A COMPREHENSIVE MARKET STUDY AND DEVELOPMENT OF A NOVEL PILLOW BAG RECLOSURE SYSTEM

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ABSTRACT

Pillow bag packaging is the dominant format in the snacks category, particularly for chips, due to its cost-efficient production, lightweight structure, and superior barrier properties against moisture, oxygen, and light. Despite these advantages, the lack of effective reclosure mechanisms poses a critical challenge in maintaining product quality upon opening the packaging. This study addresses this limitation by engineering innovative and cost-effective reclosure systems optimized for pillow bag applications. The research encompassed a comprehensive market analysis of existing reclosure technologies, consumer-driven ideation from social media insights, and the adaptation of solutions from various product categories. A diverse range of reclosure concepts were ideated with a focus on usability, manufacturability, and material efficiency. Prototypes of selected designs—Origami Fold, Fold & Tie, and Twist & Tie—were fabricated and subjected to performance evaluation testing. Barrier properties were quantified using the Gravimetric Method under standard and accelerated storage conditions, while Finite Element Analysis (FEA) was employed to investigate shape optimization aimed at reducing stress concentration and preventing progressive tearing in such materials. The selected systems demonstrated significant improvements in barrier performance over conventional open chip packaging, validating their applicability and effectiveness. This research provides a novel, user-centric, and sustainable solution to an enduring challenge in flexible food packaging, advancing both consumer convenience and the industry's sustainability objectives.

Keywords: Pillow Bag, Reclosure System, Snacks Packaging, Barrier Testing

Dedicated to
Everyone who has ever lost a bag clip—this research is for you. May it bring a little more convenience and less frustration to your snacking moments.

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CHAPTER 1 INTRODUCTION

1.1. Growth of Snacks Industry

Snack food is classified as a lifestyle food within the food ecosystem. It is habitually and conveniently consumed in small portions as part of meals (Bhattacharya, S. 2023). Often, snack food is taken in small amounts between meals and frequently labeled as junk food. Niven et al. (2014) highlighted that although there is no clear definition of junk food, it is typically quantified by the contribution of calories, the type and size of meals, and the timing—usually consumed in minimal amounts between meals.

The increase in snack consumption is evident globally, with the savory snack category showing remarkable growth. The global market for savory snacks is projected to grow from USD 67 billion in 2020 to USD 102 billion by 2028 (Research and Markets, 2021). Reports indicate that in Australia, 90% of adults consume packaged snacks weekly, with savory snacks being particularly popular, consumed by more than 66% Australian adults weekly (Roy Morgan, 2020). Similarly, in the U.S., savory snacks are a staple in over 90% of households, with two-thirds regularly consuming at least three types of savory snacks each week (Statista, 2021a). This trend is also notable in Asian markets, especially in Japan and Hong Kong, where the adoption of Western snack habits and their availability have led to increased consumption over the past decade (Statista, 2021b, Euromonitor International, 2021).

The COVID-19 pandemic further accelerated global snacking habits, with nearly half of all respondents in an international survey reporting an increase in snacking frequency during the pandemic (Fitch Solutions, 2021).

This growth is fueled by improvements in living standards and increased disposable incomes, which drive demand for a diverse array of snack foods. (Yangang, Z., 2021). As a result, the number of snack food packaging categories and the availability of various pack sizes has significantly increased. As per a market study conducted by Hei Man Emily Ng et al., package size preferences for savory snack sales per capita varied across different regions.

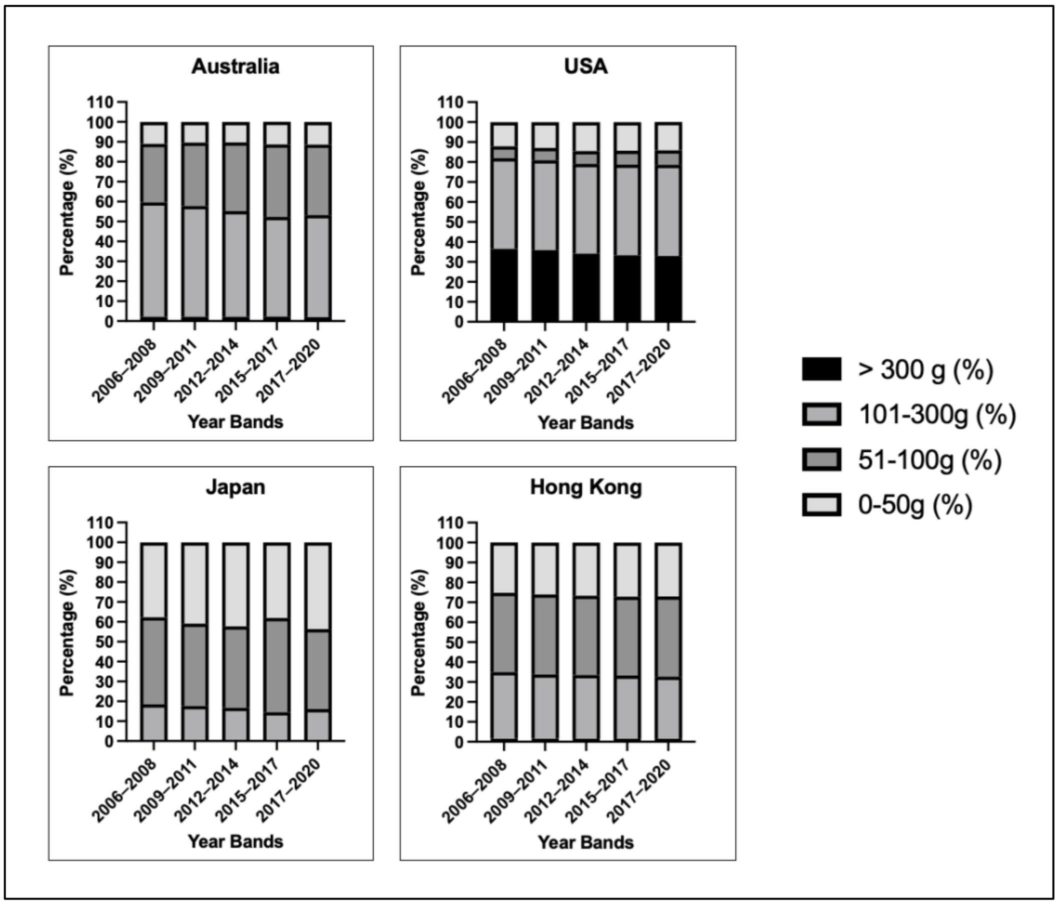

Figure 1 The share of per capita sales of savory snacks from 2006 to 2020, segmented by package size groups, over each three-year interval in (A) Australia, (B) the USA, (C) Japan, and (D) Hong Kong (Adapted from Ng, Xu, Liu, & Rangan, 2022)

Figure 1 indicates that in Japan, the 0–50 g and 51–100 g size categories were equally favored, whereas in Hong Kong, the 51–100 g category saw the highest sales. In contrast, both

Australia and the USA preferred the 101–300 g size group. The smaller size groups (0–50 g and 51–100 g) were notably more popular in Japan and Hong Kong, accounting for approximately 83.32% and 66.36% of savory snack sales respectively, in contrast to 44.35% in Australia and 20.16% in the USA. Meanwhile, the USA showed a significantly higher preference for the largest size group, >300 g, which made up 34.57% of its total savory snack sales, compared to 2.11% in Australia, 1.53% in Hong Kong, and a mere 0.02% in Japan (Ng, Xu, Liu, & Rangan, 2022). As USA shows a significant preference for >300g package size, this research study is primarily focusing on developing a reclosure system for larger package sizes.

In the highly competitive snack food market, several major companies dominate. Frito-Lay, a division of PepsiCo, holds a substantial market share, leading the industry with popular brands such as Lay's, Doritos, and Cheetos. Frito-Lay commands approximately 59% of the U.S. salty snack market (Statista, 2021a). Another significant player is Kellogg's, which owns Pringles and Cheez-It. Mondelez International, known for brands like Ritz and Triscuit, also holds a notable share. Together, these companies shape the landscape of the snack food industry, driving innovation and influencing consumer preferences.

Packaging suppliers play a crucial role in supporting the snack industry's growth. Companies like Amcor, Sealed Air, and Berry Global are key providers of high-quality packaging materials that ensure product freshness, enhance shelf appeal, and meet sustainability goals. These partnerships are vital as they supply essential raw materials, enabling snack manufacturers to maintain quality and efficiency in their packaging processes.

1.2. Increase in Food Wastage

The United Nations Sustainable Development Goals (SDGs) are a set of 17 global objectives established to address various global challenges, including poverty, inequality, climate change, and environmental degradation. One among them, SDG 12.3 is "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (Champions 12.3, 2020). Food Loss and Waste (FLW) encompasses food that is lost during production and supply chain processes and food that is wasted at the retail and consumer levels. With the 2030 deadline approaching, there is an urgent need for increased action. The food system significantly impacts land, water, and energy use, contributing to one-third of global greenhouse gas (GHG) emissions (Crippa et al., 2021). FLW contributes half of these emissions, with 35.5% attributed to food waste (FW) at the consumer stage, including household food waste (HFW) (Zhu et al., 2023).

Annually, HFW accounts for over half of global food waste, totalling 570 million tonnes (UNEP, 2021). Reducing HFW can significantly cut GHG emissions and mitigate climate change impacts on food prices, quality, and safety (Vermeulen et al., 2012; Zhu et al., 2023). Addressing HFW is essential for achieving SDG 12.3 and enhancing the sustainability of global food systems, supporting food security and environmental benefits for future generations (FAO, 2022).

Effective packaging plays a critical role in reducing Food Waste (FW) throughout the supply chain and at the consumer level (Verghese et al., 2015). In the context of snack packaging, improved reclosure systems can significantly help reduce HFW by maintaining product freshness and extending shelf life. Reclosable and resealable packaging can better align with consumer needs and contribute to sustainable food systems (Williams et al., 2012).

1.3. Impact of Packaging Reclosures on Reducing Food Wastage and Increasing Convenience

Reclosable packaging plays a crucial role in food safety and convenience by preventing cross-contamination, reducing the need for additional storage solutions, and maintaining product freshness. By securely containing purge juices from meats, it helps prevent contamination after the package is opened. This packaging also alleviates the need for consumers to repackage products, which can be frustrating and ineffective. Additionally, reclosable features extend the shelf life by slowing the exchange of air and moisture, thereby preserving the product's quality (Meussling, 2023). While it has been found that reclosable packaging solutions are important for meat, poultry, and seafood products, they are even more critical for snacks, where consumer preference for such packaging is high. According to a SurveyMonkey survey of 62 consumers conducted by Hallie Forcinio, 74 percent rated reclosability as "Very Important" or "Somewhat Important" in their purchase decisions for multi-portion meat, poultry, and seafood products (Forcinio, 2021). This underscores the broader appeal and importance of reclosable packaging across various food categories.

Reclosable packaging has evolved significantly since its inception in the 1950s, with flexible packaging for food products advancing notably. In the packaged food market, consumers increasingly expect reclosable features in flexible packaging due to several reasons. Firstly, reclosable packaging provides a strong business case by extending shelf life, preserving food quality, and reducing waste, which translates to cost savings for consumers.

Secondly, it effectively communicates the role of packaging in preventing food waste, as seen in Tillamook's investment in resealable cheese packaging that enhances consumer experience and sustainability goals. By preventing cross-contamination, reducing the need for additional storage, maintaining product freshness, and providing added security, reclosable packaging significantly enhances food safety and convenience across various food categories (Sand, 2022).

1.4. Research Goals and Objectives

The goal of this research is to develop and enhance reclosable packaging solutions specifically for snack products, with a dual focus on maximizing user convenience and reducing food waste. This study aims to conduct a thorough market analysis to understand existing commercial reclosure systems, identifying both their strengths and weaknesses. By gathering consumer insights, the research seeks to pinpoint customer-favored reclosure methods, understanding which features are most effective and user-friendly.

The final objective is to develop reclosable designs that are practical and efficient in maintaining product freshness, without adding significant material, cost and complex manufacturing process. These newly developed reclosure solutions will be tested for their ability to protect food content from the outside environment and their ability to delay food degradation.

By aligning packaging functions with consumer needs, this research aims to contribute to the field of packaging science. The improved reclosure systems are expected to offer practical and sustainable packaging options, enhancing user convenience and satisfaction while optimizing resource use and minimizing environmental impact.

1.5. Assumptions and Limitations

1.5.1. Assumptions

In this study, assumptions were essential to define the scope and focus, allowing for a controlled and systematic evaluation of reclosure systems. By isolating variables such as the impact of packaging material properties and emphasizing the performance of reclosures post-opening, the study could concentrate on the critical factors influencing product freshness. These assumptions ensured clarity in the research methodology, provided consistency across testing conditions, and enabled meaningful comparisons of reclosure performance.

Assumption 1: Relative Impact of Air Channel formed by Reclosure over Film Barrier Properties in Chip Packaging

When a chip bag, typically made from multilaminate film, is initially sealed at the manufacturer, the integrity and barrier properties of the film are crucial. The Water Vapor Transmission Rate (WVTR) of the film indicates how much moisture can penetrate through the material over a given period (Siracusa, 2012). A lower WVTR is vital to prevent moisture from reaching the chips, thus maintaining their freshness and crispness from the point of manufacture to when the consumer first opens the package.

Once the package is opened, the chips are exposed to the atmosphere, including moisture and oxygen. The role of the reclosure then becomes critical, although it is not designed to perfectly replicate the original seal’s effectiveness. Its main function is to significantly reduce the rate of moisture ingress and limit the exchange of air between the inside of the bag and the external environment. This helps slow down the processes, such as lipid oxidation, that cause the chips to become stale.

It is important to recognize that a reclosure is not a perfect seal. Factors such as human error in how the reclosure is applied, variations in reclosure design, and the mechanical limitations of reclosure systems mean that some level of air and moisture exchange is still possible. This imperfect sealing capability means the effectiveness of a reclosure is primarily assessed as a means to prolong the shelf life of the contents, rather than completely preserve them as the original seal might.

For this research, the assumption is that the passage of air through the reclosure is more significant than moisture ingress through the film once the package is opened. Therefore, moisture ingress through the film is considered insignificant. Since the material of the film is kept constant during barrier testing, the impact of the film's barrier properties on the performance of the reclosure is nullified. This assumption allows the study to focus on evaluating different reclosure systems, aiming to optimize them for practical application and consumer use.

Assumption 2: Consistency in Reclosure Performance Trends Across Different Materials

Packaging materials such as Polyethylene Terephthalate (PET), polyethylene (PE), and Polypropylene (PP) differ in their barrier properties, including WVTR, which is critical for maintaining product freshness while the package is sealed. However, once a package is opened, the reclosure system becomes the primary factor in limiting air and moisture ingress. At this stage, the material's barrier properties play a less significant role compared to the functionality of the reclosure. By standardizing the packaging material in this study, variability from differences in material properties is eliminated, allowing a direct comparison of the performance trends of different reclosure systems.

This study assumes that the performance trends of reclosure systems will remain consistent when tested on a standardized material, regardless of variations in barrier properties across other materials like PET, PE, or PP. The material's barrier properties are considered secondary since the reclosure's ability to reduce air and moisture ingress is the dominant factor after the package is opened. This approach focuses the study on evaluating reclosure functionality while neutralizing the influence of material differences.

1.5.2. Limitations

The limitations of this research study highlight the challenges and constraints encountered during its execution, providing context for the findings and identifying areas for further exploration to enhance the applicability and comprehensiveness of the results.

Limitation 1: Controlled Testing and Material Standardization

The study was conducted under controlled laboratory conditions to ensure consistency and repeatability. While this approach allowed for the isolation of variables such as reclosure performance, it does not fully replicate the variability present in real-world conditions, such as extreme temperature fluctuations, high humidity, or inconsistent consumer handling. Additionally, the study standardized the packaging material, using a single multilaminate film type across all tests to eliminate variability from material differences. While this approach was necessary to focus on the reclosure systems, it may not fully capture interactions that could occur between reclosures and other materials with distinct mechanical or barrier properties.

Limitation 2: Prototype Development Using Non-Industry Methods

The reclosure prototypes used in this study were not manufactured using industry-standard machines or methods, such as precision perforation equipment or high-speed sealing processes. Instead, the prototypes were developed using available research tools, which may differ from the methods used in a commercial production environment. This limitation may affect the applicability of the results to real-world production and performance scenarios, as production-level reclosures could exhibit different characteristics due to the precision and scalability inherent to industrial manufacturing processes.

Amcor, a leading material manufacturer, was consulted during the research to gather feedback on production preferences and feasibility. While these discussions provided valuable insights into aligning prototype designs with industrial requirements, the feedback was not formally recorded or included in this thesis. Future research could build upon these consultations to strengthen the connection between design concepts and production constraints.

Limitation 3: Consumer-Design Interaction Evaluation through Usability Study

The study did not include a formal consumer usability study to evaluate how users interact with the reclosure systems. While understanding consumer behavior is essential to assess the practicality and effectiveness of reclosures, conducting such a study was beyond the scope of this research due to its time and resource-intensive nature. Usability studies typically require extensive participant engagement, iterative testing, and detailed analysis, which were not feasible within the constraints of this study. Addressing this limitation in future research could provide valuable insights into real-world consumer handling practices and their impact on the performance and adoption of reclosure systems.

CHAPTER 2 MARKET STUDY ON COMMERCIAL AND HOUSEHOLD RECLOSURES METHODS FOR FOOD PACKAGING

2.1. Overview of Current Packaging for Chips

The research conducted by Özbağ Keçeci (2024) sought to enhance the understanding of chip demand in the U.S. market by analyzing a diverse selection of brands. This study included total 52 unique brands, covering various chips brands. It's important to note that brands with the same name but different variety, like Lay's Sour Cream & Onion and Lay's Barbeque, were treated as distinct brands. These market share and price of these brands were evaluated (Özbağ Keçeci, 2024). For the purpose of this study, the 52 brands were further examined for their packaging format and the reclosure options, refer to Table 1 in Appendix A. It is important to assess their impact on consumer convenience and product freshness, which are critical factors in purchasing decisions.

Figure 2 Product Images six brands from Walmart USA e-commerce website (Source: Walmart, https://www.walmart.com/search?q=chips, accessed on August 5, 2024)

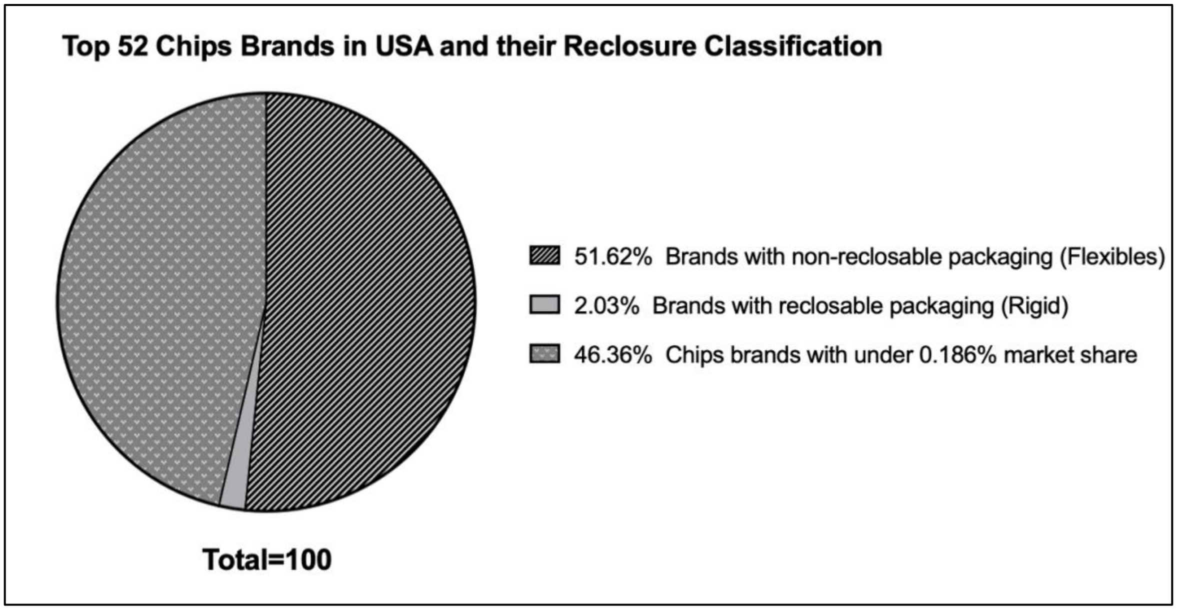

Figure 3 Market classification of top 52 Chips brand and Reclosure availability (Adopted data from Özbağ Keçec, 2024 along with Reclosure investigation using e-commerce websites)

The total percentage of all brands offering reclosable packaging together has a market share of only 2.03% as showcased in Figure 3. This highlights a significant gap in the market where reclosable packaging, which greatly enhances consumer convenience and product freshness, is underutilized. Brands like Pringles have capitalized on this feature, potentially setting themselves apart in terms of consumer preference and product longevity. The majority of the market, however, remains reliant on traditional packaging methods, which may not meet the growing consumer demand for sustainability and ease of use. This suggests an opportunity for other brands to innovate and potentially gain a competitive advantage by adopting reclosable packaging solutions.

2.2. Current Reclosure Systems used in Flexible Food Packaging

Reclosure systems play a critical role in ensuring product freshness and in some cases prolonging shelf life, especially when used in food packaging. The ability to effectively reseal a package not only maintains the sensory attributes (taste, smell, texture, and appearance) of the product but also prevents external factors like air and moisture from affecting its quality.

The upcoming sub-sections will explore the details of each packaging reclosure system chosen for the market study, focusing on understanding the current packaging reclosure systems, mechanisms, and the advantages and disadvantages of each system. Real-world market examples will also be examined to see how these systems are being utilized. Four reclosure methods were specifically chosen due to their prevalence and effectiveness in flexible packaging solutions: Peel and Reseal, Tape Reclosure, Zipper or Press to Close, and Tin Tie Reclosure. These methods have established themselves as prominent options within the industry. By analyzing these methods, their strengths and weaknesses can be recognized, ultimately guiding toward informed recommendations for optimizing pillow bag packaging reclosure solutions.

2.2.1. Peel and Reseal Reclosure

The peel and reseal closure is a widely used resealable adhesive system commonly employed in packaging formats such as pouches, sachets, semi-rigid salad trays and bags. Featuring dual adhesive layers, this system allows for both initial sealing and repeated resealing. Recent advancements have introduced sustainable variants, addressing environmental concerns (Samir et al., 2022).

Mechanism: The peel-and-seal packaging system operates through three main steps: sealing, opening, and resealing as sown in Figure 4. During the sealing process, two or more layers of the packaging material are brought together, with one layer featuring a peelable adhesive coating. This adhesive, typically a pressure-sensitive adhesive (PSA), provides high initial tack and adhesion, creating a secure bond between the layers. The PSA is formulated to offer controlled adhesion, allowing easy separation of the layers without damaging the packaging upon initial opening (Haque, 2024).

To access the package contents, the consumer applies moderate force to peel back the sealed flaps. The peelable adhesive has a specific bond strength that can be overcome with relatively low peel force, releasing cleanly from the packaging material and leaving no residue. After opening, the consumer can reclose the package by bringing the flaps back together. The resealable adhesive layer, often a different type of PSA with higher cohesive strength, allows the package to be firmly resealed. This adhesive layer enables repeated opening and closing of the package, effectively preserving the product's freshness and preventing leaks or spills (Hebert et al., 2005).

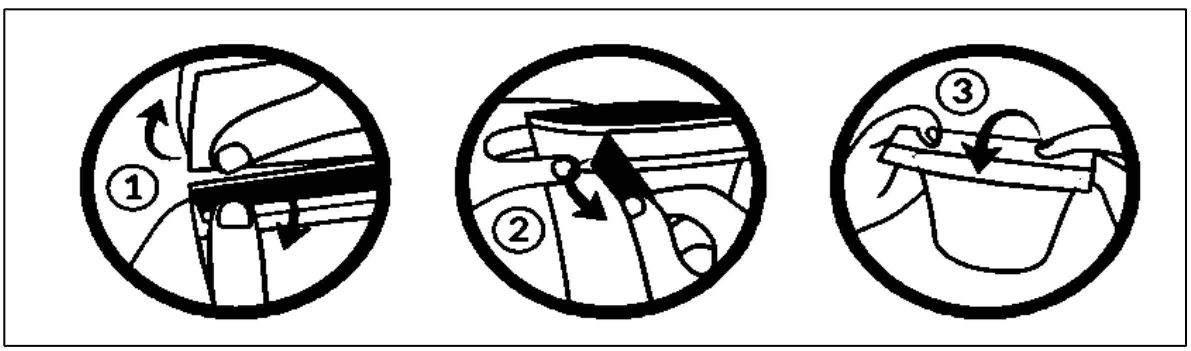

Figure 4 Sub-Category of Peel and Reseal is Peel and Fold (1) Tear, (2) Peel Liner Out, (3) Fold to Reclose (Source: Huhtamaki, https://www.huhtamaki.com/en/flexible-packaging/innovations/thailand/123-pack/, accessed on July 23, 2024)

Advantages: This reclosure provides controlled peel force, ensuring that consumers can easily open the packaging without damaging it or leaving adhesive residue behind. This feature is especially valuable for user convenience and maintaining a clean and efficient opening process. Tamper evidence is another key benefit, as this closure can include tamper-evident features, providing visual indicators if the package has been previously opened or compromised, enhancing product security and consumer trust. The resealable closure helps preserve product freshness by minimizing exposure to environmental factors such as moisture and air, thus extending the shelf life of the contents (CP Flexible Packaging, n.d.). Additionally, the enhanced user experiences resulting from easy reclosure leads to positive consumer perceptions of the brand, as it reflects convenience and practicality.

Disadvantages: One major limitation is limited reusability; over time, the adhesive properties may degrade with repeated opening and closing, making the resealing feature less effective. Additionally, material compatibility is crucial, as not all packaging materials bond well with peelable or resealable adhesives, potentially limiting the closure's functionality and application across different product types. Finally, while peel and seal closures offer significant benefits, they can increase packaging costs, particularly when specialized adhesives are needed, which could be a limiting factor for cost-sensitive production processes.

Market Examples: Table 1 showcases various types of packaging solutions that incorporate peel-and-seal closures across different industries. Resealable stand-up pouches are flexible and ideal for snacks and pet food, featuring easy-to-use closures. Resealable cups are popular in the beverage industry, ensuring spill prevention and maintaining beverage freshness. Fresh produce packaging employs pressure-sensitive adhesives for secure closure, extending shelf life and reducing food waste.

Table 1 Market Examples of Peel and Seal Packaging Systems

Type & Description	**Example**
Fresh Produce Packaging Utilizes pressure-sensitive adhesives (PSAs) for tamper-evident, easy-open, and resealable packaging, ensuring freshness and safety.	 (Sonoco, n.d.)
Wet Wipes Packaging (Personal Care) Features peel-and-seal closures for hygiene and convenience in personal care products like wet and baby wipes	 (Amazon, n.d.)
Resealable Dairy Products Packaging Used in cheese and dairy, these closures maintain freshness, prevent spoilage, and reduce food waste.	 Südpack. (n.d.)
Chips and Cookies Packaging Keeps snacks crisp and fresh, preventing staleness while extending shelf life and minimizing food waste.	 (SmugChinchilla, 2022)

Amcor, Sonoco and Belmark have led research work in this field. Amcor's resealable films, including SmartTack™ EZ Peel® Reseal™, are designed for easy access and secure resealing. These multi-layer films typically consist of an outer base layer film such as PET layer for durability, a middle layer with a resealable adhesive, and an inner barrier film such as PE layer for sealing. SmartTack™ EZ Peel® Reseal™ features a specially formulated adhesive that maintains strong adhesion through multiple openings and closings, allowing consumers to reclose the package without losing seal integrity. Amcor also uses substrates like AmFiber™, a sustainable fiber-based material, and AmFoil™, which offers high barrier properties for enhanced protection. These films are ideal for food, personal care, and pharmaceutical packaging, balancing convenience, durability, and product protection (Amcor, n.d.).

The multi-layer film structure developed by Intercontinental Great Brands with reclosure is designed for packaging, featuring resealable materials on separate layers, enabling the use of a single adhesive type between layers instead of two. This design simplifies the production process and lowers costs. The film comprises an outer portion with an embedded adhesive layer and an inner portion, created through single-step multi-layer coextrusion to eliminate the need for lamination. The embedded adhesive layer is distinct from conventional pressure-sensitive adhesives. The film's opening mechanism includes a flap formed by cuts in the outer and inner layers, making it user-friendly. The outer film consists of a top film layer, an adhesive layer, and a bottom film layer, with a permanent adhesive layer bonding the outer and inner films. This design eliminates the need for separate reclosure labels, streamlining functionality and reducing complexity (Blyth, Down, Holt, Liang, & Zerfas, 2022).

2.2.2. Tape Reclosure

The tape reclosure is designed to combine convenience and functionality, empowering consumers with the ability to access the contents with ease while ensuring reliable and secure resealing for future use. It encompasses a range of technologically advanced closure systems, including specialized flaps and advanced adhesive tapes, engineered to maintain product freshness, protection, and tamper-evident properties.

Mechanism: Some packaging solutions utilize resealable tape systems. These packages feature designated areas or specially designed flaps equipped with advanced adhesive tape. The adhesive tape used is often a high-performance pressure-sensitive adhesive (PSA) meticulously formulated for optimal tack, cohesion, and adhesion properties. To access the contents, consumers simply peel back the protective backing or lift the flap to expose the resealable adhesive tape. Upon reclosure, the advanced PSA adheres firmly to the packaging material (Packaging Strategies, 2014)

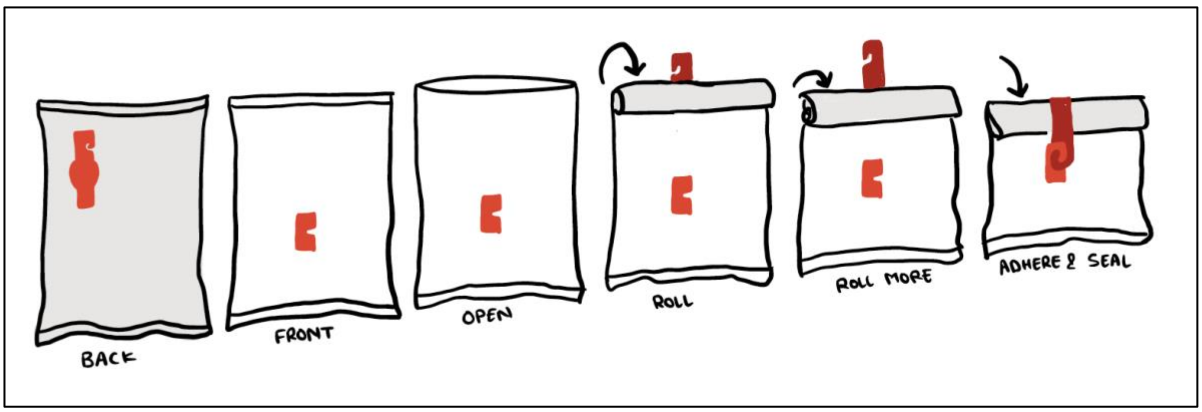

Figure 5 The Tape Reclosure Packaging Usage Instructions (Image adapted from etikouest-packaging, showing the detailed usage instructions for tape reclosure packaging. Retrieved from https://www.etikouest-packaging.com/en/reclosed-frozen-products/ on August 5, 2024)

Advantages: Tape Reclosure provides convenience through its intuitive reclosure mechanisms, contributing to a user-friendly packaging experience that enhances consumer satisfaction. The system also supports freshness retention by creating a robust and airtight seal, which helps to mitigate the exchange of air and moisture. This is a crucial feature, as it significantly extends the product's shelf life, preserving both freshness and quality. Additionally, tape reclosure allows for portion control, enabling consumers to enjoy the product at their preferred pace, while minimizing the risk of spoilage (Rice, J., 2006). The tamper-evidence feature is another valuable aspect, as any signs of tampering would become immediately visible when inspecting the integrity of the reclosure system, providing consumers with assurance regarding the safety of the product.

Disadvantages: One key limitation is its limited reusability; with repeated use, the adhesive strength of the tape can degrade, which may result in a less secure seal after multiple openings and closings. This reduces the overall effectiveness of the reclosure mechanism over time. Furthermore, while the reclosable features provide significant convenience, the overall barrier properties of the tape reclosure system may not match the performance of more specialized closure mechanisms. As a result, this could impact the product's shelf life in certain applications, particularly where long-term freshness preservation is essential.

Market Example: Table 2 highlights the diverse applications of this innovative sealing solution, showcasing its effectiveness in preserving product freshness, ensuring convenience, and minimizing food wastage. From beloved snacks and essential grains to baked goods, fresh produce, and even pet food, tape reclosure demonstrates versatility as a reliable choice for maintaining product quality and enhancing consumer experiences.

Table 2 Market Examples of Tape Reclosure Packaging Systems

Description	Example
<u>Snacks Category</u> Popular snacks like chips, nuts, dried fruits, and savory treats are often packaged with resealable tapes to maintain freshness and convenience.	 (Food and Drink Technology, 2019)
<u>Grains and Pasta</u> Commonly used for pasta, rice, and grains due to its strong adhesive properties, ensuring a reliable, long-lasting seal and easy liner removal for consumer convenience.	 (Bankey Bihari Packaging, n.d.)
<u>Baked Goods</u> Baked goods, often consumed across multiple occasions, require a secure resealing mechanism, such as tape reclosure, to preserve freshness and texture.	 (Sealstrip, n.d.)
<u>Fresh Produce</u> Tape reclosure is used for fresh produce packaging to maintain quality and freshness. It creates a secure seal, preventing air and moisture from entering and extending shelf life, reducing spoilage, and food waste.	 (Rice, 2006)

Brands leverage unique marketing opportunities through the tape, such as the 8-color printed 'RE CLOSE Tape' featured on 'Lightly Salted KETTLE Chips' sold in the U.K.

Developed in collaboration with Essentra's Design Studio, this tape enhances on-shelf visibility and significantly increases awareness of the three new products in the KETTLE line-up (refer Table 2 for depiction). This 30 mm wide resealable tape, which includes a user-friendly finger lift area along both sides, integrates easily into existing vertical form fill and seal packaging lines using Essentra's applicators. The tape allows consumers to reseal the pack after opening, maintaining the freshness of the chips. Essentra's printing capabilities also enable the addition of social media icons, prompts, seasonal messages, and loyalty codes to the tape. These features provide further engagement opportunities, directing consumers to the brand's website or showcasing different product ranges to encourage repeat purchases (Packaging Strategies, 2019).

2.2.3. Press to Close

A press-to-close zipper pouch is a type of reclosable packaging solution that incorporates a zipper closure mechanism activated by pressure. Also known as a press-to-seal or press-to-close pouch, this packaging design allows for easy opening and reclosing of the pouch, ensuring convenience and product freshness.

Figure 6 Press to Close Reclosure System Examples for Food Packaging (Image captured by the Author, July 23rd, 2024)

Mechanism: The mechanism of a press-to-close reclosure system involves interlocking plastic tracks with precision-engineered profiles. These tracks are integrated into the packaging, typically in the form of a zipper or similar closure mechanism. When the user presses the tracks together, the precision profiles engage with each other, creating a tight and secure seal along the length of the package. This pressing action causes the tracks to lock into place, preventing the package from opening unintentionally and ensuring a reliable closure. To open the package, the user pulls the tracks apart, disengaging the interlocking profiles and allowing access to the contents. When the package is resealed, the user aligns the tracks and applies pressure to re-engage the interlocking mechanism, creating a tight seal once again (Macneal, 2015).

Figure 7 Detailed magnified views of various Ziplock seals, Images captured by Rob Cockerham Retrieved from cockeyed.com, Retrieved on August 5, 2024

Advantages: Press-to-close reclosure is user-friendly, allowing consumers to intuitively align and press the tracks together, enabling easy access and reclosure without the need for additional tools or complicated steps. This ease of use enhances the consumer experience, especially in fast-paced or on-the-go scenarios. Furthermore, the reliable closure provided by the mechanism ensures a tight seal that prevents leaks, spills, and exposure to external elements such as moisture and air, which helps in maintaining the product's integrity over time (Fresh-Lock, 2018). This tight seal contributes to freshness preservation, effectively extending the shelf life of perishable items and reducing food wastage by protecting the contents from environmental factors.

Disadvantages: The intricate interlocking tracks required for this type of reclosure can result in higher manufacturing costs compared to simpler reclosure systems. Additionally, while the system works well initially, it has limited reusability. Over time, the adhesive properties of the plastic tracks may degrade, which affects the system's ability to maintain a secure seal after repeated use (Fresh-Lock, 2018). This requires careful handling and may limit its effectiveness for long-term use or in environments where frequent resealing is needed.

Market Examples: The press-to-close reclosure system is a versatile and widely adopted packaging solution used in various product categories across different industries. Some of the prominent categories where press-to-close reclosure is commonly employed include. An example of how this reclosure system helps enhance packaging security is SealStrip's patented 'TamperTear®' technology which provides clear tamper-evidence by integrating a specialized seal that is irreversibly broken upon opening. It features a distinctive break pattern which gives a visual cue to help identify any tamper. This mechanism ensures that any interference with the package is immediately visible to consumers, enhancing product security.

Table 3 Market Examples of The Press to Close Reclosure Systems

Description	Example
Food and Snacks Commonly used in packaging for snacks like chips, cookies, and nuts, helping to preserve freshness and allowing for easy access.	 (Changrong Pack, n.d.)
Pet Food Press-to-close feature ensures that pet owners can easily seal the package after each use, keeping the contents fresh and tasty for their pets.	 (ProAmpac, n.d.)
Personal Care and Home Care Used in various personal care and home care products. The system provides a convenient and hygienic way to access and seal the products	 (IMPAK Corporation, n.d.)

2.2.4. Tin Tie

Tin tie closures are a prevalent resealable method employed in the food packaging industry, particularly for bags. This closure system comprises a thin strip of metal or plastic embedded in the folded top of the bag, with an adhesive on one side to facilitate secure sealing. The primary function of a tie tin is to provide a convenient and reliable means of closing bags, such as those used for coffee or bakery products, to maintain the freshness of the contents.

The metal or plastic strip imparts rigidity to the closure, enabling repeated folding and unfolding without compromising effectiveness.

Mechanism: The tin tie reclosure system is a widely used and efficient packaging method providing resealable closures. It consists of a thin metal strip, typically made of tin, aluminum, or plastic, with an adhesive backing, as illustrated in Figure 8.

i. Initial Sealing: During the packaging process, the tin tie is positioned along the top edge of the packaging material, such as a paper bag or pouch. The adhesive side of the tin tie is affixed to the inner surface of the packaging material.

ii. Filling the Package: The package is then filled with the desired product, such as coffee beans, tea leaves, or bakery items.

iii. Folding and Sealing: After filling, the top edge of the packaging material is folded down to close the package. The tin tie, now sandwiched between the layers of the material, serves as a secure closure to hold the folded edge in place.

iv. Resealing: To access the contents, the consumer unfolds the top of the package. After use, the package can be easily reclosed by folding the top edge down again and securing it with the tin tie. The adhesive on the tin tie ensures the package is resealed, maintaining the freshness and quality of the contents (Koch, 2022).

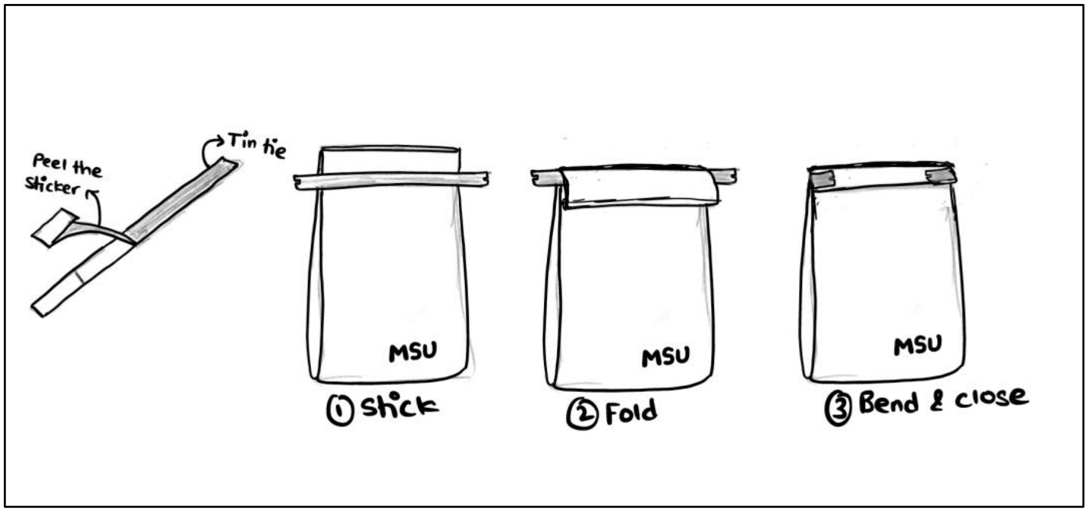

Figure 8 Tin Tie to Reclose System Mechanism

Advantages: Convenience is a key benefit, as tin ties are user-friendly, allowing consumers to easily open and reclose the package without hassle. This makes them particularly appealing for products that require frequent resealing. The system also excels in freshness preservation by providing a reliable seal that prevents exposure to air and moisture, thus extending the shelf life of perishable products. Versatility is another advantage, as tin ties can be used with a wide range of packaging materials such as paper bags, pouches, and flexible packaging, making them suitable for diverse product categories. Additionally, cost-effectiveness plays a significant role; tin ties are relatively inexpensive compared to other resealable closure options, which makes them a budget-friendly choice for manufacturers. Furthermore, sustainability is enhanced as tin ties can be made from recyclable materials, contributing to eco-friendly packaging practices and supporting broader sustainability initiatives.

Disadvantages: One key issue is limited reusability; over time, the adhesive on the tin tie may degrade, which reduces the effectiveness of the reseal after multiple uses. This limits its ability to maintain a secure closure over time. Additionally, technical challenges can arise during the packaging process, as attaching tin ties requires precision to ensure proper alignment and secure attachment. This complexity can add to the manufacturing time and cost. The aesthetic appeal of tin ties can also be a downside, particularly for premium or high-end products, as the visible tie may not match the packaging design expectations for luxury items. Another disadvantage is that barrier properties of tin tie closures may not be as strong as other reclosure options, potentially affecting the product's resistance to moisture, odors, and other external factors. Finally, while tin ties are recyclable, there can be recyclability challenges with some packaging materials that feature tin ties. The mix of materials can complicate the recycling process, potentially making it more difficult for the packaging to be fully processed.

Market Examples: The Tin Tie reclosure system demonstrates its versatility across various industries. In the food industry, it effectively maintains the freshness of baked goods, while in the consumer goods sector, it enhances convenience for products like coffee and snacks. This system's resealing functionality significantly improves user experience and product preservation. For a comprehensive display of these diverse use cases and industries, please refer to Table 4.

Table 4 Market Examples of The Tin Tie Reclosure Systems

Description	**Example**
<u>Coffee, Tea, Herbs & Spices (Granular product)</u> Tin ties are frequently found in Herbs & Spices and coffee packaging. Tea packaging also often features tin ties, allowing consumers to easily seal and reseal the tea packaging to maintain its flavor and quality.	 (Kanniah, 2022)
<u>Baked Goods and Snacks</u> Tin ties are used in packaging for cookies, nuts, dried fruits, and trail mixes, providing a reliable and user-friendly reclosure method to keep the contents fresh and flavorful	 (Walmart Business, n.d.)
<u>Spices, Grains and Cereals</u> Packaging for grains, cereals, and granola commonly includes tin ties for resealing, ensuring the contents remain crisp and protected from external elements.	 (Michlitch Spokane Spice, 2024)
<u>Pet Treats and also Repellents</u> Tin ties are employed in the packaging of pet treats, allowing pet owners to conveniently seal and maintain the freshness of their pets' favorite treats.	 (TedPack, n.d.)

Nuspark showcased that the Tin tie reclosure could be applied to bags of coffee with automation. They were tasked by Barrie House Coffee & Tea Co., based in New York, to automate the application of tin-tie reclosures to their bags of coffee. This collaboration led to the development of custom machine called the NTT-35, which streamlined the process significantly. This machine applies tin ties to various bag sizes at a rate of 25 to 35 bags per minute. By automating this process, Barrie House reduced manual labour costs substantially and improved operational efficiency. The machine's design allows for easy integration with existing and future packaging equipment, supporting flexibility and adaptation to changing production needs. It should be noted though that the machine is not suitable where bags of varying sizes are to be packaged (Reynolds, 2018).

2.3. Various Household Reclosure Methods for Flexible Snacks Packaging

Flexible snack packaging, such as pillow bags, often lacks effective reclosure or resealability features, which pushes consumers to find alternative methods to store snacks more conveniently. This need arises because packaging with built-in resealing mechanisms is not widely available, and existing designs do not always meet practical storage needs. Consumers often resort to household tools such as rubber bands, bag clips, and resealable containers. However, these methods can be time-consuming to use and depend on tools that may not always be easily accessible at all times.

This research examines the household methods consumers use for resealing flexible snack packaging, focusing on the challenges related to their practicality and availability. It explores common techniques such as different fold methods, clamp-based closures, and other consumer-driven solutions, discussing their effectiveness and limitations. By analyzing these practices, the research aims to identify ways to improve packaging design to better address consumer needs and enhance convenience.

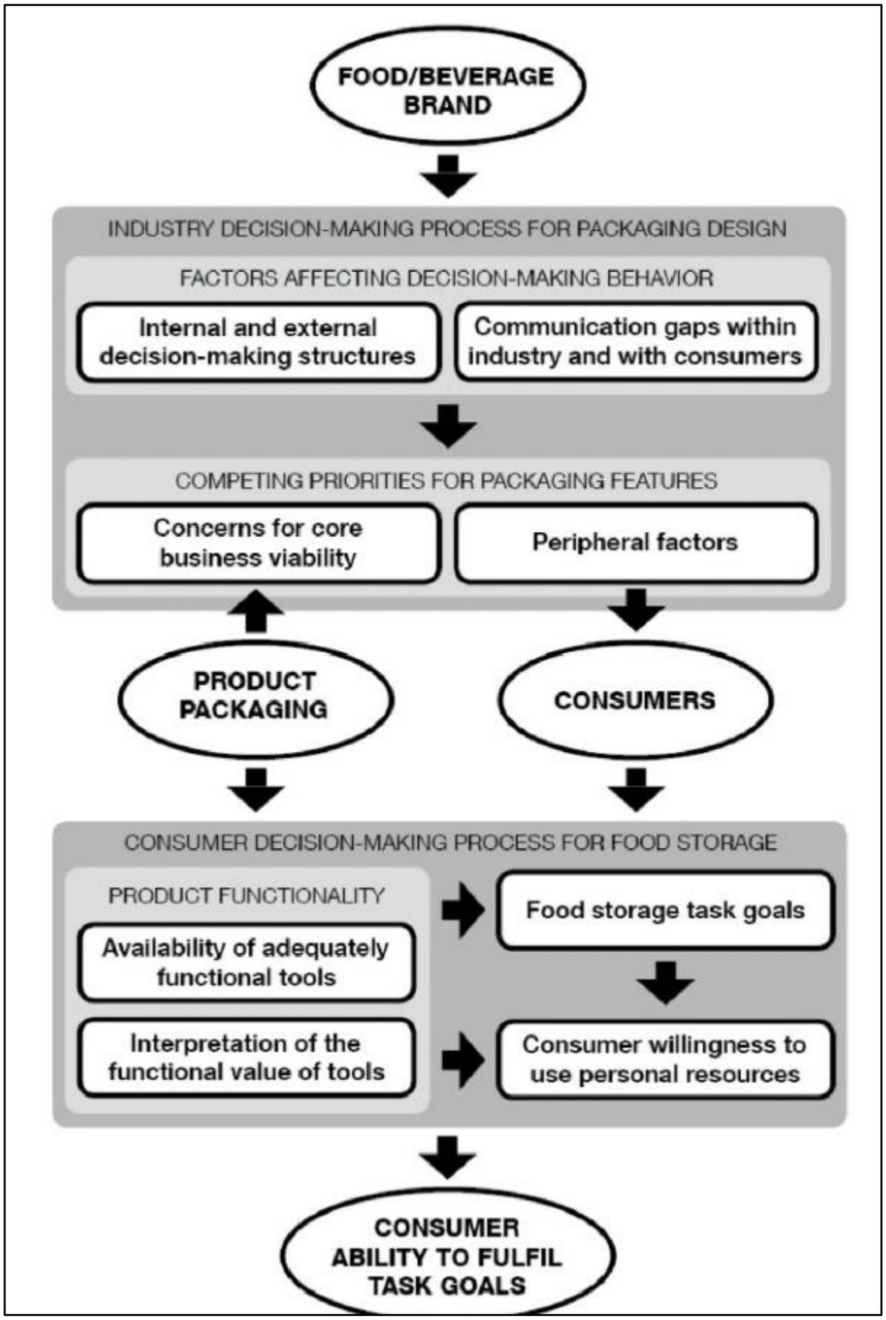

Figure 9 Interaction between various stakeholders for Food Packaging Development (Chan, 2023)

Figure 9 illustrates the interplay between industry and consumer decision-making in relation to food and beverage packaging design and food storage functionality. On the industry side, internal structures and communication gaps with consumers influence packaging design, often resulting in competing priorities between core business viability (e.g., cost and sustainability) and peripheral factors like consumer convenience. These decisions shape the final packaging, which consumers interact with to address food storage needs. Consumer decision-making is influenced by the availability and perceived functionality of packaging tools, determining their ability to meet storage goals or their reliance on personal resources (Chan 2023). Ultimately, the diagram highlights a disconnect between industry packaging design priorities and consumer needs, emphasizing the need for more functional and consumer-aligned packaging solutions.

2.3.1. Origami Bag Fold Technique

A WikiHow article by Eric McClure introduces a practical method to reseal a bag of potato chips, providing an effective way to keep snacks fresh and prevent spills without requiring additional tools. The technique emphasizes folding and securing the bag to create an airtight seal, helping to extend the shelf life of the contents. (McClure, 2024)

According to the article, the process starts by laying the chip bag flat on a surface and pressing out any excess air to flatten the top. Next, the sides of the bag are folded inward toward the center, aligning the edges neatly to form a compact structure. The top of the bag is then rolled down tightly in several iterations to create a secure seal. Finally, the folded side flaps are tucked over the rolled top, locking it in place. (refer Figure 10)

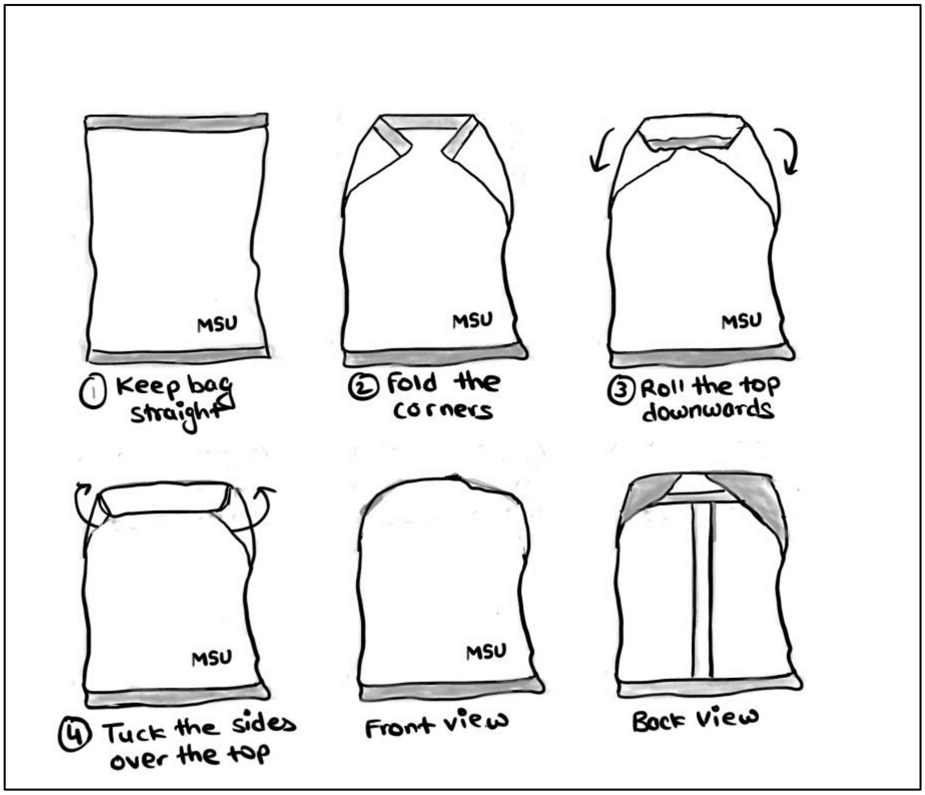

Figure 10 Origami Fold Technique

The result is a neatly resealed bag with a clean, folded appearance at the back. This method not only helps to preserve the freshness of the chips but also eliminates the need for external sealing accessories, making it a simple and eco-friendly solution for everyday use.

Advantages: It is known for its ease of use, as the folding process is simple and quick to learn, making it suitable for a wide range of consumers. The design also excels in maintaining freshness, as the folded structure minimizes air and moisture exposure, which helps extend the shelf life of the contents. Another advantage is that the Origami Bag Fold requires no additional equipment, as it uses the bag itself for reclosure. This feature adds convenience and eliminates the need for external sealing components, which can be a cost-saving advantage. Furthermore, the eco-friendly nature of the Origami Bag Fold makes it a sustainable option, as it reduces packaging waste by utilizing the bag's own structure for sealing, which can be more environmentally friendly than plastic or adhesive-based closures.

Disadvantages: Usability issues may arise with repeated folding, as this could weaken the bag material over time, reducing the effectiveness of the seal. The seal consistency can be problematic, as achieving a perfect airtight seal may be difficult, requiring practice and attention to detail. Lastly, food contact can be a concern, as handling the bag may transfer oils or contaminants from the plastic to the fingers, potentially affecting the quality of the contents, especially with perishable foods.

2.3.2. Usage of Bag Clips and Rubber Bands

Bag clips and rubber bands are widely utilized resealing mechanisms designed to maintain the integrity of packaged contents by providing secure, reusable closures. Bag clips, constructed from materials such as polymer-based plastics or corrosion-resistant metals, are engineered to accommodate a variety of packaging applications. Their design typically incorporates a clamping or spring-loaded mechanism that facilitates repeated sealing operations with minimal mechanical effort, ensuring both convenience and reliability (Uong, 2024). Rubber bands, on the other hand, are typically made from natural or synthetic elastomers, providing a flexible and cost-effective alternative for resealing. Their stretchable design allows them to adapt to various bag sizes and shapes, ensuring a snug closure around the opening.

Available in multiple dimensions, bag clips are optimized for compatibility with packaging of varying sizes and material thicknesses, ranging from lightweight single-serving snack bags to heavier bulk containers. Rubber bands offer similar versatility, functioning effectively on a wide range of bag types. The resealing process for both methods typically involves expelling residual air from the bag and either folding the open edge for enhanced security or stretching the rubber band tightly around the folded portion. Both mechanisms create a seal that minimizes permeability to air and moisture, thereby reducing oxidation and moisture ingress. This preservation process helps maintain the organoleptic properties of the contents, such as flavour, texture, and freshness, over extended periods.

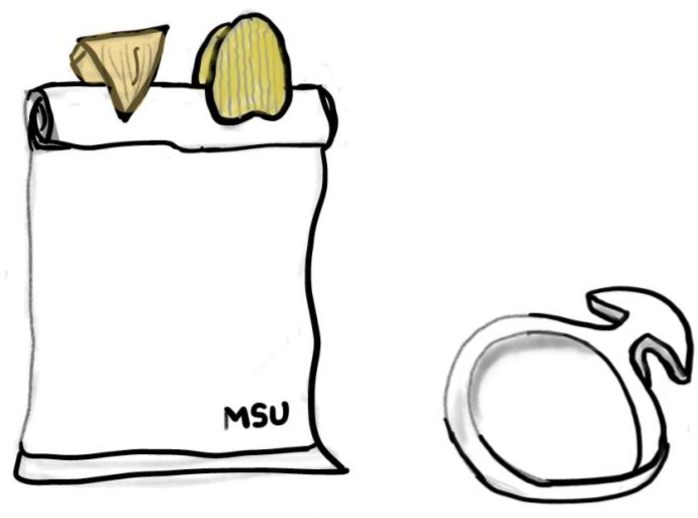

Figure 11 an example of Bag Clip and Rubber Band (Chou, 2022)

While bag clips and rubber bands are preferred household solutions for resealing, they present certain limitations. Bag clips are often misplaced, requiring frequent replacements or repurchases, which can be inconvenient over time. Rubber bands, though widely accessible, may degrade with repeated use, losing elasticity and effectiveness. Neither method provides a completely airtight seal, which can limit their effectiveness for long-term preservation. A more ideal solution would integrate a resealable closure mechanism directly into the packaging, eliminating the dependency on external tools while offering consistent functionality. Such built-in solutions could enhance user convenience, reduce waste, and provide a more reliable means of maintaining freshness.

Advantages: They are easy to use, requiring no special skills or tools to apply and remove. This simplicity makes them a convenient choice for consumers. Quick re-access to the contents is another benefit; rubber bands allow easy access to the bag contents without the need to cut or unseal the packaging, while bag clips enable effortless opening and resealing. Both options are also reusable, offering a sustainable and cost-effective solution for resealing, which contributes to reducing waste. Cost-effectiveness is another strength, especially for rubber bands, which are economical for short-term use, while bag clips offer long-term value due to their durability (gdubz_39, 2022). The versatility and variety of these tools make them adaptable to different bag types and materials, making them suitable for a wide range of products, including chips, cereals, cookies, and coffee bags.

Disadvantages: Limited airtightness is a key issue, as rubber bands do not create a fully airtight seal, which can affect freshness during long-term storage. Although bag clips offer a tighter seal, it is not hermetic, which may still limit their ability to maintain the freshness of perishable items over extended periods. Durability concerns arise with rubber bands, which degrade over time, losing elasticity and effectiveness. Bag clips, while durable, may break under heavy use or with thicker bags. Security concerns can also be an issue, as rubber bands may not provide as secure a seal against spills or contamination compared to bag clips, especially in bags that are frequently opened and closed. Furthermore, bag compatibility can be a limitation, as bag clips may struggle with thicker or uneven bag openings, and rubber bands may not grip smooth or laminated surfaces effectively (gdubz_39, 2022). Lastly, misplacement is a common problem, as both rubber bands and bag clips are small and easily lost, which can lead to inconvenience during reuse.

2.3.3. Heat Sealer

Household heat sealers are practical devices for resealing chip bags made from multi-laminate films, commonly used in the snack industry for their superior barrier properties against moisture, oxygen, and external contaminants. These bags typically consist of multiple layers, with a heat-sealable inner layer made from low-density polyethylene (LDPE) or polypropylene (PP), and outer layers like aluminum foil or polyethylene terephthalate (PET) providing additional durability and strength (Dou, 2021).

Figure 12 Heat Sealer used to seal flexible bags (Chou, A., 2022)

The heat-sealing process involves applying controlled heat to melt and fuse the inner thermoplastic layer, creating an airtight seal that preserves the freshness and crispness of the chips. While these devices offer an efficient resealing solution, their effectiveness is limited to bags with heat-sealable inner layers. Bags with excessively thick laminates or non-heat-sealable inner layers, such as certain polyester-based materials, may not work well with household heat sealers. Additionally, improper use or overheating can damage the bag, compromising its structural integrity or aesthetic appearance.

Household heat sealers, while relatively affordable compared to industrial models, require an upfront investment that may not be justifiable for occasional users. They are not universally compatible with all chip bags, and their reliance on electricity for operation adds an additional cost. Moreover, they require careful handling, as the heating element can pose a safety risk, particularly for children. The high temperatures needed to fuse plastic materials make these devices unsuitable for unsupervised use by younger individuals, as accidental contact with the heated surface.

Advantages: It provides an air-tight seal, effectively protecting the contents from exposure to air and moisture, which helps preserve freshness and quality for an extended period. This hermetic sealing capability is particularly important for perishable items. Another significant benefit is its professional appearance, as the sealed edges are neat and polished, enhancing the overall aesthetic appeal of the packaging, which is particularly beneficial for retail products. Additionally, the durability of the seal ensures long-lasting protection, maintaining the integrity of the packaged contents until the next use (Chou, A., 2022).

Disadvantages: One of the main drawbacks is the upfront cost, as heat sealers typically require a higher initial investment compared to simpler resealing methods such as clips or rubber bands. This could deter smaller operators or those seeking budget-friendly solutions. Another challenge is the operation complexity, as effectively using a heat sealer involves managing settings like temperature and pressure for consistent results, which may require a learning curve. Portability can also be an issue, as some heat sealers lack the compactness and convenience of alternative resealing tools, which can make them less practical for small-scale use or mobile operations. Moreover, material limitations exist, as heat sealing is not suitable for all bag types, especially those with heat-sensitive materials or coatings that could degrade under heat exposure (PassionateCucumber43, 2022). Additionally, the single-use seal means that once the bag is sealed, it must be cut open to access the contents, making it non-reusable compared to resealable clips or zippers. Lastly, safety concerns arise, as heat sealers generate high temperatures, presenting a burn or injury risk, particularly if left unattended or used improperly.

While household heat sealers are a practical and effective tool for resealing chip bags with compatible materials, their cost, material limitations, and safety risks—especially for households with children—are important factors to consider.

2.3.4. Slip-N-Seal and Gripstic®:

Gripstic® and plastic straws inboth serve as innovative solutions for resealing bags, offering alternatives to preserve freshness and protect contents from external elements. The Gripstic® provides a durable and reusable option by sliding over the folded edge of a bag to create a secure seal, effectively minimizing air and moisture exposure. Available in multiple sizes and dishwasher-safe, it is particularly suitable for households looking for a practical and efficient resealing tool that combines reliability and convenience (Gripstic, 2020). The airtight seal achieved with a Gripstic® makes it an excellent choice for both short-term and long-term storage.

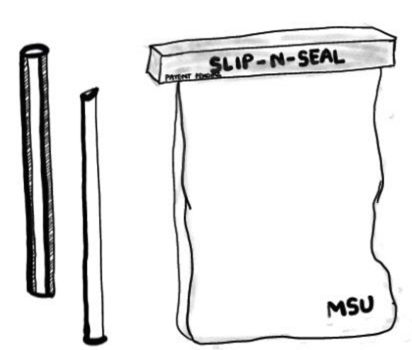

Figure 13 SLIP-N-SEAL tool to reseal bags

Plastic straws, on the other hand, offer a highly accessible and creative approach to bag resealing. This method involves cutting a straw lengthwise or trimming a portion to wrap around the folded edge of the bag. When combined with rolling the bag tightly, the straw provides a makeshift seal that prevents air and moisture ingress. While it lacks the durability and airtightness of more specialized tools like the Gripstic®, the straw method excels in situations where simplicity and availability are key, making it suitable for temporary storage or on-the-go use. However, it is less compatible with certain bag types and may not provide the same level of protection for longer-term preservation (Gripstic, 2015).

Both Gripstic® and straws highlight innovative approaches to resealing, catering to different needs and preferences. Gripstic® deliver a professional and reliable resealing solution for extended use, while straws offer a quick, low-effort option that is ideal for specific situations. Understanding the strengths and limitations of these methods allows consumers to select the most appropriate solution for their storage needs.

Advantages: Gripstic® provides excellent seal quality by ensuring airtight seals that effectively prevent air or moisture ingress, which is crucial for preserving freshness and extending shelf life. It is also highly reusable, offering long-term value as it can be used multiple times, unlike one-time solutions. In addition, Gripstic® is versatile, working with a wide variety of bag types, sizes, and materials, making it suitable for a broad range of applications. The system is designed for ease of use, with a straightforward sliding mechanism that makes it simple to apply and reapply the seal, making it accessible for all users (Gripstic, 2020). On the other hand, straws are a convenient and widely accessible option for resealing bags, though their functionality is more limited compared to Gripstic®.

Disadvantages: Straws, for example, do not provide airtight seals, which limits their effectiveness in preserving product quality over long periods. Their durability is also a concern, as they can degrade over time, losing their elasticity with repeated use. Additionally, straws may not be suitable for all bag types, particularly those that are thicker, laminated, or rigid, as they may not provide a secure seal. Aesthetics is another disadvantage, as straws tend to provide a less polished and professional appearance compared to other resealing methods like Gripstic® (Gripstic, 2020). Furthermore, the use of disposable straws contributes to environmental impact due to waste, especially in single-use scenarios. While Gripstic® offers better reusability, it has a learning curve since users must understand the sliding mechanism to use it effectively. Lastly, Gripstic® can be more expensive than simpler resealing methods, making it a less cost-effective option for some users.

2.4. Relevant Reclosure Methods from Other Product Categories

In the ever-evolving world of packaging, innovation often stems from cross-industry inspiration. Examining reclosure methods used in other product categories offers valuable insights into how successful designs can be adapted or reimagined for new applications. Flexible pillow bag packaging, commonly used for food products, presents unique challenges in terms of maintaining freshness, ease of use, and cost-effectiveness. Current solutions often fall short in providing a balance between functionality and user convenience, highlighting the need for exploring alternative designs.

By studying reclosure systems from various industries, it becomes possible to identify features and principles that can be redesigned to meet the specific demands of pillow bags. These systems may include mechanisms originally developed for products with different packaging materials, structural properties, or usage patterns. Such an approach allows for a fresh perspective, encouraging innovation that leverages proven techniques while tailoring them to the unique characteristics of flexible packaging.

The primary aim is to evaluate the adaptability of these methods for pillow bags, focusing on their effectiveness, practicality, and user-centric design. This exploration seeks to uncover potential solutions that can address the shortcomings of existing reclosures, paving the way for advancements in pillow bag packaging that meet both consumer expectations and modern packaging requirements.

2.4.1. Dry Bag Reclosure

Outdoor waterproof dry bags utilize a roll-top closure mechanism designed to protect contents from water, dust, and other environmental elements. This closure method, demonstrated in Figure 14, is particularly effective for creating a secure seal in rugged conditions. The process involves folding the top of the bag several times, followed by securing it with a buckle or similar locking system. While this system ensures excellent protection, its simplicity and adaptability make it a versatile option for various packaging needs.

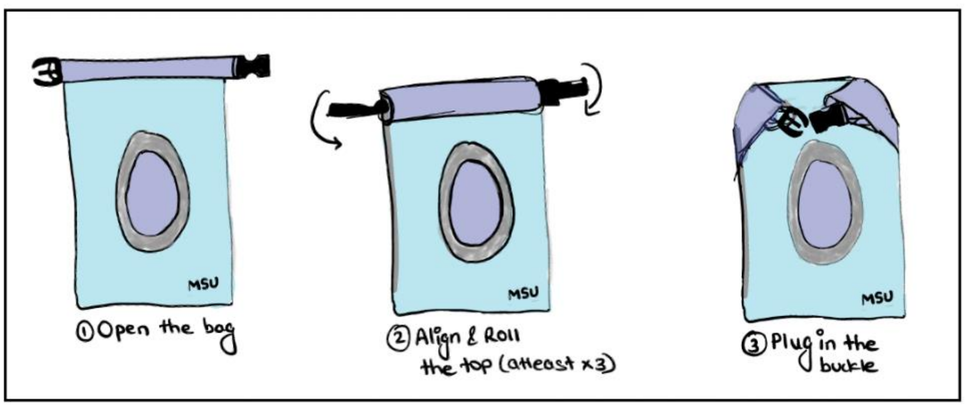

Figure 14 Closing mechanism of Dry Bag

Adapting this concept for flexible pillow bag packaging can be achieved by replacing the buckle with a tie or knot-based mechanism. This alternative provides a straightforward and cost-effective method of sealing while maintaining accessibility and freshness. The implementation involves folding the top of the bag to create a flap and then securing it with a knot or loose tie. This technique ensures the bag remains sealed, while allowing for easy reopening and resealing. Although it may not achieve the airtight properties of other methods, it offers sufficient freshness for short-term storage, particularly for snacks like chips.

Using a tie or knot-based closure can add a unique element to the packaging while eliminating the need for additional hardware. The simplicity of the system ensures it is both functional and user-friendly, provided the knot is secure yet easy to undo when needed. Additionally, the Waterproof Bag Buckling System offers a robust reclosure mechanism, particularly for moisture-sensitive contents. This method offers practical, protective, and accessible solutions for various applications.

2.4.2. Snap Lock Reclosure

The snap lock closure system is a versatile mechanism widely applied across various industries and products, including its use in eyeglass pouches, as shown in Figure 15. In such applications, an embedded metal strip acts as the snap lock mechanism. This closure design provides a distinct audible click, signaling whether the pouch is fully open or securely closed, making it highly user-friendly.

This system could be adapted for flexible pillow bag packaging of chips, offering an intuitive and consumer-friendly sealing option. The audible feedback feature ensures ease of use and enhances the consumer experience by clearly indicating the bag's open or closed status. However, implementing snap lock closures in food packaging presents challenges. The inclusion of additional components increases production costs, making it less cost-effective for pillow bag applications. Furthermore, the metal strip traditionally used in snap locks would need to be replaced with food-safe materials to meet safety standards for food packaging.

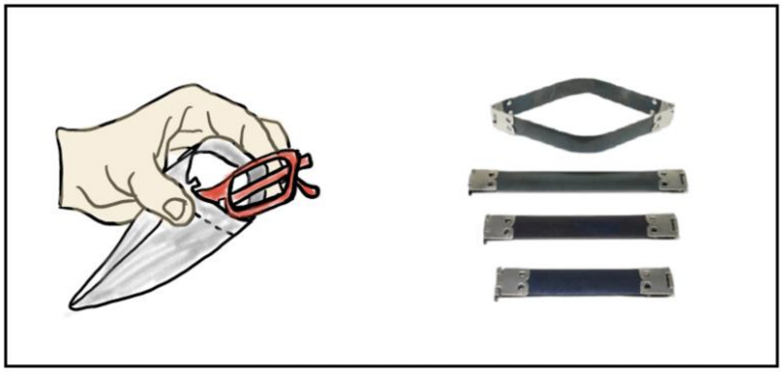

Figure 15 Snap Lock Reclosure used in eyeglass pouches

2.4.3. Drawstring Reclosure

The drawstring closure system, commonly used in trash bags, offers an alternative to interlocking closure systems. As shown in Figure 16, this mechanism eliminates the hassle of tying knots by allowing users to seal the bag effortlessly by pulling the drawstrings. This design helps prevent spillage, minimizes odour leakage, and enhances cleanliness, making it a highly user-friendly solution for securing and sealing bags.

Figure 16 Usage instructions of Drawstring reclosure used in Garbage bags (Images sourced from Amazon.com)

Incorporating a drawstring closure into a chips pillow bag involves integrating a drawstring mechanism at the bag's top opening. By cinching the drawstring, users can reseal the bag, maintaining freshness while providing easy access to the contents. This design supports portion control and convenience, offering a resealable option for snack packaging. However, it is important to note that while the drawstring closure is simple and effective, it may not provide the airtight sealing quality of professionally sealed bags.

The transposing drawstring closure system demonstrates versatility and ease of use, making it a practical solution for flexible packaging. Its potential adaptation for chips pillow bags emphasizes convenience and consumer-friendliness.

2.5. Reclosure Systems Identified for Application on Pillow Bags

In the search for effective reclosure mechanisms for pillow bags, the market study has identified two promising designs that can be adapted to meet the specific requirements of pillow bag packaging format. Origami Fold Designs, inspired by the art of Japanese paper folding, offer a unique approach by creating secure and reusable closures through intricate folds. These designs could significantly simplify the manufacturing process by eliminating the need for additional sealing components, thus reducing material usage.

Additionally, the Buckling System from Dry Bags, which employs a roll-top closure secured by a buckle, shows potential for adaptation. The system can be modified to fit the material constraints of pillow bags, ensuring a strong seal is crucial for maintaining the freshness and quality of the contents.

CHAPTER 3 DEVELOPMENT OF NEW RECLOSURE SYSTEMS

This chapter focuses on the initial stages of the design process, including ideation, design development, and Finite Element Analysis (FEA) with tear testing. Ideation involves generating creative concepts tailored to the problem statement, while design development refines these ideas into practical, feasible solutions. FEA and tear testing are used to assess structural integrity and material performance, ensuring the design meets preliminary performance criteria. The subsequent stages, such as sample preparation and testing will be discussed in the next chapter.

Design Goal: The primary objective of designing a reclosure system for pillow bags is to develop a convenient, user-centric solution that aligns with the principles of Design for Manufacturing (DFM) and Design for Usability (DFU). The reclosure mechanism must offer intuitive operation, enabling consumers to easily open, reseal, and access the bag's contents without the need for external tools or complex steps. The design should integrate seamlessly with the flexible structure of pillow bags while ensuring reliability in maintaining product freshness by minimizing air and moisture ingress.

Incorporating Design for Cost (DFC), the solution should be economical for large-scale production, minimizing material waste and component complexity without compromising functionality. Additionally, the reclosure system must adhere to Design for Sustainability (DFS) by using recyclable or eco-friendly materials where feasible. By balancing usability, manufacturing efficiency, and material considerations, the proposed reclosure mechanism will address modern consumer demands while supporting scalable and cost-effective production processes.

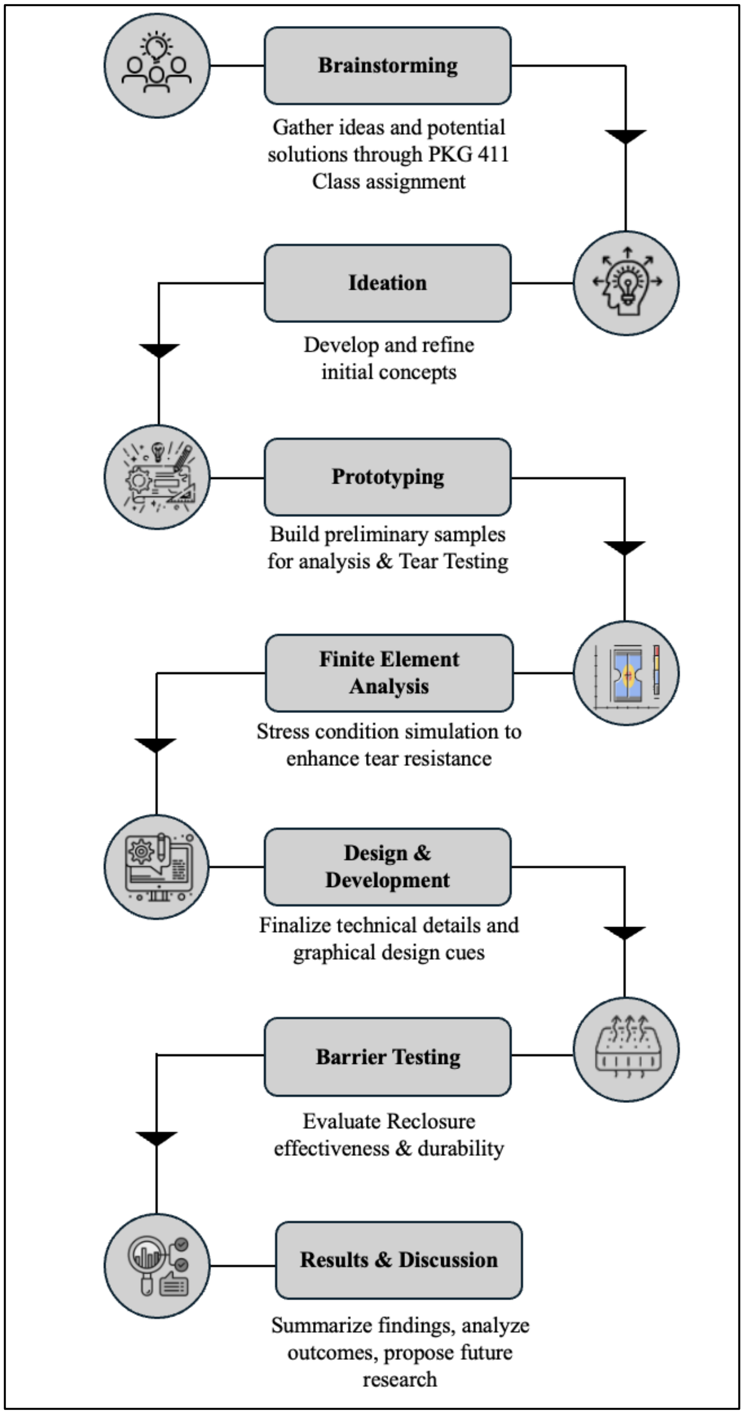

Figure 17 Overview of Reclosure Development Process

3.1. Brainstorming- Insights from PKG 411 Class Project Assignment on Pillow Bag Reclosures

PKG 411: Package Development Technology is a course offered at Michigan State University that focuses on the development of consumer packaging utilizing current technology tools. The course emphasizes the integration of package structure, graphics, and performance to create functional and innovative packaging solutions. Through the examination and application of current practices in packaging development, students are equipped with the skills necessary to address real-world challenges. This hands-on approach allows students to leverage industry-standard software, materials, and manufacturing processes, fostering both technical proficiency and creative problem-solving.

For the purpose of this research, the Individual Project 2 (IP02) assignment was introduced to assess students' preferences for reclosure mechanisms and to generate a larger pool of innovative designs for pillow bag packaging. Recognizing that these students are both future packaging engineers and active consumers, the assignment aimed to explore their inclinations toward specific reclosure solutions while encouraging them to propose diverse and technically feasible concepts. This approach sought to create a comprehensive repository of ideas that could address real-world packaging challenges, blending functionality and user convenience.

The assignment provided students with detailed specifications to guide their designs, ensuring consistency and adherence to practical constraints:

- Dimensions: Width 210.0 mm, Length 280.0 mm.
- Seals: Top seal 15.0 mm, bottom seal 15.0 mm.

- Back Seal: Size 15.0 mm; Type - overlapping icon (first icon); Order - right over left; Position - cantered.
- Appearance: Highlights - Glossy (60%); Rounding - 0.10.

Additionally, students were required to incorporate essential design elements such as a unique brand name and nutritional facts, reflecting industry standards. A significant emphasis was placed on reclosure mechanisms, with each submission requiring detailed descriptions and graphical visuals to demonstrate functionality and user interaction. Deliverables included Adobe Illustrator files, 2D PDFs, Collada files, and PDF summaries, ensuring comprehensive documentation of the designs.

The project resulted in submissions from thirty-eight (38) students, each presenting pillow bag designs with innovative reclosure concepts. These designs were categorized into five primary groups based on their mechanisms: Press to Close, Origami Fold, Tape Reclosure, Fold & Tie, and Other Unique Mechanisms as seen in Table 5.

Table 5 Summary of Reclosure designs generated through PKG 411 IP02 Assignment

Reclosure Category	**Example (Front & Back of Pillow Bag with Usage Instructions)**
Press to Close 9 submissions	
Origami Fold 9 submissions	
Tape Reclosure 7 submissions	
Fold & Tie 8 submissions	
Other Categories 5 submissions	

3.2. Ideation Stage

The ideation phase served as the foundation for developing practical reclosure solutions for pillow bag packaging. Guided by a detailed market study and multiple feedback iterations with **Amcor**, this phase focused on identifying reclosure methods that align with user preferences and functional requirements. Using digital tools (Notability), initial concepts were generated to address key objectives such as usability and resealability.

Drawing inspiration from existing solutions across various product categories, the research team explored designs such as waterproof bag buckling systems, origami folds, and twist-and-tie closures. Structured brainstorming sessions and collaborative discussions facilitated the evaluation and refinement of these ideas, ensuring their practicality and alignment with the project goals. Through this iterative process, three promising concepts—Origami Fold Design, Fold & Tie, and Twist & Tie—were identified for further exploration.

In the following sections, each of these design concepts is discussed in detail, highlighting their functionality, potential advantages, and areas for improvement as part of the iterative design process.

3.2.1. Origami Fold Design 1 & 2

The Origami Bag Fold technique is a creative and functional approach that emphasizes user convenience and food preservation. This method transforms the mundane task of resealing a bag into a practical and engaging activity. By using simple folding techniques, it can help in maintaining the freshness of the bag's contents while also serving as a fun activity for children.

Design 1: Triangular Folds

Step 1: Begin by smoothing out trapped air inside the bag to make it more compact and easier to fold.

Step 2: Fold one corner of the top edge diagonally, creating a triangular layer on one side of the bag.

Step 3: Repeat the fold on the opposite corner to form a triangular peak at the center of the bag's top. This symmetrical shape sets the foundation for a secure closure.

Step 4: Fold the top triangular portion downward toward the center, compressing the bag further and preparing it for sealing.

Step 5: Roll the top edge of the bag tightly toward the center to create a firm closure.

Step 6: Secure the folded flap by tucking it into the triangular pocket created earlier, locking the fold in place and completing the closure.

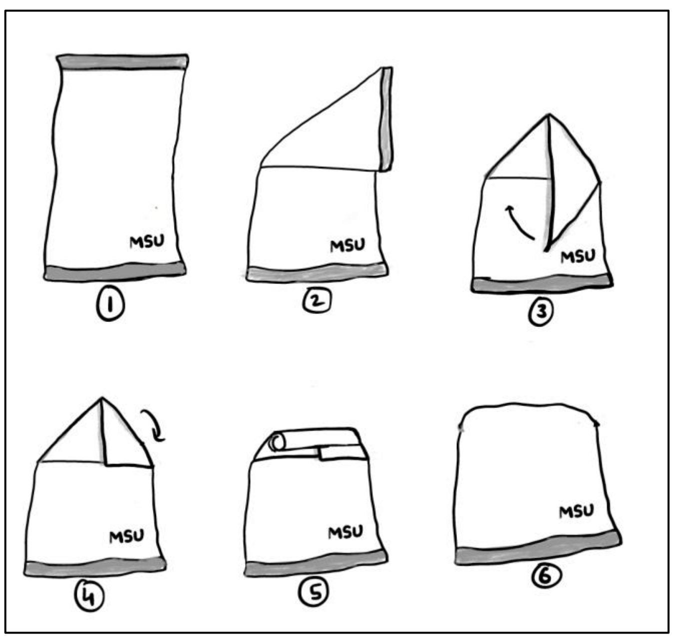

Figure 18 Origami Fold Reclosure Concept

As depicted in Figure 18, this six-step method provides a straightforward yet highly effective way to reseal bags.

Design 2: Roll-n-Tuck Origami Fold

Step 1: Keep Bag Straight: Start by smoothing out the bag to ensure it is straight and wrinkle-free.

Step 2: Fold the Corners: Neatly fold the top corners of the bag inwards to form a pointed top.

Step 3: Roll the Top Downwards: Carefully roll the pointed top downwards towards the body of the bag to create a tight roll.

Step 4: Tuck the Sides Over the Top: Secure the rolled top by tucking the sides over it, ensuring the closure stays in place.

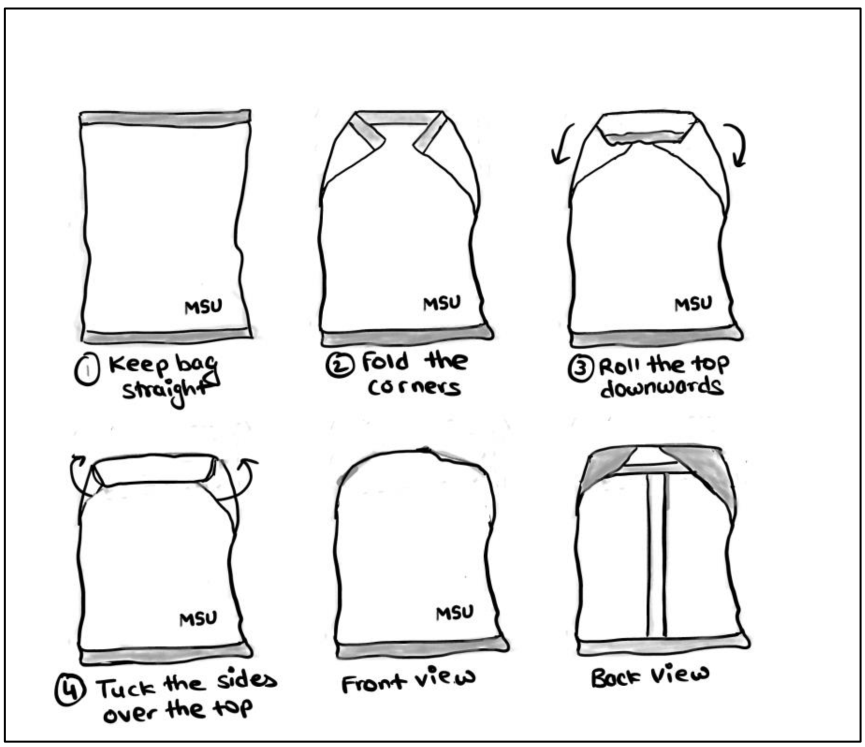

Figure 19 Reclosure Instructions for Origami Fold Design 2

While some variations of the technique may include additional modifications, such as flipping flaps outward or creating decorative fronts for chip bags, this version strikes a balance between simplicity and utility. Moreover, this folding technique offers a sustainable alternative to single-use clips or adhesives, enhancing its appeal for eco-conscious users.

3.2.2. Fold & Tie

The Fold & Tie reclosure method provides a straightforward and functional solution for resealing flexible pillow bags, focusing on user convenience and practicality. Perforations along the top edge of the bag are incorporated into the design, allowing users to easily form two arms for tying without the need for additional tools.

The method involves three key steps in Figure 20,

Step 1: Tear the perforated section at the top edge of the bag to create two arms.

Step 2: Fold the top portion of the bag multiple times to reduce the size of the opening and bring it closer to the contents, minimizing air ingress and helping maintain product freshness.

Step 3: Tie the two arms securely around the folded section to prevent the bag from unfolding, providing a firm hold that protects the contents during storage.

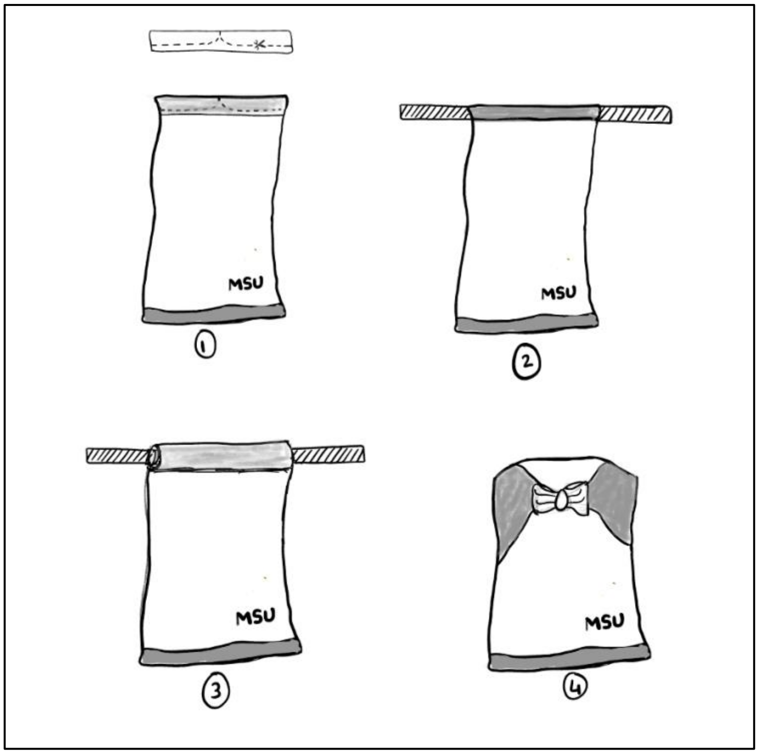

Figure 20 Fold & Tie Concept Design

3.2.3. Twist & Tie

The Twist & Tie technique simplifies resealing bags by combining an intuitive twist with a secure in-built tie, ensuring convenience. This approach offers a practical and swift method to reseal bags, making it ideal for various packaging applications.

Step 1: Tear the chips bag along the designated dashed line. This prepares the bag for resealing and ensures clean, manageable edges.

Step 2: Twist the bag two times at the top, compressing the opening and securing the contents within the bag.

Step 3: Use the built-in arm or a tie mechanism to wrap around the twisted portion of the bag, securing it tightly in place.

As illustrated in Figure 21, the Twist & Tie method provides a simple yet effective way to seal snack bags. This technique minimizes the need for additional sealing tools and supports sustainable practices, making it both functional and environmentally friendly. Its straightforward design also makes it suitable for all users.

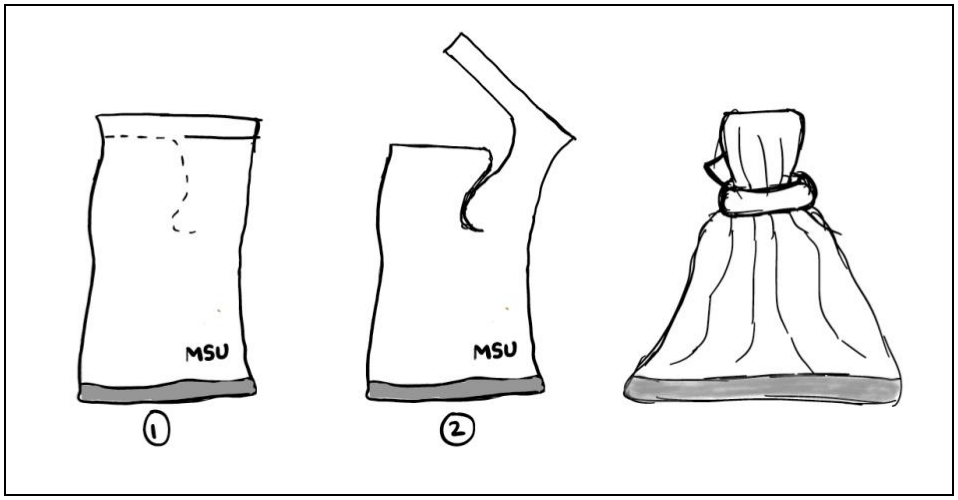

Figure 21 Twist & Tie Concept Design

3.3. Prototyping

The prototyping phase is a crucial stage in the development of innovative reclosure systems, bridging the gap between theoretical designs and practical application. This phase allows for the physical realization of concepts, enabling a comprehensive assessment of design functionality, material performance, and user interaction under realistic conditions. During this stage, prototypes are constructed to assess key attributes such as the tear resistance of materials, the effectiveness of closure mechanisms with repeated use, and the overall durability and ease of use of the design. Prototyping enables engineers and designers to analyze both quantitatively and qualitatively how various materials—such as advanced laminates and composites—perform under stresses and manipulations typical of consumer handling. This empirical evaluation is critical for refining material choices and optimizing design geometries, ensuring that the final reclosure solutions are feasible for sustainability, and consumer satisfaction.

3.3.1. Prototype Development with Multilaminate Film

Material selection was critical to this study to ensure that the proposed reclosure mechanisms could be effectively applied to existing market materials, reflecting real-world applications. The material from **Sensible Portions Garden Veggie Straws 6 oz Bags** (Figure 22) was chosen as **Control material sample** since it provided a worst-case scenario due to its low tear resistance compared to other competitive brands. Additionally, the wide seals of this material were particularly important for accommodating the Fold & Tie design, offering ample space for implementing the folding and tying mechanism effectively. While the exact composition of the multilaminate structure was not known, the material's inherent flexibility and practical dimensions made it suitable for consistent testing across all designs, including Origami Fold and Twist & Tie.

Figure 22 Product Image of Sensible Portions Garden Veggie Straws 7 oz Bag from Amazon USA e-commerce website Source: Amazon (https://www.amazon.com/Sensible-Portions-Garden-Veggie-Straws/dp/B012W327D0, accessed on November 15th, 2024)

The initial phase of prototype development involved using multilaminate film, a common material in flexible packaging, to test various reclosure mechanisms. This stage was crucial for evaluating the practical application and durability of the film under different reclosure designs such as Twist & Tie, Fold & Tie, and Origami Fold as seen in Figure 23. Despite its favorable properties for packaging, the multilaminate film often failed under the mechanical stresses imposed by the reclosure techniques. Notably, mechanisms requiring significant manipulation of the material frequently led to tearing, compromising the integrity and functionality of the prototypes. This recurrent issue with tearing, particularly evident in the testing of Twist & Tie and Fold & Tie designs, highlighted a critical material limitation. These observations emphasized the need for materials with enhanced mechanical durability and tear resistance, prompting the exploration of alternative materials that could better withstand the demands of innovative reclosure systems.

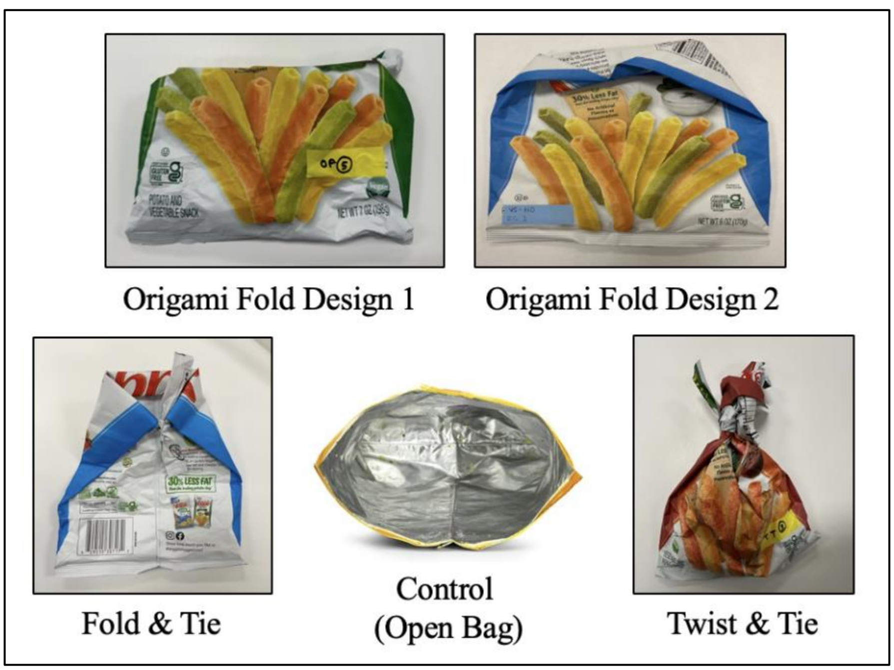

Figure 23 Reclosure Designs with Veggie Straws Multilaminate Film

3.3.2. Prototype Development Using AmFiber™ and Metal-Free Laminates (MFL):

AmFiber™ Performance Paper as shown in Figure 24 is a recyclable, paper-based material that offers high oxygen and moisture barrier properties, providing product protection comparable to metalized Oriented Polypropylene (OPP) packaging. With over 80% paper fiber content and a Polyvinylidene chloride (PVDC)-free composition, it aligns with sustainability goals while maintaining excellent performance. Machine trials by Amcor have demonstrated its seamless compatibility with existing production lines, eliminating common paper-related issues such as tearing or reduced line speeds. The material roll, supplied by the Amcor, was selected for its unique combination of barrier properties and mechanical flexibility.

This material was particularly suited for the Origami Fold Reclosure design due to its excellent foldability, a result of its metallized Biaxially Oriented Polypropylene (BOPP) and paper composition. Its structural properties allowed for precise folding and secure closure, making it an ideal choice for prototyping and testing this reclosure concept.

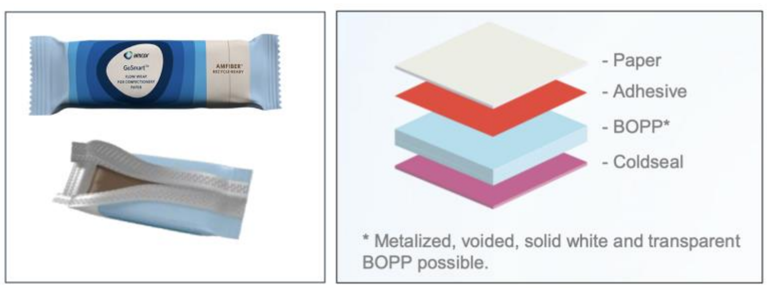

Figure 24 AmFiber™ Performance Paper GoSmart™ Flow wrap and Material Composition (Amcor, 2022)

Amcor's Metal-Free Laminates (MFL) are a recyclable, high-barrier packaging material engineered to deliver superior oxygen and moisture protection without relying on traditional metalized structures. These laminates achieve performance levels comparable to materials such as Polyethylene Terephthalate (PET) and Aluminum (ALU) while offering enhanced sustainability. The transparent film supplied by Amcor was composed of Oriented Polyethylene Terephthalate (OPET) and High-Density Polyethylene (HDPE), which provided the tear resistance necessary for reclosure applications. This characteristic was particularly beneficial for the Fold & Tie and Twist & Tie reclosure designs, as it ensured the material could withstand repeated folding and twisting. Additionally, the material's compatibility with standard manufacturing equipment facilitated smooth integration during prototyping and testing.

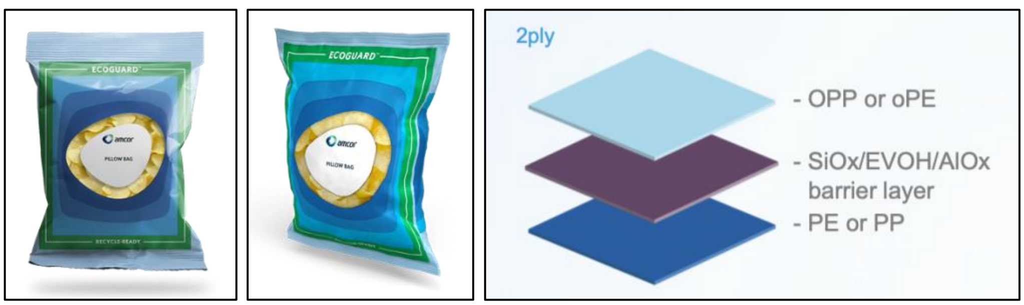

Figure 25 Amcor's Metal-Free Laminates Pillow Bag and Material Composition (Amcor, 2022)

Building on the insights gained from the tear resistance tests, the next set of prototypes were developed using AmFiber™ and Metal-Free Laminates (MFL) provided by Amcor.

Figure 26 Fold & Tie and Twist & Tie with MFL and Origami Fold with AmFiber™

During the prototype creation process, AmFiber™ demonstrated its excellent dead-fold properties, crucial for maintaining precise folds in the Origami Fold design without unwinding. Meanwhile, the high tear resistance strength of MFL was pivotal in enhancing the durability and reliability of the Twist & Tie and Fold & Tie designs, requiring precise handling to ensure optimal functionality and integration into the closure system. Overall, the usability of the reclosure methods was significantly enhanced by these materials, that confirmed each prototype's functionality and durability, establishing their capability to maintain structural integrity under standard usage.

3.3.3. Material Characterization and Verification through Tear Testing

The material used in packaging for veggie straws has been reported to tear easily, compromising its functionality and durability. Numerous customer complaints from Reddit and other forums highlight frustrations with the packaging failing during regular use, leading to spills and product wastage. These feedback instances are presented in Figure 27, showcasing the recurring issues and the need for improved material performance in such packaging.

(clhonu05, 2019) (Honey-Badger-42, 2023) (SLII, 2015)

Figure 27 Packaging Failure Examples by Veggie Straws Consumers

Tear testing was conducted to evaluate the tear resistance of materials discussed in the previous sub-section. The objective of this evaluation was to assess the materials' behavior during the opening and reclosure processes, ensuring a balance between controlled tearing for ease of use and maintaining structural integrity for durability. By understanding the tear propagation characteristics of different materials, the test study aimed to provide insights into material performance under real-world conditions, enabling the selection of suitable materials and designs for optimized packaging solutions. The testing followed the **ASTM D1922**, which specifies the propagation tear resistance of plastic films using a pendulum method (ASTM International, 2020). This standardized approach allowed for consistent and reproducible measurements of the force required to propagate a tear. A total of 49 samples were prepared, including three materials: Veggie Straws Multilaminate Film, AmFiber™ Performance Paper, and Amcor's Metal-Free Laminates (MFL).

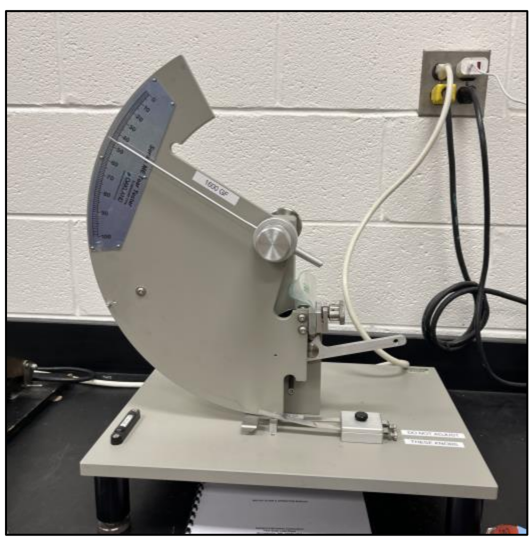

Figure 28 Elmendorf Tear Tester at School of Packaging

Each sample was pre-notched to ensure uniform tear initiation and mounted on a pendulum apparatus that applied a controlled force to propagate the tear. The forces required in the Machine Direction (MD) and Cross Direction (CD) were recorded in millinewtons (mN), providing valuable data for evaluating the tear resistance of each material.

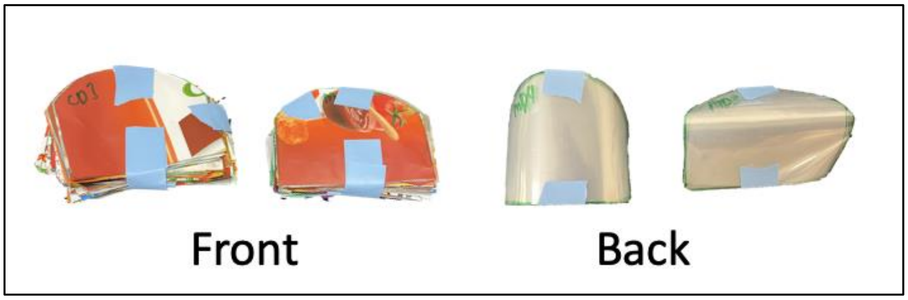

Figure 29 Material Sample Preparation for Tear testing

The results revealed significant variations in tear resistance among the materials tested. MFL exhibited the highest tear resistance, with values of 977.08 mN in the Machine Direction and 784.9 mN in the Cross Direction. This indicates its superior strength and durability, making it suitable for applications requiring robust materials.

Table 6 Tear Testing Results and Analysis

Material	**Tear Resistance (in mN)**		**Suitable Designs**	**Reason**
	MD	**CD**		
MFL (HDPE+OPET)	977.08	784.9	Twist & Tie, Fold & Tie	High tear resistance ensures durability and prevents unintended tearing.
Metallized Paper (Amfiber™)	403.3	596.45	Origami Fold	Dead-fold properties allow the material to hold its shape after folding.
Veggie Straw Multilaminate Film	264.87	294.3	Easy Open Applications	Low tear resistance prioritizes ease of opening but limits durability.

Metallized Paper (Amfiber) showed moderate tear resistance, recording 403.3 mN in the Machine Direction and 596.45 mN in the Cross Direction. This material strikes a balance between durability and ease of use, making it a viable option for applications where moderate strength is sufficient. Veggie Straw Multilaminate Film demonstrated the lowest tear resistance, with values of 264.87 mN in the Machine Direction and 294.3 mN in the Cross Direction. Its lower resistance makes it easier to open but potentially less durable for applications requiring high mechanical strength.

The analysis highlighted the alignment of material properties with specific packaging designs to balance tear resistance and usability. Materials with higher tear resistance, like MFL, are more durable and suitable for designs such as Twist & Tie and Fold & Tie, where durability and resistance to unintended tearing are essential. Conversely, materials with moderate tear resistance, such as Metallized Paper (AmFiber™), are better suited for applications like the Origami Fold, leveraging its dead-fold properties to maintain shape and provide secure reclosure. For designs where ease of opening is prioritized, materials with lower tear resistance, such as Veggie Straw Multilaminate Film, can be utilized, though their durability may be limited under higher mechanical stresses during handling and transportation.

3.4. Reducing Unintended Tear through Finite Element Analysis

3.4.1. **Overview of Opening techniques used for a Pillow Bag with Chips**

The opening techniques used for pillow bags containing chips varied among consumers. The three most common methods were analyzed to understand how each technique affected the packaging's usability. This overview focused on the different approaches used to open chips bags, highlighting the most frequently employed methods.

Figure 30 Opening mechanism with Pre-cut Notch (McGee, 2017; Andreasson & Kao-Walter, 2013)

The opening of pillow bags in Figure 30 begins with a tear at a pre-cut notch (Step 1) and continues with peeling to access the contents (Step 2). To analyze the tearing behavior, a Mixed-Mode Trouser Test is comparable. This involves a trouser-shaped test piece where a crack propagates from an initial incision (Andreasson & Kao-Walter, 2013). The path of future crack growth, represented by the broken line, is influenced by the material properties and applied forces. Finite Element Analysis (FEA) helps optimize these factors, ensuring controlled tear propagation and user-friendly packaging.

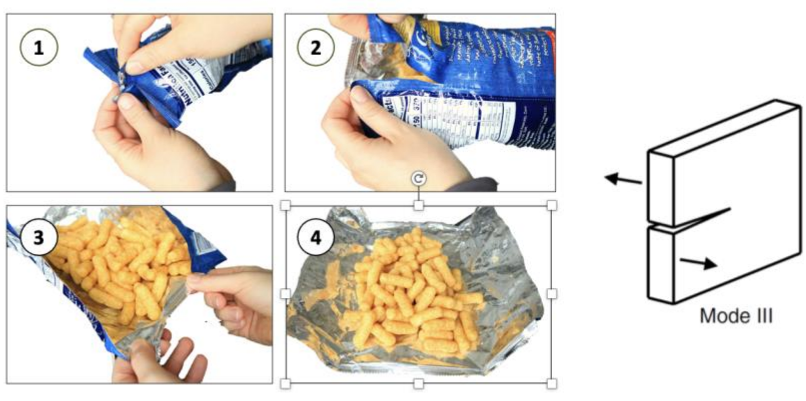

Figure 31 Opening a Pillow bag entirely to make "Picnic basket"(Reinmann, 2023; Andreasson & Kao-Walter, 2013)

The method in Figure 31 utilizes the vertical seam on the back of the bag, which could be a flap or a pressed seam, as the starting point. Once the top of the bag is opened (Step 1), the seam is split vertically down the back by pulling along the center (Step 2). For pressed seams, careful ripping ensures a clean split. Once the seam is fully opened (Step 3), the bag is flattened out, turning the bottom seam into a makeshift "picnic blanket" (Step 4). This technique involves Mode III (Anti-Plane Shearing), where opposite forces applied along the seam create shear stress that propagates the crack downward (Andreasson & Kao-Walter, 2013). The anti-plane shearing mode ensures controlled crack propagation along the seam, providing maximum accessibility to the contents while maintaining stability for sharing or serving snacks.

Figure 32 Opening Technique: Side Bowl Tear with Mode I (In-Plane Opening) (Reinmann, 2023; Andreasson & Kao-Walter, 2013)

Figure 32 Figure 44 involves technique involves creating a wide and shallow opening by ripping a strip down the side of the bag. Instead of opening the top seam, the user pulls along the bag’s edge (Step 1), creating a shallow "bowl" for easy access to the contents (Step 2). The bag retains its structure, providing security while allowing for better sharing. Mechanically, this corresponds to Mode I (In-Plane Opening) in fracture mechanics. In this mode, the applied forces separate the crack surfaces perpendicularly to the plane of the crack, propagating it cleanly along the edge (Andreasson & Kao-Walter, 2013). The material's resistance to this in-plane separation defines the effort required for the tear. FEA can simulate the stress distribution and tearing mechanics to optimize the notch design and material properties, ensuring ease of opening while maintaining bag integrity.

3.4.2. Finite Element Method and Analysis

FEA is a computational tool that enables the simulation of stress and strain distribution in materials under specific loading conditions (Huebner, Dewhirst, Smith, & Byrom, 2001; Pathare & Opara, 2014). In the context of flexible packaging, like pillow bags, FEA is employed to analyze and mitigate stress concentrations that could lead to undesired tearing. Stress concentrations typically arise in areas such as seams, notches, or weak points in the material, where applied forces become unevenly distributed. These high-stress areas can compromise the structural integrity of the packaging, resulting in premature failure (Cook et al., 2002; Pathare & Opara, 2014). The goal of using FEA is to design a resistance shape that effectively redistributes stress, preventing <u>undesirable continuous tearing</u> and enhancing the durability of the packaging.

The process involves creating a virtual model of the packaging and dividing it into small finite elements, each with defined material properties such as tensile strength and elasticity (Moaveni, 2008; Roduit et al., 2005). Simulations are then conducted to evaluate how the material reacts to external forces, such as those exerted during opening or transportation. By identifying areas with high stress, modifications can be made to the design, such as smoothing sharp corners or adjusting seam geometries, to reduce stress intensity. For instance, transitioning from sharp edges to rounded features can lower stress peaks and improve the package's resistance to tearing under mechanical loads.

FEA also reduces the need for physical testing by providing detailed insights into material behavior under various scenarios. This approach is cost-effective and accelerates the design process. In packaging, achieving optimal tear resistance is critical to ensuring product protection and user convenience. For example, materials that are too weak may result in unintended tears, while overly rigid designs can make the package difficult to open. By fine-tuning the geometry and material properties through FEA simulations, packaging can be made both functional and consumer-friendly (Gupta & Meek, 1996; Pathare & Opara, 2014).

The application of FEA in this study is aimed at preventing tearing in pillow bags by creating designs that minimize stress concentrations. This approach not only aids in application of reclosure methods but also enhances its usability and reduces waste. Ultimately, FEA enables more efficient and robust packaging development, balancing durability and user experience (Cook et al., 2002; Hughes, 2012; Schaldach et al., 2000).

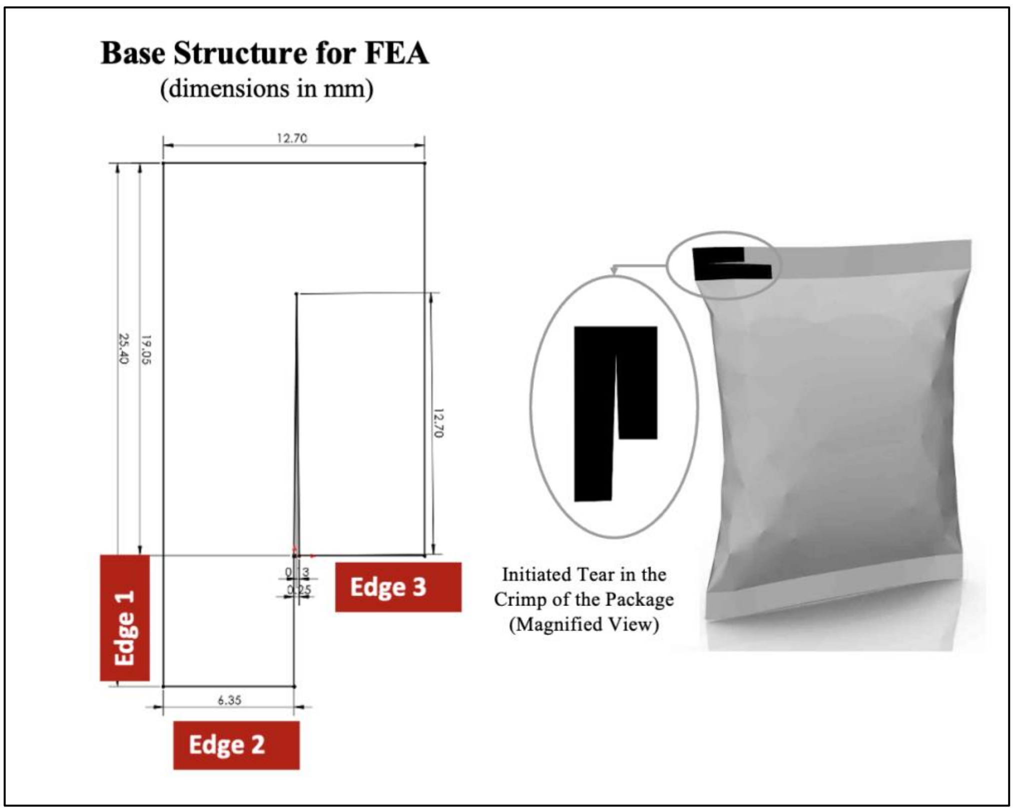

Figure 33 The Base Structure used in FEA study

To meet the objectives of the FEA study, various shape configurations were analyzed, with a focus on stress-prone areas, to identify designs that minimize stress concentration. Simulations were conducted using SolidWorks 2023, incorporating realistic loading and boundary conditions to mimic real-world usage scenarios. The base structure used in the FEA study, as shown in Figure 33, was designed to replicate the portion of the bag near the perforation zone. Low-Density Polyethylene (LDPE) was selected as the material of construction due to its prevalent use in flexible packaging. The modeled object included specific dimensions designed to mimic functional portions of a chip bag, with Edge 1 and Edge 2 fixed to simulate the structural constraints of the surrounding bag. A force of 0.1 N was applied to Edge 3 in two directions, representing the typical stresses encountered during opening and reclosing. To evaluate the impact of shape dimensions, the diameter of a circular feature was incrementally increased from 2.5 mm to 6.5 mm in steps of 0.5 mm, while maintaining a triangular shape as the standard for comparison, as illustrated in Figure 33 and Figure 34.

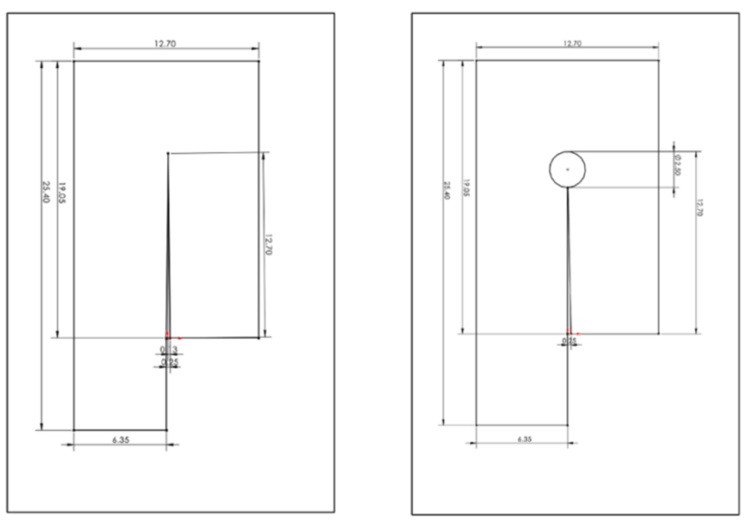

Figure 34 Base Structure used in FEA: Triangle (standard) and circle (variation 2.5 to 6.5 mm diameter)

The simulation results provided valuable insights into the relationship between shape dimensions and stress distribution within the material. As the diameter of the circle increased, stress levels consistently decreased until a local minimum was reached at 4.5 mm. Beyond this point, stress levels began to rise again, indicating the existence of an optimal diameter for minimizing stress concentrations. This behavior is depicted in Figure 35, it highlights the stress distribution patterns for both shapes, demonstrating the superior performance of the circle at the optimal dimension.

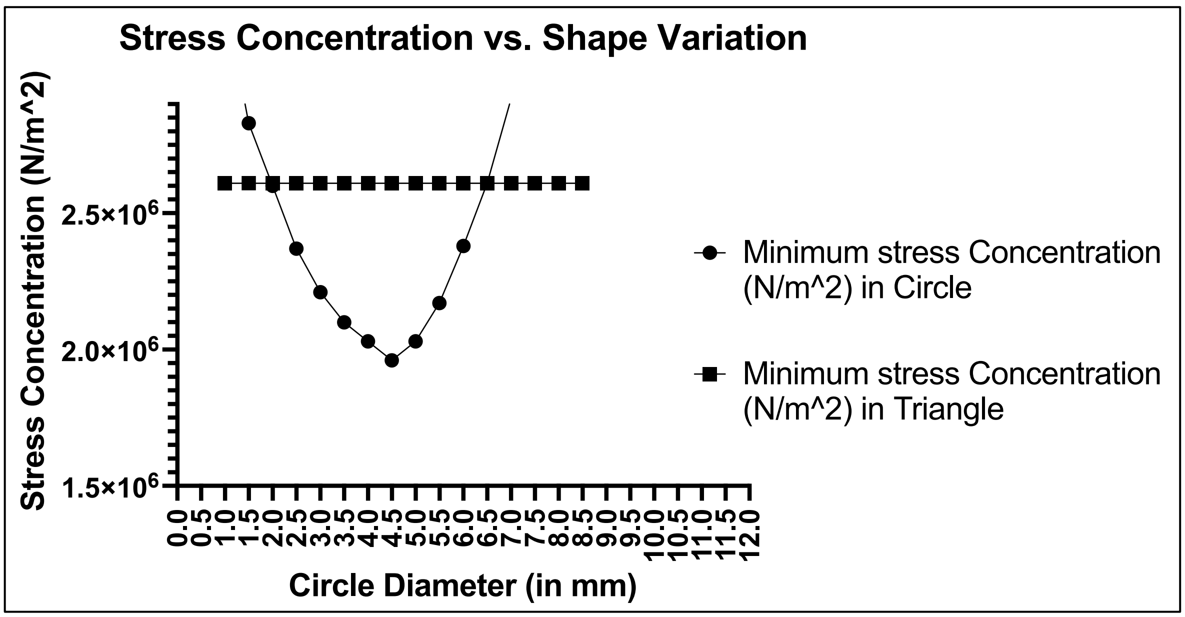

Figure 35 Stress Distribution versus Shape Variation

The triangular shape, maintained as a standard, exhibited a maximum stress of 2.02 x 107 N/mm^2, whereas the circular shape at its optimal dimension exhibited a reduced maximum stress of 1.60 x 107 N/mm^2. These dimensions are summarized in Table 7, which also details the comparative performance of the triangle and circle shapes. Dimensions and Stress Compression for two shapes, i.e. Triangle and Circle.

Table 7 Dimensions and Stress Compression for two shapes, i.e. Triangle and Circle

Shape	Triangle	Circle
Dimensions (in mm)	Height: 12.7 Base: 2.5	Diameter: 4.5
Maximum Stress (in N/mm^2)	2.02E+07	1.60E+07

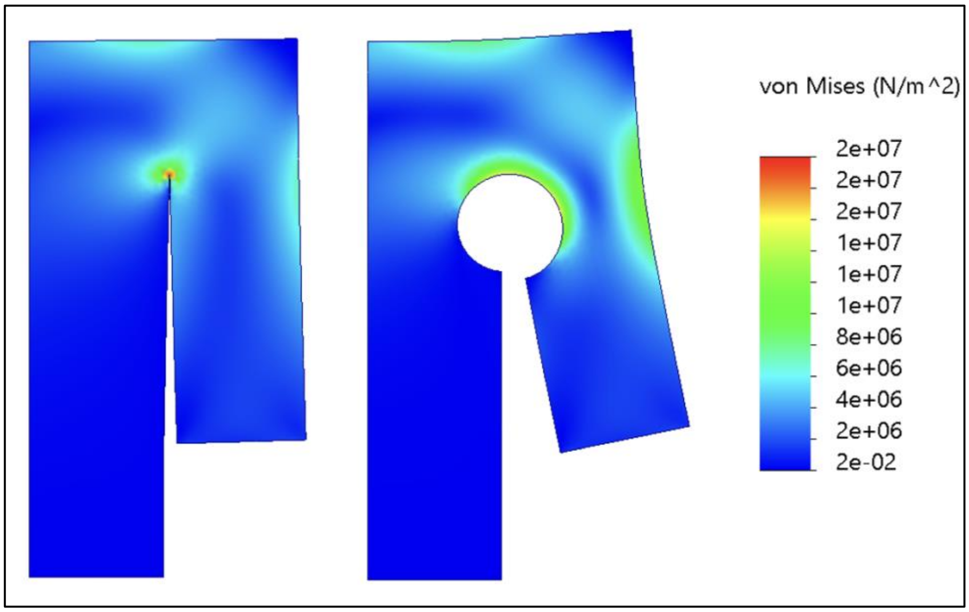

Figure 36 Von Mises Stress Plots of a Triangle and a Circle with 4.5 mm diameter

The stress reduction achieved with the optimized circular shape signifies improved tear resistance and enhanced durability, both critical factors for integrating effective reclosure mechanisms. The study demonstrates that by leveraging FEA simulations, designers can reduce reliance on physical prototyping while developing packaging that is both durable and consumer friendly. Such advancements ensure that packaging performs reliably under real-world conditions, offering better user experience and reducing material failures. Figure 36 further illustrates the stress concentration and Von Mises stress plots for both shapes, respectively, reinforcing the value of simulation in guiding packaging improvements. The integration of these findings into design processes can significantly enhance the functionality and longevity of pillow bag packaging with proposed reclosure designs.

3.5. Design and Development

During the ideation phase, three innovative concepts were shortlisted based on their potential for dimensional precision, optimal component placement, and enhanced usability. Adobe Illustrator was used to refine these designs and create detailed artwork, facilitating precise communication and robust feedback from our supplier, Amcor. This collaborative review focused on ensuring compatibility with pillow bag packaging, maintaining structural integrity, and designing an intuitive user interface. The refined concepts were foundational in transitioning smoothly to the prototyping phase, where these ideas were materialized into functional prototypes for thorough testing and evaluation. This transition marked a critical step towards the design and development phase, which was characterized by a systematic approach that balanced technical feasibility with the needs and expectations of consumers. The progression from conceptualization to practical application was seamless, setting the stage for successful implementation and future scalability.

For the **Fold & Tie** design, the graphical layout was strategically developed around the tearable top flap, which forms two arms for tying. The design incorporates dashed lines as cutting or tearing guides to help users easily create these arms. A notable enhancement based on FEA is the inclusion of a circular shape at the end of each tear line, which acts to prevent unintended propagation of the tear. Arrows and other visual cues were added to indicate where folds should occur, ensuring that users could precisely align the folds before tying.

Figure 37 Fold & Tie, Back and Side View (L to R)

For the **Twist & Tie**, the graphical design focused on the integration of twisting functionality into the packaging. The top flap was designed to extend slightly longer, providing ample material for twisting. Dashed lines were incorporated to indicate where users should tear or cut, enabling the creation of a arm/flap suitable for twisting. Visual arrows and step markers indicated the twisting direction, ensuring consistency and ease of use. These visual and functional cues ensured that the Twist & Tie mechanism was user-friendly and effective for resealing.

Figure 38 Twist & Tie Front, Back and Side View (L to R)

CHAPTER 4 TESTING OF NEW RECLOSURE SYSTEM

4.1. Sample Preparation

To evaluate the performance of the reclosure mechanisms, 80 samples were prepared using three materials: Veggie Straws Multilaminate Film, AmFiber™ Performance Paper, and Amcor's Metal-Free Laminates (MFL). The Veggie Straws bags were purchased from Meijer store in East Lansing. They were emptied to remove the product and repurposed for testing. Pouches of the same size were fabricated using AmFiber™ and MFL provided by Amcor, utilizing a heat sealer at the MSU School of Packaging. Reclosure designs—Fold & Tie, Twist & Tie, and Origami Fold—were applied to the respective samples, while some bags were left open to serve as control pouches.

Figure 39 Product Image of Sensible Portions Garden Veggie Straws showcased on a supermarket shelf

Indicating **DRIERITE** as shown in Figure 40, a cobalt chloride-impregnated desiccant, was selected to monitor moisture absorption within the bags. This material changes color from blue (dry) to pink (saturated), providing a clear and visible indication of moisture presence. Its dual functionality as a desiccant and visual indicator made it particularly suitable for this study, allowing for real-time assessment of the barrier performance of the reclosure mechanisms. Indicating DRIERITE also offers comparable efficiency to regular DRIERITE while providing a slightly greater desiccating capacity due to the cobalt chloride. This enhanced capacity ensured reliable testing conditions throughout the study.

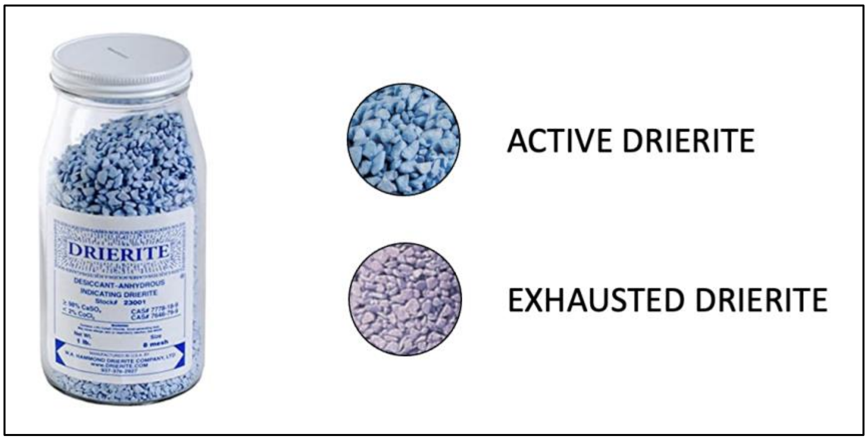

Figure 40 Indicating DRIERITE by W.A. HAMMOND DRIERITE CO. LTD

Each pillow bag was filled with 100 grams of Indicating DRIERITE using a precision scale to ensure consistent sample weights. The bags were then closed according to one of the three reclosure methods—Fold & Tie, Twist & Tie, or Origami Fold—or left open as control pouches as shown in Table 8. This systematic preparation ensured a systematic evaluation of each material and reclosure mechanism under simulated real-life conditions, enabling meaningful comparisons across designs and materials.

Table 8 Sample Classification of Reclosure Designs and materials for Barrier Testing

Material/Reclosure Method	Multilaminate Film	AmFiber™	Metal-Free Laminates (MFL)
Origami Fold Design 1	10 Samples	-	-
Origami Fold Design 2	10 Samples	12 Samples	-
Fold & Tie	10 Samples	-	10 samples
Twist & Tie	10 Samples	-	10 Samples
Control Samples	10 Samples (material selection does not impact performance)		

4.2. Barrier Testing

In typical households, chips bags (pillow bags) are exposed to a variety of storage conditions upon opening, ranging from ambient indoor environments to high-temperature settings, such as near a stove, or low-humidity areas. These diverse conditions can significantly impact the performance of packaging, particularly in preventing moisture ingress to maintain product stability. Extreme temperatures and elevated humidity levels accelerate the diffusion of moisture, potentially compromising the quality of the product, while lower temperatures and reduced humidity can slow this process but still require robust barriers to preserve the contents. Recognizing these scenarios, the barrier testing aimed to replicate real-world storage conditions within the capabilities of lab equipment to evaluate the effectiveness of the three reclosure mechanisms.

This study is based on Research Assumption 1, which states that after a chips/snacks bag is opened, the air passage through the reclosure system becomes more critical to maintaining product quality than the barrier properties of the film. While the Water Vapor Transmission Rate (WVTR) of the multilaminate film plays a significant role in preserving freshness when the bag is sealed, once opened, the reclosure system's ability to limit air exchange takes precedence. Air exchange directly impacts oxygen exposure, leading to lipid oxidation and chip staling. With the material kept constant as shown in, this study focuses on evaluating the performance of the reclosure system as the primary variable.

The **ASTM E96** Standard Test Methods for Water Vapor Transmission of Materials: Procedure for Desiccant Method was selected and adapted for its reliability and relevance in evaluating flexible resealable packaging, particularly for dry products like chips, where moisture control is critical (ASTM, 2024). The standard provides a reproducible framework to quantify moisture ingress, ensuring consistency and comparability with existing industry benchmarks. WVTR is commonly used to evaluate the intrinsic barrier properties of packaging materials by quantifying the rate at which water vapor permeates through a material. However, the primary objective of this study is to assess the performance of reclosure mechanisms integrated into flexible packaging rather than the inherent permeability of the material. Since reclosure mechanisms introduce potential pathways for moisture ingress, evaluating the cumulative impact of these factors was more relevant than isolating the material's permeability. Per the WVTR calculation provided in ASTM E96 (ASTM, 2024),

$$WVTR = \frac{G}{t.A} = \frac{(G/t)}{A}$$

Where (in International System of Units (SI units)),

G = steady state weight change (from the straight line),g,

t = time, h,

G/t = slope of the straight line, g/h,

A = Area of test specimen, m^2

WVTR = Water Vapor Transmission Rate, $g/h{\cdot}m^2$

Although ASTM E96 does not specifically address seal areas, it focuses on testing materials with uniform thickness to ensure accurate WVTR measurements. Seal regions, altered by overlapping layers or adhesives, lack uniformity and exhibit different permeability properties. Including them would distort results, as seals are designed for containment rather than vapor transmission. Their minimal contribution to the overall area makes their impact negligible

To calculate the Total Surface Area of back and front panel of the pillow bag sample,

$$Total\ Surface\ Area = 2 \times (Length \times Width)$$

$$Total\ Surface\ Area = 2 \times (280\ \text{mm} \times 210\ mm)$$

$$Total\ Surface\ Area = 117{,}600\ mm^2 = \ 0.1176\ m^2$$

Since Total Surface Area remains constant for all samples subjected to barrier testing, it ensures that variations WVTR are solely due to the material properties and not influenced by differences in the sample size or exposed surface area. Therefore, the WVTR values are directly proportional to weight gain per day and thus evaluating those values are critical. The testing methodology involved placing desiccants inside pillow bags made from the selected multilaminate film (as detailed in Table 8) and integrated with reclosure systems. Weight gain was measured periodically over a 21-day period, with readings taken on alternate days. This approach provided a direct and reliable method to assess the effectiveness of the reclosure mechanisms in preventing moisture ingress under controlled environmental conditions. By monitoring weight changes, the method captured real-world challenges such as seal integrity, reclosure alignment, and other practical factors that WVTR testing of material alone does not address. The extended testing duration allowed for the observation of long-term performance trends of the reclosure systems.

The effectiveness of the reclosure mechanisms was evaluated across two distinct environmental conditions: Accelerated Conditions and Room Conditions. The primary objective of this testing was to assess the reclosure systems' ability to reduce moisture ingress, thus indirectly preserving the quality of product, and to ensure durability under varying scenarios.

<u>Room Conditions:</u>

- A temperature of 23°C and a Relative Humidity (RH) of 50% represented typical indoor environments.
- These conditions reflected everyday household storage scenarios, providing insights into the mechanisms' performance under normal usage.

Figure 41 Environmental Growth Chamber set at Room Conditions settings (School of Packaging, MSU)

Accelerated Conditions:

- A temperature of 37.8°C and a RH of 85% were maintained to replicate extreme storage scenarios.
- These conditions were designed to stress-test the barrier systems, accelerating the diffusion of moisture and identifying potential weaknesses in the reclosure mechanisms.

Figure 42 Environmental Chamber set at Accelerated Conditions settings (School of Packaging, MSU)

The combination of these conditions ensured that the reclosure mechanisms were evaluated across a broad spectrum of challenges, simulating both real-world and extreme storage scenarios. The samples were tested for 21 days, with readings taken every alternate day to measure weight gain as an indicator of moisture ingress. Any samples that showcase major tear or puncture were discarded. In an instance when minor tears were observed, they were repaired with small adhesive tape and the weight of the tape was subtracted from the readings there on.

4.3. Results and Data Analysis

The dataset in obtained from performing barrier testing represents the weight gain trends of various combinations of packaging materials and reclosure designs over time. Measurements were taken at regular intervals to assess how effectively each combination minimizes weight gain under controlled conditions. The primary focus is to determine how different material and design combinations perform in preventing weight gain, which serves as an indicator of their ability to protect against external factors such as moisture and air.

The materials used in the study include MLF and MFL, selected for their barrier properties and relevance in modern packaging applications. Designs such as Origami Fold, Twist & Tie, and Fold & Tie were chosen based on their practical utility and popularity in consumer packaging. The Control group, lacking a reclosure system, serves as a baseline to assess the relative effectiveness of these systems. By evaluating these combinations, the study aims to identify configurations that optimize performance while maintaining usability and sustainability.

To analyze the data, Prism software was used to plot the weight gain trends and perform statistical analyses. Linear regression was applied to evaluate the relationship between time (number of days) and weight gain for each material-design combination. This method models the observed data as a straight line, allowing for the quantification of key parameters. The slope of the regression line represents the rate of weight gain per day, with lower slopes indicating more effective systems. The y-intercept reflects the initial weight (day zero), expected to be zero under controlled conditions. The 1/slope value provides a practical measure of efficiency, indicating how many days are required to accumulate one gram of weight.

P-values play a critical role in validating the results of the regression analysis. In this study, the p-value determines whether the observed relationship between time and weight gain is statistically significant or could have occurred by random chance. A low p-value (typically <0.05) indicates that the slope is significantly different from zero, confirming a real relationship between the variables. For this analysis, all p-values are <0.0001, signifying high statistical significance. This means that the trends observed for all material-design combinations are highly reliable and not due to random variation. The low p-values allow the null hypothesis (that there is no relationship between time and weight gain) to be rejected with confidence. Furthermore, the tight confidence intervals for the slope estimates reinforce the precision and reliability of the results.

Goodness-of-fit values (Sy.x) were calculated to assess the consistency of the data and the accuracy of the regression model. The low Sy.x values across all combinations confirm that the regression models fit the observed data well, ensuring reliable interpretation. By using Prism software, the statistical analyses and visualizations were performed with precision, providing robust insights into the performance of the reclosure systems. This approach enables a systematic comparison of material and design combinations. By integrating experimental data with statistical tools, this section provides a detailed evaluation of their performance and highlights trends that inform the development of effective reclosure systems.

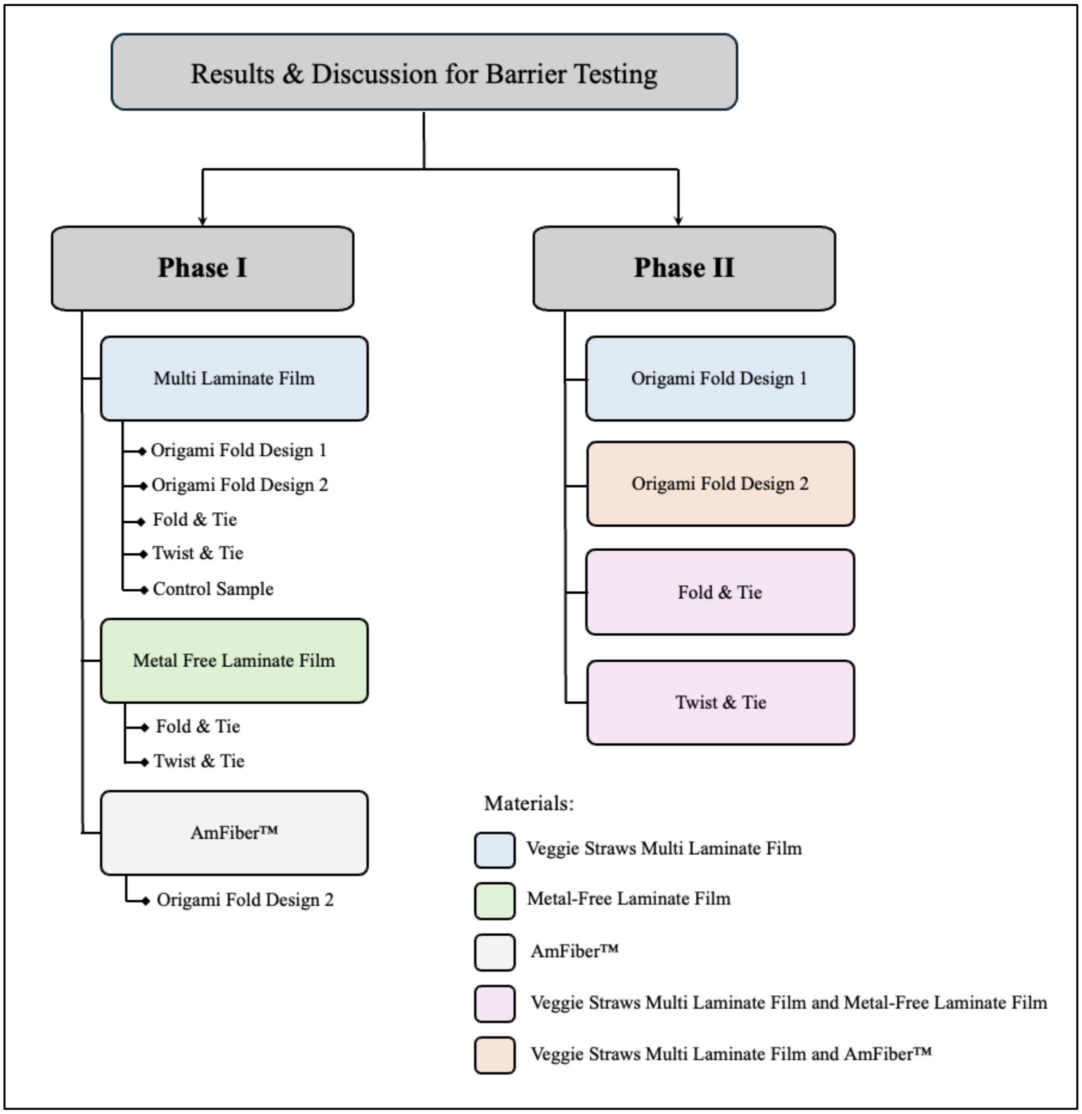

Figure 43 Sample Distribution across two phases for Results & Discussion

4.3.1. Phase I: Comparison of Reclosure Designs keeping material constant

4.3.1.1. Reclosure Designs using Veggie Straws Multilaminate film

Multilaminate film was used to create multiple reclosure designs, Figure 44 highlights distinct weight gain trends across the reclosure designs and the Control group over time. Weight gain increases consistently across all samples, but the rates differ significantly. The Control group displays the steepest rise in weight, reflecting its inability to limit exposure to external conditions. Among the reclosure designs, Twist & Tie shows a higher rate of weight gain compared to Fold & Tie, while Origami Fold Design 1 and Origami Fold Design 2 demonstrate the slowest and most controlled trends. The performance hierarchy is as follows: **Origami Fold Design 1 ≈ Origami Fold Design 2 < Fold & Tie < Twist & Tie < Control**.

The regression analysis reinforces these trends in Table 9. The Control group, with the highest slope (0.1555), exhibits the fastest weight gain, requiring only 6.429 days per gram, indicating its ineffectiveness. Twist & Tie, with a slope of 0.04994, shows limited efficacy, while Fold & Tie offers a better balance with a slope of 0.02665. The most effective systems, Origami Fold Design 1 (0.01926) and Origami Fold Design 2 (0.01956), require over 51 days per gram, highlighting their superior performance.

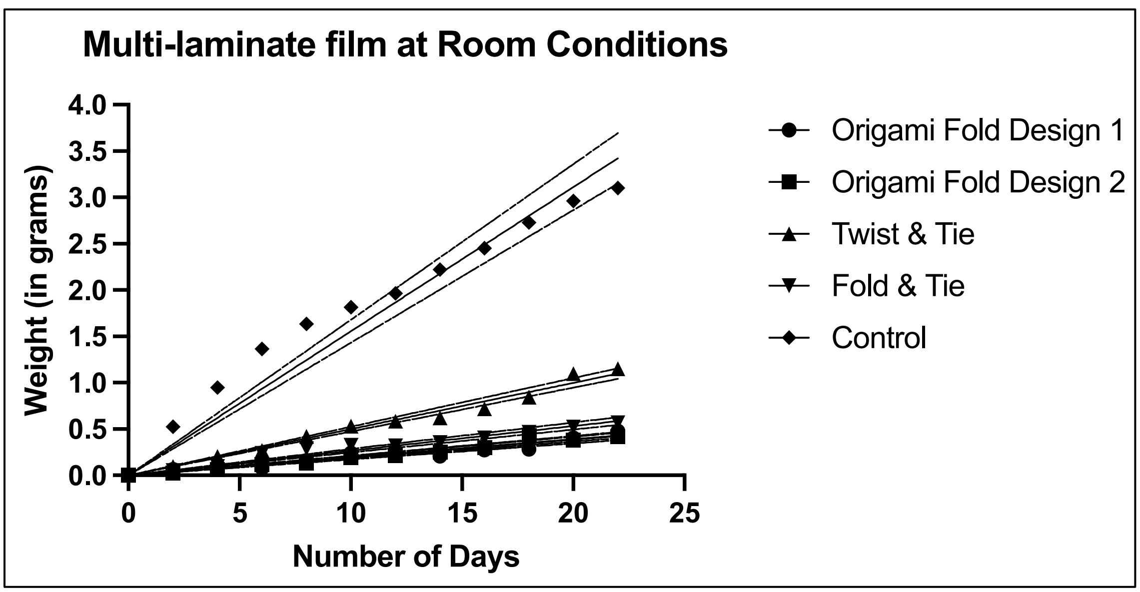

Figure 44 Multilaminate Film (MLF) at Room Conditions

The goodness-of-fit values (Sy.x) are low for all designs, confirming the reliability of the linear regression models. Statistical significance ($P < 0.0001$) across all slopes ensures the trends are meaningful and not due to random variation. These findings indicate that Origami

Fold Designs are the most effective reclosure systems for minimizing weight gain, followed by Fold & Tie. Twist & Tie offers moderate performance but lags behind the other reclosure systems. The Control group's rapid weight accumulation emphasizes the necessity of effective reclosure systems in maintaining product stability and quality over time.

Table 9 Regression analysis summary for reclosure designs and Control group

Parameter	Origami Fold Design 1	Origami Fold Design 2	Twist & Tie	Fold & Tie	Control
Slope	0.01926	0.01956	0.04994	0.02665	0.1555
Std. Error (Slope)	0.0009112	0.0006041	0.001171	0.0008657	0.005626
Goodness of Fit (Sy.x)	0.04099	0.02718	0.05269	0.03895	0.2531
Significance (P Value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trend Summary	Most effective	Most effective	Moderate	Balanced	Least effective

Figure 45 illustrates the weight gain trends across different reclosure designs and the Control group. All designs exhibit a positive trend, indicating weight gain over time. The Control group shows the steepest increase in weight, highlighting its inability to provide adequate protection. Among the reclosure systems, Twist & Tie demonstrates a relatively faster rate of weight gain, while Fold & Tie offers a more controlled increase. Origami Fold Design 1 and Origami Fold Design 2 exhibit nearly identical and minimal weight gain, marking them as the most effective designs. The hierarchy of performance is as follows: **Origami Fold Design 1 ≈ Origami Fold Design 2 < Fold & Tie < Twist & Tie < Control**.

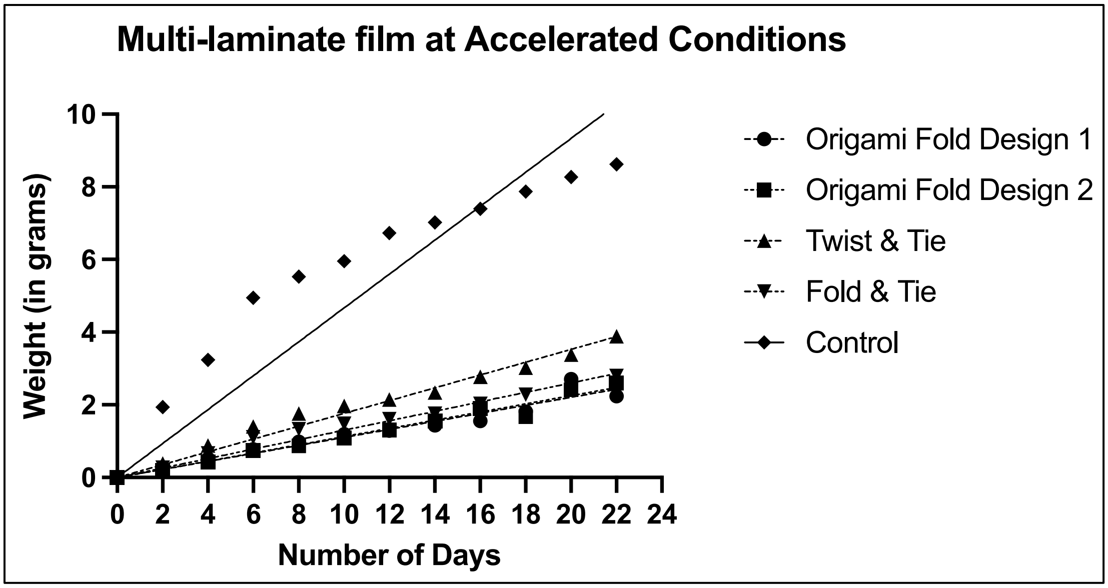

Figure 45 Multilaminate Film (MLF) at Accelerated Conditions

The linear regression analysis in Table 10 quantifies these trends. The Control group exhibits the highest slope (0.4666), with a 1/slope value of 2.143 days per gram, indicating the least effective system for preserving weight. Twist & Tie, with a slope of 0.1763, is moderately effective, while Fold & Tie shows improved performance with a slope of 0.1301. Origami Fold Design 1 and Origami Fold Design 2 demonstrate the most effective results, with slopes of 0.1103 and 0.1126, respectively, corresponding to 1/slope values of 9.063 and 8.883 days per gram. These results highlight the significantly slower weight gain trends for the Origami Fold Designs compared to other systems.

Table 10 Regression analysis summary for reclosure designs and Control group at Accelerated Conditions

Parameter	**Origami Fold Design 1**	**Origami Fold Design 2**	**Twist & Tie**	**Fold & Tie**	**Control**
Slope	0.1103	0.1126	0.1763	0.1301	0.4666
Std. Error (Slope)	0.004264	0.002919	0.004152	0.003506	0.02844
Goodness of Fit (Sy.x)	0.1919	0.1313	0.1868	0.1577	1.279
Significance (P Value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trend Summary	Effective	Effective	Moderate	Balanced	Least effective

Goodness-of-fit values (Sy.x) indicate that the regression models accurately capture the trends, with Sy.x values being lowest for Origami Fold Design 2 (0.1313) and highest for the Control group (1.279), reflecting greater variability in the latter. The slopes are statistically significant ($P < 0.0001$) for all systems, confirming that the observed trends are robust and not attributable to random variation.

4.3.1.2. Fold & Tie and Twist & Tie using Metal free Laminate Film (MFL)

The evaluation of Fold & Tie and Twist & Tie reclosure designs with MFL material at room conditions reveals notable differences in their performance. The Fold & Tie design demonstrated a slower rate of weight gain with a slope of 0.03824 compared to 0.04326 for Twist & Tie. This indicates better resistance to moisture ingress, as reflected in its higher 1/slope value (26.15 days/gram) versus Twist & Tie's 23.12 days/gram. These results suggest that Fold & Tie is more effective in maintaining stability over time under standard room conditions.

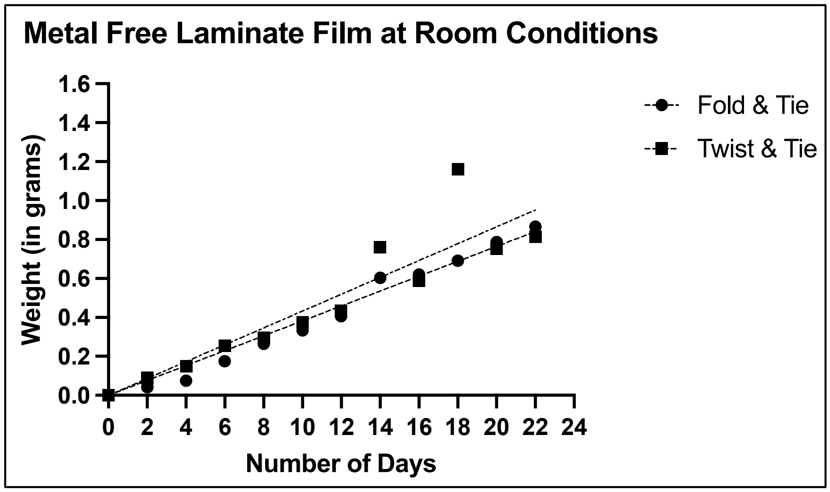

Figure 46 Fold & Tie and Twist & Tie reclosure designs with MFL at Room Conditions

The statistical analysis further highlights the advantages of the Fold & Tie design. Its goodness-of-fit value (Sy.x) of 0.04556 is significantly lower than the 0.1434 observed for Twist & Tie, indicating a tighter fit of the data to the regression model and more consistent performance. Additionally, Fold & Tie exhibited a narrower standard error for its slope (0.001013) compared to Twist & Tie (0.003188), which emphasizes greater precision in its performance measurements. Both designs exhibited statistically significant slopes ($P < 0.0001$), confirming their consistent weight gain trends. However, the wider variability in Twist & Tie's performance is evident from its higher Sy.x and standard error values, which could compromise its reliability for applications requiring extended storage stability. On the other hand, the Fold & Tie design shows greater control and predictability in weight gain, making it more suitable for scenarios demanding consistent performance.

Table 11 Regression analysis summary for Fold & Tie and Twist & Tie reclosure designs with MFL at Room Conditions

Parameter	**Fold & Tie**	**Twist & Tie**
Slope	0.03824	0.04326
Std. Error (Slope)	0.001013	0.003188
95% Confidence Interval	0.03601 to 0.04046	0.03624 to 0.05027
Goodness of Fit (Sy.x)	0.04556	0.1434
Significance (P Value)	<0.0001	<0.0001
Trend Analysis	Slower weight gain, more consistent	Faster weight gain, higher variability

Under room conditions, these observations highlight the performance differences between the two designs. While Fold & Tie offers a more controlled and reliable resistance to weight gain, Twist & Tie exhibits faster weight gain with less stability over time, which could influence its suitability for specific applications.

The analysis of Fold & Tie and Twist & Tie designs using MFL material under accelerated conditions reveals distinct yet comparable performance trends. Both designs exhibit statistically significant linear regression slopes, with Twist & Tie demonstrating a slightly higher slope (0.3123) than Fold & Tie (0.3098), indicating a marginally faster weight gain rate. However, the difference in slope values is minimal, reflecting comparable performance under these conditions.

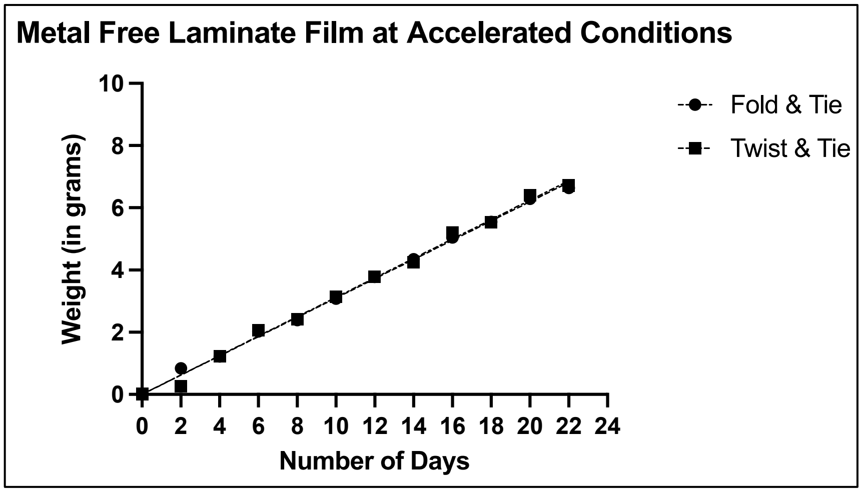

Figure 47 Fold & Tie and Twist & Tie reclosure designs with MFL at Accelerated Conditions

The confidence intervals for the slopes are narrow for both designs (Fold & Tie: 0.3043 to 0.3153; Twist & Tie: 0.3043 to 0.3202), showcasing a high degree of reliability in the data and consistent weight accumulation trends. The standard errors for the slopes (Fold & Tie: 0.002479; Twist & Tie: 0.003630) further reinforce the accuracy of these results. The P-values (<0.0001) confirm the statistical significance of both slopes, indicating that the observed trends are not due to random variability.

The goodness of fit (Sy.x) values indicate that Fold & Tie (0.1115) demonstrates slightly less variability in weight gain compared to Twist & Tie (0.1633). This suggests that while both designs perform well, Fold & Tie exhibits more stability under accelerated conditions. The trend analysis highlights that both designs achieve steady weight gain, with Twist & Tie slightly outperforming Fold & Tie in terms of weight accumulation rate. This could be attributed to differences in the sealing geometry or the surface area exposed during the reclosure process. However, the higher variability observed in Twist & Tie suggests a need for further optimization to ensure uniform performance over extended periods.

Table 12 Regression analysis summary for Fold & Tie and Twist & Tie reclosure designs with MFL at Accelerated Conditions

Parameter	**Fold & Tie**	**Twist & Tie**
Slope	0.3098	0.3123
Std. Error (Slope)	0.002479	0.00363
95% Confidence Interval	0.3043 to 0.3153	0.3043 to 0.3202
Goodness of Fit (Sy.x)	0.1115	0.1633
Significance (P Value)	<0.0001	<0.0001
Trend Analysis	Stable weight gain with moderate variability	Slightly faster weight gain with consistent performance

Overall, the results demonstrate the efficacy of both Fold & Tie and Twist & Tie designs under accelerated conditions, with Twist & Tie showing a slight performance edge. Nonetheless, Fold & Tie provides a more controlled and stable weight gain trend, making it a potentially better choice for applications requiring consistent barrier properties under extreme conditions.

4.3.1.3. Origami Fold Design 2 using AmFiber™

The performance of Origami Fold Design 2 using AmFiber material at room conditions was evaluated based on its weight gain over time, as shown in Figure 48. The experimental data reveals a gradual increase in weight, reflecting the ingress of moisture through the packaging material. The slope of the linear regression model was determined to be 0.01896, with a standard error of 0.001151, indicating a consistent but slow moisture ingress rate over the 22-day testing period.

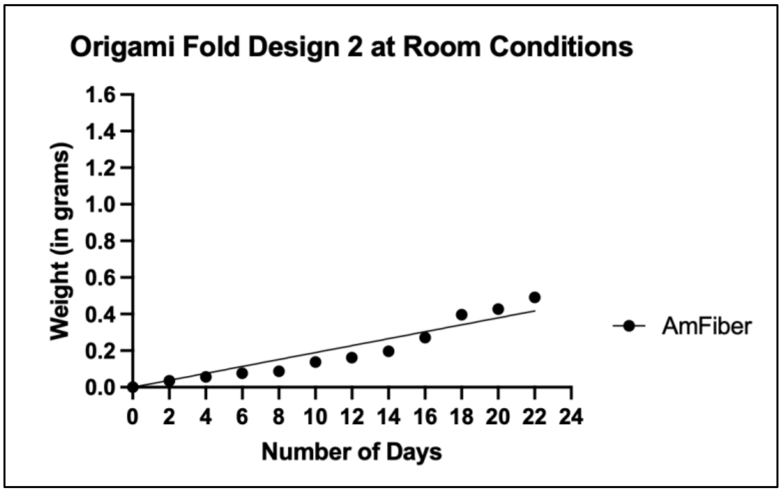

Figure 48 Origami Fold Design 2 with AmFiber™ at Room Conditions

The goodness-of-fit parameter (Sy.x = 0.05180) confirms the accuracy of the regression model in representing the observed data. The F-statistic of 271.2, with a corresponding P-value < 0.0001, demonstrates the statistical significance of the slope, confirming a non-zero moisture ingress trend. The 95% confidence intervals for the slope (0.01643 to 0.02150) further validate the reliability of these findings.

Origami Fold Design 2 paired with AmFiber material exhibited a high resistance to moisture ingress, as evidenced by its 1/slope value of 52.74 days per gram. This reflects the effectiveness of the AmFiber material's barrier properties under room conditions. However, the design's performance suggests that it is optimized for scenarios requiring slow and consistent moisture ingress control. This may limit its applicability for smaller or irregularly shaped packages, where a more adaptable design might be required.

Table 13 Regression analysis summary for Origami Fold Design 2 with AmFiber™ at Room Conditions

Parameter	AmFiber™
Slope	0.01896
Std. Error (Slope)	0.001151
95% Confidence Interval	0.01643 to 0.02150
Goodness of Fit (Sy.x)	0.0518
Significance (P Value)	<0.0001
Trend Analysis	Slow and consistent moisture ingress control, optimal for long-term storage under room conditions.

The Origami Fold Design 2 with AmFiber demonstrates excellent moisture resistance and durability under typical storage conditions, making it a good option for preserving product quality over extended periods. However, its applicability may be restricted to specific use cases due to its reliance on larger surface areas for reclosure. Further research could explore modifications to enhance its versatility without compromising its barrier properties.

The performance of Origami Fold Design 2, tested under accelerated conditions using AmFiber material, demonstrates a significant increase in moisture ingress compared to room conditions. The linear regression analysis reveals a slope of 0.05242, indicating a higher rate of weight gain over time due to increased exposure to stress at elevated temperature and humidity levels (37.8°C and 85% RH). This slope is notably higher than the value observed under room conditions, highlighting the impact of accelerated environmental factors on the barrier properties of AmFiber material.

The 95% confidence interval for the slope (0.04381 to 0.06104) confirms the reliability of the observed trend, while the low standard error (0.003914) further supports the precision of the measurements. The goodness of fit (Sy.x = 0.1761) suggests a moderate degree of variability in the data, likely attributed to the interplay of environmental stresses with material properties. The significant P value (<0.0001) indicates that the slope is statistically non-zero, validating the observed trend of moisture ingress.

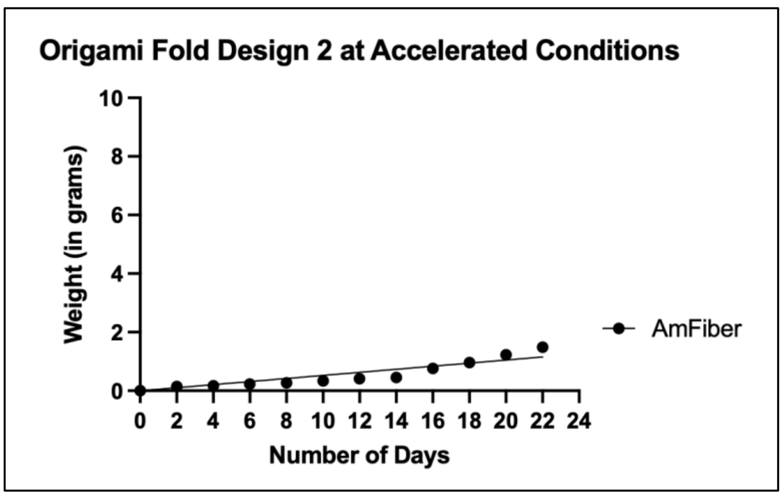

Figure 49 Origami Fold Design 2 with AmFiber™ at Accelerated Conditions

The results analysis demonstrates the limitations of AmFiber under accelerated conditions, as the faster rate of weight gain reflects reduced barrier effectiveness. While AmFiber’s dead-fold property remains advantageous for the origami fold, the material's susceptibility to moisture ingress under extreme conditions raises concerns about its suitability for long-term storage in similar environments. These findings underline the importance of considering material performance under varying environmental scenarios when selecting packaging solutions for specific application.

Table 14 Regression analysis summary for Origami Fold Design 2 with AmFiber™ at Accelerated Conditions

Parameter	**AmFiber™**
Slope	0.05242
Std. Error (Slope)	0.003914
95% Confidence Interval	0.04381 to 0.06104
Goodness of Fit (Sy.x)	0.1761
Significance (P Value)	<0.0001
Table 16 (cont'd)	
Trend Analysis	Faster moisture ingress due to higher stress at elevated temperature and humidity conditions, indicating reduced barrier effectiveness compared to room conditions.

4.3.2. Phase II: Comparison of Materials keeping Design constant

Origami Fold Design 1 requires the pillow bag to be more than 50% empty to function effectively, which limits its application for partially or recently opened chips bag. Due to this constraint, the design is less adaptable for practical applications and will not be discussed in great detail during Phase 2 of this research. This decision allows the focus to remain on designs that can be evaluated more comprehensively under various material conditions.

4.3.2.1. Origami Fold Design 2

The weight gain behavior of AmFiber™ and MLF materials when used for Origami Fold Designs 2 was analyzed under room conditions (23°C, 50% RH). The results reveal similar performance trends for the two materials, as indicated by their comparable slope values (AmFiber: 0.01896, MLF: 0.01956). These slopes suggest that both materials accumulate weight at nearly identical rates over time. The 1/slope values further confirm this observation, with AmFiber™ requiring 52.74 days per gram of weight gain, slightly more than MLF's 51.13 days per gram.

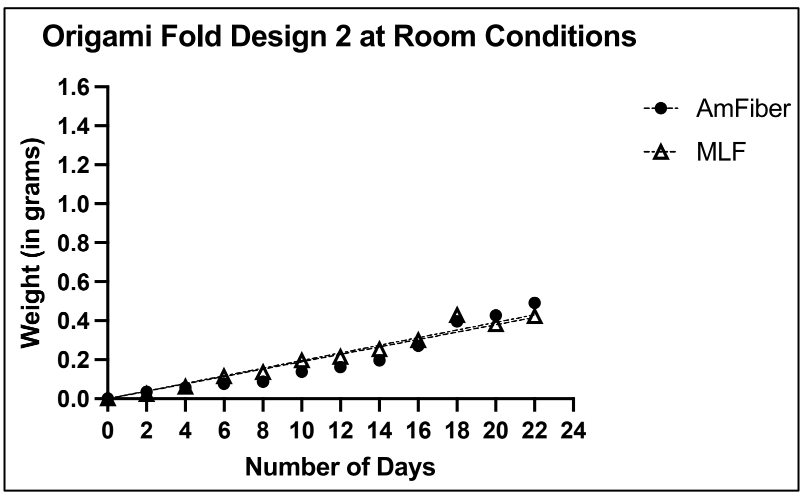

Figure 50 Origami Fold with AmFiber™ and MLF at Room Conditions

The confidence intervals for the slopes are narrow (AmFiber: 0.01643–0.02150, MLF: 0.01823–0.02089), and the P-values (<0.0001) for both materials indicate that the slopes are statistically significant. The goodness-of-fit (Sy.x) values are low (AmFiber: 0.05180, MLF: 0.02718), showing that the linear regression models accurately describe the weight gain behavior. The equations derived from the regression analysis were Y = 0.01896X for AmFiber™ and Y = 0.01956X for MLF. While the slopes and overall trends are closely aligned, MLF exhibits a slightly steeper slope and lower variability, suggesting marginally better performance in maintaining barrier integrity over time.

Table 15 Regression analysis summary for Origami Fold at Room Conditions

Parameter	**AmFiber®**	**MLF**
Slope	0.01896	0.01956
Std. Error (Slope)	0.001151	0.0006041
95% Confidence Interval	0.01643 to 0.02150	0.01823 to 0.02089
Goodness of Fit (Sy.x)	0.0518	0.02718
Significance (P-Value)	<0.0001	<0.0001
Trend Analysis	Slower weight gain with slightly higher variability	Slightly faster and more consistent weight gain

AmFiber™ with a slightly lower slope, demonstrates slower weight gain, which could be beneficial for applications requiring extended storage with minimal moisture ingress. However, the small differences between the two materials indicate that both Origami Fold Designs are effective for maintaining product stability under room conditions.

At accelerated conditions (37.8°C and 85% RH), AmFiber™ and MLF showed notable differences in their performance as materials for Origami Fold Designs. The analysis revealed that AmFiber™ had a lower slope of 0.05242 compared to MLF's 0.1301. This indicates that AmFiber™ gained weight more slowly, requiring 19.08 days per gram (1/slope) compared to MLF's 7.686 days per gram. This slower weight gain rate suggests that AmFiber™ provides better resistance to moisture diffusion under these conditions.

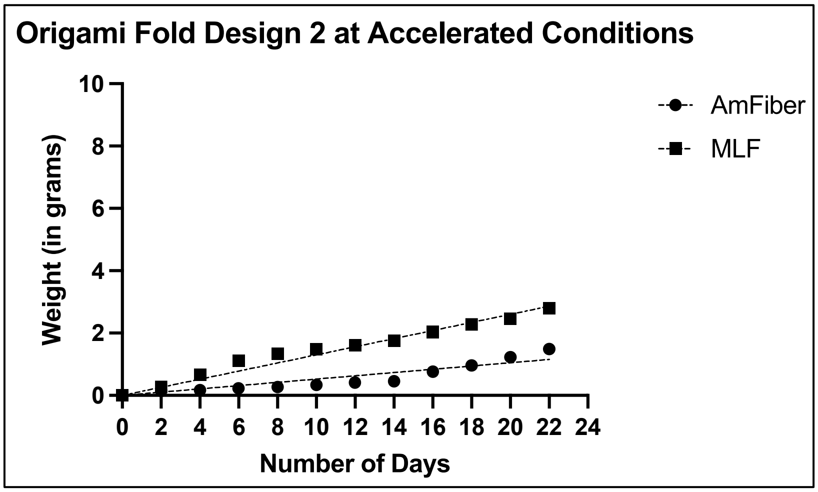

Figure 51 Origami Fold with AmFiber™ and MLF at Accelerated Conditions

Regression data highlights the statistical significance of the findings. For AmFiber, the 95% confidence interval for the slope ranged from 0.04381 to 0.06104, while MLF had a tighter range of 0.1224 to 0.1378. Both materials had P-values of <0.0001, confirming the robustness of the observed trends. The derived equations, $Y = 0.05242X$ for AmFiber™ and $Y = 0.1301X$ for MLF, effectively represent the relationship between time and weight gain. Despite slight variations, both models showed good alignment with the experimental data, as indicated by Sy.x values (AmFiber: 0.1761; MLF: 0.1577).

Table 16 Regression analysis summary for Origami Fold at Accelerated Conditions

Parameter	AmFiber®	MLF
Slope	0.05242	0.1301
Std. Error (Slope)	0.003914	0.003506
95% Confidence Interval	0.04381 to 0.06104	0.1224 to 0.1378
Goodness of Fit (Sy.x)	0.1761	0.1577
Significance (P-Value)	<0.0001	<0.0001
Trend Analysis	Slow and controlled weight gain, ideal for designs requiring fold retention	Faster weight gain, reduced suitability for fold-dependent applications

4.3.2.2. Fold & Tie Reclosure

The performance of the Fold & Tie reclosure system at room conditions (23°C, 50% RH) was assessed through linear regression analysis of weight gain data over time for Metal Free Laminate (MFL) and Multi Laminate Film (MLF) materials. MFL demonstrated a higher slope value (0.03824) compared to MLF (0.02665), signifying a faster rate of weight accumulation. Conversely, MLF exhibited a slower and more controlled weight gain trend, with a calculated 1/slope value of 37.53 days per gram, indicating its superior ability to resist moisture ingress under these conditions. For MFL, the 1/slope was calculated to be 26.15 days per grams.

The regression model provided a strong fit for the experimental data, as evidenced by the narrow 95% confidence intervals for the slope values (MFL: 0.03601–0.04046, MLF: 0.02474–0.02855) and the low standard errors (MFL: 0.001013, MLF: 0.0008657). The significance of the P-values (<0.0001) confirmed that the observed trends were statistically robust and not due to random variation. Additionally, the low goodness-of-fit (Sy.x) values for both materials (MFL: 0.04556, MLF: 0.03895) indicated that the regression equations (MFL: Y = 0.03824X, MLF: Y = 0.02665X) accurately captured the data trends.

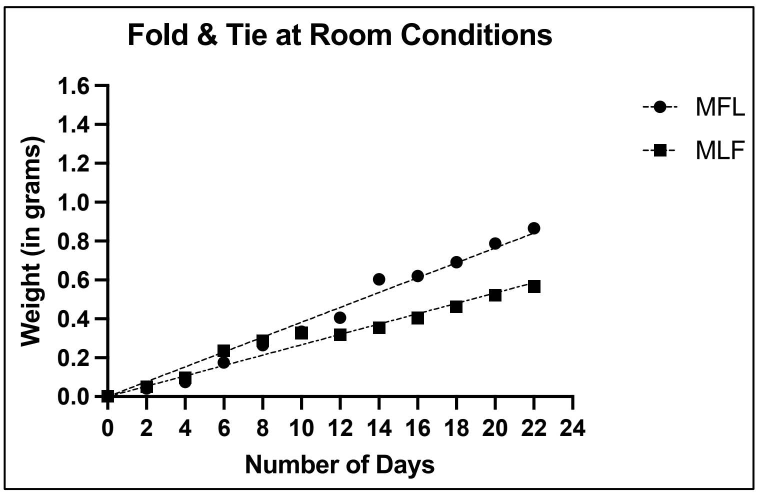

Figure 52 Fold & Tie with MFL and MLF at Room Conditions

The slower weight gain exhibited by MLF under room conditions reflects its lower permeability and better barrier properties compared to MFL. This trend suggests that MLF may be more suitable for applications requiring sustained storage under stable environmental conditions. On the other hand, MFL's higher rate of weight gain might point to limitations in its moisture resistance, possibly influenced by its structural composition or environmental interactions.

Table 17 Regression analysis summary for Fold & Tie at Room Conditions

Parameter	**MFL**	**MLF**
Slope	0.03824	0.02665
Std. Error (Slope)	0.001013	0.0008657
95% Confidence Interval	0.03601 to 0.04046	0.02474 to 0.02855
Goodness of Fit (Sy.x)	0.04556	0.03895
Significance (P Value)	<0.0001	<0.0001
Trend Analysis	Faster weight gain, less control over time	Slower weight gain, more stable performance

External factors, such as the quality of the heat-sealing process, may have contributed to the observed differences in material performance. Any inconsistencies in sealing could introduce variability in the moisture barrier, especially for MFL, which displayed faster weight gain. The Fold & Tie reclosure system, when paired with MLF, demonstrated greater reliability under room conditions, underscoring its efficacy for long-term storage applications.

Under accelerated conditions (37.8°C, 85% RH), the Fold & Tie reclosure system exhibited significant differences in performance between MFL and MLF materials. The weight gain for MFL progressed at a much faster rate, with a slope of 0.3098 compared to 0.1301 for MLF. This difference is further quantified by the 1/slope values, where MFL showed a rapid weight gain every 3.228 days per gram, while MLF required 7.686 days for the same. These metrics highlight MLF’s ability to provide better moisture resistance in challenging environments.

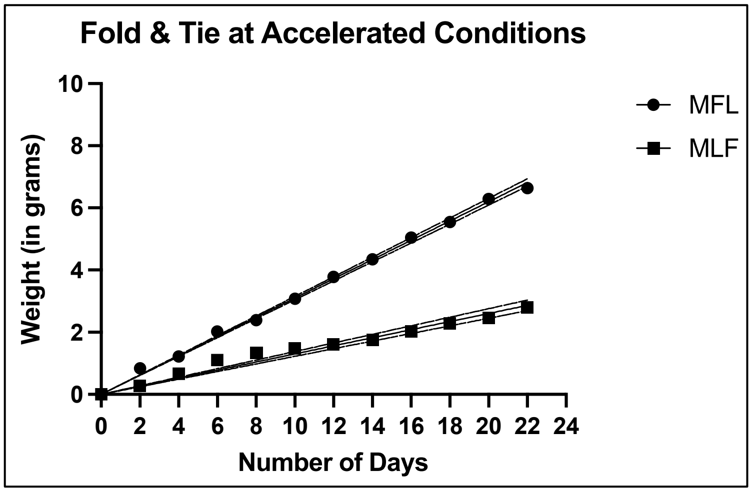

Figure 53 Fold & Tie with MFL and MLF at Accelerated Conditions

The regression analysis yielded narrow confidence intervals for the slopes (MFL: 0.3043 to 0.3153; MLF: 0.1224 to 0.1378) and low standard errors (MFL: 0.002479; MLF: 0.003506), indicating precise and consistent trends in the data. The goodness-of-fit values (Sy.x) for both materials were low (MFL: 0.1115; MLF: 0.1577), signifying that the linear models closely align with the observed behavior. The statistical analysis demonstrated a high level of significance, with P-values of <0.0001 for both materials, confirming the reliability of these results.

Table 18 Regression analysis summary for Fold & Tie at Accelerated Conditions

Parameter	**MFL**	**MLF**
Slope	0.3098	0.1301
Std. Error (Slope)	0.002479	0.003506
95% Confidence Interval	0.3043 to 0.3153	0.1224 to 0.1378
Goodness of Fit (Sy.x)	0.1115	0.1577
Significance (P-Value)	<0.0001	<0.0001
Trend Analysis	Faster weight gain, less control over time	Slower weight gain, more stable performance

The regression equations derived from the analysis, Y = 0.3098X for MFL and Y = 0.1301X for MLF, illustrate the disparity in their weight gain rates over time. MFL's higher slope indicates faster moisture ingress, likely due to its material structure being more susceptible to extreme conditions. MLF, in contrast, demonstrated more stable and gradual weight gain, indicating its suitability for applications demanding enhanced barrier properties in high humidity and temperature scenarios.

4.3.2.3. Twist & Tie Reclosure

The comparison between MFL and MLF materials in Figure 54 highlights differences in their performance in controlling weight gain over time with the Twist & Tie design.

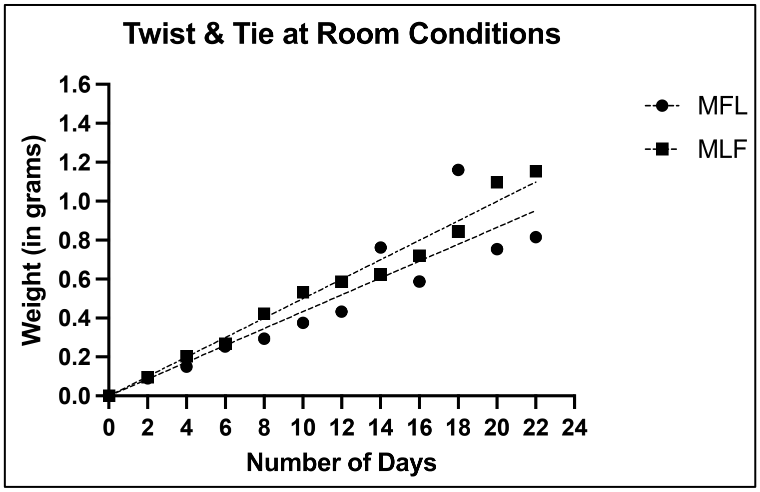

Figure 54 Twist & Tie with MFL and MLF at Room Conditions

The weight gain trends for both materials show an upward trajectory, indicating their relative ability to mitigate external factors influencing weight accumulation. While both materials provide some level of protection, noticeable differences emerge in their efficacy as the number of days increases, particularly in later stages. MLF demonstrates a sharper increase in weight gain compared to MFL, suggesting a potential limitation in its long-term performance.

Table 19 Regression analysis summary for Twist & Tie at Room Conditions

Parameter	**MFL**	**MLF**
Slope	0.04326	0.04994
Std. Error (Slope)	0.003188	0.001171
95% Confidence Interval	0.03624 to 0.05027	0.04736 to 0.05252
Goodness of Fit (Sy.x)	0.1434	0.05269

Table 19 (cont'd)

Significance (P Value)	<0.0001	<0.0001
Trend Analysis	Lower weight gain with consistent performance over time	Higher weight gain, more variability at later stages

The regression analysis in Table 19 quantitatively supports these observations. MLF exhibits a steeper slope (0.04994) compared to MFL (0.04326), indicating that it accumulates weight at a faster rate. The 1/slope values further highlight this difference, with MFL requiring 23.12 days per gram compared to 20.02 days for MLF. The goodness-of-fit values (Sy.x) indicate that the regression model fits better for MLF (Sy.x = 0.05269) than for MFL (Sy.x = 0.1434), although MLF shows slightly higher variability in weight gain trends. Both slopes are statistically significant ($P < 0.0001$), confirming that the observed trends are reliable.

These results of regression analysis suggest that MFL offers better long-term consistency in minimizing weight gain, as evidenced by its lower slope and higher 1/slope value. MLF, while effective, exhibits faster weight accumulation over time, particularly at later stages, making it less favorable for applications requiring prolonged stability.

The weight gain trends over time for MFL and MLF are shown in Figure 55. Both materials exhibit positive trends, indicating continuous weight gain with increasing duration. However, there is a clear difference in their performance. MFL shows a consistently steeper slope compared to MLF, signifying faster weight gain. This suggests that MFL is less effective at limiting weight gain over extended periods.

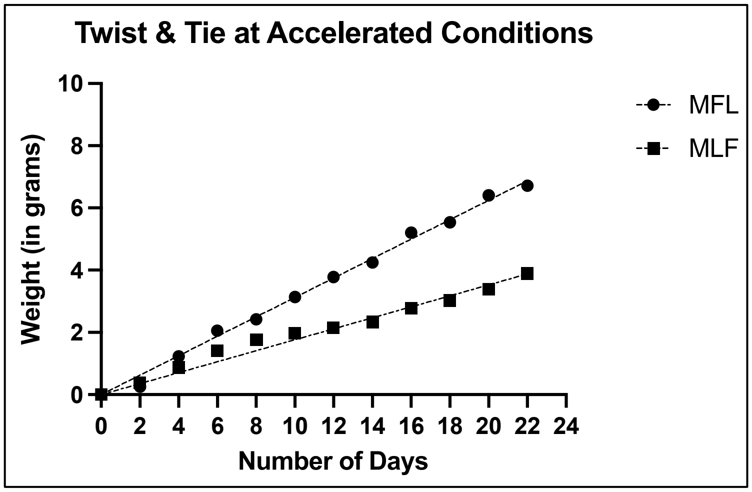

Figure 55 Twist & Tie with MFL and MLF at Accelerated Conditions

The regression analysis confirms in these trends. MFL has a higher slope (0.3123) compared to MLF (0.1763), indicating that it accumulates weight faster. Conversely, MLF requires more time to accumulate the same amount of weight, as shown by its higher 1/slope value of 5.674 days per gram compared to 3.203 for MFL. The confidence intervals for the slopes are narrow for both materials (MFL: 0.3043 to 0.3202, MLF: 0.1671 to 0.1854), and the P-values for the slopes are <0.0001, confirming their statistical significance. The goodness-of-fit (Sy.x) values are low for both materials (MFL: 0.1633, MLF: 0.1868), indicating that the regression models accurately represent the observed data.

The regression analysis confirms in these trends. MFL has a higher slope (0.3123) compared to MLF (0.1763), indicating that it accumulates weight faster. Conversely, MLF requires more time to accumulate the same amount of weight, as shown by its higher 1/slope value of 5.674 days per gram compared to 3.203 for MFL. The confidence intervals for the slopes are narrow for both materials (MFL: 0.3043 to 0.3202, MLF: 0.1671 to 0.1854), and the P-values for the slopes are <0.0001, confirming their statistical significance. The

goodness-of-fit (Sy.x) values are low for both materials (MFL: 0.1633, MLF: 0.1868), indicating that the regression models accurately represent the observed data.

Table 20 Regression analysis summary for Twist & Tie at Accelerated Conditions

Parameter	MFL	MLF
Slope	0.3123	0.1763
Std. Error (Slope)	0.00363	0.004152
95% Confidence Interval	0.3043 to 0.3202	0.1671 to 0.1854
Goodness of Fit (Sy.x)	0.1633	0.1868
Significance (P Value)	<0.0001	<0.0001
Trend Analysis	Faster weight gain, less control over time	Slower weight gain, more stable performance

At room conditions, MFL performs better due to its rigidity and lower permeability, resulting in slower weight gain. In contrast, MLF shows a faster rate of weight accumulation, likely due to its higher baseline permeability. These results align with typical household storage conditions, where MFL excels in maintaining product stability. Heat-sealing inconsistencies or human error may influence these results, particularly under accelerated conditions, by introducing weak edges or partial openings that increase moisture ingress. However, the trends observed under room conditions are more representative of real-life scenarios, emphasizing the relevance of MFL for everyday use and MLF for applications in extreme environments.

4.3.3. Comparative Analysis of all Reclosure Designs

Comparative analysis of design-material combinations is essential to identify the optimal solutions for packaging applications, particularly in scenarios requiring moisture resistance and design stability. Each design and material pairing demonstrates unique properties that influence overall performance under specific environmental conditions. This study evaluates multiple combinations to determine their effectiveness, focusing on key metrics such as resistance to weight gain and overall design performance. The analysis aims to provide data-driven insights for selecting the most suitable combinations in diverse packaging applications.

Ranking Criteria

- Weight Gain Resistance (1/Slope): Indicates the time taken to gain weight, with higher values reflecting better resistance to moisture absorption.
- Overall Performance: Combines weight gain resistance with material-specific and design-specific strengths.

Table 21 Comparison of Design-Material Combinations Based on Weight Gain Resistance and Overall Performance Metrics

Rank	Design	Material	Weight Gain Resistance (1/Slope)	Overall Performance
1	Origami Fold Design 1	AmFiber	52.74 days/gram	Best for fold retention due to dead fold property and superior moisture resistance.
2	Origami Fold Design 2	MLF	51.13 days/gram	Effective for moisture control and consistent performance in fold-based designs.
3	Fold & Tie	MLF	37.52 days/gram	Reliable and consistent with moderate moisture resistance for long-term storage.
4	Fold & Tie	MFL	26.15 days/gram	Slower weight gain with highly consistent performance for moisture-sensitive applications.
5	Twist & Tie	MFL	23.12 days/gram	High moisture control with slightly faster weight gain.
6	Twist & Tie	MLF	20.02 days/gram	Effective for applications requiring moderate moisture control but with higher variability.
7	Control	N/A	6.429 days/gram	Baseline for comparison; significantly lower resistance to moisture ingress.

The results of the comparative analysis indicate that Origami Fold Design 1 with AmFiber™ exhibits the highest resistance to weight gain (1/Slope = 52.74 days/gram), making it the most effective design for applications requiring superior fold retention and moisture resistance. Origami Fold Design 2 with MLF closely follows, demonstrating excellent moisture control (1/Slope = 51.13 days/gram). Among the reclosure systems, Fold & Tie with MLF and MFL both perform reliably (1/Slope = 26.15 days/gram), with MFL offering slightly more consistency. Twist & Tie with MLF shows strong performance (1/Slope = 23.12 days/gram), though with higher variability compared to Fold & Tie. The Control, with significantly lower resistance (1/Slope = 6.429 days/gram), highlights the effectiveness of the reclosure mechanisms in reducing moisture ingress. Thus, these reclosures are effective in reducing moisture ingress.

CHAPTER 5 CONCLUSION

This research aimed to address the long-standing challenge of reclosure in pillow bag packaging, specifically within the snack food industry. Pillow bags are favored for their cost-effective production, lightweight design, and excellent barrier properties against moisture, oxygen, and light. However, the lack of effective reclosure mechanisms limits the ability to preserve product freshness after the package has been opened. Through this study, a comprehensive approach was taken, integrating market research, consumer preferences, and testing of various reclosure designs to offer a sustainable and user-friendly solution.

The initial market study, which included analyzing existing reclosure mechanisms and consumer preferences, revealed a clear demand for packaging solutions that not only preserve the product's quality upon opening but also enhance convenience for consumers. Insights from social media and consumer feedback highlighted the importance of ease of use and the ability to maintain freshness over time, guiding the ideation process. The research identified and further developed three promising reclosure designs—Origami Fold, Fold & Tie, and Twist & Tie—and focused on optimizing these systems for barrier performance, durability, and usability.

This study also incorporated Finite Element Analysis (FEA) to design stress-resistant shapes aimed at enhancing the durability of flexible packaging. The goal of using FEA was to create a resistance shape that effectively redistributes stress, preventing undesirable continuous tearing. The simulations confirmed that incorporating optimized perforation designs could significantly enhance the packaging's structural integrity. While the analysis was focused on stress redistribution, the findings highlight the importance of design improvements to mitigate progressive tearing, ensuring better durability and usability in flexible packaging applications.

Experimental testing on the moisture barrier properties of these designs revealed that Origami Fold, particularly when paired with AmFiber® material, performed the best in terms of moisture resistance. This design demonstrated superior sealing properties, reducing moisture ingress significantly compared to other reclosure mechanisms. Origami Fold requires a larger surface area for reclosure, which limits its adaptability for smaller chip bags or products with varying contents. This design, though effective in protecting product freshness, may be less suitable for packaging of smaller or irregularly shaped products. The Fold & Tie design, while slightly less effective in moisture protection than Origami Fold, provided a balance of good barrier properties and ease of reclosure, making it the more versatile and practical solution for most packaging applications. Twist & Tie, although it offered a simple and user-friendly reclosure mechanism, showed higher moisture ingress, making it less effective in maintaining product quality over time.

Material selection played a crucial role in the performance of each design. The combination of MFL with Fold & Tie and Twist & Tie showed optimal results, providing a good balance between barrier performance and ease of reclosure. The superior moisture resistance of AmFiber® in Origami Fold designs confirmed the impact of material properties on the overall effectiveness of reclosure mechanisms. The findings reinforce the importance of choosing the right combination of design and material to meet the packaging requirements of specific product types.

In conclusion, this study successfully addressed a critical issue in flexible packaging by designing innovative reclosure systems that enhance product preservation and consumer satisfaction. The Fold & Tie design, when paired with Metal Free Laminate Film, emerged as the most practical and effective solution for most applications, offering a good balance of moisture resistance, ease of use, and versatility. Origami Fold, while offering the best barrier performance, was less adaptable due to its larger surface area requirement but remains the optimal choice for packaging requiring superior moisture protection. This study paves the way for sustainable and efficient packaging solutions, contributing to the food packaging industry's goals in enhancing consumer experiences.

CHAPTER 6 FUTURE SCOPE OF WORK

To advance the development of reclosure mechanisms in flexible packaging, the findings of this study serve as a foundational framework for further research and innovation. The integration of material properties, structural design, and consumer usability highlights the multifaceted approach necessary to optimize packaging systems. While the study has addressed critical aspects of reclosure performance, additional considerations are required to ensure broader adaptability and scalability across the packaging industry.

Future research should focus on evaluating manufacturing capabilities to determine the feasibility of implementing these designs at scale. This includes assessing the compatibility of proposed reclosure mechanisms with existing production lines, analyzing material wastage during manufacturing, and identifying potential modifications required to accommodate innovative designs. Furthermore, a comprehensive consumer usability study is recommended to gather real-world insights into the ease of operation, perceived effectiveness, and overall acceptance of these reclosure solutions.

Exploring advanced materials with enhanced barrier properties, recyclability, and reduced environmental impact should remain a priority. Material advancements, coupled with design refinements, can lead to packaging systems that achieve higher durability, superior moisture resistance, and improved sustainability. Additionally, investigating cost-effective solutions for small and irregularly shaped packages, particularly for designs like Origami Fold, could expand the application range of these reclosure systems.

Finally, developing robust testing protocols to simulate diverse environmental conditions and stress scenarios will be essential for validating the long-term performance of these mechanisms. This multi-pronged approach will ensure that reclosure mechanisms meet the evolving demands of the food packaging industry, aligning with sustainability goals while enhancing consumer satisfaction.

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APPENDIX

Top Fifty-two Chips Brands in United States of America:

Table 22 Top 52 brands identified by Özbağ Keçeci (2024) and their reclosure availability

Rank by Market Share	Brand Name	Type	Manufacturer	Market Share (%)	Price ($/Oz.)	Packaging format	Reclosable Packaging
1	CHEETOS CHEESE	CORN SNACK	FRITO LAY	5.2647	0.2820	Flexible, Pillow Bag	No
2	DORITOS NACHO CHEESE	TORTILLA CHIP	FRITO LAY	5.1952	0.2504	Flexible, Pillow Bag	No
3	FRITOS ORIGINAL	CORN CHIP	FRITO LAY	3.5844	0.2603	Flexible, Pillow Bag	No
4	SANTITAS ORIGINAL	TORTILLA CHIP	FRITO LAY	2.7370	0.1671	Flexible, Pillow Bag	No
5	CALIDAD TRIANGLE	TORTILLA CHIP	CALIDAD FOODS INC	2.6896	0.1333	Flexible, Pillow Bag	No
6	FRITOS SCOOPS ORIGINAL	CORN CHIP	FRITO LAY	2.6340	0.2458	Flexible, Pillow Bag	No
7	WAVY LAY'S ORIGINAL	POTATO CHIP	FRITO LAY	2.5118	0.2450	Flexible, Pillow Bag	No
8	CHEETOS FLAMIN' HOT	CORN SNACK	FRITO LAY	1.7698	0.2960	Flexible, Pillow Bag	No
9	LAY'S BARBECUE	POTATO CHIP	FRITO LAY	1.6783	0.2566	Flexible, Pillow Bag	No

Table 22 (cont'd)

Rank by Market Share	Brand Name	Type	Manufacturer	Market Share (%)	Price ($/Oz.)	Packaging format	Reclosable Packaging
10	ON THE BORDER TRIANGLE	TORTILLA CHIP	TRUCO ENTERPRISES	1.6701	0.2191	Flexible, Pillow Bag	No
11	LAY'S SOUR CREAM & ONION	POTATO CHIP	FRITO LAY	1.5872	0.2546	Flexible, Pillow Bag	No
12	RUFFLES ORIGINAL	POTATO CHIP	FRITO LAY	1.5482	0.3317	Flexible, Pillow Bag	No
13	DORITOS COOL RANCH	TORTILLA CHIP	FRITO LAY	1.5330	0.2365	Flexible, Pillow Bag	No
14	LAY'S CLASSIC	POTATO CHIP	FRITO LAY	1.4569	0.2906	Flexible, Pillow Bag	No
15	BARCEL TAKIS FUEGO	TORTILLA CHIP	BARCEL USA	1.1250	0.2701	Flexible, Pillow Bag	No
16	TOSTITOS SCOOPS	TORTILLA CHIP	FRITO LAY	0.9642	0.2587	Flexible, Pillow Bag	No
17	PRINGLES ORIGINAL	POTATO CHIP	PROCTER & GAMBLE	0.9365	0.2682	Rigid, Telescopic tube	Yes, lid
18	DORITOS SPICY NACHO	TORTILLA CHIP	FRITO LAY	0.9004	0.2308	Flexible, Pillow Bag	No
19	FRITOS CHILI CHEESE	CORN CHIP	FRITO LAY	0.8525	0.2493	Flexible, Pillow Bag	No
20	WAVY LAY'S HICKORY BBQ	POTATO CHIP	FRITO LAY	0.7366	0.2586	Flexible, Pillow Bag	No

Table 22 (cont'd)

Rank by Market Share	Brand Name	Type	Manufacturer	Market Share (%)	Price ($/Oz.)	Packaging format	Reclosable Packaging
21	LAY'S CHEDDAR & SOUR CREAM	POTATO CHIP	FRITO LAY	0.6640	0.2518	Flexible, Pillow Bag	No
22	MISSION ROUNDS	TORTILLA CHIP	MISSION FOODS INC	0.6472	0.1711	Flexible, Pillow Bag	No
23	LAY'S LIMON	POTATO CHIP	FRITO LAY	0.6330	0.2718	Flexible, Pillow Bag	No
24	MISSION STRIPS	TORTILLA CHIP	MISSION FOODS INC	0.6217	0.1726	Flexible, Pillow Bag	No
25	PRINGLES SOUR CREAM & ONION	POTATO CHIP	PROCTER & GAMBLE	0.6039	0.2466	Rigid, Telescopic tube	Yes, lid
26	RUFFLES CHEDDAR & SOUR CREAM	POTATO CHIP	FRITO LAY	0.5966	0.3672	Flexible, Pillow Bag	No
27	FUNYUNS	CORN SNACK	FRITO LAY	0.5230	0.5046	Flexible, Pillow Bag	No
28	WAVY LAY'S RANCH	POTATO CHIP	FRITO LAY	0.5190	0.2521	Flexible, Pillow Bag	No
29	EL MILAGRO	TORTILLA CHIP	EL MILAGRO	0.5154	0.2391	Flexible, Pillow Bag	No
30	ON THE BORDER ROUNDS	TORTILLA CHIP	TRUCO ENTERPRISES	0.4920	0.2162	Flexible, Pillow Bag	No

Table 22 (cont'd)

Rank by Mark et Share	Brand Name	Type	Manufa cturer	Market Share (%)	Price ($/Oz.)	Packagi ng format	Reclos able Packa ging
31	DORITOS TOASTED CORN	TORTIL LA CHIP	FRITO LAY	0.4441	0.2282	Flexible, Pillow Bag	No
32	CHEETOS CHEDDAR JALAPENO	CORN SNACK	FRITO LAY	0.4397	0.2693	Flexible, Pillow Bag	No
33	LAY'S CHILE LIMON	POTAT O CHIP	FRITO LAY	0.4163	0.2664	Flexible, Pillow Bag	No
34	MISSION TRIANGLE S	TORTIL LA CHIP	MISSIO N FOODS INC	0.4052	0.1762	Flexible, Pillow Bag	No
35	FRITOS TWIST HONEY BBQ	CORN CHIP	FRITO LAY	0.3207	0.2342	Flexible, Pillow Bag	No
36	TOSTITOS ORIGINAL	TORTIL LA CHIP	FRITO LAY	0.3201	0.2501	Flexible, Pillow Bag	No
37	SUNCHIPS ORIGINAL	MULTI GRAIN CHIP	FRITO LAY	0.3190	0.3249	Flexible, Pillow Bag	No
38	SUNCHIPS GARDEN SALSA	MULTI GRAIN CHIP	FRITO LAY	0.3184	0.3267	Flexible, Pillow Bag	No
39	DORITOS SALSA VERDE	TORTIL LA CHIP	FRITO LAY	0.3161	0.2313	Flexible, Pillow Bag	No
40	LAY'S GARDEN TOMATO & BASIL	POTAT O CHIP	FRITO LAY	0.3158	0.2616	Flexible, Pillow Bag	No
41	SUNCHIPS HARVEST CHEDDAR	MULTI GRAIN CHIP	FRITO LAY	0.3107	0.3299	Flexible, Pillow Bag	No

Table 22 (cont'd)

Rank by Market Share	Brand Name	Type	Manufacturer	Market Share (%)	Price ($/Oz.)	Packaging format	Rank by Market Share
42	KETTLE KRINKLE SALT AND PEPPER	POTATO CHIP	KETTLE	0.2717	0.3131	Flexible, Pillow Bag	No
43	PRINGLES CHEDDAR CHEESE	POTATO CHIP	PROCTER & GAMBLE	0.2690	0.2421	Rigid, Telescopic tube	Yes, lid
44	RUFFLES QUESO	POTATO CHIP	FRITO LAY	0.2537	0.3676	Flexible, Pillow Bag	No
45	RUFFLES REDUCED FAT	POTATO CHIP	FRITO LAY	0.2407	0.3891	Flexible, Pillow Bag	No
46	BAKED CHEETOS FLAMIN' HOT	CORN SNACK	FRITO LAY	0.2342	0.3531	Flexible, Pillow Bag	No
47	BAKED LAY'S ORIGINAL	POTATO CHIP	FRITO LAY	0.2306	0.4292	Flexible, Pillow Bag	No
48	BAKED CHEETOS CHEESE	CORN SNACK	FRITO LAY	0.2202	0.3468	Flexible, Pillow Bag	No
49	PRINGLES BBQ	POTATO CHIP	PROCTER & GAMBLE	0.2159	0.2495	Rigid, Telescopic tube	Yes, lid
50	BAKED TOSTITOS SCOOPS	TORTILLA CHIP	FRITO LAY	0.2032	0.4246	Flexible, Pillow Bag	No
51	KETTLE SEA SALT	POTATO CHIP	KETTLE	0.2023	0.3091	Flexible, Pillow Bag	No
52	BAKED LAY'S BARBECUE	POTATO CHIP	FRITO LAY	0.1860	0.4192	Flexible, Pillow Bag	No