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Beyond Expiry: Visualizing Degradation to Build Consumer Trust and Reduce Food Waste

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Abstract of Master's Thesis of Academic Year 2025

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Category: Design

Summary

Consumer trust in printed expiration dates often leads to the premature disposal of still-edible food, contributing to significant household waste and raising questions about the reliability of "Use by" labels. This study investigates whether real-time, data-driven visualizations of spoilage, particularly of invisible processes such as microbial growth, can recalibrate that trust and extend perceived edibility. Addressing a key research gap in how invisible food degradation is communicated, the project explores whether making microbial activity visually interpretable can help consumers better assess food safety.

A user study involving twelve participants evaluated eighteen alternative freshness cues, including color-shift labels, gas-inflation packaging, and visible sample windows, using a 7-point trust scale. In the second phase, a mobile application was prototyped to assist consumers with food organization and waste prevention. Drawing on mold cultivation experiments, a series of animated timelines visualizing the microbial degradation of a slice of bread were created to simulate spoilage. Lastly, the animations were embedded as a feature of the app and tested in a user study with twelve participants.

Quantitative and qualitative data revealed that participants appreciated the combination of sensory cues and interpretable visual data and responded positively to using such features to inform their food decisions. The study concludes that embedding real-time spoilage data within accessible visual narratives can enhance consumer trust and reduce avoidable food waste. These findings suggest a promising direction for promoting sustainable consumption by empowering consumers with more transparent and intuitive food safety information.

Keywords:

expiration date, use-by, sell-by, sustainability, food waste, visual communication design, consumer trust

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Chapter 1
Introduction

1.1. Motivation

1.1.1 The Expiry-date Dilemma

Have you ever considered whether the food was still edible even after the expiration date had passed? In that moment of decision, when you are standing in front of your fridge or trash can, an abundance of thoughts can rush through your mind: guilt over wasting food, a hopeful gamble that it might still be safe, and the fear of potential illness. I first encountered this dilemma five years ago while volunteering at a food bank, where I was tasked with sorting expired ground beef collected from local supermarkets. Although all the packages were technically past their expiration dates, I had to determine whether each was still fit for donation. Relying solely on visual inspection, I placed meat that appeared normal into the donation box and discarded any that looked slightly discolored. The uncertainty and pressure of making the right decision in those moments left a lasting impression. It prompted me to question how food safety decisions are made and how often such judgments may be flawed.

These everyday dilemmas reflect deeper issues. The over abundance of resources reassures that the post-consumed disposal is trivial, and 'best-by' dates project a sense of permission to discard food in a slightly untasteful stage though fully edible. Even before that, when food is still sold in markets, the waste mechanism has already been established by a profit-driven rather than need-driven production system, that when anything unsold, no matter how edible, becomes waste destined for landfills [8]. To accelerate turnover and keep store shelves full, food is over produced, and one third is wasted, resulting in 8 to 10 percent of global greenhouse gas emissions. [9] According to the UNEP Food Waste Index Report 2024, nearly

79 kg per capita of household food has been wasted annually compared to 74 kg in 2021. [10] Well in advance of food being made or produced, the manufacturer and brand owners in capitalist consumer markets fight for attention by creating carefully designed packaging, printing verified labels, sympathetic slogans, turning expendable into value-laden products that cultivate consumer trust and loyalty. Some even say that most expiration date labels are meaningless, accurate date labels are just a priority to keep customers happy. [11]

The chain reaction, beginning with brand owners and regulators and ending with consumer actions, has had a significant impact on the environment. This chapter unpacks each link in that chain: how expiration dates are determined, how sensory and institutional trust is formed and often misplaced, and how evolving attitudes toward food sustainability can help realign our disposal habits. Furthermore, the chapter extends the discussion to address a key research gap: the need for cognitive tools that can shift consumer behavior and recalibrate trust in the face of capitalist market dynamics and consumerism. It also highlights how cultural values, such as the Japanese concept of *mottainai*, can inspire more socially and environmentally responsible practices.

1.1.2 "Use by", "Best if used by", "Sell by", "Enjoy by"

Expiration dates are established through varied and often conservative standards that differ significantly by country. In the United States, manufacturers select dates based on several approaches, including meeting minimum legal requirements, conducting shelf-life tests, analyzing consumer complaint data, consulting published industry guidelines, or following competitor practices. These dates primarily indicate optimal quality rather than food safety, and, due to minimal federal regulation, result in a collection of varied and sometimes conflicting dating practices. Consequently, it not only confuses consumers but also contributes to unnecessary food waste.

In the 2025 National Survey of Consumer Perceptions of Food Date Labels, the survey suggests that among the foods evaluated (including deli meats), raw chicken prompted the most cautious consumer behavior. 58% said they would throw it away if it had a "sell by" date, increasing to 65% for a "best if used by" label, and reaching 71% for a "use by" label. Nearly half of respondents (49%)

indicated they would discard milk if marked with a "sell by" date. This figure increased to 53% for a "best if used by" label and 58% for "use by." For lettuce sold in bags or boxes, 45% would dispose of it upon seeing a "sell by" date. This number went up slightly to 48% for "best if used by," and 50% for "use by." Despite being non-perishable, 38% would throw out cereal with a "sell by" label, 36% if labeled "best if used by," and 37% if marked "use by." [12]

1.1.3 How Trust Is Built and Distrust Emerges

Trust in food, shaped by packaging, labeling, and sensory cues, silently guides our choices. Understanding this dynamic is essential for rethinking sustainable food practices and reducing unnecessary waste. However, when sensory perceptions conflict with institutional guarantees, most consumers default to trusting dates and discarding potentially edible food right away. [13] Those who rely strictly on date labels generate more waste compared to those who use sensory checks, revealing a contradiction: In modern society, trust is expected to simplify and enhance our decision making, yet it leads to less sustainable outcomes.

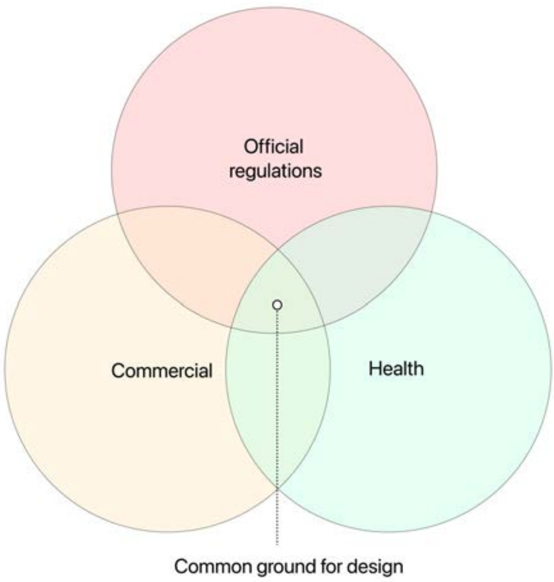

Figure 1.1 Design for common ground

Institutional trust is the confidence that consumers have in actors (government regulators, certification bodies, producers, and retailers) to ensure that food is safe and of reliable quality. Studies show that faith in these institutions strongly shapes perceptions of food safety and purchase intent: higher trust in agencies or certification logos increases consumers' willingness to buy and eat a product even when they lack direct knowledge of its production processes. [14] In contrast, sensory trust is based on the consumer's own senses. Shoppers visually inspect color, texture, or mold growth, and at home they smell or taste small samples to decide whether an item is still edible. Because labels appear objective while our senses feel subjective, people defer to the stamp even when the yogurt still smells fine, this is where trust is misplaced.

Information asymmetry in the food system occurs when producers or manufacturers hold essential knowledge about food safety, quality, and shelf life that consumers cannot verify independently. Particularly when food is packaged in not transparent or in protective containers. This imbalance forces consumers to rely on abstract indicators, such as date labels, instead of using their senses to determine edibility. [15]

Such dependence creates vulnerability. If consumers cannot clearly understand the meanings of "best before" or "use by" dates, their trust in food safety weakens. Some people may discard food too early, fearing contamination, while others might unknowingly consume expired products, putting their health at risk. The inconsistent terminology of date labels across countries and brands accelerates this distrust, revealing that the truth about food conditions is often obscured by a system that does not function effectively.

When consumers feel uncertain about the safety of their food, they may begin to mistrust not only expiration labels but also the broader food system, including manufacturers, retailers, and regulators. This skepticism often stems from the information gap between producers and consumers, underscoring the need for clearer, standardized, and easily interpretable labeling systems to restore trust. Design can play a critical role in bridging this gap by fostering trust through understanding rather than mere instruction. By using design to build new forms of trust that makes individuals through understanding, not just instruction, and find a common ground for design which can balance safety, trust, and market viability between official regulations, commercial interests, and health concerns.

1.1.4 A Cognitive Tool to Recalibrate Trust in the Context of Consumerism

In a consumerist food system, trust is synthesized via printed indicators like expiration dates, which are shaped by industry norms, legal liability, and conservative estimates rather than real-time food conditions. This institutionalized form of trust, while convenient, encourages passive decision-making and contributes to the premature disposal of edible food. As a result, consumers are left with limited means to independently assess the safety or quality of what they consume.

Despite growing awareness of food waste and sustainability, there remains a critical gap in cognitive tools that help individuals recalibrate their trust based on tangible evidence rather than abstract labels. According to Judith E. Fan et al. (2023), visualized information design can reduce the gap between what people know intuitively and what they can observe concretely. [16] Applying this concept to food systems, the visualization of invisible processes like microbial spoilage works as a cognitive tool to allow consumers to make decisions grounded in both data and perception.

1.1.5 *mottainai*

The Japanese concept of mottainai, which conveys a deep sense of regret over waste and reverence for the value of resources, offers a culturally resonant framework for addressing food waste. Despite this long-standing ethic, Japan discards an estimated 4.64 million tons of edible food each year, with households alone responsible for 2.33 million tons. [17]

This stark contrast between cultural values and consumer behavior underscores the need for interventions that can bridge this gap. In the context of food systems, this ethic can inspire more mindful consumption and strengthen the emotional and moral dimensions of trust that is beyond institutional cues such as expiration dates. In areas where expiration dates are less commonly used and individuals tend to rely more on sensory judgment, the design could serve as an educational tool to support and validate these intuitive practices. Conversely, urban users who live in standardized packaging and fast-paced consumer environments may rely on the tool as a primary mechanism for building trust in the absence of direct sensory access. Designing with these cultural and geographic distinctions in mind can help ensure that interventions are both contextually relevant and demographically inclusive.

1.2. Research Questions

The research questions are the following:

1. How do the three sources of trust, institution signals, technology, and individual sensory cues interact to influence a consumer's decision to keep or discard food once the printed date has passed?

2. How can a real-time spoilage visualization reshape consumer reliance from expiry labels toward sensory assessment, and thereby reduce food disposal?

1.3. Goals and Contributions

The research aims to shift attention away from the institutional promise embodied in the label and towards the actual condition of the product, by increasing sensory trust by observing visual cues of the food degradation process.

1.4. Research Objectives

1. To investigate how consumers make decisions about food edibility in the absence or presence of expiration labels.

2. To evaluate the effectiveness of alternative freshness cues such as visual and data-driven indicators in communicating spoilage and building trust.

3. To develop animated visualizations based on real microbial growth to simulate spoilage in a recognizable and interpretable way.

4. To prototype a mobile application that integrates spoilage visualizations as part of a tool to assist in food organization and waste reduction.

5. To assess user perceptions, trust, and behavioral intentions in response to the integrated design through user testing.

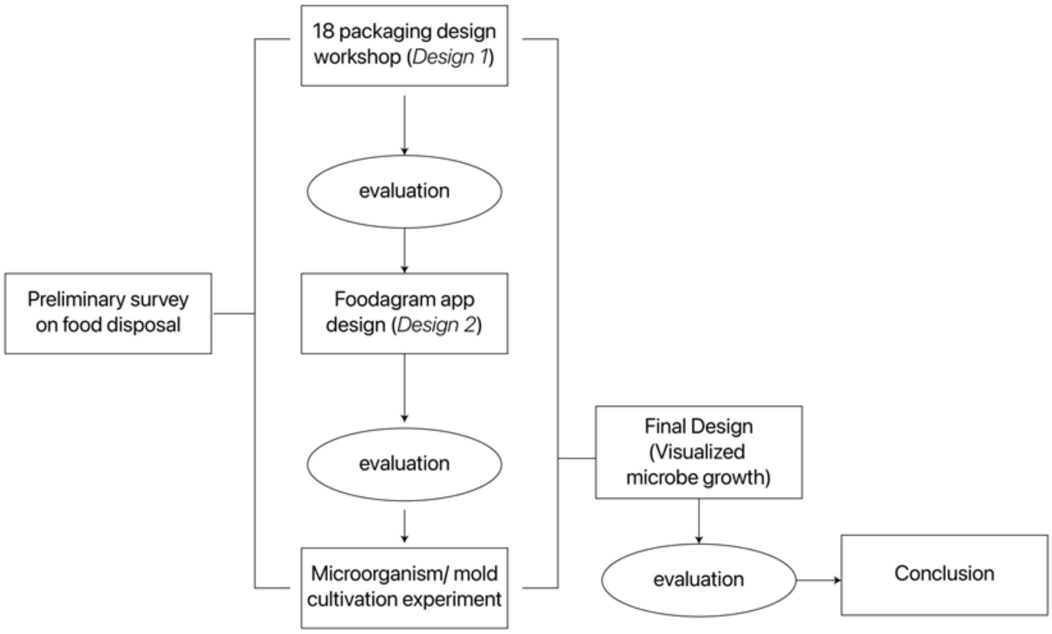

Figure 1.2 Thesis outline

Chapter 2
Literature Review

To better understand the context and scope of this research, this chapter reviews the relevant literature and related studies in multiple disciplines.

2.1. Food Waste Control As A Common Theme

Since the United Nation created SDG 12.3 which calls on every country to reduce per-capita food waste and cut food losses along supply chains by 2030, research on food waste has been a huge topic when talking about sustainability. According to studies, the carbon footprint of food produced and not consumed is estimated to be 3.3 billion tons of carbon dioxide worldwide, compared to the US which generates about 170 million metrics tons of carbon dioxide, which implies that "if food waste were a country, it would be the third largest emitter of greenhouse gases after China and the United States." [18]

Research suggests that in high-income countries, food waste is more prevalent at the retail and consumer levels, where large amounts of edible food are discarded due to cosmetic standards, overpurchasing, and confusion around expiration labels. According to the UNEP 2021 Food Waste Index Report, households in high-income countries generated an average of 74 kilograms of food waste per person annually, compared to 32 kilograms from the food service sector and 15 kilograms from the retail sector per capita per year. [19] The most recent data from the UNEP 2024 Food Waste Index Report shows an increase across all sectors, with household waste rising to 79 kilograms, food service to 36 kilograms, and retail to 17 kilograms per person per year. [10]

Parallel to this, food packaging has received growing attention in academic discourse, with a notable increase in publications since 2016. [20] Food waste, as defined by the UN metadata, includes all food that exits the human food chain via landfill, incineration, composting, or other non-food destinations at the consumer level. It is distinct from food loss, which occurs earlier in the supply chain. A clear and consistent definition allows for more accurate tracking and policy development across regions.

Design-driven initiatives such as IDEO's Food Studio have contributed to this discourse by framing food waste not as an isolated issue, but as a systemic problem embedded in larger structures, from corporate logistics to public health. [21] Collaborations with companies like UberEATS and Revolution Foods illustrate how design thinking can reshape both products and systems to address food deserts and reduce waste across the value chain.

2.2. The Topic on Trust and Its Issues

Psychometric research suggests that trust itself is hard to measure consistently. The evaluation of three consumer brand trust scales, Chaudhuri & Holbrook (2001) [22], Lau & Lee (1999) [23] and Sirdeshmukh, Singh & Sabol (2002) [24], discovered that only the Sirdeshmukh et al. scale met the unidimensionality criteria, the other two only obtain the result of the reliability of brands; as a result, it will mistake consumers' temporary favorability for long-term trust in the brand sustainability commitment [25]. Separating measurement criteria is important when scaling trust, and thus when scaling consumer trust toward food, institutional trust, sensory trust, and technology trust are set to individual scale without mixing them up.

Cultural differences and regional economics were also counted as variables when scaling the trust of the consumer. Research shows that Australian shoppers usually rely on straightforward labels that state the exact cut of meat to measure food quality, whereas Asian shoppers seek richer label details, such as country and region of origin, health-related claims and information on producer standards. [14]

In many countries, geographical labels serve as a primary tool for consumers to distinguish high-quality products from others. These labels allow producers and marketers to leverage existing positive perceptions of consumers associated with particular regions. Shoppers often rely on their general impression of the country of origin of the product as a convenient indicator of food safety, authenticity, and quality. [14]

Another scale that differentiates subject groups involves demographics such as age, gender, and income. The research segmented consumers into different age categories (18–29, 30–44, 45–60, and over 60 years) to examine their likelihood of consuming food past label dates and their propensity to discard food due to label confusion or perceived risks. [26] Younger consumers demonstrated greater reliance on institutional cues such as expiration dates, making them the most likely group to use date labels as a primary measure of food edibility. Gender also influenced label trust, with more women than men accurately understanding the meaning of the “best by” or ”use by” date. [26] Additionally, participants cited trust in their own food management behaviors, noting that food waste often resulted from buying too much or forgetting about previously purchased items. This shows that trust that influences consumer decisions extends beyond institutional labels to personal routines and memory, revealing the nuanced layers of trust that drive food consumption and waste behaviors. [26]

2.3. Smart Packaging

Indicators and sensors in smart packaging are in forms like films, labels, sachets, and devices, with detection methods that include redox reactions, analyte binding, enzyme reactions, pH changes, electron transfer, conformational changes, and electrode reactions. [20]

2.3.1 Gas Indicators and Sensors

Oxygen, carbon dioxide, and ammonia are reliable spoilage markers because they track package leakage, enzymatic browning, lipid oxidation, and microbial growth. The research has analyzed colorimetric methods for oxygen indicators during redox dye reactions, which translate into an observable color or signal that directly showcases the current status of the food without opening the package. However, the current state of the technologies in indicators and sensors presents several challenges when applied to commercial food packaging due to requirements of higher accuracy and precision and material stability. [20]

2.3.2 Anthocyanin-based pH Indicators and Sensors

Anthocyanin-based materials are also used to detect pH changes as a result of their color-changing properties. Anthocyanins are red-to-purple pigments that give berries, red cabbage, black carrot, purple sweet potato, hibiscus, and many other plants their vivid color. [27] Furthermore, anthocyanin extracted from Bauhinia blakeana Dunn flower can be immobilized in chitosan and could also be used as a pH sensing film. [1] To convert these naturally food-grade dyes into intelligent packaging indicators, they need to be first extracted with acidified water or ethanol, and more recently with techniques such as ultrasound or microwave-assisted extraction. The concentrated anthocyanin solution is then formed in a breathable, food-contact matrix like cellulose, starch, and agar. This casting or printing step traps the dye in a thin film that can be laminated to the inside of a package or attached as an external tag. [27] The sensing mechanism is based on the pH sensitivity of the pigments. In acidic conditions ($pH<3$) anthocyanins exist mainly as red flavylium cations; as the environment becomes neutral they shift to purple, and under alkaline conditions generated by spoilage volatiles such as ammonia and biogenic amines, they turn green or yellow. [28]

The pH value of foods such as pork and fish is closely related to their freshness level, serving as an effective indicator of spoilage during storage. As these foods deteriorate, microbial activity generates volatile compounds such as trimethylamine, dimethylamine, and ammonia which gradually increase within the package headspace and cause the pH to increase. [1] Zhang et al. found that fish samples typically exhibit spoilage after about 12 hours of storage at room temperature, with the pH rising to approximately 5.8, and the spoilage becomes more apparent around 16 hours and reaches 6.2. Eventually, it reaches a saturation point near 22 hours ($pH>6.9$). Similarly, pork freshness can be categorized according to pH: fresh meat generally has a pH between 5.18 and 6.12, sub-fresh meat ranges from 6.13 to 6.16 and spoilage meat exceeds pH 6.17. [1]

Although smart packaging such as pH-responsive indicators can be beneficial in generating new opportunities for both consumers and producers, industrial use is still limited, which has a major concern with poor thermal stability, high water solubility, and weak barrier properties. Future work must focus on scale-up methods and stabilization strategies to overcome these shortcomings. [27]

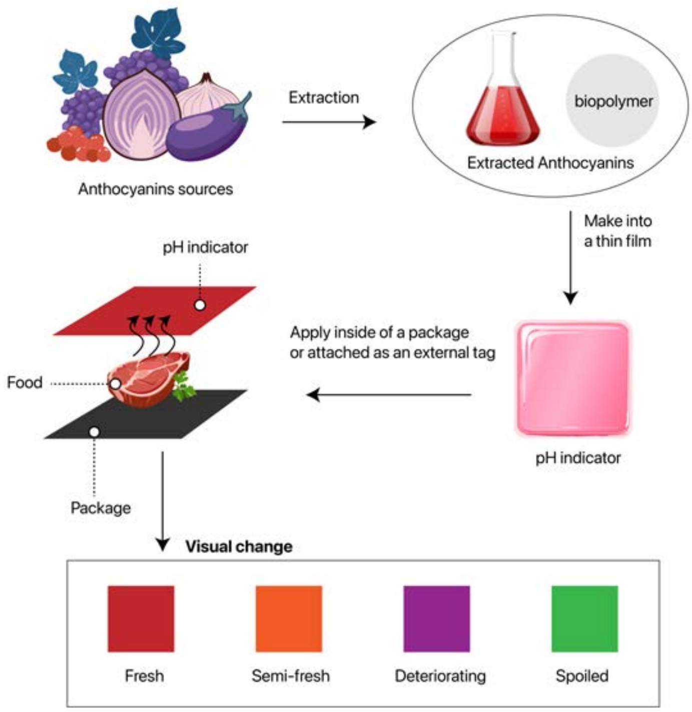

Figure 2.1 How anthocyanin-based food freshness indicator works

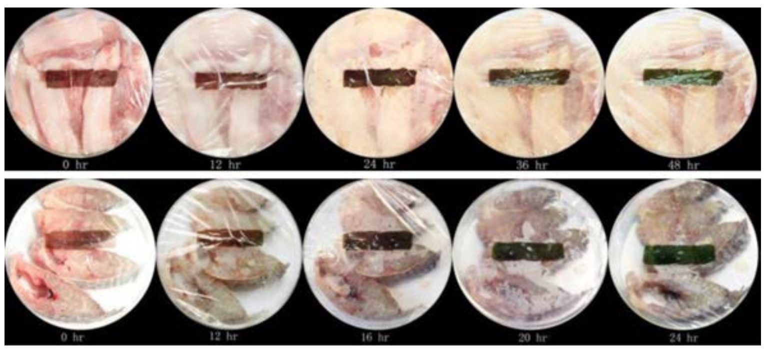

Figure 2.2 Application of sensing film as a sticker sensor for pork and fish freshness, adapted from [1]

2.3.3 Carbon dioxide Responsive Color Changing Packaging

Insignia Technologies has developed a range of smart packaging solutions aimed at reducing food waste by providing real-time, visible indicators of freshness. At the core of their innovation is a patented pigment technology that changes color in response to shifts in carbon dioxide levels or temperature. This technology is used in several label types, including FreshTags, which act as time–temperature indicators throughout the supply chain; After Opening Timers, which track product freshness post-opening; and Leak Detection Labels, which reveal micro-perforations in modified atmosphere packaging. These solutions are primarily designed for use by retailers, manufacturers, and food service providers to optimize stock rotation and maintain cold chain integrity. [29]

Figure 2.3 Leak Detection Labels which reveal micro-perforations in modified atmosphere packaging, adapted from [2]

The key limitation in food waste reduction resulted from poor chill chain management and uncertainty about how long food has been open. While Insignia's tags have improved staff behavior and reduced product rejections in commercial settings, their impact on consumer behavior remains limited. The system lacks direct interactivity or feedback for end-users at home, offering only qualitative color changes without educational context or personalized data. As such, it serves as a powerful B2B tool for improving freshness visibility but falls short of empowering consumers to make informed decisions independently.

2.3.4 Temperature Sensitive Indicator

Bump is a tactile freshness indicator designed to reduce food waste by providing a physical signal of spoilage in place of printed expiration dates. It comes in two versions: a tag for packaged items like meat and fish, and a cap for bottles of juice or other drinks. The surface of the tag or cap feels smooth when the product is still fresh. As the food spoils, a special layer inside the label reacts to changes in temperature and slowly becomes soft, allowing small bumps underneath to be felt by touch. This offers an easy and inclusive way for people, including those with visual impairments, to check freshness without relying on printed expiration dates. [3]

Figure 2.4 Usage of tactile freshness indicator and its structure, adapted from [3]

The key limitation is that it only responds to temperature changes and doesn't detect actual bacteria or chemical spoilage, which can vary between products. It also lacks digital feedback or precise information about remaining shelf life. Each product type requires a specific version of the label to align with its spoilage profile, which can make it harder to use widely.

2.4. Art and Designs

2.4.1 Makro's Life Extending Stickers

Launched in April 2023, Makro's Life Extending Stickers offer an innovative packaging solution aimed at reducing food waste by visually communicating the freshness of fruits and vegetables. Made from biodegradable materials and printed with ecological ink, the stickers mirror the natural color progression of each item's ripening process. This simple yet effective design not only helps extend the lifespan of produce but also empowers consumers to make more informed and sustainable decisions when purchasing and storing fresh food.

Figure 2.5 Makro's Life Extending Stickers, adapted from [4]

2.4.2 Kathleen Ryan's *Sliced Bread (Golden Hour)*

Kathleen Ryan's work investigates themes of excess, decay, and the passage of time through the lens of everyday objects. [5] Sliced Bread (Golden Hour) brings attention to items that are often overlooked or thrown away, revealing unexpected beauty in the ordinary. Whether it's two delicate lemon slices or repurposed car bumpers transformed into metallic peels, her sculptures uncover a sense of value and elegance in the mundane, inviting viewers to reconsider the aesthetics of the discarded. [5]

2.4.3 Craig Ward's *Subvisual Subway*

Craig Ward's Subvisual Subway is an art project that visualizes microbial life collected from surfaces in the New York City subway system, transforming oth-

Figure 2.6 Kathleen Ryan, Sliced Bread (Golden Hour), 2025, adapted from [5]

erwise invisible bacteria and fungi into vivid, abstract imagery. [6] By cultivating samples in petri dishes and presenting the resulting growth as aesthetic forms, the work draws attention to the hidden biological layers that exist in everyday environments. [6] This project serves as a conceptual reference for the visualization of molds as a trust scale in the current research. By emphasizing the role of sensory cues, such as visual signs of spoilage, Subvisual Subway underscores the potential to make the invisible visible. Similarly, this design study highlights the importance of sensory information in consumer decision making around food expiration, proposing a system that communicates freshness through gradual and interpretable microbial growth rather than static date labels.

2.4.4 Tal Danino's *Microbial Rainbow, 2018*

In the work of Tal Danino, *Microbial Rainbow, 2018* features a central 3D glass element with an embedded circular display showing time-lapse footage of bacterial activity. Proteus mirabilis, a distinctive bacterium commonly found in our surroundings, was selected for the central time-lapse sequence. [7] The images in this project are paired with an AR app on the smartphone for deeper engagement,

Figure 2.7 Craig Ward's Subvisual Subway, adapted from [6]

allowing users to view time-lapse videos of bacterial growth, and explore detailed information about each species. This project invites viewers to question the hidden world of microbes and to reflect on the striking similarities in patterns that emerge across different scales of the universe. [7]

Figure 2.8 Tal Danino's *Microbial Rainbow, 2018*, adapted from [7]

2.5. Literature Review Analysis and Theoretical Framework

Consumers often made decisions on food safety are shaped by a complex interplay of trust, perceived risk and their long-term behavioral patterns. Trust theories show that people often rely on multiple cues ranging from institutional signals, technological indicators or references and their own sensory cues. Each of these cues provides different degrees of reliability and immediacy, which create potential conflicts and causes confusion when printed date does not align with sensory judgment. Risk perception shows that consumers typically discard food out of uncertainty and want to prioritize their health over sustainable behavior. Behavioral change models indicate that providing clear and intuitive information can change habitual behaviors by reducing uncertainty and shifting trust away from conservative, market oriented institutional guidelines toward personal and evidence-based judgment. The design intervention proposed in this thesis integrates insights from trust and behavioral theories to facilitate informed consumer decision-making, thereby reducing unnecessary food waste.

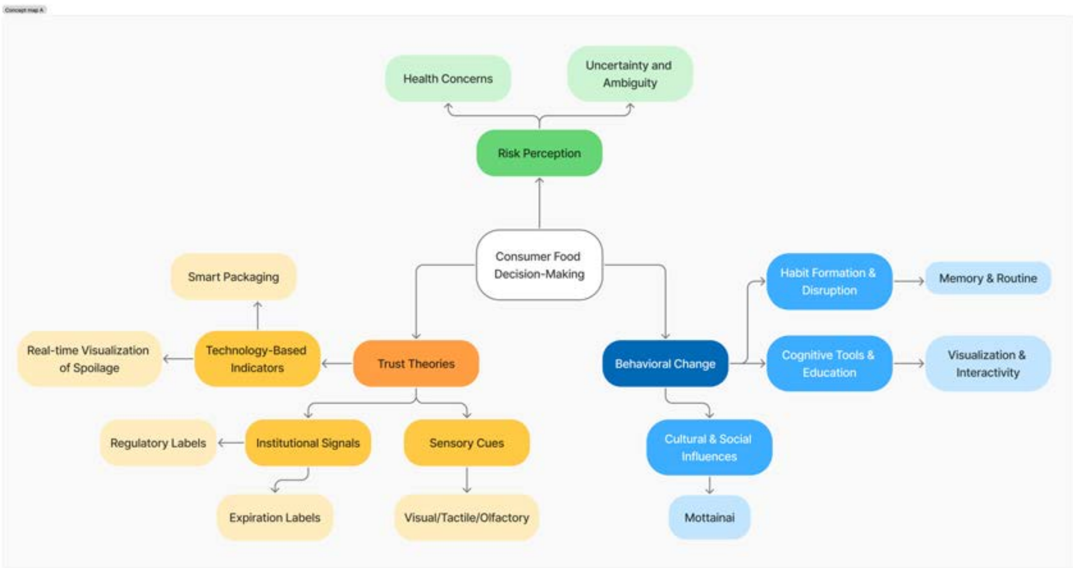

Figure 2.9 Thesis concept map

Chapter 3
Design Process

3.1. Concept Statement

In this chapter, the goal is to define the final form of the visualized degradation system: a design intervention that mirrors the process of food spoilage in real time as an alternative to conventional expiration labels. This concept explores how sensory cues can be reintroduced into consumer decision making through visualization, encouraging a shift from institutional trust to more embodied perception-based forms of judgment. The design process involves translating microbial activity into visual language, aligning it with actual food conditions, and testing its ability to raise trust and influence disposal behavior.

To develop and validate the effectiveness of the system, Designs 1 and 2 were created and tested. A final design was then implemented, with experiments involving daily interactions with food samples and visualized degradation animations.

This chapter outlines the development of ideas, how the visualization concept was progressed, and discusses how these findings shape the final design outcome.

3.2. Preliminary Survey on Food Disposal

To understand consumer perceptions of food waste and expiration dates, a survey of ten combinations of multiple choices and scales was conducted on 34 individuals. The survey touches on topics such as sell-by-date and use-by-date, short- and long-expiration-date food, decision making on food disposal, and possible use of technology to extend the longevity of food in the future. Respondents ranged in age from 20 to 30 and represented diverse nationalities, including Japan, China, the United States, Canada, and South Korea. The participant group included both students and non-students, with varied living arrangements, including those living alone and those living with family or roommates.

3.2.1 Survey Results

The first question(Figure 3.1) aimed to assess the understanding of the respondents of the difference between 'sell-by' and 'use-by' dates. The results indicate that 70.6% have only a basic understanding of the distinction, while 11.8% reported being highly knowledgeable, including a knowledge of how such dates are determined. In contrast, 17.6% indicated that they do not understand the difference at all.

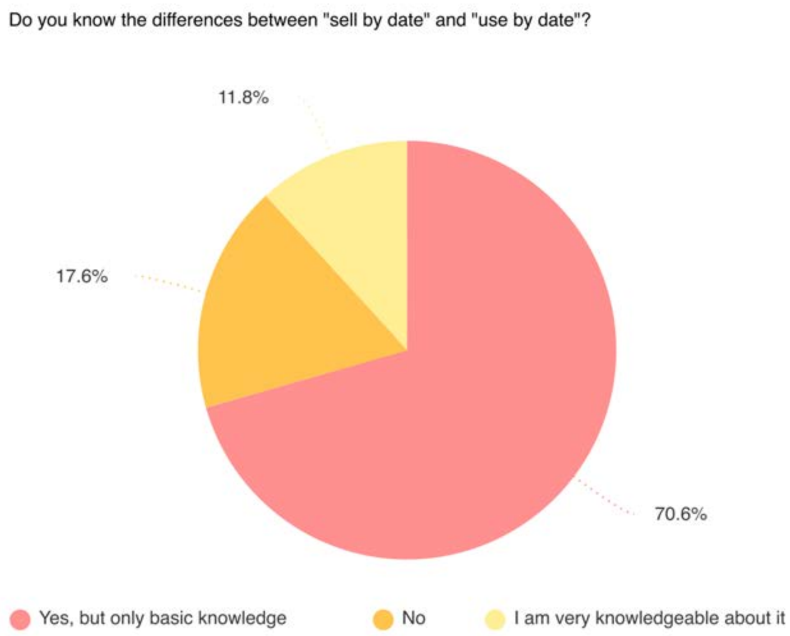

Figure 3.1 Question 1 on differentiating the "sell-by" and "use-by"

The second question(Figure 3.2) asked participants to identify the food categories they believe are the most frequently discarded. The responses most commonly selected were produce items and foods with short expiration periods.

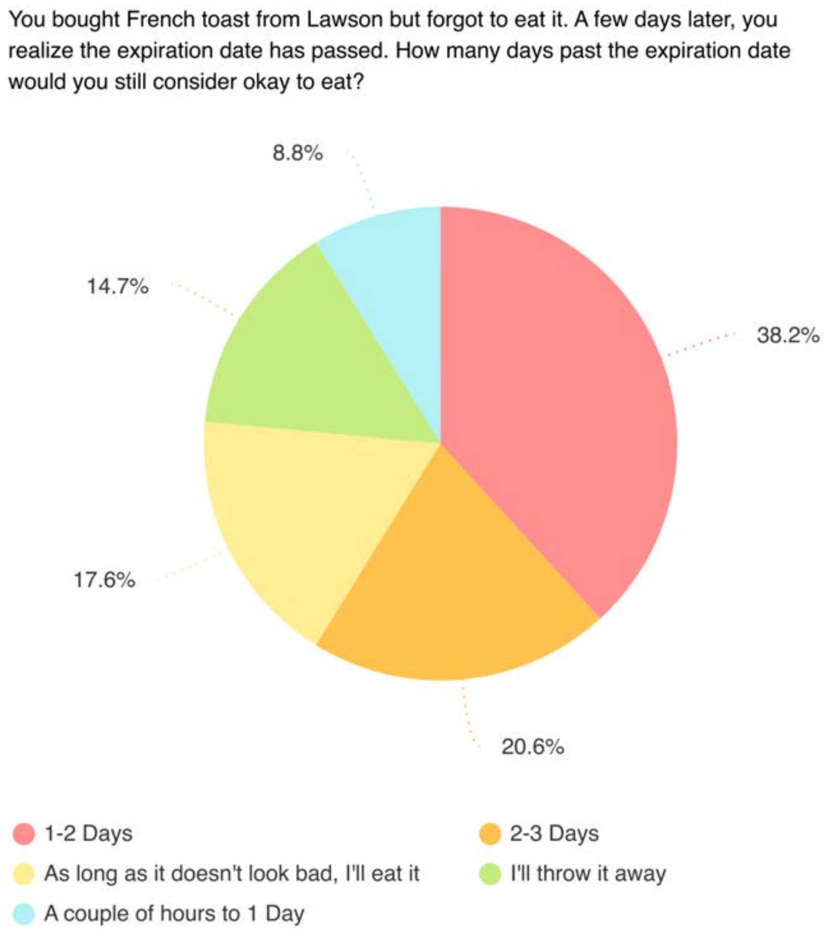

Figure 3.2 Question 2 on food categories that most frequently discarded

Questions 3, 4, and 5 presented respondents with different scenarios related to food disposal decision making. Question 3(Figure 3.3) focused on foods with short expiration dates, revealing the general willingness of the consumer to consume such products beyond the printed date. Question 4 addressed foods with a long shelf life, while Question 5 examined the behavior when expired food had been stored in the refrigerator.

Figure 3.3 Question 3 on consuming short expiration food beyond printed date

Most of the participants were willing to stretch the labeled date by at least one full day. The largest group, 38.2%, said that they would consume the product 1 to 2 days after the printed date, while another 20.6% accepted a window of 2 to 3 days. An additional 17.6% adopted visual cues, indicating that they would eat the toast 'as long as it does not look bad.' In contrast, only 14.7% would discard the item immediately, and 8.8% limited themselves to a grace period of "a couple of hours to one day."

Compared to short shelf life food, food like cup noodles receives different results. The majority, 38.2% of the respondents were comfortable consuming the product up to a month after the date labeled, while 26.5% accepted less than a week. A small portion 8.8% were willing to consume the product even three months or longer after expiration. In contrast, 17.6% of the respondents indicated that they would throw the product away immediately, and another 8.8% accepted a narrow margin of 1 to 2 days.

Figure 3.4 shows the factors that influence participants' decisions to discard food, even when the food appears or smells acceptable. Among the 34 respondents, the most frequently cited reason was concern about food safety, selected by 44.1% of the participants. This was followed by a general unwillingness to take risks, reported by 35.3%. Only 14.7% indicated that the expiration date alone would lead them to discard food, while a minimal 2.9% stated that they would only throw away food if it was moldy or tasted bad. Another 2.9% cited prior knowledge or experience with that specific food as their guiding factor.

Figure 3.5 shows the frequency with which respondents check for spoilage indicators such as smell, texture, or appearance before deciding whether to discard food that has passed its expiration date. 64.7% of participants reported that they always check for signs of spoilage, while 26.5% stated they sometimes do so. Only a small portion of the respondents said that they rarely check for such indicators.

3.2.2 Findings

The results of the survey indicate the following: Even though the expiration date has passed, the majority of people still reconsider the edibility of food under emotional and heuristic which play a larger role in decision making. Behaviors often include a sensory check and a fixed short extension. Perceived freshness

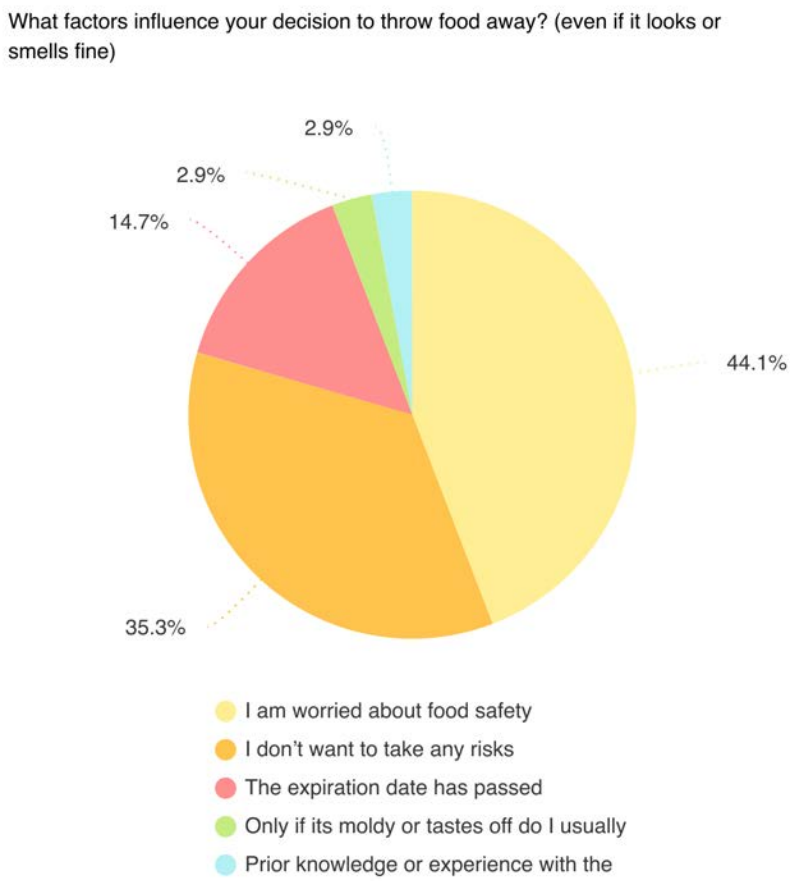

Figure 3.4 Question 6 on factors that influence disposal decision

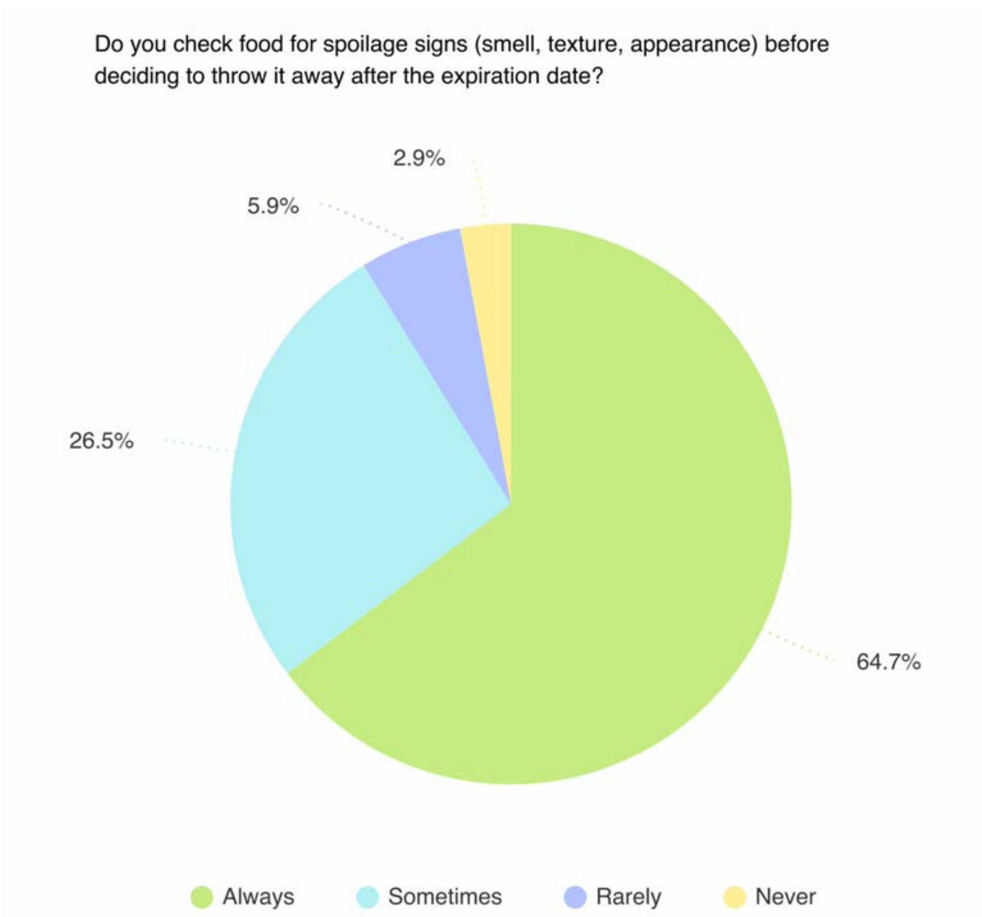

Figure 3.5 Question 7 on spoilage signs before disposal decision

cues and risk assessment frequently outweigh labeled information, which is important for both food reduction and label design. Compared to perishable food, the consumer's tolerance window for long expiration foods, such as cup noodles, reflects that disposal decisions are highly contextual, influenced by product type and storage conditions.

3.3. Design 1: 18 Packaging Design

3.3.1 Concept

To examine what influences consumer disposal decisions, a set of 18 packaging designs was developed and evaluated through a workshop that explored three dimensions of trust: functional, institutional, and sensational.

- Functional trust relates to the materials (plastic, paper, aluminum) and technological features incorporated into packaging, such as freshness monitors, smart tags, and QR codes.
- Institutional trust addresses the credibility of information presented on the packaging, particularly certification labels from recognized authorities or organizations.
- Sensational trust involves sensory cues, such as visual, tactile, and olfactory that help consumers assess freshness or spoilage.

Each packaging variation was informed by literature review and inspired by both existing and speculative market examples. Starting from a base model, the 18 variations were generated using Midjourney, applying combinations of functional and sensational features across the three materials. To specifically evaluate consumer reliance on institutional information, eight designs featured certification labels.

All designs were conceptually tested under same temperature and storage conditions, ensuring that differences between them were limited exclusively to their material composition, presence or absence of certified labels, and sensory or technological functionalities.

3.3.2 Methodology

The workshop was conducted in two parts with a total of 13 participants, all of whom were KMD students aged between 20 and 30 in diverse nationalities. Part 1 involved four participants and collected both quantitative and qualitative data, while Part 2 involved nine participants and focused on quantitative data. All participants completed an online survey via Google Forms, in which they evaluated 18 packaging design images with brief descriptions, rating each design on a trust scale from 1 (lowest trust) to 7 (highest trust). Part 1 was conducted face-to-face and included interviews where participants answered the following questions:

1. What is your highest rating and what is your lowest, how did you rate them?
2. What is the biggest factor in making a successful trustworthy packaging design?
3. What is your future imagination of packaging?

Interview responses were documented as written transcripts.

3.3.3 Design

The specific variations for each packaging design are listed in Table 3.1. A total of ten functionalities were included: the Freshness Indicator appeared three times; the Time-Temperature Indicator, Tactile Change, and Odor Neutralizer with Lemon Scent each appeared once; and the remaining functionalities appeared twice.

Figures 3.6, 3.7, and 3.8 present the packaging design variations.

Packaging	Name	Sensory Cues	Institutional Information	Funtionality	Material Quality
1	Freshness Indicator	Visual		pH indicator	Plastic
2	Freshness Comparison	Visual	○	Sample mirroring as reference	Plastic
3	Gas Inflation Indicator	Visual		Gas Indicator	Plastic
4	Time Temperature Indicator	Visual	○	Color change under cumulative temperature	Plastic
5	Material Degradation	Tactile	○	Packaging material degrades as spoilage	Plastic
6	Tactile Change	Tactile	○	Packaging material develop wrinkles	Aluminum
7	Freshness Monitor Smart Tag	Technology	○	Collect real-time data	Plastic
8	Freshness Monitor QR Code	Technology		Real-time freshness data through QR code link	Paper
9	Odor-Detecting Strips	Olfactory		Release odor of spoilage	Plastic
10	Odor Neutralizer-Lemon Scent	Olfactory		Activate lemon scent capsule when spoilage	Plastic
11	Freshness Indicator (2)	Visual		pH indicator	Aluminum
12	Freshness Comparison (2)	Visual		Sample mirroring as reference	Aluminum
13	Gas Inflation Indicator (2)	Visual		Gas Indicator	Aluminum
14	Freshness Monitor Smart Tag (2)	Technology	○	Collect real-time data	Paper
15	Odor-Detecting Strips (2)	Olfactory		Release odor of spoilage	Paper(coated)
16	Material Degradation (2)	Tactile		Packaging material degrades as spoilage	Paper
17	Freshness Indicator (3)	Visual	○	pH Indicator	Paper
18	Freshness Monitor QR Code (2)	Technology	○	Real-time freshness data through QR code link	Aluminum

Table 3.1 18 packaging design variations characteristics

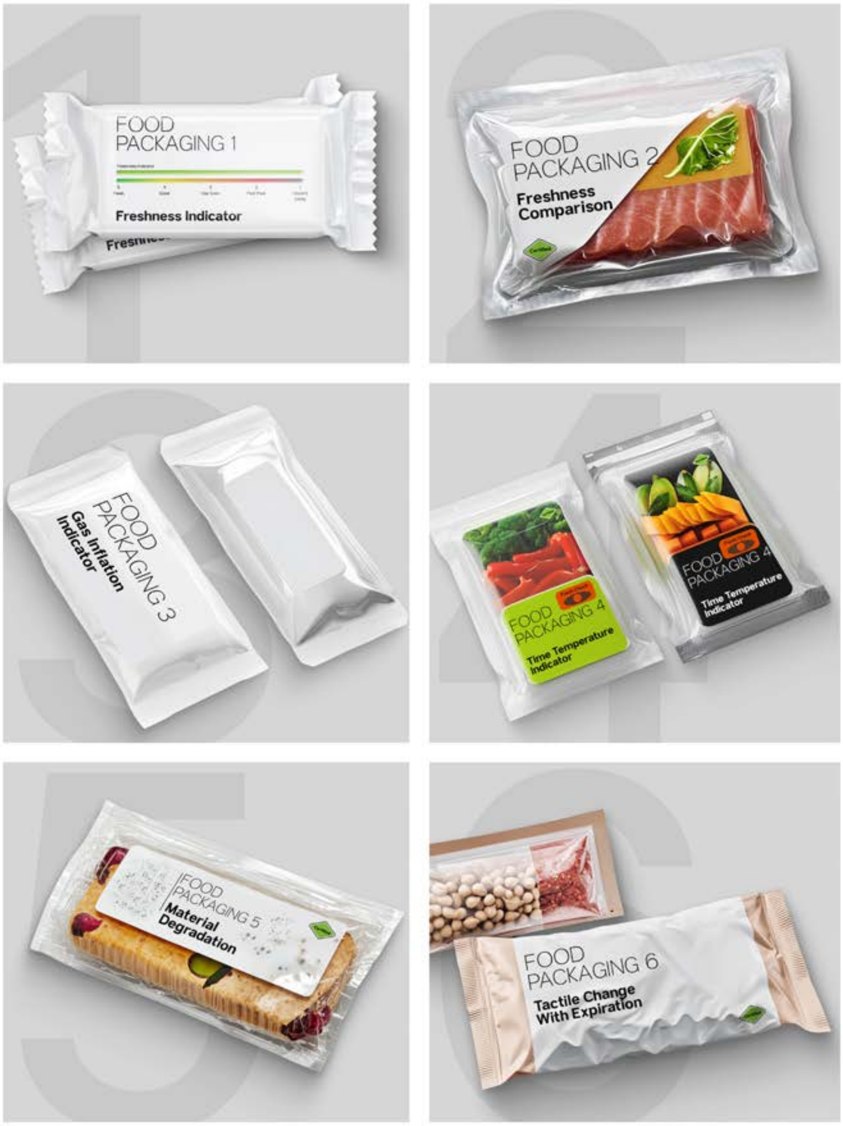

Figure 3.6 Design 1 to 6 from 18 packaging design variations categorized based on visual, tactile, olfactory, and technological

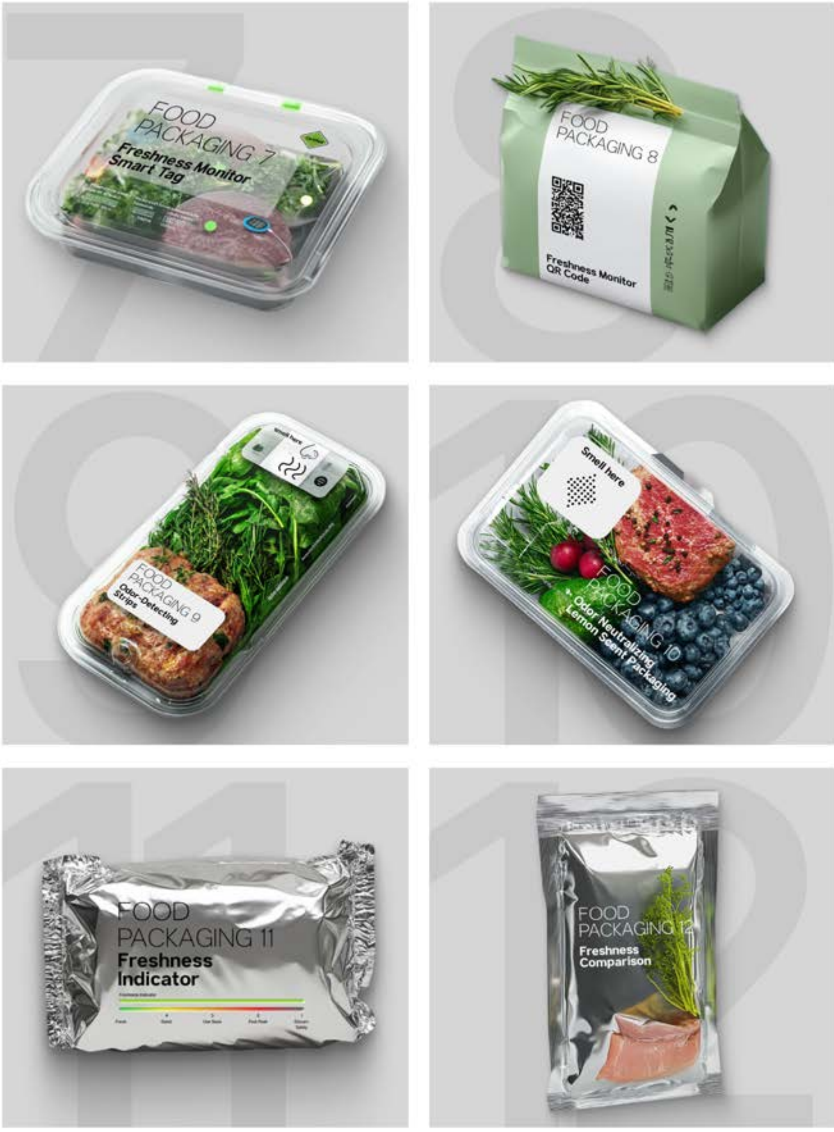

Figure 3.7 Design 7 to 12 from 18 packaging design variations categorized based on visual, tactile, olfactory, and technological

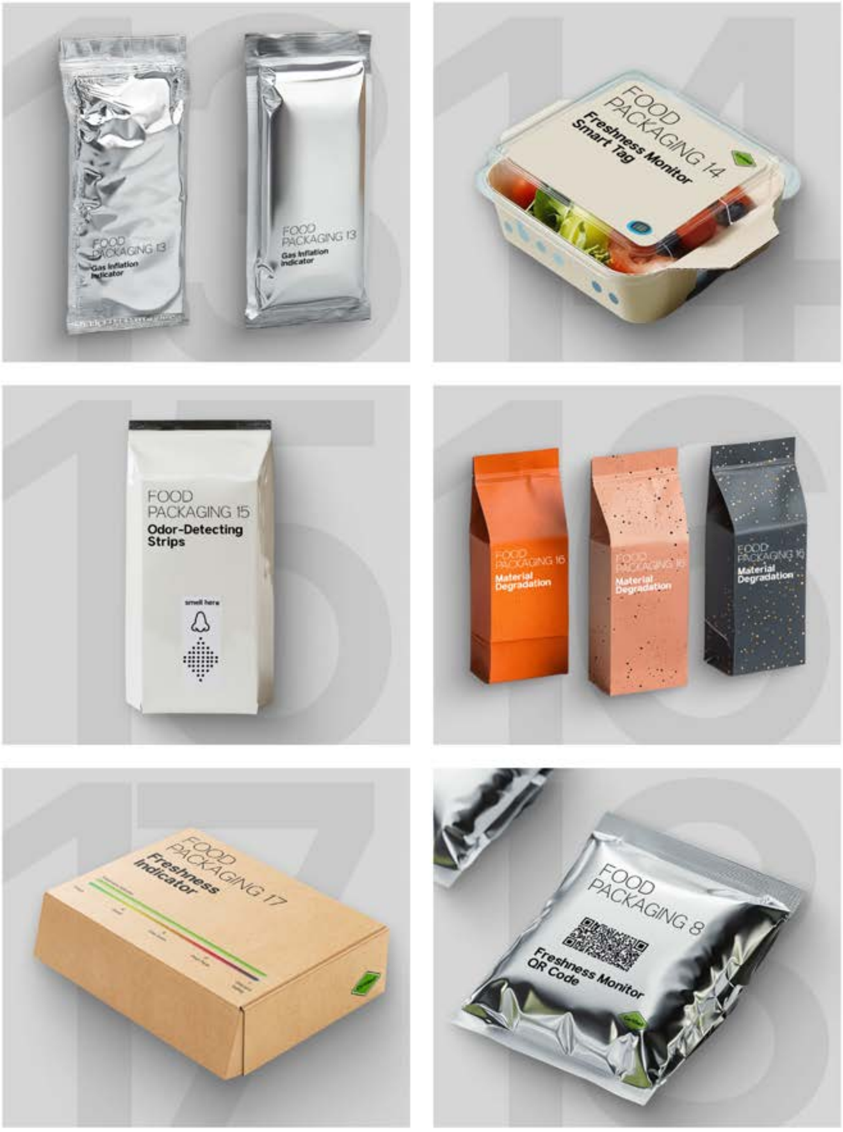

Figure 3.8 Design 13 to 18 from 18 packaging design variations categorized based on visual, tactile, olfactory, and technological

3.3.4 Results and Findings

To quantitatively analyze the trust ratings of participants in the 18 speculative packaging designs, mean values and standard deviations were used.

The mean provides a measure of central tendency, allowing a straightforward comparison of which designs, on average, were perceived as more or less trustworthy. This metric helped identify general agreement in participant responses and illustrate the relative effectiveness of different trust cues, encompassing sensory, institutional, and technological categories.

The standard deviation measured the variability of the responses for each design. This allowed us to understand the degree of agreement or disagreement among the participants. A high standard deviation indicates polarizing responses, suggesting that a design might be interpreted differently by individuals. In contrast, a low standard deviation suggests a greater consensus among the participants. Table 3.2 shows each formula for the mean and standard deviation.

Statistic	**Formula**
Mean	$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$
Standard Deviation (SD)	$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2}$

Table 3.2 Statistical Formulas for Mean and Standard Deviation

Packaging	Mean	SD
P1	4.31	1.49
P2	4.85	1.68
P3	4.92	1.32
P4	4.77	1.24
P5	4.77	1.42
P6	3.53	1.39
P7	5.15	1.68
P8	4.62	1.39
P9	3.69	1.84
P10	3.30	1.44
P11	4.30	1.49
P12	5.0	1.15
P13	4.15	1.21
P14	4.62	1.66
P15	3.62	1.45
P16	4.38	1.26
P17	4.15	1.28
P18	4.23	1.69

Table 3.3 18 Packaging trust rate statistic-means and standard deviation

The study revealed several findings on consumer trust in speculative food packaging designs. As illustrated in Figure 3.9, visual signals were generally perceived as more trustworthy than olfactory signals. Furthermore, technological trust was consistently higher overall compared to other categories. Among the designs that incorporate technological elements, those that use QR codes demonstrated the most consistent scores, although their effectiveness varied depending on the accompanying material. In particular, most of the participants expressed uncertainty about olfactory signals, and two participants specifically mentioned the expectation of predicting future freshness and understanding food quality before consumption.

As shown in Table 3.3, designs incorporating visual cues generally received the highest average trust scores. For instance:

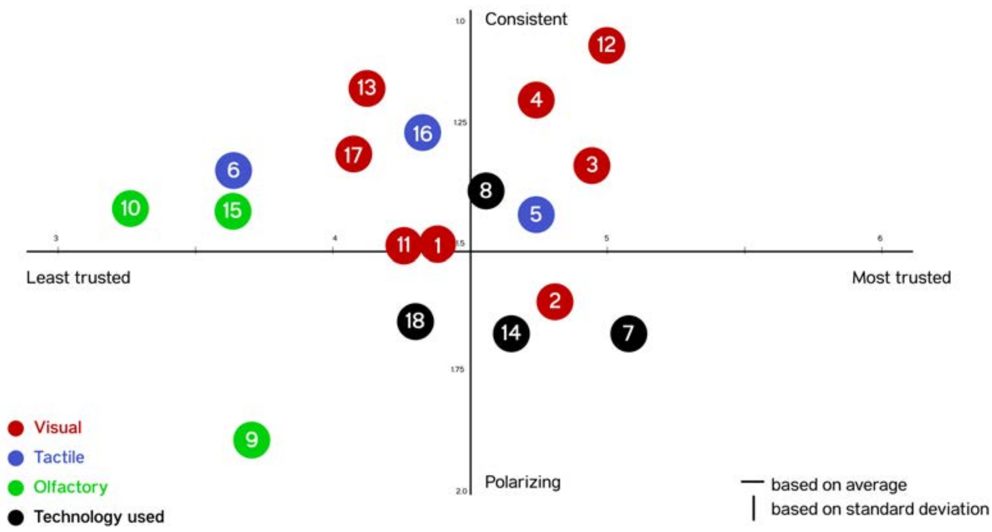

Figure 3.9 Quadrant chart of trust rate statistics

- Packaging 12, described as "A small, visible sample is attached to the outside of the aluminum package. This sample mirrors the spoilage timeline of the actual product, giving consumers a freshness reference without opening the package," received a mean trust score of M=5 with a standard deviation of SD=1.15.

- Similarly, Packaging 7, which features "embedded digital tags that monitor and collect real-time data on food freshness, spoilage conditions, and storage environment," also achieved a high mean trust score of M=5.15. However, this particular design exhibited one of the greatest polarizations in responses, with a high standard deviation of SD=1.68. Over half of the responses for Packaging 7 fell at the extremes of the rating scale, indicating that technology features elicited divided reactions: participants either trusted them strongly or remained highly skeptical.

Established visual cues consensus: The narrow standard deviation in packaging 12 suggests that the respondents share a common understanding when interpreting a visible reference sample. When the mini-packet shows a sign of fuzziness, the food in the package should be discarded. This approach is rooted in everyday sensory reasoning rather than specialized knowledge, which explains why very few participants rated it extremely low. These findings align with long-standing research on risk communication, which emphasizes that concrete and observable indicators are more effective than abstract labels when individuals must make a decision about safety.

Polarized opinions on technology: Packaging option 7 received the highest ratings from the respondents, indicating that many prefer a sensor that always checks the conditions over a simple date printed on the package. However, the high SD (= 1.68) in the responses shows that some users are skeptical about whether these hidden electronic devices can truly be reliable, secure and respect their privacy. This uncertainty reflects a wider hesitation people have about ”smart” devices in areas like food and healthcare, while many appreciate the accuracy these technologies offer, concerns arise when faced with issues like data leaks or food contamination.

The key takeaway is not to discard technology altogether, but to make it more transparent, such as adding a color indicator that shows what the sensor detects, could help make the technology more understandable to users. This approach has worked well with Packaging option 12 and could help bridge the gap in opinions about these advanced features.

Olfactory cues as the lowest scores: Olfactory-triggered designs received relatively low average trust scores, P9 ($M = 3.69$), P10 ($M = 3.31$), and P15 ($M = 3.61$), suggesting that smell-based trust cues require careful calibration and may raise hygiene concerns. Research in food psychology indicates that disgust and contamination fears can override trust in olfactory perception.

Among the three olfactory-based designs, P9 and P15 shared the same functionality, using “odor-detecting strips,” but differed in material: the former used plastic, while the latter used coated paper. P9 had a higher standard deviation than P15, indicating greater disagreement among participants, possibly due to concerns that the plastic carrier might introduce chemical residue or off-odors. Both P9 and P15 received higher average trust scores than P10, which included an “odor neutralizer with lemon scent.” This suggests that artificially masking the product’s natural smell can confuse consumers and diminish trust in the olfactory cue.

Institutional cue of green “Certified” label: Of the 18 packages, eight carry a green “Certified” badge (P2, P4, P5, P6, P7, P14, P17, P18). Yet only five—P2, P4, P5, P7, and P14—obtain mean trust ratings above 4.5; P17 and P18 are slightly below this threshold, while P6 has the lowest score overall. This pattern indicates that the badge may often be overlooked, reducing its potential to enhance consumer confidence.

As a result, it appears that the label functions effectively as a trust amplifier only when paired with a freshness cue that consumers can readily comprehend.

At the end of the first part of the workshop, four participants were interviewed to share their visions for future packaging and to identify the improvements they considered most important for reducing food waste.

Responses that relate to technologies and direct sensory cues indicates that friction-free access to verified data is essential:

> *“Packaging can get wrinkled just by handling it, digital smart tags can monitor humidity, and a lot more. I think technology is going to be more integrated in our daily lives in the future.”*
>
> *“QR codes provide easy access to factual information about the product’s freshness or spoilage, it’s more direct and reliable. The future packaging I imagine, in a speculative way, is that we can taste the food before we purchase it.”*

Participants welcome “digital smart tags” and QR codes because they promise humidity tracking, spoilage alerts, and on-demand facts, showing an expectation towards immediately distinct feedback—ideally something “more direct and reliable” than static dates. There are also responses that suggest embodied cues still secures trust more strongly than abstract dates:

> *“Future packaging I imagine is the olfactory experience when purchasing food and you will know if the smell is matching your expectation of the food.”*

> *"I like how you can see the process of spoilage, you know how fresh it could be and how bad it could go and it makes me feel safer consuming it."*

There are also participants who ranked material integrity and safety as the top determinants of credibility:

> *"Safety and eco-friendly plays the biggest factor in making sustainable and trustworthy packaging."*

Taken together, the gathered responses suggests that an effective food-waste-reducing package must blend multi-model transparency such as digital diagnostics for precision and sensory affordances for intuition.

3.4. Design 2: A Food Organizer App

3.4.1 Concept

Figure 3.10 Foodagram logo

Design 2 was developed concurrently with Design 1, incorporating insights gained from Design 1's initial data analysis to guide its direction. Design 2, named Foodagram, is a mobile application that addresses household food waste by a food management system with a social game-like user experience. Based on the growing reliance of consumers on digital tools for daily planning and waste due to lack of management [26], the app turns sustainable behavior into a reward-driven daily exercise. An interactive prototype was developed in the later stages and evaluated by 12 participants aged between 20 and 30 with diverse nationalities. Both quantitative and qualitative feedback were collected during testing.

3.4.2 Methodology

A low-fidelity prototype was first created and refined based on informal feedback from peers and advisors. After making it interactive, 12 user test participants were asked to perform tasks such as logging groceries, setting up spoilage reminders, and engaging with the reward system.

Quantitative data were collected via Likert-scale questions on usability, engagement, and perceived effectiveness. Qualitative data were gathered through text feedback in Google Forms. The resulting data were used to assess the viability of Foodagram's core features and inform future design iterations. Design 3 was later embedded and tested within the prototype.

3.4.3 Design

The initial concept was informed by insights from existing literature on digital consumption habits and behavioral psychology, particularly the influence of routine, reward mechanisms, and management tools in promoting sustainable behaviors. As illustrated in Figure 3.11, the full user experience flow was designed with intentional touch points that each section serving a specific purpose to guide and reinforce positive consumer actions throughout their interaction with the app.

The app is designed with following key Features:

- Users import purchases by scanning grocery receipts or synchronizing online-order data from partner supermarkets.
- The system logs the 'use by' date of each item and issues just-in-time notifications to minimize spoilage.
- After cooking, users photograph their dishes and swipe to tag the ingredients consumed.

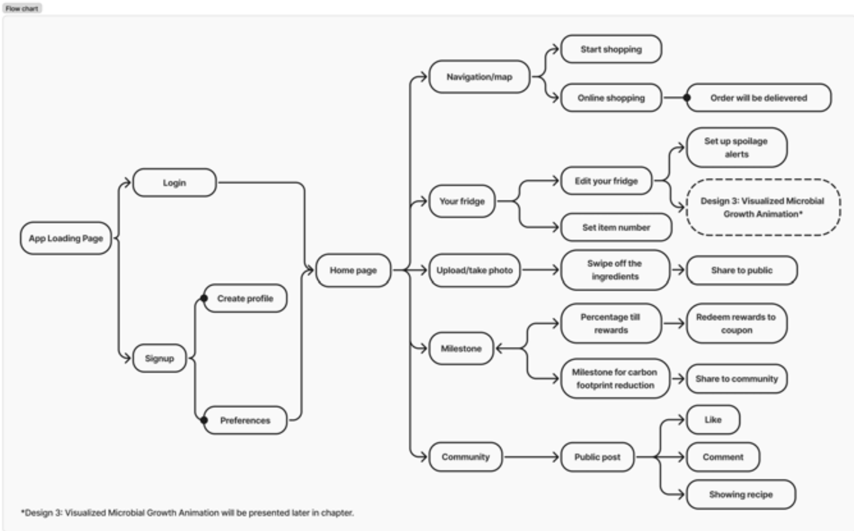

Figure 3.11 Foodagram UX flow

- Each verified meal contributes a percentage-based score towards periodic rewards.
- Progress bars and achievement badges visualize the impact of personal waste reduction, which will reinforce continued engagement.
- The sharing feature also offers positive feedback to users, which reinforces repeat engagement. In the study by Brudner et al., participants were significantly more influenced by positive feedback than negative feedback when choosing who to share with, suggesting that consistent encouragement can shape behavior over time. [30]

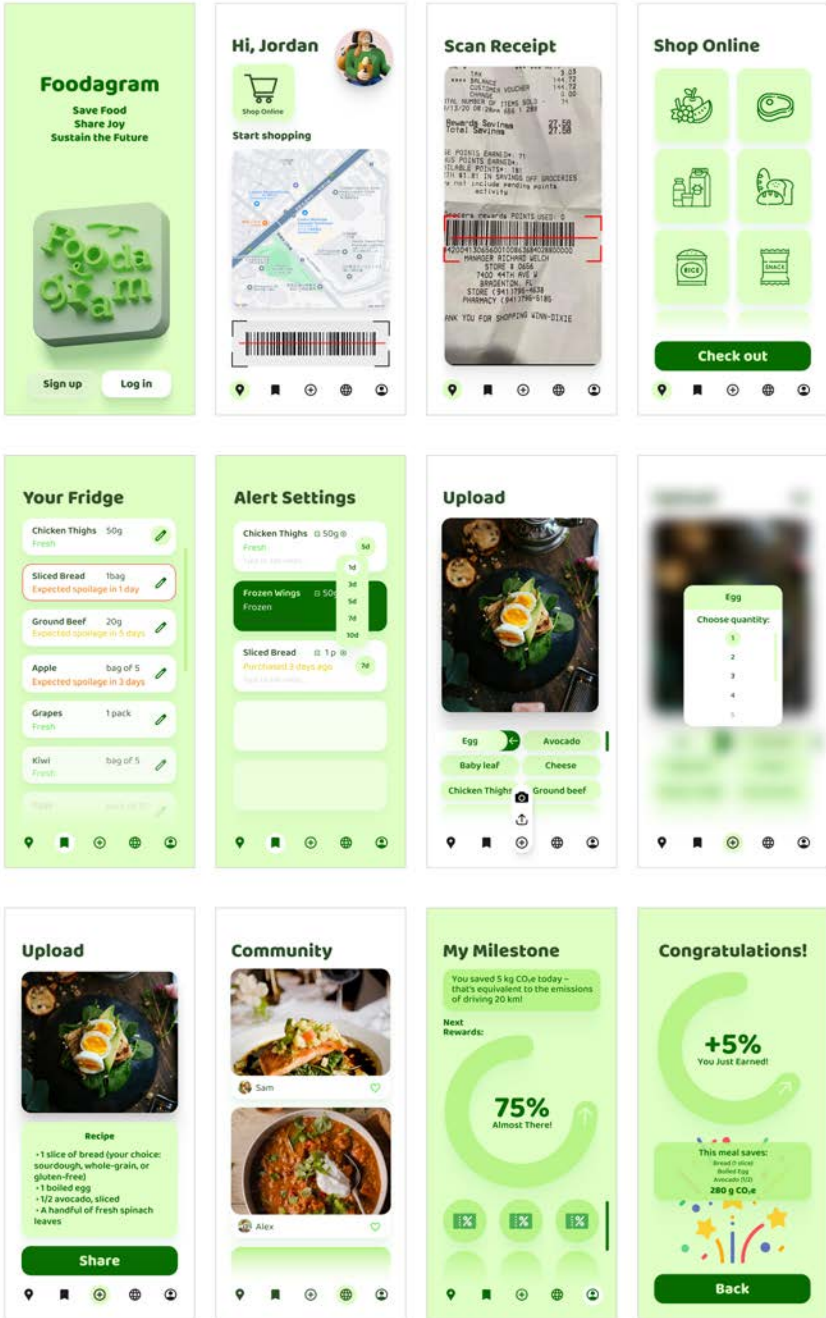

Figure 3.12 Foodagram UI

3.4.4 Results and Findings

As the Table 3.4 shown, the quantitative results from user testing indicate an overall positive reception toward the Foodagram app, with the "Overall experience" rated at 4.08 out of 5, referring to a "Good" user perception. Participants showed a reasonably strong likelihood of installing and using the app, as evidenced by an average score of 3.83 out of 5. Additionally, the app's perceived effectiveness in managing household food waste was rated favorably at 3.91 out of 5, suggesting participants generally view the app as a potentially valuable tool for sustainable food management.

	Average score	Anchor label (on the scale)
Overall experience	4.08/5	Good
How likely to install and use	3.83/5	More likely
Perceived effectiveness	3.91/5	More likely

Table 3.4 Quantitative data gathered from user testing

By using thematic analysis to categorize the qualitative data given from the participants, it highlights several recurring themes concerning desired features and usability improvements:

Health and Safety Insights: Participants expressed interest in receiving more comprehensive information related to food health and safety. This includes knowing whether foods are still safe to eat as they near expiration, especially with minor bacterial growth, and understanding potential health risks associated with expired items. Such features would increase users' confidence in making safe food decisions and potentially reduce premature food disposal.

Storage Tips and Freshness Management: There were demands for detailed guidance on proper food storage methods such as distinguishing between refrigeration and freezing as well as techniques for extending freshness. Participants also suggested adding a feature that offers recipes using food close to expiration, helping reduce waste while adding practical daily value.

Sustainability Education and Impact Awareness: While participants appreciated the app's focus on expiration tracking, some found its sustainability messaging unclear. There was a noted need to communicate how Foodagram contributes to carbon footprint reduction or CO2e savings. Suggestions included tracking food waste's financial cost, integrating expenses monitoring via receipt scanning, and clarifying the app's environmental goals. Several users also recommended clearer social or group-sharing features to connect with cohabitants, along with gamified elements like mascots to enhance engagement.

3.5. Design 3: Visualized Microbial Growth Animation

3.5.1 Concept

To support consumers in making informed food disposal decisions, this research explores visual cues that convey both transparency and an intuitive understanding of food conditions. While packaging can offer limited information, direct observation remains a powerful tool for assessing freshness. To investigate this, a mold growth experiment was conducted using a package of bread, documenting visible spoilage over the course of a week. Insights from this study informed the final design proposal: a feature embedded in the Foodagram app that links to an animation visualizing the degradation process of the actual product inside the package. This animation reflects the spoilage curve based on empirical data collected from the mold culture experiment.

By simulating visual evidence of decay, the system helps bridge the gap between sensory trust and informational asymmetry. The design also draws on findings from the user testing phase, in which Packaging 2, featuring a visible food sample, received the highest trust ratings, underscoring the importance of clear, observable indicators in shaping consumer behavior.

3.5.2 Experiment

The experiment was carried out in the following steps:

- Scrub the surface of the bread and spread it on the surface of the agar sheet.
- Break the bread into smaller pieces and spread them over the cultivation agar sheet.
- Add distilled water
- Place them in a paper box and keep them away from moisture.

As a result, the mold on the bread was recorded every day in the following way(Figure 3.13):

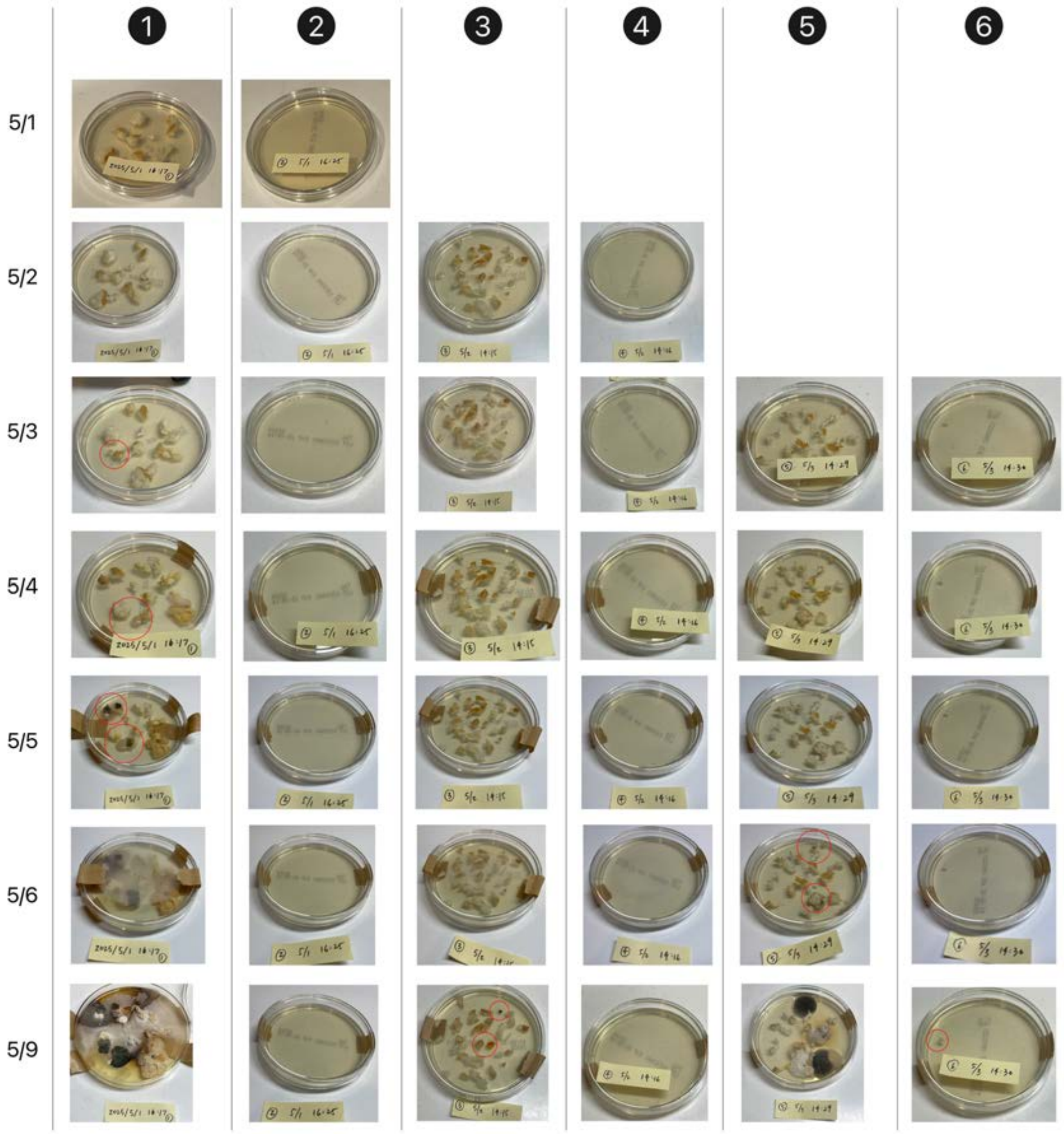

Figure 3.13 Mold cultivation on bread as visualized spoilage cues

3.5.3 Observation

To compare mold growth in bread samples exposed on different days, six petri dishes were prepared: Dishes 1 and 2 were cultivated on May 1st, Dishes 3 and 4 on May 2nd, and Dishes 5 and 6 on May 3rd. The main differences in the setup were as follows: Dishes 1, 3, and 4 contained distilled water, while Dish 5 remained dry. Additionally, Dishes 1, 3, and 5 included small pieces of bread, whereas Dishes 2, 4, and 6 were inoculated only with microbial swabs. (Table 3.5)

Microbial growth in Dish 1 became visible on the third day after exposure, with a noticeable acceleration starting on May 6th. The observed colonies appear to include species resembling Penicillium, Rhizopus, Aspergillus, as well as possible bacterial or yeast growths. Although the bread's labeled "Use by" date was May 2nd, no visible microbial activity was detected until May 3rd, suggesting that spoilage was not immediately apparent upon expiration.

Microbial growth in Dish 3 progressed significantly more slowly than in Dishes 1 and 5. No visible microbial activity was observed until May 9th, and the types of mold that developed appeared to differ from those in the other dishes. This result suggests that microorganisms grow more slowly in colder environments compared to room temperature, potentially extending the shelf life of food and delaying visible signs of spoilage.

Dish 5 was exposed to the petri dish one day after the bread's expiration date and began to show signs of microbial growth on May 6th (Day 4), similar to the timeline observed in Dish 1, despite being opened on different dates. Mold growth accelerated over time, with visible Penicillium colonies appearing by May 9th. (Figure 3.14) However, the overall quantity and diversity of microorganisms in Dish 5 differed significantly from those in Dish 1. This contrast suggests that short-shelf-life foods like bread may still remain edible for a period after their expiration date, particularly when the packaging remains unopened and environmental conditions are controlled.

Dishes 2, 4, and 6 showed minimal microbial activity during the early stages of the experiment. This suggests that swabbing the surface of the bread onto the agar may not be an effective method for cultivating mold under these conditions. In Dish 6, a small piece of bread was accidentally left in the dish, and interestingly, microbial growth became visible on the final day of the experiment. This

	Dish 1	Dish 2	Dish 3	Dish 4	Dish 5	Dish 6
5/1	Inoculation	Inoculation				
5/2	No visible growth	No visible growth	Inoculation	Inoculation		
5/3	Visible Growth	No visible growth	No visible growth	No visible growth	Inoculation	Inoculation
5/4	Visible Growth	No visible growth	No visible growth	No visible growth	No visible growth	No visible growth
5/5	Colonization	No visible growth	No visible growth	No visible growth	No visible growth	No visible growth
5/6	Colonization	No visible growth	No visible growth	No visible growth	Visible Growth	No visible growth
5/9	Peak Growth	No visible growth	Visible Growth	No visible growth	Colonization	Visible Growth

Table 3.5 Microbial growth in petri dishes over time

observation further supports the idea that direct contact with the bread sample promotes more reliable mold development than surface swabbing alone.

Figure 3.14 Cultured mold from Dish 1(left) and Dish 5(right) on May 9th

As shown in Figure 3.15 and Table 3.6, the recorded results were then analyzed using ImageJ to quantify the progression of microbial growth, providing a reference for later digitization and animation. To ensure accuracy, the area of each visible microbial colony was measured multiple times at different points. The mean values of these measurements were calculated to minimize error and account for potential inconsistencies in visual estimation.

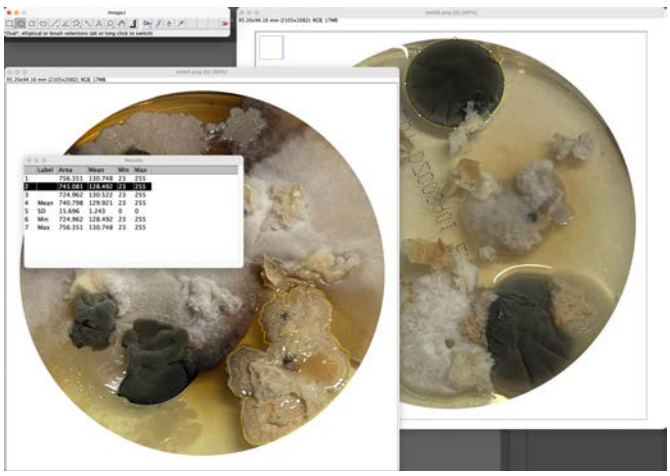

Figure 3.15 Mold growth measurement in bread samples of Dish 1 and 5 in Day 9 using ImageJ

The names of microorganisms shown in parentheses in Table 3.6 represent approximate identifications based on observation of color, texture, and growth pattern compared with descriptions in the literature. No microscopic or molecular analyzes were performed. Other environmental microbes may have entered the plates during handling; some colonies could be incidental contaminants rather than originally present in the food sample. The primary aim of the project is to visualize the different stages of food degradation, and for this purpose the current level of approximation is considered sufficient at this stage of the design.

	Area (mm^2)
dark-green rim with pale centre (Cladosporium)	424.388
Brown cottony group 1	531.939
White round cottony group 2	49.237
Thick cottony/mycelial mat (Rhizopus)	2229.709
Small, dark-olive (Penicillium)	139.155
Large, dark-olive (Penicillium)	332.664
Yellow, fungi-like texture	740.798

	Area (mm^2)
Green-blue, fuzzy (Penicillium)	417.261
White, fuzzy or cottony group 1	377.064
White, fuzzy or cottony group 2	609.992
Green-blue, fuzzy (Penicillium 2)	470.249
Yellow, glowy (yeast colony)	14.808
White, glowy	21.941

Table 3.6 Mold growth measurement in mm^2 from Dish 1(left) and 5(right) in Day 9

3.5.4 Design

The cultivation process was digitized into a time-lapse animation (Figure 3.16) that simulates real-time microbial growth, visually reflecting the actual decomposition process of a slice of bread. Based on the parameters described in Table 3.6, visual data was quantitatively measured and spatially aligned to ensure precision. Embedded in the Foodagram app, this feature (Figures 3.17 and 3.18) presents the degradation process from day 1 to day 5 after the expiration date of a product, giving users an intuitive, science-based reference to support more informed disposal decisions.

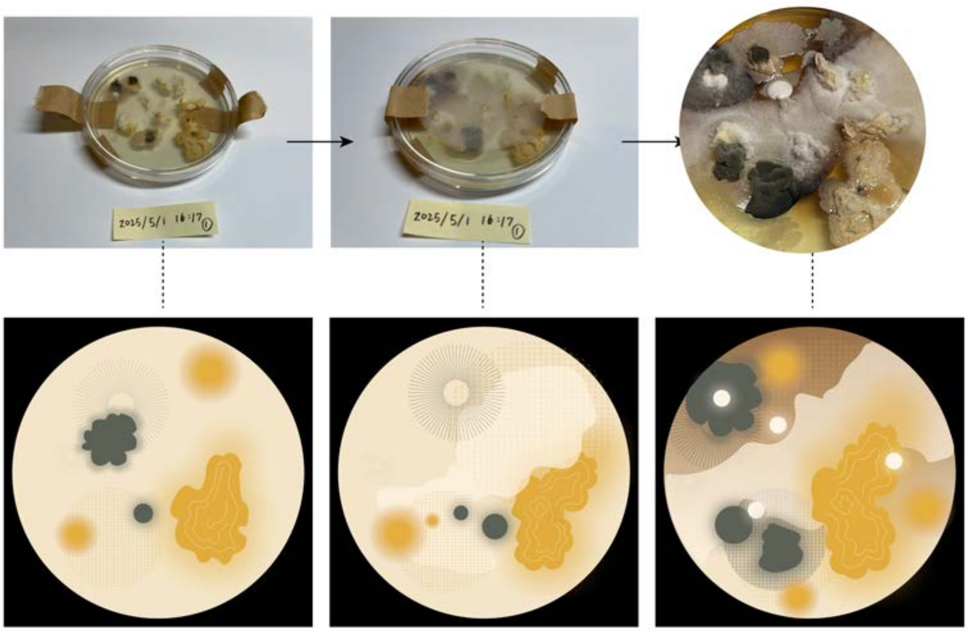

Figure 3.16 Digitalized microbial colony

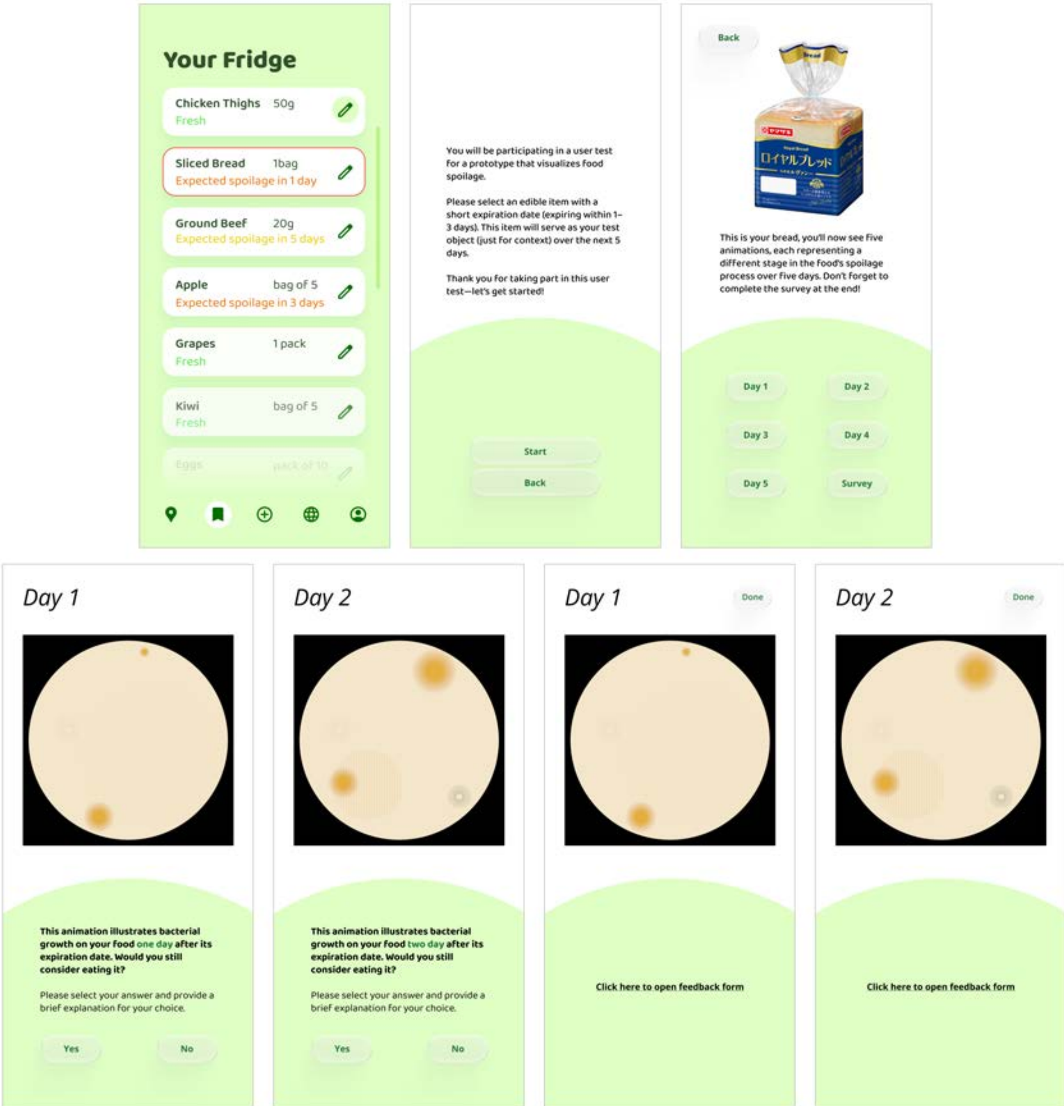

Figure 3.17 Microbial growth animation feature embedded in the Foodagram app for user testing(part 1)

Figure 3.18 Microbial growth animation feature embedded in the Foodagram app for user testing(part 2)

Chapter 4
Implementation and Evaluation

4.1. Methodology

The same participants from the Design 2 user test were invited to take part in a 5-day study exploring trust in alternative expiration labeling. At the beginning of the session, each participant will have their own fully edible bread or be asked to imagine a realistic food context, along with an explanation of a pre-set expiration date assigned for the user test. They will then receive a link to the prototype of the time-lapse animation, which is embedded in the "My Fridge page", designed to mirror the degradation process of the food item over time. Participants will be informed that the bread is safe to consume throughout the duration of the study and that the assigned expiration date is not indicative of actual spoilage, but is used for experimental consistency.

During the 5 days, participants will observe the bread in conjunction with the corresponding degradation animation. They will be asked to evaluate, daily, whether they believe the bread is still safe to eat, and to rate their level of trust in the visualization using a Likert scale from 1 to 5. In addition, they will be asked what their typical disposal behavior is after a certain day and whether the animation has changed their usual decision-making. At the end of the study, participants will submit written reflections on their experience, addressing how their perceptions may have changed over time, and comparing their initial impressions of the design with their post-workshop insights.

4.1.1 Testing Process

The user test flow is shown in the following:

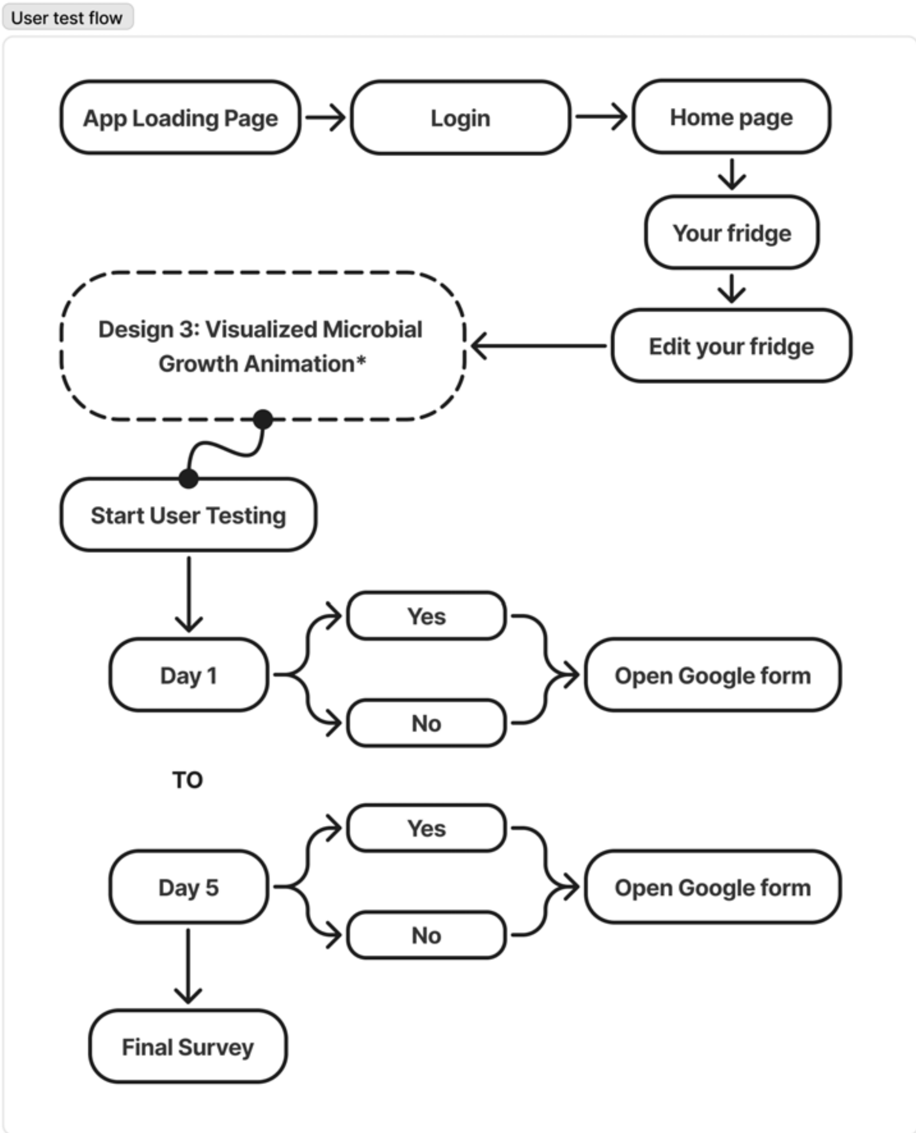

Figure 4.1 Design 3 user testing flow

4.2. Results and Evaluations

4.2.1 Quantitative Results

Based on the test results shown in Table 4.1, on Day 1, 8 participants voted that the food was still edible, and 3 reported that the visualization had altered their typical decision-making process. On Day 2, while 7 participants stated that their decision-making was influenced by the visualization, only 2 voted the food was edible, and 5 voted no. From Day 3 onward, microbial growth accelerated noticeably; as expected, all participants voted that the food was inedible, and 9 indicated that their perception had shifted compared to their usual judgment.

These results suggest that the visualization did have a measurable impact on participants' decision-making, especially in encouraging reassessment when the spoilage became more visually apparent.

Day	Total Responses	Yes Count	No Count	Edibility Rating (mean)	Altered typical decision making process
1	12	8	4	4.0	Yes: 3 / Maybe: 4 / No: 5
2	12	5	7	3.14	Yes: 7 / Maybe: 3 / No: 2
3	12	0	12	1.0	Yes: 9 / Maybe: 1 / No: 2
4	12	0	12	1.0	Yes: 7 / Maybe: 2 / No: 3
5	12	0	12	1.0	Yes: 8 / Maybe: 1 / No: 3

Table 4.1 Quantitative data gathered from the user test

The other results from the participant responses indicate generally positive perceptions of the visualized spoilage animation feature.

In the survey, the question "Does seeing the visualized bacterial growth make you feel safer?"participants rated 4.17 out of 5, suggesting that the animation contributed to a sense of reassurance by providing a visible and understandable cue of food decay.

In response to the question, "Do you find it informative to understand what is happening to the bread?", the average rating was 4.42 out of 5, indicating that most participants found the animation effective in communicating the biological process of spoilage.

However, when asked, "How trustworthy did the spoilage animation feel to you?", participants gave a slightly more moderate score of 4.92 out of 7. While still above average, this lower relative score suggests that despite the animation being informative and comforting, some participants may still question its accuracy or generalizability. The difference between how informative something appears and the level of trust it gives shows the challenges of fostering trust in visual tools that rely on speculation or data, especially in relation to food safety. Overall, the responses validate the animation's potential as a helpful resource, while also emphasizing the importance of transparency, the credibility of sources, and the context of the user in building trust.

4.2.2 Qualitative Results

A thematic analysis of participant feedback revealed three key factors influencing trust in the visualized spoilage animation: preference for real-time or real-food cues, the tension between scientific credibility and perceived authenticity, and the effect of visual style on perceived risk.

A key theme that emerged from the analysis was the strong preference for real-time or real-food cues when making disposal decisions. Many participants noted that while the animation was informative, they would still rely on visible mold or personal observation to determine whether food was safe to consume. Comments such as:

"I prefer to trust what I see on the real food."

"I would still make the decision... based on if there is visible mold on the bread"

"If it could show the bacteria of your actual bread that would be most trustworthy..."

Which highlight a tendency to prioritize direct sensory input over abstracted or generalized visualizations. This preference was reinforced by quantitative feedback, with 9 participants indicating that they found realistic visuals more trustworthy than stylized or simplified alternatives. These findings underscore the importance of immediacy and personal experience in building trust around food safety decisions.

The second theme focused on the tension between scientific credibility and perceived authenticity. Although the animation was based on empirical mold culture data, several participants questioned whether it could truly reflect the condition of their own food. One participant noted, *"Because there are different kinds of bread and I think how you initially stored it might impact how fast/ slow the bacteria grows?"*

Only 5 participants preferred scientifically framed explanations (e.g., "Mold has grown 1 cm"), suggesting that while science adds credibility, it may lack trustworthiness if it fails to feel personally relevant or specific. This theme highlights the need for trust-building strategies that combine data with contextual alignment.

The third theme involved how visual style influences perceived risk. While the animation was generally well-received, some participants noted that its soft or "cute" art style diminished its effectiveness as a warning tool. One participant stated,

"The art style is cute, which can be good, but doesn't feel like a warning of expiration."

"The animation is slow so it makes it look like safer than it should be."

Although 6 participants expressed a preference for simplified visual styles, the qualitative feedback revealed that aesthetic choices significantly shaped emotional responses and risk perception. If the visual design is too abstract or playful, it may inadvertently reduce the sense of urgency or seriousness associated with spoilage. This indicates that visual communication must carefully balance clarity, tone, and perceived severity to effectively influence user behavior.

Chapter 5
Discussion

5.1. Study Comparison

Based on the design studies throughout Chapter 3 and 4, it can be concluded that the findings from the research align with the cognitive studies discussed in the literature review, that visual productions are powerful cognitive tools shaping how people understand information. Previous research on food labeling has focused primarily on institutional information, such as expiration dates and third-party certifications, and most package designs with functionalities, both commercialized and in lab stage, more or less face limitations such as retailer oriented or difficult to mass-produce. In contrast, this study offers a novel perspective by examining the role of visual cues and emerging technologies in building consumer trust and reducing food waste at the household level.

The second phase of the research introduces an innovative design approach: a real-time visualization that simulates the degradation of an actual food item. By replacing static date labels with sensory-informed representations, the research explores how trust can be reconfigured through more embodied and intuitive forms of interaction.

5.2. Design Limitation

One major limitation of the study lies in its small sample size and short testing period. With only a limited number of participants engaged, the findings offer only a preliminary understanding of user responses to the design. This constrained timeframe does not allow for the observation of longer-term behavioral changes or shifts in trust and decision-making over time.

The microbial growth animation, though based on actual mold culture data, lacked photorealistic detail, which may have influenced its perceived trustworthiness. Several participants noted that the stylized or simplified visual style made the food appear safer than it actually might be, or did not resemble spoilage in a way they found convincing.

Another key limitation is that the design was based on simulations rather than real-world, functioning systems. The degradation timeline was modeled on controlled experiments and visualized as a general approximation, but no real-time data from sensors or actual spoilage processes were integrated into the user experience. Users might behave differently if the animation were tied to the specific food item in their home, reflecting its actual state rather than a generic timeline. Therefore, the study measures perception based on a speculative concept rather than an operational product, which affects the strength of conclusions about real-life usability.

The absence of technologies that provide real-time freshness data also constrained the realism and applicability of the prototype. The design and study did not account for the wide range of environmental and storage conditions that influence microbial growth. Factors such as temperature, humidity, and storage method can significantly affect the rate and appearance of spoilage. This limitation weakens the generalizability of the design across different household environments

Finally, the design reflects behavioral patterns common in urban, consumer-driven contexts where over-purchasing and food waste are prevalent. The concept assumes a level of technological access, app engagement, and disposability that may not apply to users in rural areas or cultures where food has strong values.

5.3. Future Work

As a next step, I am developing an interactive prototype using p5.js that allows users to explore microbial growth under varying conditions. This version introduces parametric controls, enabling users to input variables such as storage location, temperature, and number of days since expiration. By adjusting these parameters, users can observe how different environmental factors influence the spoilage progression across various food types.

In addition to expanded functionality, the updated prototype will feature improved visual design and be presented as a web-based experience rather than being embedded within the Foodagram app. The new visual will balance between scientific clarity and emotional resonance, and to better communicate the seriousness of spoilage while maintaining user engagement. This version is intended to serve both as a practical tool and as a communication piece for exhibitions or public engagement around food waste and sustainability.

To evaluate the long-term behavioral impact of the spoilage visualization tool, a follow-up study is planned to monitor actual food disposal practices in real households over an extended period. This study will use a pre–post testing design [31], combining both qualitative feedback and quantitative measures such as self-reported disposal logs and, where possible, direct measurement of household food waste. Participants will be asked to use the interactive prototype regularly, adjusting parameters such as storage conditions and food types to simulate spoilage. Their disposal decisions and perceptions of trust and risk will be tracked over several weeks or months to assess whether exposure to the animation fosters more mindful consumption or reduces unnecessary food waste. This longitudinal approach aims to determine whether the tool not only informs but reshapes daily food management habits, contributing to sustained behavioral change in line with sustainability goals.

Chapter 6
Conclusion

This thesis investigated how visual communication design can influence consumer trust and decision-making in the context of household food waste. It explored alternatives to conventional expiration labeling by developing and testing visual tools, including microbial growth animations and an interactive prototype, to support more informed and sustainable food disposal behaviors.

User studies revealed complex attitudes toward trust, risk, and credibility in spoilage-related visual cues. While participants found the animation feature informative, many expressed a preference for visual representations that closely resembled real food. This highlights the continued dominance of sensory-based judgment in food decisions and indicates the importance of visual realism in building trust. Additionally, the perceived tone and clarity of the animation played a key role in how users interpreted the level of food safety risk, suggesting that the aesthetic framing of visual information is critical in shaping behavioral outcomes.

Looking ahead, this research will be extended through the development of a web-based prototype that enables users to simulate spoilage progression across different food types, temperatures, and storage conditions. A future longitudinal study will assess whether such tools can influence household food waste behavior over time by combining interactive visualization with personalized tracking and data input.

Positioned within the broader challenge of over-consumption and habitual waste in consumer culture, the design offers a meaningful step toward re-framing everyday food practices within a sustainability-focused economy. While limitations remain, this research opens new directions for how design interventions can support both individual action and environmental responsibility through tools that are educational, engaging, and grounded in behavioral insight.

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Appendices

A. Preliminary Survey on Food Disposal

B. 18 Packaging Design Survey

C. User Test Instructions

Timestamp	Do you know the differences between "sell by date"	What types of food do you think you discard the mo	You bought French toast from Lawson but forgot to	You bought a cup noodle months ago but forgot to	When you have food in the refrigerator that has bee	What factors influence your decision to throw food	Do you check food for spoilage signs (smell, textur	How do you feel when you throw away food?	Would you be willing to use more methods or techr	Do you think more education on extending the life o
10/17/2024 12:53:11	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Processed food (s	1-2 Days	In a month	Put it back and deal with it next time	I don’t want to take any risks	Always	4	Yes	Yes
10/17/2024 12:58:11	Yes, but only basic knowledge	Processed food (snacks, seasoning, etc)	As long as it doesn't look bad, I'll eat it	Less than a week	Make it into something else (jam, sauce etc)	I am worried about food safety	Always	5	Yes	Yes
10/17/2024 13:04:02	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Processed food (s	1-2 Days	In a month	Put it back and deal with it next time	I don’t want to take any risks	Always	3	Maybe	Maybe
10/17/2024 13:06:44	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	As long as it doesn't look bad, I'll eat it	In a month	Cook and eat it	I don’t want to take any risks	Sometimes	2	Yes	Yes
10/17/2024 13:09:12	Yes, but only basic knowledge	Processed food (snacks, seasoning, etc), Food witl	2-3 Days	In a month	Immediately throw it away	I am worried about food safety	Always	2	Maybe	Yes
10/17/2024 13:14:33	I am very knowledgeable about it and understand h	Processed food (snacks, seasoning, etc), Food witl	A couple of hours to 1 Day	In a month	Immediately throw it away	I don’t want to take any risks	Sometimes	5	Yes	Yes
10/17/2024 13:29:37	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Grain produce (ric	2-3 Days	In a month	Cook and eat it	I am worried about food safety	Always	5	Maybe	Maybe
10/17/2024 13:31:49	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	1-2 Days	In a month	Immediately throw it away	prior knowledge or experience with the taste or foo	Sometimes	5	Yes	Yes
10/17/2024 13:40:06	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	1-2 Days	Less than a week	Immediately throw it away	I don’t want to take any risks	Sometimes	4	Yes	Yes
10/17/2024 13:52:01	I am very knowledgeable about it and understand h	Produce (meat, vegetables, etc), Food with short ex	As long as it doesn't look bad, I'll eat it	Less than a week	Put it back and deal with it next time	The expiration date has passed	Always	5	Yes	Yes
10/17/2024 13:54:08	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Frozen food	2-3 Days	I'll throw it away	Put it back and deal with it next time	I am worried about food safety	Always	2	Yes	Yes
10/17/2024 14:12:10	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	1-2 Days	3 months or longer	Cook and eat it	I don’t want to take any risks	Always	5	Maybe	Maybe
10/17/2024 14:19:27	Yes, but only basic knowledge	Processed food (snacks, seasoning, etc), Food witl	2-3 Days	In a month	Immediately throw it away	I don’t want to take any risks	Always	1	Maybe	No
10/17/2024 14:31:56	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Processed food (s	1-2 Days	I'll throw it away	Immediately throw it away	I am worried about food safety	Always	4	Maybe	Yes
10/17/2024 14:37:14	Yes, but only basic knowledge	Produce (meat, vegetables, etc)	As long as it doesn't look bad, I'll eat it	3 months or longer	Cook and eat it	Only if its moldy or tastes off do I usually throw aw	Always	5	Yes	Yes
10/17/2024 14:46:35	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Grain produce (ric	1-2 Days	Less than a week	Immediately throw it away	The expiration date has passed	Rarely	3	No	Maybe
10/17/2024 14:51:50	Yes, but only basic knowledge	Processed food (snacks, seasoning, etc), Food witl	As long as it doesn't look bad, I'll eat it	I'll throw it away	Immediately throw it away	I don’t want to take any risks	Always	5	Maybe	Yes
10/17/2024 15:01:03	No	Produce (meat, vegetables, etc), Grain produce (ric	I'll throw it away	In a month	Immediately throw it away	The expiration date has passed	Rarely	3	No	Maybe
10/17/2024 15:08:27	No	Frozen food, Food with short expiration date	I'll throw it away	1-2 Days	Immediately throw it away	I am worried about food safety	Always	5	Maybe	Yes
10/17/2024 15:19:36	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	2-3 Days	Less than a week	Put it back and deal with it next time	I am worried about food safety	Sometimes	5	Maybe	Yes
10/17/2024 15:28:45	Yes, but only basic knowledge	Grain produce (rice, bread, etc), Frozen food, Proce	1-2 Days	1-2 Days	Immediately throw it away	I am worried about food safety	Always	4	Maybe	Yes
10/17/2024 15:33:40	Yes, but only basic knowledge	Food with short expiration date	1-2 Days	In a month	Immediately throw it away	The expiration date has passed	Always	4	Maybe	Yes
10/17/2024 15:37:48	Yes, but only basic knowledge	Produce (meat, vegetables, etc), Food with short ex	1-2 Days	In a month	Put it back and deal with it next time	I am worried about food safety	Always	3	Yes	Yes
10/17/2024 16:01:31	No	Processed food (snacks, seasoning, etc)	1-2 Days	I'll throw it away	Immediately throw it away	I am worried about food safety	Sometimes	3	Maybe	Yes
10/17/2024 16:03:45	No	Produce (meat, vegetables, etc), Food with short ex	A couple of hours to 1 Day	Less than a week	Immediately throw it away	I don’t want to take any risks	Always	5	Maybe	Yes
10/17/2024 16:08:11	No	Produce (meat, vegetables, etc), Food with short ex	I'll throw it away	Less than a week	Immediately throw it away	I am worried about food safety	Sometimes	4	Yes	Yes
10/17/2024 16:47:11	Yes, but only basic knowledge	Processed food (snacks, seasoning, etc)	I'll throw it away	I'll throw it away	Immediately throw it away	I don’t want to take any risks	Always	1	No	No
10/17/2024 18:04:32	Yes, but only basic knowledge	Produce (meat, vegetables, etc)	2-3 Days	Less than a week	Immediately throw it away	I am worried about food safety	Sometimes	4	Yes	Yes
10/17/2024 18:12:37	Yes, but only basic knowledge	Frozen food, Food with long expiration date	1-2 Days	In a month	Cook and eat it	I am worried about food safety	Always	5	Maybe	Yes
10/17/2024 18:54:48	Yes, but only basic knowledge	Grain produce (rice, bread, etc), Frozen food, Food v	2-3 Days	3 months or longer	Make it into something else (jam, sauce etc)	I don’t want to take any risks	Always	5	Yes	Yes
10/17/2024 22:10:10	I am very knowledgeable about it and understand h	Food with short expiration date	As long as it doesn't look bad, I'll eat it	In a month	Cook and eat it	I am worried about food safety	Always	5	Maybe	Yes
10/18/2024 1:04:02	No	Produce (meat, vegetables, etc), Processed food (s	A couple of hours to 1 Day	Less than a week	Cook and eat it	I am worried about food safety	Always	2	Yes	Yes
10/18/2024 13:51:13	I am very knowledgeable about it and understand h	Produce (meat, vegetables, etc), Processed food (s	I'll throw it away	I'll throw it away	Immediately throw it away	The expiration date has passed	Never	2	Maybe	Maybe
10/18/2024 16:51:12	Yes, but only basic knowledge	Produce (meat, vegetables, etc)	1-2 Days	1-2 Days	Immediately throw it away	I don’t want to take any risks	Sometimes	1	Yes	Yes

Figure A.1 Preliminary survey on food disposal

Timestamp	A food packaging de	A small, visible sar	The packaging inflates	A time-temperature	The packaging r	As the food near	Packaging features emb	A displayed QR code links	The package includ
12/17/2024 12:29:49	6	4	3	3	6	1	7	6	5
12/17/2024 22:43:23	5	3	6	6	7	2	7	5	1
12/18/2024 18:35:23	4	6	2	3	5	5	5	6	5
12/18/2024 21:43:13	6	5	6	6	5	3	4	5	6
6/16/2025 14:56:37	5	6	6	5	6	3	6	3	6
6/16/2025 15:06:04	4	6	5	6	4	4	6	7	4
6/16/2025 15:14:41	5	3	6	5	6	4	6	4	3
6/16/2025 15:14:53	2	5	4	4	6	6	3	4	2
6/16/2025 15:16:44	6	7	6	4	3	3	2	3	2
6/16/2025 16:48:05	5	6	6	5	4	4	5	5	6
6/16/2025 17:48:55	2	3	4	3	2	2	3	5	3
6/16/2025 23:52:46	4	2	5	6	4	5	6	2	1
6/17/2025 8:04:09	2	7	5	6	4	4	7	5	4
	4.307692308	4.846153846	4.923076923	4.769230769	4.769230769	3.538461538	5.153846154	4.615384615	3.692307692
	1.493575988	1.675616993	1.320450584	1.23516842	1.423250163	1.391365314	1.675616993	1.386750491	1.84321347

Timestamp	The packaging contain	A food packaging c	A small, visible samp	The packaging inflate	Packaging features er	The package includes a	The packaging mater	A food packaging c	A displayed QR code
12/17/2024 12:29:49	1	6	6	5	7	3	4	4	6
12/17/2024 22:43:23	1	5	4	6	6	6	7	4	2
12/18/2024 18:35:23	5	3	5	3	5	3	3	3	5
12/18/2024 21:43:13	4	6	5	6	5	4	5	6	7
6/16/2025 14:56:37	3	6	6	5	6	5	5	5	4
6/16/2025 15:06:04	4	5	5	4	6	4	4	5	6
6/16/2025 15:14:41	4	2	6	5	4	2	4	3	4
6/16/2025 15:14:53	2	3	5	4	2	1	5	3	3
6/16/2025 15:16:44	3	5	6	3	3	2	2	5	3
6/16/2025 16:48:05	5	5	5	4	5	5	5	6	5
6/16/2025 17:48:55	2	2	4	2	3	3	3	3	5
6/16/2025 23:52:46	4	5	2	3	2	5	5	5	1
6/17/2025 8:04:09	5	3	6	4	6	4	5	2	4
	3.307692308	4.307692308	5	4.153846154	4.615384615	3.615384615	4.384615385	4.153846154	4.230769231
	1.436698495	1.493575988	1.154700538	1.214231845	1.660244035	1.445594545	1.260850344	1.28102523	1.690850188

Figure B.1 18 Packaging Design Survey

User Test Instructions

Thank you so much for participating in this user test.

Foodagram is an app designed to reduce household food waste by combining a **food organization system** with **social networking** and **gamified features**. As part of its spoilage prediction function, the app includes an **animated visualization of microbial growth**. This user test aims to examine how such visual information can influence consumer perception compared to their usual decision-making process.

The test is divided into two sections:

1. Foodagram App Prototype Testing

You will explore the current features and interface of the Foodagram app. Please note that some parts of the app are still under development and may not be fully interactive.

2. Visualized Food Spoilage Animation Testing

This section focuses on the inventory feature, where you'll view an animated representation of microbial growth from Day 1 to Day 5 after a food item's expiration date. The testing is located at Your Fridge —> Sliced Bread—>Start.

Each day, you will:

- Decide whether the food seems edible
- Complete a short Google Form survey

There are a total of 5 daily surveys, one for each day of spoilage. After completing these, you'll be asked to fill out one final overall survey.

Total surveys: 5 daily + 1 final (6 in total)

Thank you again for contributing to the development and refinement of this prototype. Your feedback is invaluable!

Figure C.1 User Test Instructions