RESEARCH ARTICLE

Ecofriendly and Sustainable Pharmaceutical Primary Packaging Materials of Solid Dosage Form

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Abstract

The selection of appropriate paper-based materials for pharmaceutical primary packaging is crucial to ensure protection, stability, and compliance with regulatory standards. Various paper types, including butter paper, bleached kraft paper, glassine paper, glossy paper, cellophane paper, and Whatman paper, were evaluated based on key parameters such as thickness, tensile strength, folding endurance, water absorption, water permeability, GSM, and moisture content. Among these, glassine paper was identified as the most suitable material, as its properties closely matched the standard requirements for pharmaceutical-grade packaging. Despite its advantages, glassine paper exhibits limitations in terms of moisture resistance, mechanical strength, and barrier properties. To enhance its functionality and performance, coating techniques were explored to develop an eco-friendly paper-based packaging material for solid dosage forms. These coatings aim to improve moisture resistance, increase mechanical durability, and enhance barrier properties, making the material more effective for pharmaceutical applications. The development of such sustainable packaging aligns with the growing demand for environmentally friendly alternatives while ensuring the safety and stability of pharmaceutical products. This study provides a framework for optimizing paper-based packaging solutions in compliance with pharmaceutical packaging standards.

Highlights:

- Evaluate different existing primary paper-based packaging materials.
- From the existing packaging materials selection of Glassine paper based on quality control test of the packaging materials.
- Glassine paper has limitations in moisture resistance, mechanical strength and barrier properties, necessitating further enhancement.
- Enhancing paper functionality by coating techniques improves moisture resistance and durability, making it more suitable for pharmaceuticals.

Keywords: Ecofriendly Material, Pharmaceutical Packaging, Primary Packaging, Glassine Paper.

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Introduction

Packaging is a technique that maintains a pharmaceutical product from the generation to its use. Pharmaceutical packaging materials are utilized for enclosing pharmaceutical products. Packaging helps in protecting the products during storage transportation and also while usage. Packaging serves an important purpose of retaining the product in a long shelf life, by avoiding atmospheric. (Amarji et.al., 2018) The selection of eco-friendly paper-based primary packaging materials ensures natural decomposition, thereby reducing long-term environmental impact. Using eco-friendly paper-based primary packaging materials helps us to achieve natural decomposition, which is less effective at affecting the environment in the long run (Aminabhavi et.al., 2006). It can be recycled many times, promoting circularity. It disposes perfectly well at the end of its life. Various research and development projects have been initiated to encourage the usage of eco-friendly and biodegradable packing materials. Sustainable Packaging materials are materials that are sourced, developed and used for packaging solutions to have minimal impact on the environment and that best fit a product's life cycle (Ashiwaju et.al, 2024). In other words, sustainable packaging materials earth-friendly packaging and cause the exhaustion of natural resources (Adibi et.al, 2023).

Conversely, not all eco-friendly packaging materials can decompose, but all biodegradable materials are eco-friendly (Basak et.al, 2024). Moreover, the terms are sometimes used interchangeably, though they represent different facets of environmental sustainability, for instance, the confusion between "eco-friendly" and "biodegradable" (Deshwal et.al, 2019). All biodegradable materials are eco-friendly, whereas not all environmentally sustainable materials are biodegradable. Moreover, not every biodegradable is compostable, while every compostable material is biodegradable by nature. Primary packaging means the package that touches the medicine directly or the pharmaceutical product. Its main function is to protect the formula from natural, chemical, mechanical, and other hazards (Das et.al, 2018). Secondary packaging, however, is the outermost layer that encloses the primary packaging. It is an extra layer of protection and frequently also offers logistical and branding functions.

Tertiary Packaging are package used for warehouse storage and transport shipping (El-Sakhawy et.al, 2016).

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An ideal pharmaceutical-grade paper must meet several essential criteria to ensure the safety, stability, and effectiveness of the packaged drug product. Firstly, it must be chemically inert, ensuring no interaction or contamination with the pharmaceutical formulation. High moisture resistance is crucial, as it protects the contents from degradation due to humidity. Additionally, the paper should be free from any excipients, harmful additives, or toxic substances that may pose health risks. Its composition must consist of high-quality fibers, and manufacturing should occur under controlled conditions to prevent the presence of impurities or microbial contamination. Mechanically, the paper should be strong and durable enough to endure various physical stresses during storage, handling, and transportation without tearing or puncturing (Fadel et al., 2022). Furthermore, it should offer excellent printability to support clear labelling and regulatory compliance, ensuring that critical product information is legible. As part of a comprehensive packaging system, the paper must act as a barrier to environmental factors such as moisture, contaminants, and light, thereby preserving the integrity and shelf life of the pharmaceutical product. Finally, compliance with international regulatory standards, including those set by the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMA), is essential for its acceptance and use in the pharmaceutical industry (Gadhave et al., 2022).

Types of Major Packaging Materials

Plastic Packaging Materials

Plastic is widely utilized in packaging applications due to its excellent strength, durability, and cost-effectiveness. Its lightweight nature not only makes handling and transportation more efficient but also contributes to energy savings during production and distribution. Various types of plastics are commonly used in the packaging industry, including Polypropylene (PP), Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), Polystyrene, PETG (Polyethylene Terephthalate Glycol Copolymer), and Cellulose Acetate Butyrate (CAB). These materials offer versatility, as they can be molded into different shapes and sizes to accommodate a wide range of packaging needs.

One of the major benefits of plastic packaging is its mechanical strength and ability to protect contents from external damage. Its flexibility in design allows for innovative and functional packaging solutions. In addition, the transparency of certain plastics enables consumers to visually inspect the product without opening the package. Some types of plastics have also been developed to be biodegradable, offering a more environmentally conscious option compared to traditional plastics.

However, despite these advantages, plastic packaging poses several environmental concerns. When subjected to heat or prolonged exposure to sunlight, some plastics may release potentially harmful chemicals. Moreover, plastic waste can degrade into microplastics, which are persistent in the environment and pose risks to ecosystems and human health. As most conventional plastics are not biodegradable, they contribute significantly to long-term pollution, making plastic packaging a major environmental challenge worldwide.

Metal Packaging Materials

Metal packaging plays a crucial role in product preservation, particularly in the form of "canning," a process widely used to protect goods—including pharmaceuticals—from microbial contamination and spoilage. This method has become an integral part of modern packaging systems, especially in industrialized regions where long shelf life and product stability are essential. Common metals used for packaging include aluminium, steel, and tin, each offering unique protective properties.

One of the primary benefits of metal packaging is its exceptional strength and durability, which ensures product integrity during storage and transportation. Additionally, metals like aluminium and steel are highly recyclable and can undergo multiple recycling processes without significant degradation in quality, supporting sustainability efforts within the packaging industry.

Despite these advantages, metal packaging presents certain challenges. It is generally heavier than alternative materials like plastic or paper, which can increase transportation costs and environmental impact. Furthermore, metal—especially aluminum—can be more costly to produce and process compared to other packaging materials. In terms of design, metals are less flexible than plastics and may not be suitable for complex shapes or intricate packaging forms, limiting their versatility in some applications.

Paper Packaging Materials

Paper-based packaging materials are primarily sourced from renewable resources, including trees and recycled paper fibers, making them an environmentally sustainable choice. These materials are widely used due to their biodegradability and recyclability, and they represent one of the most recycled packaging types by weight, particularly in countries like the United States. Common examples of paper-based packaging include kraft paper, vegetable parchment paper, bleached kraft paper, wrapping tissue, sulfite paper, and greaseproof paper.

One of the key advantages of paper-based packaging is its compatibility with adhesives and ease of printability, which allows for cost-effective labelling and branding. Many of these materials are approved for direct contact with food, further enhancing their versatility in pharmaceutical and food packaging. Additionally, paper can perform better than some plastics under extreme temperatures, offering stability in both high and low thermal environments.

However, paper materials also have notable limitations. They are naturally permeable to moisture, vapours, and various solvents, which can compromise product integrity in certain applications. Most paper types are not inherently resistant to grease or oil unless specially treated. Moreover, they generally lack heat stability, which can restrict their use in applications requiring thermal processing or high-temperature exposure.

Different paper-based materials

Craft Paper

Craft paper is a robust, adaptable material widely utilized in packaging due to its high tensile strength, durability, and environmental compatibility. It is produced through the Craft process, where wood pulp is chemically treated to remove lignin while retaining cellulose fibers, resulting in a strong and tear-resistant structure. Typically brown in color, Craft paper can also be bleached for specific applications. Its flexibility, moderate moisture resistance, and recyclability make it a popular choice for pharmaceutical primary packaging, food wrapping, industrial applications, and the manufacture of corrugated boxes. In pharmaceutical settings, Craft paper is often used for pouch packaging, protective wrapping, and labelling, owing to its mechanical resilience, biodegradability, and printability. It may also be coated or laminated to improve its resistance to moisture, grease, and external contaminants, enhancing its functionality in more demanding environments (Hamdani et al., 2023).

Despite these benefits, Craft paper has several limitations that restrict its use in certain pharmaceutical applications. Its high absorbency and limited moisture barrier capabilities can compromise the stability of moisture-sensitive dosage forms. Additionally, the material lacks inherent protection against light, air, and microbial intrusion, which are essential factors for preserving drug integrity and shelf life. Although relatively strong, Craft paper remains susceptible to tearing and puncturing under mechanical stress during storage and transportation. Furthermore, it has poor heat-sealability and a porous surface that may hinder print clarity, potentially affecting labelling accuracy and regulatory compliance.

Butter paper

Butter paper is a specialized packaging material valued for its durability, grease resistance, and moderate moisture resistance, making it suitable for food and pharmaceutical applications. It is produced by treating refined cellulose fibers with sulfuric acid or zinc chloride, which partially gelatinizes the fiber surface. This treatment increases the paper's density and imparts enhanced barrier properties against oil, air, and water, while maintaining its flexibility and ease of folding. Due to its chemical stability and non-stick characteristics, butter paper is frequently used for packaging moisture-sensitive pharmaceutical dosage forms, such as tablets and capsules. It offers a smooth surface ideal for printing and labelling, supporting regulatory compliance. Furthermore, its biodegradable nature and low environmental impact make it a sustainable alternative to synthetic packaging materials (Hui et al., 2020).

However, despite these beneficial properties, butter paper has several limitations in pharmaceutical packaging. Its resistance to moisture and humidity is limited, making it less effective for protecting products from water-induced degradation. In terms of mechanical properties, it falls short when compared to other packaging papers like glassine or bleached kraft paper, being more prone to tearing and physical damage. The material also lacks sufficient chemical resistance, which may pose a risk of interaction with sensitive pharmaceutical formulations. Additionally, vegetable parchment paper exhibits poor heat-sealability, resulting in less secure sealing and reduced tamper-evidence—both critical requirements in pharmaceutical packaging.

Whatman paper

Whatman paper, often produced through the paper pulping process, is a high-strength material derived from wood pulp that has undergone chemical treatment to remove lignin and achieve a bright white appearance. This processing not only enhances its aesthetic appeal but also contributes to its excellent tensile strength, durability, and flexibility. Its smooth surface and clean finish make it particularly suitable for applications that require high print quality, such as pharmaceutical secondary packaging, labelling, and branding. The paper's mechanical integrity supports its use in various industrial and packaging contexts where tear resistance and visual clarity are important (Ibrahim et al., 2021).

Despite these advantages, Whatman paper presents several limitations when used in pharmaceutical packaging. Its low resistance to moisture and humidity makes it unsuitable for protecting formulations that are sensitive to environmental conditions. Additionally, the paper lacks sufficient barrier properties against oxygen, light, and external contaminants, which are critical for maintaining drug stability and shelf life. Its chemical resistance is also limited, meaning exposure to solvents, oils, or active pharmaceutical ingredients may compromise the packaging's integrity and lead to contamination. Furthermore, Whatman paper does not possess inherent heat-sealing capabilities, which restricts its use in applications requiring secure and tamper-evident closures.

Glossy paper

Glossy paper is a specialized packaging material engineered to resist oil and fat penetration, making it suitable for food and certain pharmaceutical applications. It is produced through an intensive refining process in which cellulose fibers are densely compacted to form a non-porous structure that effectively blocks grease. This compact composition allows for lightweight, biodegradable, and durable packaging, while also providing a smooth surface suitable for printing and labelling. In some cases, greaseproof paper may be further treated with wax or chemical agents to enhance its oil-resistant properties. Its eco-friendly profile and functionality make it a viable choice for applications where oil resistance is essential but moisture protection is less critical (Indiarto et al., 2020).

However, glossy paper presents several drawbacks when evaluated for pharmaceutical primary packaging. Its poor resistance to moisture makes it unsuitable for protecting formulations vulnerable to humidity and water vapor. Additionally, its mechanical strength is limited in comparison to more robust paper materials like glassine or laminated films, rendering it more susceptible to tearing during handling and transportation. It also lacks sufficient chemical and gas barrier properties, which are essential for maintaining drug stability and extending shelf life. Furthermore, glossy paper offers weak heat-sealing capability, compromising its effectiveness in forming secure and tamper-evident packaging. Due to these limitations, it often does not meet the stringent regulatory standards required for direct-contact pharmaceutical packaging.

Glassine Paper

Glassine paper is a lightweight, smooth, and translucent material produced through supercalendering, a finishing process that compacts and polishes the paper to increase its density, gloss, and grease resistance. Made from highly refined wood pulp, it exhibits non-porous, pH-neutral, and chemically stable characteristics, making it a reliable choice for a variety of packaging applications. Its semi-permeable nature allows for moderate resistance to moisture and air while maintaining flexibility and mechanical integrity. These properties make glassine paper especially suitable for use in pharmaceutical, food, and industrial packaging. In the pharmaceutical sector, it is commonly applied in strip packs, blister pack backings, and protective liners due to its favourable combination of moisture resistance, printability, and environmental sustainability. Moreover, glassine is both biodegradable and recyclable, supporting eco-conscious packaging practices (Jasmani et al., 2021).

Despite these advantages, glassine paper has notable limitations. Its inherent resistance to moisture and humidity is relatively low, which can compromise the stability of sensitive pharmaceutical products. Additionally, its mechanical durability and barrier performance may fall short of the stringent requirements set by pharmaceutical regulatory bodies for primary packaging. As a result, uncoated glassine may not fully meet compliance standards for direct-contact pharmaceutical use. However, these deficiencies can be mitigated through the application of functional coatings that enhance its water resistance, sealability, and overall protective capabilities.

Materials and Methods

Different existing primary packaging materials like Butter paper, aluminium paper, Glossy paper, Whatman paper, Bleached craft paper were purchased from the Gujarat Scientific Rajkot, White cardboard paper, Food Packaging materials were purchased from the Arpan Globe Rajkot, Sugarcane packaging materials were purchased from the local market in Rajkot, glassine paper gift sample was provided from the SunPro Group of Companies Ahmedabad, Cellophane packaging materials. Fig 1a illustrates the currently available eco-friendly materials.

Weighing balance (made by Shimadzu, ATX224, Japan), Desiccator (made by HOVERLABS HV-DE-505, Haryana), Digital Calipers (made by INSIZE INDIA, IP67, Ahmedabad), Tensile tester (made by HEICO, HE500.15, New Delhi), were used to for study.

The following strategies were used to fabricate and optimize eco-friendly packaging materials. Paper-based materials such as Butter paper, aluminium paper, glossy paper, Whatman paper, bleached craft paper, white cardboard paper, glassine paper, food Packaging materials, sugarcane packaging materials, etc. Table 1, mentions the Properties of Existing Eco-friendly Materials.

Methods for selection of suitable paper for pharmaceutical packaging involves evaluating several key physical parameters, including thickness and moisture content, among others.

Thickness

Also referred to as calliper, is a fundamental property that influences the mechanical performance of paper. It is typically measured using digital vernier callipers, where a single sheet is placed between the instrument's jaws, and the distance between them is recorded. A single sheet of paper's thickness can be seen with digital callipers as shown in Fig 1b. For more accurate measurement using manual callipers, a bundle of sheets may be used, and the total thickness is divided by the number of sheets to calculate the average thickness (Kirwan et al., 2011).

Moisture content

Moisture content is another critical factor, as it affects the paper's stability, barrier properties, and suitability for pharmaceutical applications. In Fig 1c shown the moisture content study of paper. To determine this, the initial weight of each paper sample is recorded before placing it in a desiccator containing anhydrous calcium chloride, which acts as a drying agent to maintain a low-humidity environment. A thin layer of silicone oil is applied at the junction between the lid and body of the desiccator to ensure an airtight seal. After remaining in the desiccator overnight, the samples are reweighed to calculate the moisture loss, which reflects the material's moisture content (Kjellgren et al., 2006).

Grammage

Grammage or basis weight, is a measure of the mass of paper per unit area and is expressed in grams per square meter (GSM). According to Indian Standard IS 1060-Part I (1987), this test involves cutting paper samples into uniform dimensions, typically 10 cm × 10 cm, and weighing them using a precision balance. Multiple samples (at least ten) are tested, and the

Table 1: Properties of Existing Eco-Friendly Materials

Types of Paper	*Properties of Paper*	*Manufacturing Company*	*Applications*
Glassine Paper	Moisture Resistance	Pudumjee Paper Products Ltd.	Strip Package
Butter Paper	Moisture resistance, Greaseproof, heat resistance	RK Enterprise Mumbai	Weighing of excipient and API
Whatman Paper	High purity, chemical resistance, Thermal stability	Pall Corporation	Commonly used for gravity filtration in chemical and biological experiments.
Glossy Paper	Smooth surface, strength, durability	Fantac Culture Development	Primary used for packaging and labelling.
PVDC Film	Transparency, Chemical resistance	Rajat Vinyl PVT LTD.	Pharmaceutical industry for primary packaging.
Craft Paper	Smooth, Translucent, Greaseproof, Biodegradable	Ekvee Food Wrapping Paper	Used for inner liner for secondary packaging to prevent ingress.
Currently used Alu-Alu film	Tensile strength, thickness, durability, greaseproof	Erva Healthcare	Used for pharmaceutical primary packaging

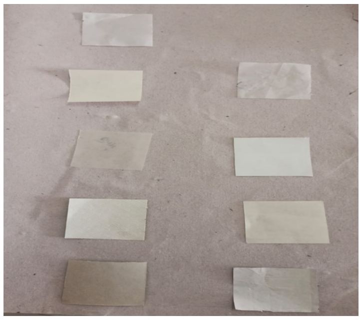

Fig. 1a: Existing Eco-friendly materials

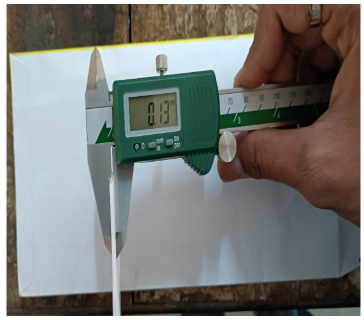

Fig. 1b: Measure Thickness of Paper

Fig. 1c: Moisture content

average value is calculated to ensure consistency and accuracy (Kumar S. et al., 2012; Kumar P. et al., 2022).

Water permeability test

Water permeability test assesses the ease with which water or vapor passes through the paper's surface, indicating its effectiveness as a barrier. For this test, square samples measuring 15 mm × 15 mm are mounted on a water permeability tester. One side of the paper is exposed to water, while the opposite side is subjected to controlled air pressure. The amount of air that permeates through the sample within a specific time is recorded using a timer, providing an estimate of the paper's permeability to moisture (Kunam et al., 2024).

Water absorption test

The water absorption test determines the material's ability to retain water, which is particularly relevant for moisture-sensitive pharmaceutical applications. The test begins by drying the paper samples in an oven under controlled conditions. After cooling in a desiccator, the samples are weighed, then immersed in water maintained at 23°C for a 24-hour period or until saturation. Post-immersion, excess surface water is removed using a lint-free cloth, and the samples are reweighed. The difference in weight before and after immersion indicates the amount of water absorbed by the paper (Khwaldia et al., 2010; Li Z et al., 2018).

Grease resistance test

The Grease resistance test evaluates the paper's ability to prevent penetration by oily substances. In this procedure, the paper sample is placed on a mound of sand with the surface to be tested facing upward. A drop of turpentine oil is applied to the paper without allowing the dropper to touch the surface. The specimen is then placed in a preheated oven at 60°C for six minutes. After removal, any excess oil is gently blotted using an absorbent medium. The paper is then examined for signs of penetration such as black staining, pinholes, or discoloration at the drop site. The highest concentration of the test solution that does not result in visible failure is recorded as the grease resistance threshold (Lotoshynska et al., 2021; Langmaier et al., 2008).

Tensile Strength

The tensile strength test measures the paper's resistance to breaking under tension, reflecting its mechanical integrity and durability. Paper strips, approximately 1 inch wide and 6 inches long, are clamped into a tensile testing machine with careful alignment to prevent slippage. As the machine applies force, it records the maximum load the strip can withstand before breaking. This value is used to calculate tensile strength in kilonewtons per meter (kN/m) by dividing the average breaking force by the sample width. The test is typically performed in quintuplicate to ensure accuracy and reproducibility (Muhlfeld et al., 2012).

Folding endurance test

The folding endurance test assesses the paper's capacity to resist repeated folding, which simulates mechanical stress during packaging, handling, or use. Uniform paper strips are first inspected to ensure they are free from visible defects. One end of the strip is held in place while the free end is manually or mechanically folded at an approximate angle of 135 degrees, repeatedly in the same direction. The number of folds completed before the paper tears is recorded as the folding endurance. This measure reflects the flexibility and fiber integrity of the material (Mukhopadhyay et al., 2017).

GSM

The GSM (grams per square meter) is a standard metric used to determine the basic weight of paper or paperboard. It serves as an important indicator of the material's thickness, density, and overall strength. Typically, a higher GSM corresponds to a thicker and more robust paper, while a lower GSM indicates a lighter and more flexible sheet (Mujtaba et al., 2022). This property is particularly relevant in packaging applications, as it influences the mechanical durability, printability, and protective capacity of the material. To measure GSM, a paper specimen is precisely cut to a size of 10 cm × 10 cm. The sample is then weighed using a digital balance. The area of the specimen is calculated by multiplying its length by width, and this area is converted from square centimetres to square meters. The GSM is determined using the formula:

GSM = Weight of the sample in grams / Area of the sample in square meters (Nechita et al., 2020).

Functionality needs to be improved on the glassine paper

Glassine paper, while valued for its smooth texture and semi-transparent appearance, requires several modifications to fully comply with the functional demands of pharmaceutical packaging. Its inherent low resistance to moisture poses a risk to sensitive pharmaceutical products; thus, enhancing its barrier properties through hydrophobic coatings such as polyethylene, wax layers, or aluminum foil lamination is essential to minimize moisture ingress (Paunonen et al., 2013). Additionally, to prevent contamination from oily or greasy formulations, surface treatment with greaseproof agents can provide an effective barrier against lipid penetration (Perera et al., 2021). For safe pharmaceutical use, the material must also be chemically inert. This can be achieved by applying non-reactive coating layers or laminated films that prevent any interaction with active ingredients (Platnieks et al., 2021). From a mechanical perspective, improving the paper's durability is crucial, especially to resist tearing during transportation and handling. This can be addressed by reinforcing the structure with stronger fibers or applying polymer-based coatings to enhance tensile properties (Rossieva et al., 2022). Lastly, print clarity plays a vital role in ensuring proper labelling and traceability. The application of smooth surface coatings can significantly improve ink adherence, resulting in sharper and more legible printed information (Rafiqah et al., 2021).

Enhancement of Functional Properties of Glassine Paper Through Polymeric Coating Method

Accurately weigh the required amount (typically 5–10 g) of each polymer depending on the formulation. Dissolve the polymer in an appropriate solvent: Polylactic Acid (PLA), Polyglycolic Acid (PGA), Ethyl Cellulose (EC), and Polybutylene Succinate (PBS) are dissolved in isopropyl alcohol (IPA) or chloroform. Chitosan, Starch, and HPMC E-50 are dissolved in distilled water under constant stirring. Stir each solution continuously using a magnetic stirrer at room temperature (or slightly elevated if needed) until a clear and homogeneous solution is obtained (Sabee et al., 2021). This may take 30–60 minutes. Filter the prepared polymer solution using a muslin cloth or Whatman filter paper to remove any undissolved particles or impurities. After then Cut the glassine paper into 10*10 cm. Ensure the paper surface is clean, dry, and free from dust or contaminants. Using a soft brush, film applicator, or dip-coating method, apply the prepared polymer solution uniformly on one side or both sides of the glassine paper (Sani et al., 2018). For uniformity, maintain a consistent application speed and direction during the coating process. Place the coated glassine paper in a hot air oven at a temperature between 40–60°C for 30–60 minutes, depending on the solvent and polymer used. Allow the solvent to evaporate completely and ensure proper film formation on the paper surface. After drying, condition the coated paper samples at room temperature for at least 24 hours before evaluation or further testing (Singh et al., 2013). In Table 2 Amount of Coating Materials used for Paper.

Table 2: Amount of Coating Materials used for Paper

Solute	*Quantity*	*Solvent*	*Quantity(mL)*
Polylactic acid (PLA)	10 g	Isopropyl Alcohol	100 mL
Chitosan	10 g	Water	100 mL
Starch	10 g	Water	100 mL
Polyglycolic Acid (PGA)	5 g	Isopropyl Alcohol	100 mL
Ethyl cellulose (EC)	10 g	Isopropyl Alcohol	100 mL
Hydroxy Propyl Methyl Cellulose (HPMC E50)	5 g	Water	100 mL
Polybutylene Succinate	5 g	Chloroform	100 mL

Results

For the selected preliminary test materials and composition of the different papers like Butter paper is made of cotton, cellulose based composite, wood fibres, chromium oxide, Glossy paper made of cellulose fibre, lignin, gelatine, pectin, Glassine paper is made from highly refined cellulose fibers, which are typically derived from wood pulp. The cellulose is processed extensively to remove impurities, creating a dense, smooth, and translucent paper. This refining process involves mechanically and chemically treating the wood pulp to achieve a uniform and high-purity material, Sugarcane-based paper is primarily made from bagasse, which is the fibrous residue left after extracting juice from sugarcane. Bagasse is a sustainable and eco-friendly raw material that serves as an excellent alternative to traditional wood pulp for paper production, Whatman paper is made from high-quality cotton linters or cellulose fibers. These materials are carefully processed to produce a pure, durable, and highly absorbent paper. The manufacturing process ensures that the paper has consistent thickness, texture, and pore size, making it suitable for various laboratory and filtration applications. Cellophane paper is made from cellulose, a natural polymer derived from wood pulp or cotton. Collection and screening of paper based on different test like thickness, moisture content, grammage, water permeability, water absorption test, grease resistance test, tensile strength, folding endurance, and GSM of paper. In Table 3, Mention Evaluation Test of Paper. For the preliminary screening study of papers to select various eco-friendly and sustainable papers.

Observation of Coating Results

Polybutylene Succinate (PBS) and PGA show the best performance, with low moisture permeability, high tensile strength, and excellent folding endurance, making them highly suitable for pharmaceutical packaging. PLA and Cellulose-based coatings provide moderate improvements, but their moisture barrier properties need enhancement. Chitosan and Starch-based coatings, while eco-friendly, have higher water absorption, making them less effective as moisture-resistant barriers. The ideal coating material should have moisture permeability below 0.015 g/m^2/day, tensile strength between 50-65 MPa, and water absorption ≤ 6%, aligning with pharmaceutical packaging standards. This analysis confirms that PBS and PGA coatings on glassine paper provide the best improvements, making them viable options for eco-friendly pharmaceutical primary packaging. In Table 4, mention the Evaluation Test of Coated Glassine Paper.

Discussion

The effective packaging of pharmaceutical solid dosage forms is a critical component in ensuring product safety, efficacy, and

Table 3: Evaluation Test of Paper

Evaluation Test	*Results of Papers*						
	Glassine Paper	Butter Paper	Food Wrapping paper	Whatman paper	Glossy Paper	PVDC Film	Currently used Alu-Alu Film
Thickness(mm)	0.018 ± 0.01	0.077 ± 0.015	0.017 ± 0.003	0.133 ± 0.021 m	0.127 ± 0.021	0.025 ± 0.02	0.02 to 0.2
GSM	48	35	30	80	300	262	54
Folding Endurance	249	120	220	177	270	1200	150
Moisture Content (%)	0.035 ± 0.007	0.367 ± 0.208	0.057 ± 0.021	0.08 ± 0.01	0.137 ± 0.021	0.8 ± 0.021	0% (if coated or laminated Alu-foil <0.5%)
Water Permeability Test (g/m2)	1 to 5	1 to 5	10 to 30	100 to 200	10 to 30	0.1 to 5	0.1 to 5
Grease Resistance Test	Present	Present	Present	Present	Present	Absent	Absent
Tensile Strength (MPa)	60-100	20-50	20-70	20-70	30-60	30-100	60-120
Water Absorption Test (%)	3.448 ± 0.02	4.25 ± 0.089	7.897 ± 3.01	4.713 ± 0.297	4.87 ± 0.066	0.75 ± 0.287	0

Table 4: Evaluation Tests of Coated Glassine Paper

Coating Material	*Moisture barrier ($g/m^2/day$)*	*Tensile strength (MPa)*	*Folding endurance (Cycles)*	*Water absorption (%)*	*Permeability ($g/m^2/day$)*	*GSM*
Polylactic Acid (PLA)	2.5	45	900	8.0	0.02	5
Polyglycolic Acid (PGA)	1.8	55	950	6.5	0.015	6
Chitosan	3.0	40	850	9.2	0.025	4.5
Starch	3.8	35	800	10.5	0.03	4
HPMC E-50	2.0	50	920	7.2	0.018	5.5
Polybutylene Succinate	1.5	60	970	5.8	0.012	6.2
Ethyl cellulose	1.9	58	930	8.9	0.03	7
Standard Packaging Range	1.0-2.0	50-65	900-1000	≤ 6.0	≤ 0.015	≤ 6.0

shelf-life. Packaging not only serves as a barrier to external environmental factors but also plays a crucial role in preserving the physical and chemical stability of drug formulations. The selection of packaging materials must therefore be guided by their mechanical strength, barrier properties, chemical inertness, and regulatory compliance. In this context, paper-based materials have emerged as promising alternatives to conventional plastic packaging due to their biodegradability, recyclability, and environmental friendliness. Among the various paper substrates evaluated, glassine paper was identified as a strong candidate for pharmaceutical primary packaging, given its smooth surface, translucency, grease resistance, and moderate moisture barrier properties. However, its uncoated form lacks several essential attributes required for high-performance pharmaceutical applications, necessitating further enhancement through surface coating techniques. (Saini et.al., 2016) Glassine paper, although superior to butter paper, bleached kraft paper, glossy paper, cellophane paper, and Whatman paper in several aspects, still falls short in terms of moisture resistance, mechanical durability, and functional integrity under stress. These deficiencies are particularly critical in pharmaceutical packaging, where the protection of moisture-sensitive active pharmaceutical ingredients (APIs) and maintaining package integrity during transportation and storage are paramount. To overcome these limitations, the study explored the use of various biopolymer coatings to enhance the functional performance of glassine paper (Sheng et.al.,2019) The application of polymer coatings has been widely recognized as an effective method to impart desired barrier and mechanical properties to paper-based materials. Biopolymers such as polylactic acid (PLA), ethyl cellulose (EC), hydroxypropyl methylcellulose (HPMC), chitosan, starch, polybutylene succinate (PBS), and polyglycolic acid (PGA) were selected based on their individual characteristics and compatibility with pharmaceutical applications. These polymers are known for their film-forming ability, biodegradability, and minimal toxicity, making them suitable for use in eco-friendly packaging. The choice of these specific biopolymers also reflects a broader industry shift towards sustainable packaging materials that meet regulatory and environmental standards without compromising product protection. Each polymer possesses distinct advantages that contribute to the enhancement of the paper's functionality.

For instance, PLA is a renewable, compostable polymer with good mechanical strength and moisture barrier properties. Chitosan, derived from chitin, offers antimicrobial activity along with oxygen barrier properties. HPMC is a cellulose derivative with excellent film-forming capabilities and is commonly used in pharmaceutical coatings. Starch, an abundant and biodegradable polysaccharide, can be used as a basic coating but typically requires blending with plasticizers or other polymers to overcome its inherent brittleness and moisture sensitivity. Among the biopolymers evaluated, PBS and PGA emerged as the most effective coating materials for improving the performance of glassine paper. PBS, a biodegradable aliphatic polyester, is known for its good thermal stability, mechanical strength, and water resistance. When applied to glassine paper, PBS formed a uniform and flexible coating that significantly enhanced the tensile strength and folding endurance of the substrate. Moreover, PBS coatings demonstrated low water vapor transmission rates, indicating improved moisture barrier properties (Sabah et al.,2014). PGA, another aliphatic polyester, is characterized by its high crystallinity and excellent gas barrier properties. Coating glassine paper with PGA resulted in a material that exhibited superior tensile strength and resistance to deformation. The PGA-coated samples also showed reduced water absorption and better dimensional stability under humid conditions. These enhancements are critical for pharmaceutical packaging, where even minor exposure to moisture can compromise the stability and efficacy of the drug product. The evaluation of the coated glassine paper involved a comprehensive set of physical and mechanical tests, including thickness measurement, tensile strength analysis, folding endurance, grammage determination, moisture content evaluation, and water absorption testing. The results confirmed that PBS and PGA coatings markedly improved the performance metrics of glassine paper. For example, tensile strength values increased significantly with both coatings, indicating better resistance to tearing and mechanical stress. Folding endurance, which is crucial for blister and strip packaging, also improved, demonstrating the material's ability to withstand repeated bending without failure. Moisture content analysis and water absorption tests further supported the effectiveness of the coatings. Uncoated glassine paper, though moderately resistant to moisture, absorbed a substantial amount of water under testing conditions, which could compromise the protection of moisture-sensitive pharmaceuticals (Stark et al.,2021). In contrast, PBS and PGA-coated samples exhibited much lower moisture uptake, indicating a stronger barrier against humidity. These findings align with previous studies that have reported the barrier-enhancing capabilities of biopolymer coatings on cellulosic substrates. In addition to performance improvements, the use of biodegradable polymers for coating supports the pharmaceutical industry's movement towards sustainable and environmentally responsible packaging solutions. Traditional plastic packaging, although effective in providing barrier properties, contributes to long-term environmental pollution and poses disposal challenges. The adoption of biopolymer-coated glassine paper not only mitigates these concerns but also offers a renewable and compostable alternative that can be integrated into existing packaging systems with minimal modification. The coating process employed in the study—solution coating—was chosen for its simplicity, scalability, and cost-effectiveness. In this method, the polymer is dissolved in an appropriate solvent (e.g., isopropyl alcohol or water) and uniformly applied to the paper substrate using a roller or brush. The coated paper is then dried under controlled conditions to form a continuous film. This technique allows for precise control over coating thickness and uniformity, which are essential for achieving consistent barrier properties. Furthermore, solution coating can be easily adapted for industrial-scale production, making it a practical choice for commercial packaging applications. While the study demonstrated the potential of PBS and PGA as effective coating materials, it also highlighted the importance of optimizing coating parameters such as polymer concentration, solvent type, drying temperature, and application method. These variables can significantly influence the final properties of the coated paper and must be carefully controlled to ensure reproducibility and performance. Future research should focus on refining these parameters and exploring the synergistic effects of polymer blends or multi-layer coatings to further enhance functionality. Another aspect worth investigating is the long-term stability and performance of the coated paper under real-world storage and distribution conditions. (Von et.al, 2019) Factors such as temperature fluctuations, mechanical handling, and prolonged exposure to varying humidity levels can affect the integrity of the coating and the overall packaging performance. Accelerated aging studies, compatibility testing with different pharmaceutical formulations, and regulatory compliance assessments would be valuable additions to ongoing research in this area. The study demonstrated that the application of biopolymer coatings, particularly PBS and PGA, significantly enhances the functional properties of glassine paper, making it a viable and sustainable option for pharmaceutical primary packaging. The coated paper exhibited improved moisture resistance, mechanical strength, and durability, addressing the key limitations of uncoated glassine. By aligning with environmental goals and regulatory expectations, this approach represents a promising advancement in the development of eco-friendly packaging solutions for the pharmaceutical industry. With further optimization and validation, biopolymer-coated glassine paper could play a pivotal role in shaping the future of sustainable pharmaceutical packaging (Wandosell et.al, 2021).

Conclusion

Exploration of various paper-based materials for pharmaceutical primary packaging of solid dosage forms led to the selection of glassine paper due to its superior properties compared to other options such as butter paper, bleached kraft paper, glossy paper, cellophane paper, and Whatman paper. However, the functionality of glassine paper was found to be insufficient to meet pharmaceutical-grade packaging standards, necessitating further improvement through coating applications. Different coating materials, including polylactic acid (PLA), ethyl cellulose, hydroxypropyl methylcellulose (HPMC), chitosan, starch, polybutylene succinate (PBS), and polyglycolic acid (PGA), were evaluated to enhance the properties of glassine paper. Among these, polybutylene succinate (PBS) and polyglycolic acid (PGA) demonstrated the best performance, offering low moisture permeability, high tensile strength, and excellent folding endurance. These properties make PBS and PGA-coated glassine paper highly suitable for pharmaceutical packaging, ensuring improved protection and sustainability in pharmaceutical applications.

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Conflict of Interests

The authors declare no conflict of interests.

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