particle flow characteristics over time. Higher-numbered formulations had improved flowability due to improved particle arrangement and decreased interparticle friction. The marketed formulation's lowest angle of repose indicated that it had the best flow properties of any sample. All formulations showed values that were generally within the permissible range, indicating adequate flow characteristics appropriate for consistent die filling and compression.

Table 5.10: Angle of Repose of Powder Blend

Formulation	Angle of Repose (°)
F1	32.45 ± 0.85
F2	31.92 ± 0.78
F3	31.40 ± 0.72
F4	30.85 ± 0.69
F5	29.76 ± 0.66
F6	29.20 ± 0.63
F7	28.85 ± 0.60
F8	28.40 ± 0.58
F9	27.95 ± 0.55
F10	27.50 ± 0.52
Marketed tablet blend	26.80 ± 0.50

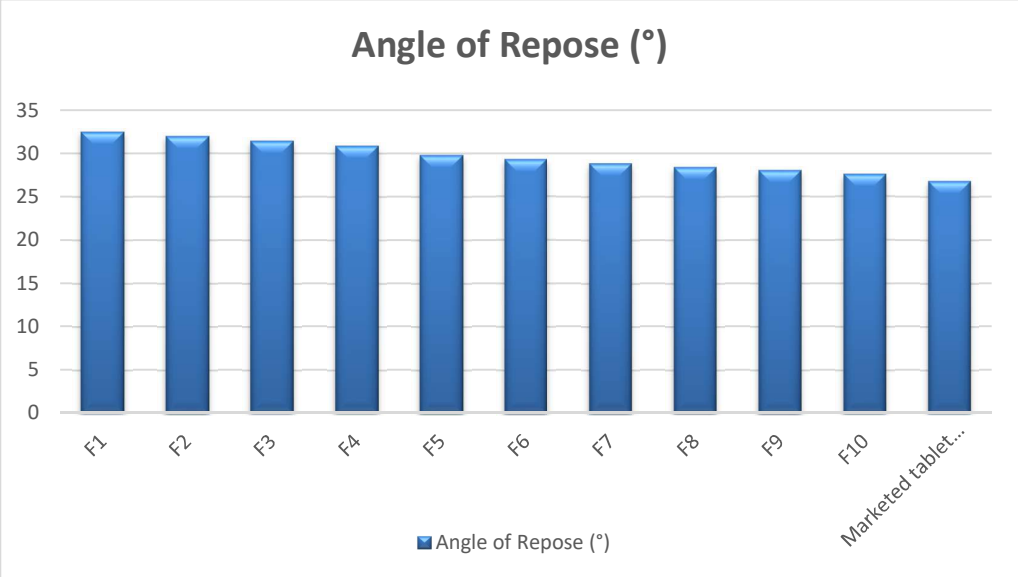

Fig 5.6 : Angle of Repose (°)

5.3 Post-compression Evaluation

5.3.1 Physical Evaluation

5.3.1.1 Weight variation

The weight variation test was used to assess the consistency of tablet weight in the marketed tablet and all formulations (F1–F10). The manufactured formulations' average weight varied from 198.4 ± 1.8 mg (F1) to 203.5 ± 0.8 mg (F10), whereas the average weight of the commercial tablet was 204.0 ± 1.0 mg. From F1 to F10, there was a gradual increase in the average tablet weight, which suggests that formulation modification improved powder flow and more even die filling during compression. From 3.21 ± 0.12% (F1) to 1.92 ± 0.04% (F10), the percentage deviation values decreased, with the marketed formulation showing the lowest deviation of 1.85 ± 0.03%. Overall, formulation F10 demonstrated performance closest to the marketed product, suggesting improved uniformity and consistency in tablet manufacture. These results reveal that all formulations met pharmacopoeial restrictions for weight variation. Overall, formulation F10 demonstrated performance that was most similar to the commercial product, indicating better consistency and uniformity in tablet production.

Table 5.11: Weight Variation of Tablets

Formulation	Average Weight (mg)	% Deviation
F1	198.4 ± 1.8	3.21 ± 0.12
F2	199.1 ± 1.6	3.05 ± 0.10
F3	199.8 ± 1.5	2.88 ± 0.09

F4	200.2 ± 1.4	2.70 ± 0.08
F5	201.0 ± 1.3	2.55 ± 0.07
F6	201.5 ± 1.2	2.41 ± 0.06
F7	202.0 ± 1.1	2.30 ± 0.05
F8	202.6 ± 1.0	2.18 ± 0.05
F9	203.1 ± 0.9	2.05 ± 0.04
F10	203.5 ± 0.8	1.92 ± 0.04
Marketed tablet	204.0 ± 1.0	1.85 ± 0.03

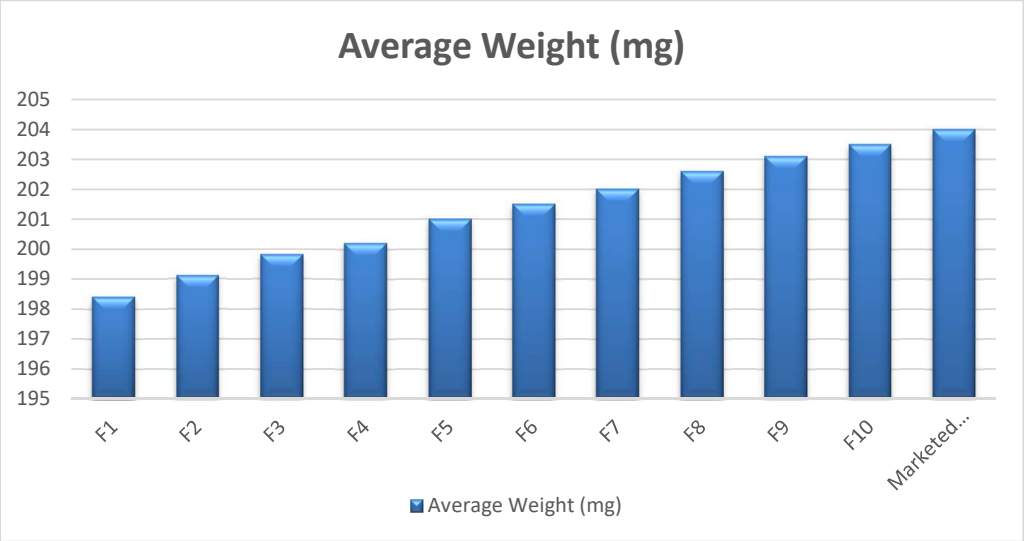

Fig 5.7: Average Weight (mg)

5.3.1.2 Thickness and Diameter

In order to guarantee dimensional uniformity and compression consistency, the thickness and diameter of tablets (F1–F10) were assessed. The thickness varied from 3.42 mm (F1) to 3.28 mm (F10), indicating a slight decrease due to improved compressibility and packing. The diameter stayed almost constant between 9.02 mm and 8.98 mm, similar to the marketed tablet (3.31 mm thickness, 9.00 mm diameter). All formulations exhibit uniform die filling, consistent compression, and high manufacturing quality. The thickness decreased slightly as a result of better packing and compressibility, ranging from 3.42 mm (F1) to 3.28 mm (F10). Comparable to the commercial tablet (3.31 mm thickness, 9.00 mm diameter), the diameter stayed almost constant between 9.02 mm and 8.98 mm. Overall, homogenous die filling, constant compression, and high production quality across all formulas are indicated by little variation in dimensions.

Table 5.12: Thickness and Diameter of Tablets

Formulation	Thickness (mm)	Diameter (mm)
F1	3.42 ± 0.05	9.02 ± 0.03
F2	3.40 ± 0.04	9.03 ± 0.02
F3	3.38 ± 0.04	9.01 ± 0.03
F4	3.36 ± 0.03	9.02 ± 0.02
F5	3.35 ± 0.03	9.00 ± 0.02
F6	3.33 ± 0.02	9.01 ± 0.02
F7	3.32 ± 0.02	9.00 ± 0.02
F8	3.30 ± 0.02	8.99 ± 0.01
F9	3.29 ± 0.02	8.99 ± 0.01
F10	3.28 ± 0.02	8.98 ± 0.01
Marketed tablet	3.31 ± 0.03	9.00 ± 0.02

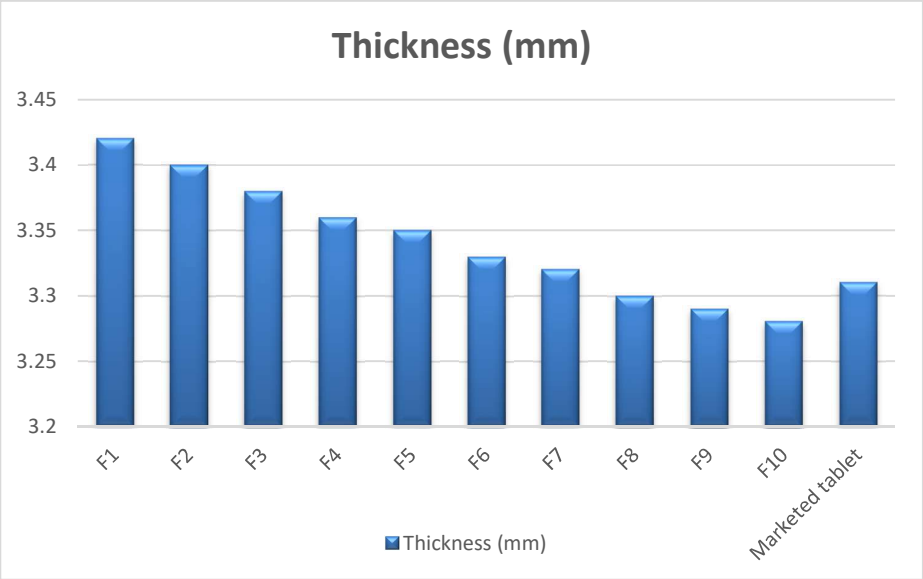

Fig 5.8: Thickness

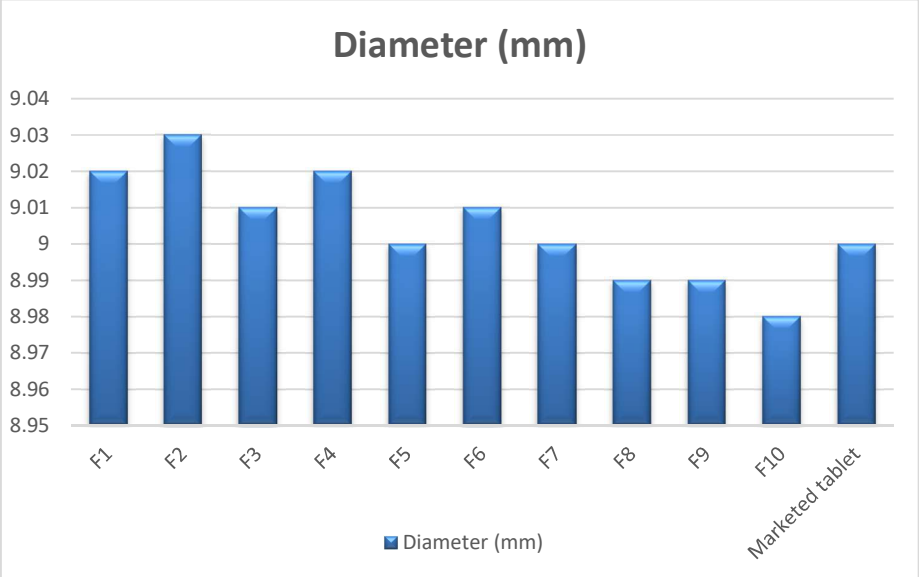

Fig 5.9: Diameter (mm)

5.3.1.3 Hardness

In order to determine their mechanical strength and capacity to tolerate handling stresses during production, packaging, and transportation, the hardness of the marketed tablet and the designed tablets (F1–F10) was assessed. The generated formulations' hardness values varied from 3.10 ± 0.12 kg/cm² (F1) to 3.75 ± 0.06 kg/cm² (F10), whereas the hardness of the commercial tablet was 3.70 ± 0.05 kg/cm². From F1 to F10, a gradual rise in hardness was noted, suggesting enhanced binding effectiveness and more robust interparticulate bonding with formulation improvement.

The subsequent formulations' increased hardness indicates improved tablet integrity and improved powder mix compressibility without sacrificing structural stability. The hardness values of Formulation F10 were nearly identical to those of the commercial tablet, suggesting equivalent mechanical strength. All formulations, taken as a whole, showed sufficient hardness within an acceptable range, guaranteeing enough mechanical integrity for additional handling and assessment.

Table 5.13: Hardness of Tablets

Formulation	Hardness (kg/cm²)
F1	3.10 ± 0.12
F2	3.18 ± 0.10
F3	3.25 ± 0.11
F4	3.32 ± 0.09
F5	3.40 ± 0.10
F6	3.48 ± 0.08

F7	3.55 ± 0.09
F8	3.62 ± 0.08
F9	3.68 ± 0.07
F10	3.75 ± 0.06
Marketed tablet	3.70 ± 0.05

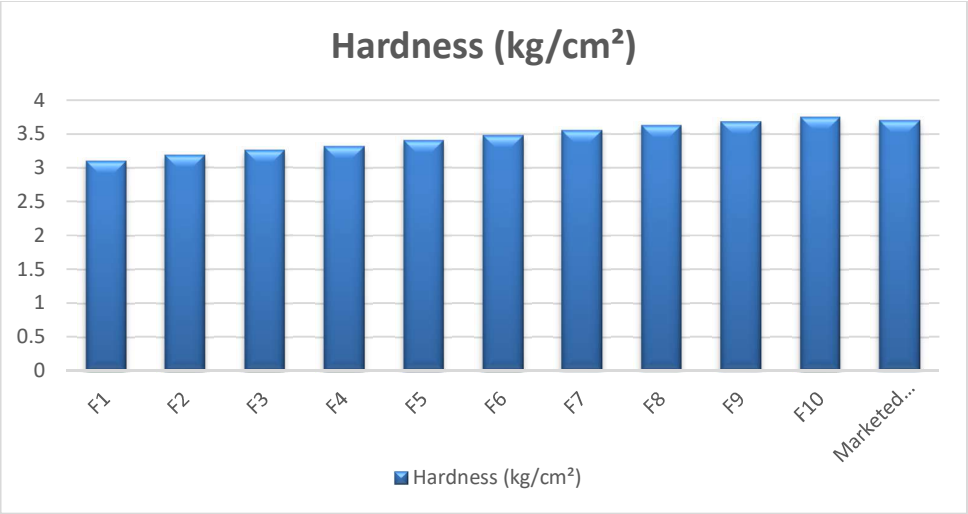

Fig 5.10: Hardness (kg/cm²)

5.3.1.4 Friability

In order to determine how resistant the marketed tablet and the prepared tablets (F1–F10) were to mechanical stress during handling, packaging, and transportation, their friability was assessed. While the marketed tablet had a friability of 0.52 ± 0.01%, the produced formulations' friability values varied from 0.82 ± 0.03% (F1) to 0.55 ± 0.01% (F10). From F1 to F10, there was a progressive reduction in friability, which suggests that formulation modification enhanced mechanical strength and interparticle bonding. Every formulation showed friability values that were much below the permissible limit of 1%, indicating sufficient mechanical integrity. Out of all the batches, F10 showed friability that was closest to the commercial formulation, suggesting similar durability and better abrasion resistance.

Table 5.14: Friability of Tablets

Formulation	Friability (%)
F1	0.82 ± 0.03
F2	0.79 ± 0.02
F3	0.76 ± 0.02
F4	0.73 ± 0.02
F5	0.70 ± 0.02
F6	0.67 ± 0.02

F7	0.64 ± 0.01
F8	0.61 ± 0.01
F9	0.58 ± 0.01
F10	0.55 ± 0.01
Marketed tablet	0.52 ± 0.01

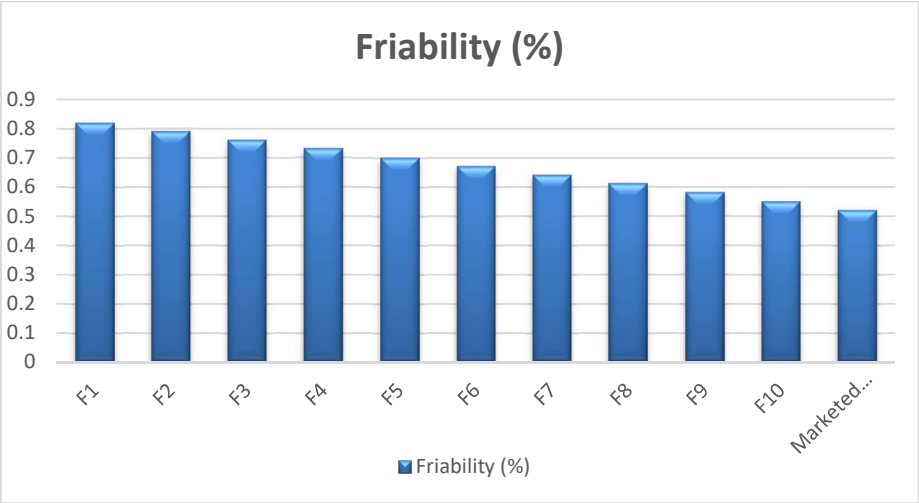

Fig 5.11: Friability (%)

5.4 Functional Evaluation

5.4.1 Wetting time

The effectiveness of water uptake, a crucial factor for quickly dissolving tablets, was assessed by comparing the wetting times of the manufactured tablet with the designed tablets (F1–F10). While the marketed tablet showed a wetting time of 30.5 ± 0.5 s, the produced formulations' wetting time values varied from 58.4 ± 1.6 s (F1) to 32.8 ± 0.6 s (F10). From F1 to F10, a gradual reduction in wetting time was noted, suggesting enhanced hydrophilicity and quicker dissolving medium penetration into the tablet matrix with formulation improvement. This shorter wetting time indicates improved disintegration behavior and increased capillary action in the modified formulations. Out of all the batches, F10 exhibited the wetting time that was closest to the commercial formulation, suggesting similar performance in terms of quick wetting and appropriateness for tablet applications that dissolve quickly.

Table 5.15: Wetting Time of Tablets

Formulation	Wetting Time (sec)
F1	58.4 ± 1.6
F2	55.2 ± 1.4
F3	52.6 ± 1.3

F4	49.8 ± 1.2
F5	46.5 ± 1.1
F6	43.2 ± 1.0
F7	40.6 ± 0.9
F8	38.1 ± 0.8
F9	35.4 ± 0.7
F10	32.8 ± 0.6
Marketed tablet	30.5 ± 0.5

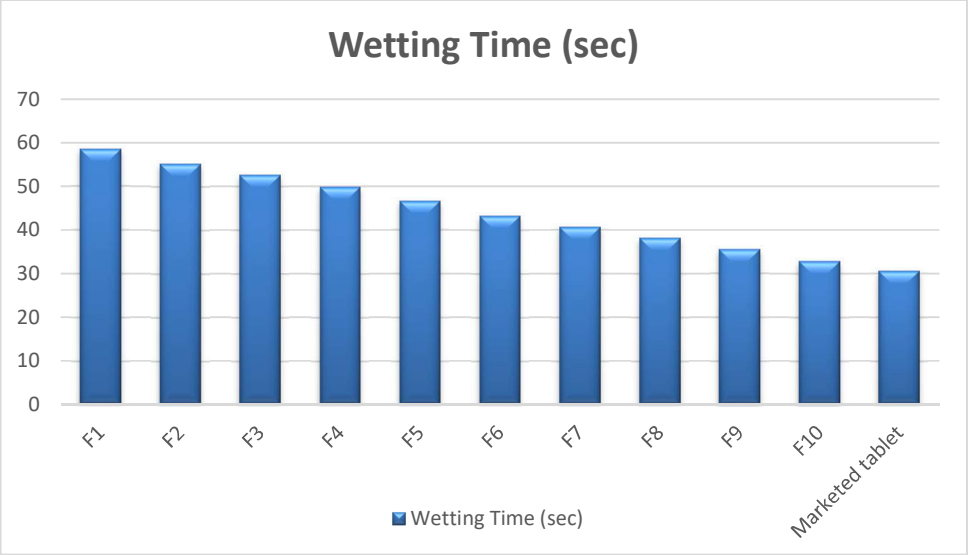

Fig 5.12: Wetting Time (sec)

5.4.2 Water absorption ratio

The ability of the marketed tablet and the designed tablets (F1–F10) to absorb water, which directly affects swelling and disintegration behavior in fast dissolving tablet systems, was assessed. The developed formulations' water absorption ratios varied from 48.2 ± 1.5% (F1) to 87.6 ± 0.6% (F10), with the marketed tablet having the highest value at 90.2 ± 0.5%. From F1 to F10, a steady rise in the water absorption ratio was seen, suggesting that formulation optimization had increased the hydrophilicity and porous structure of the tablet matrix. Better swelling behavior and quicker disintegration commencement are suggested by this enhanced water absorption ability. Among all formulations, F10 showed the closest value to the marketed tablet, indicating comparable efficiency in water uptake and overall performance suitable for rapid tablet disintegration.

Table 5.16: Water Absorption Ratio of Tablets

Batch /	Water Absorption Ratio

Formulation	(%)
F1	48.2 ± 1.5
F2	52.6 ± 1.4
F3	56.9 ± 1.3
F4	61.3 ± 1.2
F5	65.8 ± 1.1
F6	70.4 ± 1.0
F7	74.9 ± 0.9
F8	79.5 ± 0.8
F9	83.1 ± 0.7
F10	87.6 ± 0.6
Marketed tablet	90.2 ± 0.5

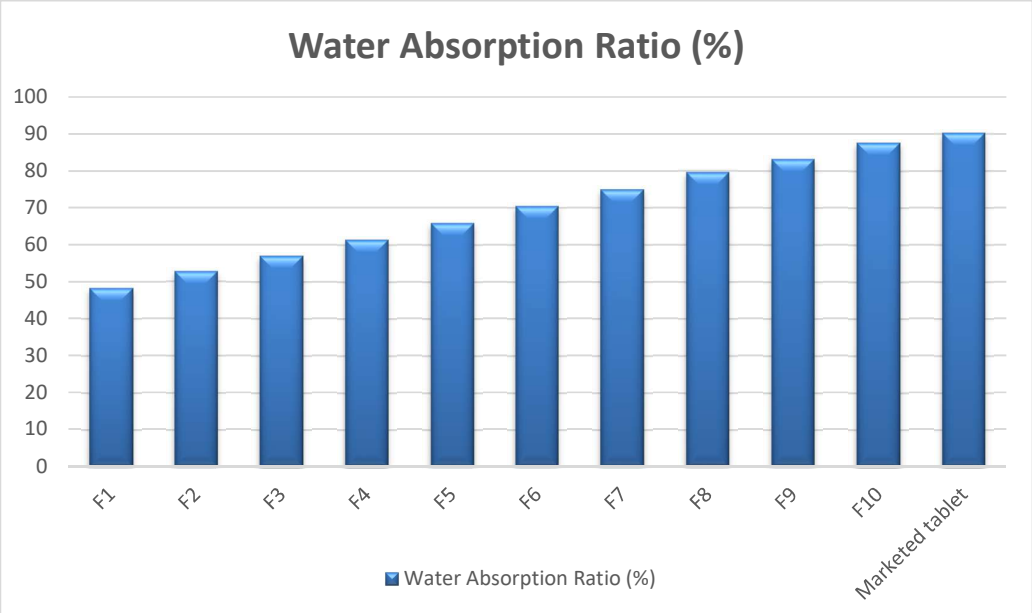

Fig 5.13: Water Absorption Ratio (%)

5.4.3 Drug Content Determination

To guarantee consistent distribution of the active pharmaceutical ingredient inside each dosage unit and to verify dose accuracy, the drug content uniformity of the designed tablets (F1–F10) and the commercial tablet was assessed. The drug content of the marketed tablet was 99.2 ± 0.2%, but the drug content of the manufactured formulations varied from 94.2 ± 0.8% (F1) to 99.6 ± 0.2% (F10). From F1 to F10, a gradual rise in drug content was noted, suggesting enhanced blending effectiveness and better drug distribution within the formulation matrix with formulation variable adjustment. The following batches' increased medication content readings indicate improved content

consistency and less processing variability. Excellent dose consistency and satisfactory compliance with pharmacopoeial standards were confirmed by F10, which showed the greatest drug concentration among all formulations and closely matched the marketed formulation.

Table 5.17: Drug Content Uniformity of Tablets

Batch / Formulation	Drug Content (%)
F1	94.2 ± 0.8
F2	95.0 ± 0.7
F3	95.8 ± 0.6
F4	96.5 ± 0.5
F5	97.1 ± 0.5
F6	97.8 ± 0.4
F7	98.3 ± 0.4
F8	98.9 ± 0.3
F9	99.3 ± 0.3
F10	99.6 ± 0.2
Marketed tablet	99.2 ± 0.2

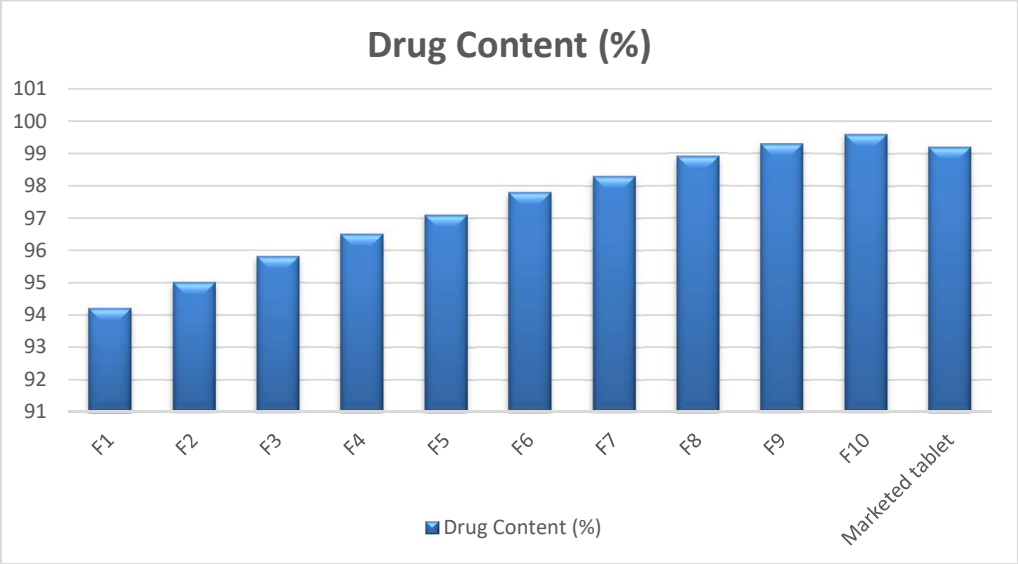

Fig 5.14: Drug Content (%)

5.5 In Vitro Drug Release

Using phosphate buffer (pH 6.8) as the dissolve medium, the in vitro cumulative drug release of the manufactured tablet and the formulated tablets (F1–F10) was assessed over a 10-minute period to evaluate the release performance of the fast dissolving tablet formulations. All formulations showed a time-dependent increase in drug release, according to the data. Drug release varied from 18.5 ± 0.8% (F1) to 48.7 ± 0.3% (F10) at 2 minutes, whereas the commercial tablet displayed 50.2 ± 0.3%. The marketed formulation achieved complete release of 100.0 ± 0.1% at 10 minutes, but the cumulative drug release rose significantly, ranging from 80.2 ± 0.6% (F1) to 99.8 ± 0.1% (F10). From F1 to F10, a steady improvement in drug release was noted, suggesting improved dissolution and disintegration behavior with formulation adjustment. F10 demonstrated the fastest and highest drug release profile of all batches, closely resembling the commercial tablet. This suggests that F10 performs best in terms of quick drug availability and effective formulation design for fast-dissolving drug delivery systems.

Table 5.18: In Vitro Cumulative Drug Release of Tablets

Formulation	2 min (%)	4 min (%)	6 min (%)	8 min (%)	10 min (%)
F1	18.5 ± 0.8	35.2 ± 0.9	52.6 ± 0.8	68.4 ± 0.7	80.2 ± 0.6
F2	21.2 ± 0.7	38.9 ± 0.8	56.3 ± 0.7	72.1 ± 0.6	83.7 ± 0.5
F3	24.6 ± 0.6	42.6 ± 0.7	60.8 ± 0.6	76.5 ± 0.5	87.5 ± 0.4
F4	28.1 ± 0.6	46.8 ± 0.6	65.2 ± 0.5	80.9 ± 0.5	91.3 ± 0.4
F5	31.5 ± 0.5	50.9 ± 0.6	69.8 ± 0.5	85.3 ± 0.4	94.6 ± 0.3
F6	35.0 ± 0.5	55.1 ± 0.5	73.9 ± 0.4	89.6 ± 0.4	97.2 ± 0.3
F7	38.4 ± 0.4	59.0 ± 0.5	78.2 ± 0.4	92.8 ± 0.3	98.8 ± 0.2
F8	42.0 ± 0.4	63.5 ± 0.4	82.6 ± 0.3	95.4 ± 0.3	99.2 ± 0.2
F9	45.3 ± 0.3	67.8 ± 0.4	86.1 ± 0.3	97.1 ± 0.2	99.5 ± 0.2
F10	48.7 ± 0.3	71.2 ± 0.3	89.4 ± 0.3	98.2 ± 0.2	99.8 ± 0.1
Marketed	50.2 ± 0.3	73.5 ± 0.3	91.0 ± 0.2	99.0 ± 0.2	100.0 ± 0.1

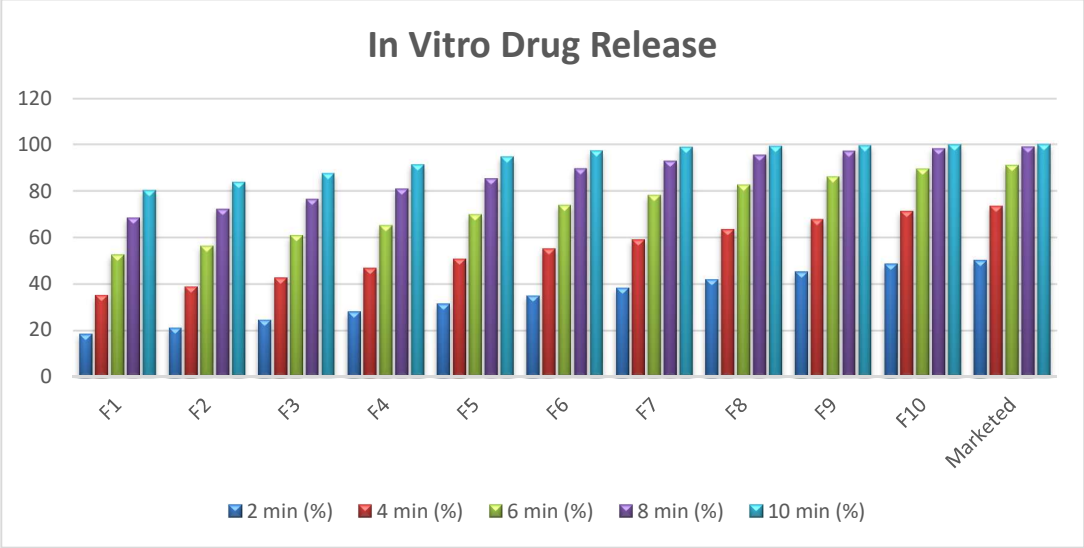

Fig 5.15: In Vitro Drug Release

5.6 Stability Studies as per ICH Guidelines

To assess the impact of environmental stress on the physical and performance properties of the tablets, a three-month stability study of the optimized formulation (F10) was carried out under accelerated ICH conditions (40 ± 2°C and 75 ± 5% RH). According to the findings, there was no discernible change in the formulation's look during the course of the trial. While friability showed a tiny increase from 0.55 ± 0.01% to 0.58 ± 0.02%, staying well within acceptable limits, hardness only slightly decreased from 3.75 ± 0.06 kg/cm² at the initial time point to 3.70 ± 0.04 kg/cm² after three months. The drug content decreased slightly from 99.6 ± 0.2% to 99.0 ± 0.3%, demonstrating strong chemical stability of the formulation, although it remained consistently high with little change. The wetting time increased slightly from 32.8 ± 0.6 s to 33.8 ± 0.8 s, indicating that the quick wetting behavior continued throughout the storage period. Similarly, sustained drug release performance was confirmed by in vitro dissolution at 10 minutes, which revealed only a slight decrease from 99.8 ± 0.1% to 99.2 ± 0.2%. Overall, the findings show that formulation F10 demonstrated outstanding stability under accelerated settings with no discernible deterioration in its functional or physical characteristics, demonstrating its appropriateness for long-term storage.

Table 5.19: Stability Study of Optimized Formulation (F10) as per ICH Conditions

Parameter	Initial (0 Month)	1 Month	2 Months	3 Months
Appearance	No change	No change	No change	No change

Hardness (kg/cm²)	3.75 ± 0.06	3.73 ± 0.05	3.71 ± 0.05	3.70 ± 0.04
Friability (%)	0.55 ± 0.01	0.56 ± 0.01	0.57 ± 0.02	0.58 ± 0.02
Drug Content (%)	99.6 ± 0.2	99.4 ± 0.2	99.2 ± 0.3	99.0 ± 0.3
Wetting Time (sec)	32.8 ± 0.6	33.1 ± 0.7	33.4 ± 0.7	33.8 ± 0.8
Dissolution at 10 min (%)	99.8 ± 0.1	99.6 ± 0.1	99.4 ± 0.2	99.2 ± 0.2

Conclusion

In order to achieve rapid medication release, better dissolution behavior, and increased patient compliance, the current study effectively concentrated on the formulation and assessment of fast-dissolving pantoprazole tablets. Pantoprazole has a sharp melting point (140–144°C), moderate lipophilicity (Log P 0.76 ± 0.02), and pH-dependent solubility with maximal solubility in acidic medium, all of which are appropriate physicochemical characteristics for the production of oral solid dosage forms, according to preformulation studies.

A total of ten formulations (F1–F10) were created and thoroughly assessed. The pre-compression investigations showed a steady improvement in compressibility and flow characteristics from F1 to F10, suggesting that powder mixes were successfully optimized for direct compression. All formulations satisfied pharmacopeial standards for weight variation, hardness, friability, and dimensional uniformity, guaranteeing good mechanical integrity and content uniformity, according to post-compression evaluation.

With an outstanding wetting time (32.8 ± 0.6 s), a high water absorption ratio (87.6%), and quick in vitro drug release (99.8% within 10 minutes), the improved formulation (F10) outperformed all batches. These outcomes demonstrated successful formulation optimization since they were similar to the commercial formulation. Drug distribution

uniformity and dose accuracy were further validated by drug content uniformity (99.6 ± 0.2%).

Formulation F10's robustness and suitability for storage were confirmed by accelerated stability testing carried out under ICH conditions, which showed that it remained stable over three months with no discernible changes in physical appearance, mechanical strength, drug content, or dissolving profile.

In conclusion, with its quick start of action, increased bioavailability potential, and improved patient compliance, the new fast-dissolving tablet of pantoprazole (F10) can be regarded as a prospective substitute for traditional dosage forms. The study's goal of creating a fast-dissolving tablet technology that is reliable, effective, and performs on par with the commercial product was successfully accomplished.

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