Overpacked?

A case study on aseptic packed beverages

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Abstract

Introduction: The current Tetra Brik Aseptic packaging contains a polyethylene-aluminium layer that is difficult to recycle. Alternative materials have been explored to eliminate this aluminium layer, resulting in reduced carbon emissions but a 30% shorter shelf life. This trade-off raises concerns about potential increases in food waste due to reduced shelf life. Therefore, this study aims to explore the relationship between shelf life and food waste for long-life foods, contributing to a more optimal packaging design.

Method: The research was conducted through an exploratory case study on ultra-high-temperature treated plant-based beverages in aseptic packaging. The system boundary included the food manufacturer and retailer levels. Data was gathered through a literature review, database searches, and semi-structured interviews with supply chain representatives and retailers.

Results:

1. The current total shelf life requirement is 12 months, with the remaining shelf life set at 75% of the total. This is to allow flexibility for logistics and sales, and is based on historical precedents.
2. Insignificant amount of food waste was found due to expiry at both the food manufacturer and retail levels.
3. The 12-month total shelf life is not fully utilized, indicating overpacking. Understanding the necessary shelf life allows for appropriate use of packaging material that provides sufficient protection without increasing product waste.

Conclusion: Packaging design and materials should be selected to accommodate the necessary shelf life. Further research can be conducted to include consumer behaviour, further geographical areas, and a wider range of product categories.

Keywords: Shelf life, food waste, food packaging, sustainability

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Lund, May 2024,

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List of abbreviations

EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
LCA	Life Cycle Analysis
PPWR	Packaging and Packaging Waste Regulations
RGR	Returned Goods Ratio
RQ	Research Question
SDG	Sustainable Development Goals
UHT	Ultra High Treatment
UK	United Kingdom
US	United States

1 Introduction

This chapter provides the background, highlighting the main problems that motivated the purpose of the thesis. The research questions, scope, and boundary are presented.

1.1 Background

Food waste is a huge problem from an environmental, social and economical perspective. The Food and Agricultural Organization (FAO) reported that 1.3 billion tons of food produced for human consumption gets wasted (Gustavsson et al., 2011). When food is wasted, not only the food itself is lost but also all the resources used to produce, process, and distribute it. This includes energy, water, land, and labor, leading to increased environmental pressures and unnecessary emissions. Food waste contributes to approximately a third of all human-caused greenhouse gas (GHG) emissions (Crippa et al., 2021).

For a long time, food packaging has been used as a way to reduce food waste by prolonging the shelf life of food products (Marsh & Bugusu, 2007). However, there has been a growing concern over the environmental impact of food packaging in recent years. The United States Environmental Protection Agency (EPA, 2023) reported that approximately 292 million tons of municipal solid waste was produced in 2018 with food and packaging materials making up to almost half of the amount. This underlines the importance of developing packaging that strives for the balance between the environmental impact of the package itself and the impact stemming from food loss.

Additionally, with the emergence of European Union (EU) regulations aimed at promoting sustainable packaging, such as the Extended Producer Responsibility (EPR) schemes and Packaging and Packaging Waste Regulations (PPWR), food companies and packaging producers are compelled to act fast to make their packaging more sustainable.

As an example, Tetra Pak, a leading global enterprise in aseptic packaging technology, has a commitment to “making food safe and available everywhere while protecting the food, people and the planet” (Tetra Pak, n.d.). As part of its sustainable strategy, the company has developed an alternative composite material that produces lower carbon emissions for the Tetra Brik Aseptic packaging. The current Tetra Brik Aseptic composite material comprises layers of paperboard, aluminium and plastic (Zhang et al., 2014). The new packaging materials aim to remove the aluminium layer and replace them with polymer and paper respectively, resulting in a 25% reduction in carbon emission (Mustafina, 2023).

While the new packaging has a more positive direct environmental impact, it is also estimated to have a 30% reduction in shelf life, which can be assumed as a negative indirect environmental impact (Mustafina, 2023). There is a concern that this reduction in shelf life might cause an increase in food waste rates and defeat the purpose of creating a more sustainable packaging. An effective packaging design should balance shelf life, packaging material quantity, and food waste generation to achieve true sustainability.

This prompts questions: Does extending shelf life inevitably lead to reduced food waste? Is there an optimal shelf life beyond which further increase does not affect food waste rates? Are the long shelf life products currently on the shelf overpacked?

1.2 Project purpose and research questions

1.2.1 Purpose

The purpose of this study is to explore the relationship between shelf life and food waste, aiming to inform more optimal packaging design. This research is motivated by the aspiration to support United Nations Sustainable Development Goal (SDG) 12: Responsible Consumption and Production, with a particular focus on goals 12.2, 12.3 and 12.5 as summarized below (United Nations, n.d):

SDG 12.2: Sustainable management and efficient use of natural resources, emphasizing resource efficiency, waste reduction, and environmental sustainability.

SDG 12.3: Halve global food waste by addressing waste along production and supply chains and reducing per capita food waste at the retail and consumer levels.

SDG 12.5: Responsible waste management, advocating for waste reduction, recycling, and reuse to promote sustainable consumption and production practices.

1.2.2 Research questions

To accomplish the objectives of this thesis, the following research questions (RQs) were posed:

1. What are the shelf life requirements set by various stakeholders in the supply chain, and what are the rationales for these requirements?
2. How much food waste is found for long-life foods due to expiry?
3. How can optimal shelf life balance the environmental impact from packaging material and food waste?

1.3 Scope and boundary

This study focuses solely on food waste resulting from product expiration in the food manufacturer, and retail and distribution stages (Figure 1). The chosen category for evaluation is Ultra High Temperature (UHT) processed plant-based beverages packed in a beverage carton. The findings are based on case studies conducted in Europe, particularly in Sweden and the United Kingdom (U.K.). The optimal shelf life and packaging evaluation is guided by the balance between packaging material and environmental impact, referring to the Innventia AB model in Figure 4.

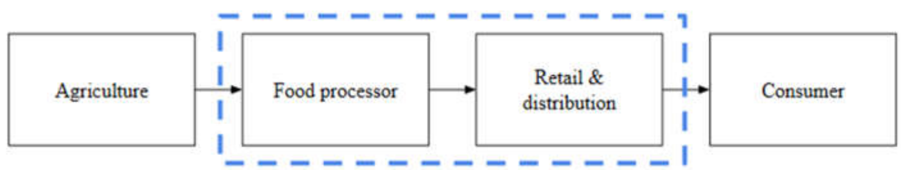

Figure 1 System boundary of this research from a general supply chain

1.4 Thesis structure

Following the Introduction (Chapter 1), where the background, project purpose, research questions, scope and boundaries are defined, the Theoretical framework (Chapter 2) is presented, covering topics including food packaging, the beverage carton, food waste and shelf life, to provide a basis for the rest of the paper. Here, research gaps are also addressed to guide the research questions. Following this, the Methodology (Chapter 3) is introduced based on secondary and primary research methods, gathering both qualitative and quantitative data to answer the research questions. The Results (Chapter 4) depict the findings of the research, which will then be further discussed in Discussions (Chapter 5), displaying the links between the results, using literature to support the findings, and discussing the role of the consumer. Finally. Conclusions, limitations and recommendations (Chapter 6) are extended at the end of the paper.

2 Theoretical framework

This chapter provides the theoretical basis for this research study and identifies gaps in current research that can further guide the study. It is divided into three main topics: Food Packaging; The Beverage Carton; and Food Waste and Shelf Life.

2.1 Food packaging

2.1.1 Role of food packaging

Food packaging is used to effectively contain food in a manner that meets industry standards and consumer preferences, while ensuring safety and reducing environmental harm. The roles can be categorised into its fundamental roles and secondary roles (Marsh & Bugusu, 2007). The three fundamental roles include protecting and preserving, containment and to provide nutritional and ingredient information to consumers. The secondary functions are to provide traceability, convenience and tamper indication.

Fundamental roles:

Protection and preservation: Food packaging helps to slow down product deterioration, prolong shelf life, and uphold food quality and safety. It does so by shielding the food from external chemical , biological and physical factors.

Containment and food waste reduction: Food packaging helps reduce waste by keeping food fresh longer. Without proper packaging, food often goes to waste due to inadequate preservation and storage.

Marketing and information: Packaging serves as the product's first impression for consumers and can significantly impact sales, particularly in competitive markets. It also offers consumers essential information, such as product identification, nutritional value, ingredients, weight, and manufacturer details.

Secondary roles:

Traceability: Traceability allows food to be followed from production to distribution. Manufacturers use codes on packaging to track products during distribution, in different formats like printed barcodes or electronic radio frequency identification (RFID).

Convenience: Convenience in food packaging include accessibility, handling, disposal, visibility, resealability, and microwavability. These convenient features not only simplify food preparation and serving but also impact product and packaging waste.

Tamper indication: Intentional tampering with food and pharmaceuticals has led to the development of special packaging features to minimize the risk of tampering and contamination. While no package is completely tamper-proof, tamper-evident features are difficult to replicate once breached.

2.1.2 Environmental impact of food packaging

The two ways to describe the environmental impacts of food packaging are direct and indirect impact. Direct impacts include the environmental effects of producing packaging materials and managing packaging waste. Indirect impacts involve product waste caused by packaging, as well as the logistical efficiencies (Pålsson, 2018).

Direct environmental concerns related to packaging have largely centered on packaging waste, driven by legislations like the Packaging and Packaging Waste Regulation (PPWR) and Extended Producer Responsibility (EPR) schemes in the EU. The PPWR mandates the prohibition of single-use plastics and ensures all packaging is recyclable or reusable (European Parliament, 2013). The EPR scheme assigns packaging sustainability responsibility to producers, covering product development to end-of-life collection and treatment (Naturvardsverket, 2023). These regulations aim to progress toward achieving carbon neutrality by 2050.

While it is crucial to address the direct environmental impact of packaging material and waste, the food waste attributable to packaging is frequently neglected but equally significant in packaging development (Heller et al., 2019; Wikström & Williams, 2010). Food packaging should aim to reduce both food and packaging waste, prioritizing the minimization of food waste, which has a larger environmental impact throughout the food packaging system's lifecycle (Hosse, 2021; Mustafina, 2023; Wikström & Williams, 2010). Achieving this balance requires optimizing the quantity of packaging used to reduce food waste, while considering the environmental impact from the development and waste management of the packaging material (Verghese et al., 2015).

The Innventia AB model, also known as the Sörås curve, plots the relationship between amount of packaging used and the environmental impact (Figure 2). It suggests that underpacking can lead to bigger environmental problems than using more packaging material to ensure product protection (The Consumer Goods Forum, 2011).

Figure 2 The Innventia AB model for optimum pack design (The Consumer Goods Forum, 2011)

To put it into context, Conte et al. (2015) compared the environmental impact of cheese packed in a multilayer packaging with modified atmosphere which extends shelf life, to a thinner, recyclable packaging that gives less shelf life. The results showed that the thicker packaging material that reduce the most food waste have a greater overall environmental benefit than the production and disposal of packaging materials. This is due to the high environmental impact of cheese production.

2.2 The beverage carton

Beverage cartons are used for a range of food products including juices, long-life milks, plant-based alternative products, sauces and so on. The term 'beverage carton' refers to a type of packaging primarily made from fiberboard, laminated with layers of plastic and often aluminium to prevent leaks and provide aseptic and enhanced barrier properties. Beverage cartons are lightweight, strong, and food-safe, offering extended shelf life for both ambient and chilled products. Their simple, block shape also allows for efficient storage and transportation (Zero Waste Europe, 2020).

2.2.1 Aseptic packaging technology

Aseptic processing and packaging is widely used across the globe in the food and beverage industry due to its reputation for safety and long shelf life. Aseptic processing entails sterilizing the product, using methods such as Ultra High Temperature (UHT) treatment while aseptic packaging involves packing products in a sterile container such as a beverage carton or pouch, under sterile conditions (Sanajan et al., 2019).

Aseptic packaging keeps food products from quality-reducing factors such as water vapour, oxygen and microbial contamination, hence preserving its colour, flavour, and nutritional value. It is important for the packaging material to have good barrier properties to both conserve the quality of the food, and protect the product from damages caused by physical handling and distribution (Sanajan et al, 2019). To achieve this, the packaging material typically consists of multiple layers (Zhang et al, 2009). This method was commercialized in 1961 by Tetra Pak Company to give milk a long shelf life without using conservatives or refrigeration (Sanajan et al., 2019).

2.2.2 Laminated paperboard aseptic packaging

The aseptic packaging utilizes multiple layers composed of three materials: paper, plastic and aluminium distributed in layers as seen in Figure 3.

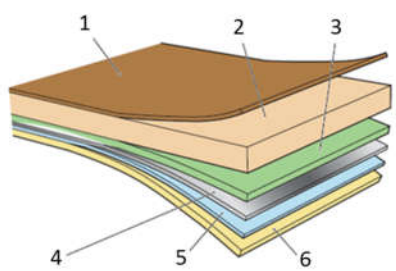

Figure 3 The structure of laminated paperboard for aseptic packaging (Bolzon et al., 2015)

The structures and function can be summarized as (Bolzon et al., 2015; Mustafina, 2023):

(1) External polyethylene layer helps protect against outside moisture
(2) Paperboard provides mechanical rigidity and allows printing
(3) Polyethylene lamination layer acts as a binder between aluminium foil and paperboard

(4) Aluminium layer is a barrier for oxygen, flavor and light
(5) Polyethylene adhesive layer to act as a barrier between aluminium foil and the internal plastic layer
(6) Polyethylene internal layer to provide a liquid barrier and enable sealing

The aluminium layer serves an important function by acting as an impermeable shield, protecting the product against oxygen, light, and microorganisms, thus ensuring its safety over an extended duration whilst being kept in an ambient environment. It is known to be the lightest 'complete barrier' and is infinitely recyclable (Askew, 2022). Despite its thinness, this layer is made from a non-renewable material, requiring intricate and energy-intensive processes for its production. It accounts for one-third of the greenhouse gas emissions connected to the base materials (Askew, 2022; Connolly, 2022).

Furthermore, the polymer/aluminium layer, also known as 'PolyAl', has been known to be difficult to recycle. Previously, the challenge in separating the adhesive polymers from the aluminium layer had caused the PolyAl layer to be non-recyclable and disposed via incineration (Plasteurope, 2024; Zero Waste Europe, 2020). However, since 2021, multiple investments have been made on PolyAl recycling projects across Europe to separate the layers and recycle into other products such as logistics, packaging, storage, and gardening equipment (Plasteurope, 2024; Tetra Pak, 2024).

According to the EU Waste Framework Directive (Directive 2008/98), preventing waste is still the preferred option, hence, ongoing development was found to omit this aluminium layer. Mustafina (2023) investigated two alternative structures for their environmental impact - one polymer-based and the other paper-based. The study revealed that both alternatives generated 25% fewer carbon emissions than the aluminium-based material. However, it came with a trade-off of 30% reduction in shelf life.

2.3 Food waste and shelf life

2.3.1 Food loss and waste

Food losses and waste is described as food initially intended for human consumption that exists in the human food chain, whether it is repurposed for non-food uses or not. Food losses occur in the production, post-harvest, and processing stages of the supply chain, leading to reduced edible food mass for human consumption. In contrast, food waste happens at the retail and consumption stages and is linked to retailer and consumer behaviors (Parfitt et al., 2010). Food loss and waste can occur in any part of the supply chain. Food losses are more prominent in lower income countries whereas food wastes occur predominantly in more developed countries (Gustavsson et al., 2011). For this study, the focus will be on food waste that occurs in the retail and distributor stage.

2.3.2 Food waste in retail and distribution

Despite the retail stage of the supply chain having relatively less waste compared to other stages, the volumes are still substantial. Around 70,000 tons are wasted annually in Sweden, and in the EU-27, the figure reaches approximately 4.4 million tons per year (Eriksson, 2015).

Between 2010 and 2014, a combined total of 2.4 kilotons of food waste was documented across the six chosen supermarkets in the five departments under scrutiny. The largest portion, comprising 84% (2.0 kilotons), was observed in the fresh fruit and vegetables department due to rejection on delivery (Eriksson, 2015).

The causes of food waste can be categorized in two management related categories. The first aspect pertained to supply matters, encompassing elements such as forecasting, planning, management of promotions, as well as availability and inventory control. The second aspect focused on the quality of both the product and the process, particularly in terms of product specifications, process monitoring, managing shelf life, and the aspects of packaging and labeling (Mena et al., 2014).

2.3.3 Shelf life

To put it simply, shelf life is the duration a product remains usable while on a shelf. Throughout its journey in the manufacturing and supply chain, a product will sit on various shelves: in the food processing facility, in warehouses, in retail stores, and finally, in consumers' homes.

For the context of this thesis, the 'total shelf life' refers to the period following production, and sometimes after maturing and aging, along with packaging, during which a food product maintains specified quality attributes under certain storage conditions. This quality level is what makes the product suitable for consumption. (Nicoli, 2012). From a supply chain perspective, the term 'remaining shelf life' is often used to describe the time until expiration as a percentage of the total shelf life (Akkas & Honhon, 2023).

Under the EU regulation (Regulation 1169/2011), food must be labeled with either a 'best before' or 'use by' date to indicate its minimum durability. The 'best before' date signifies the period of optimal quality for foods when stored properly and unopened. It applies mainly to canned, dried, ambient, and frozen foods. While safe to eat, foods beyond this date may have reduced quality. For highly perishable foods posing immediate health risks, the 'use by' date is used. It indicates the last date for safe consumption, cooking, or processing after proper storage. After this date, Regulation EC No. 178/2002 states that such foods cannot be sold. This applies mainly to fresh, ready-to-eat, and chilled foods like yogurt, milk, meat, and unpasteurized fruit juices.

2.3.4 Relationship between shelf life and food waste

A longer shelf life for food products is typically desired as it helps with the problem of food waste and provides economic benefits. Nilsson and Silva (2023) summarized numerous studies that showed increasing the shelf life of a food product reduces the probability of food wastage. For example, Settier-Ramirez et al. (2022) found that by extending the shelf life of their pastry cream by using an improved packaging, resulted in a 47% decrease in food waste. In a study by Eriksson et al. (2016), a food waste reduction potential of 34% for juice and milk was achieved by extending the shelf life through lowering the storage temperature. Falcone (2017) estimates that by extending the shelf life of mozzarella cheese by 50% could lead to 50% reduction in unsold products.

Present studies show that most data were collected from products with up to 30 days shelf life (Settier-Ramirez et al., 2022; Eriksson et al., 2016; Falcone, 2017). Few studies were done on long-life products. Notably, Spada et al. (2018) found an inverse relationship between the rate of product returns from the market due to expiry, and their shelf life, using data from products with a shelf life exceeding 30 days (Figure 4). This study observed a decrease in product returns due to expiry for products with a shelf life of over 50 days. While the study proves that a longer shelf life does reduce food waste, there are a few limitations. Firstly, it did not provide a comprehensive view of food waste, as it only considered products returned to the manufacturer by retailers, excluding those discarded directly. Second, it did not take into account of the environmental impact caused by packaging.

Long shelf life triggers behavior that influences economic efficiencies in the supply chain. Some companies may attempt to capture economies of scale for lower-demand products by producing large batches infrequently, while others may opt for cheaper transportation methods, which can lead to longer travel distances and increased product handling (Amani & Gadde, 2015; Mena et al., 2011). The studies by Amani & Gadde (2015) and Mena et al. (2011) showed that prioritizing service efficiency over waste can result in high stock levels, potentially leading to unsold products being wasted. However, these studies did not specify the shelf life threshold of the products that influenced these conclusions.

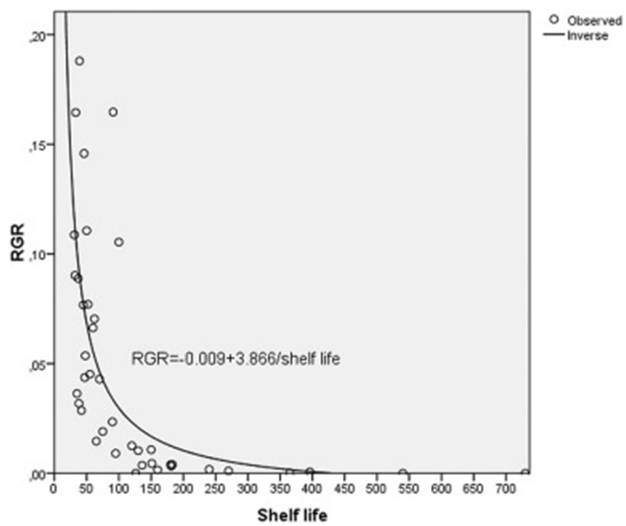

Figure 4 Inverse plot of Returned Goods Ratio (RGR) against shelf life (Spada et al., 2018)

Therefore, this demonstrates that while there are economic efficiencies to gain from these companies, the environmental impact directly from food waste should also be considered.

Referring to the Innventia AB model in Figure 2, to achieve an optimum between the amount of packaging material and environmental impact (food waste), the shelf life of the product provided by the packaging is crucial to balance the two aspects. There is a clear correlation between extended shelf life and improved protective packaging solutions, but there might be an optimum shelf life before more packaging material outweighs the environmental benefits of food waste. This study will fill the gap in research where the optimum shelf life is explored for long-life food products, where further increase in shelf life does not necessarily reduce food waste any further.

3 Methodology

This chapter explains the research approach, data collection methods used, and research quality, to complete this research.

3.1 Research approach and design

Due to the limited research on the relationship between shelf life and food waste for long-life products, and the interdisciplinary and complex nature of the topic, this study has adopted an exploratory approach using a case study design.

The research design consists of five components (Yin, 2009):

1. Overall research question
2. Research proposition
3. Case description
4. Logic linking of data to the propositions
5. Criteria for interpreting the findings

The overall purpose and research proposition framed as research questions have been defined in section 1.2.

The product selected to be studied in the case are UHT processed plant-based beverages, packed in laminated paperboard aseptic packaging. This includes the different actors in the supply chain that manage the product, such as food manufacturers and retailers/ retail distributers.

Logical linking of data to the propositions represents the data analysis phase in the case study methodology (Yin, 2009), as illustrated in Figure 5 using the format proposed by Hosse (2021). First, the shelf life requirements and the reasons behind them for UHT plant-based beverages were gathered through qualitative and quantitative insights from various supply chain actors: packaging producers, food manufacturers, and retail management. Second, to determine if food waste is a significant issue for this product category, food manufacturers and retail stores were surveyed on the amount of food waste occurring due to expiry. Finally, the total and remaining shelf life, along with food waste rates, were plotted on a supply chain map to determine the optimal shelf life for UHT plant-based beverages.

An optimal shelf life can be proposed based on the data collected on the relationship between shelf life requirements and food waste occurrence. This study also explores the link between packaging design and environmental impact in relation to shelf life.

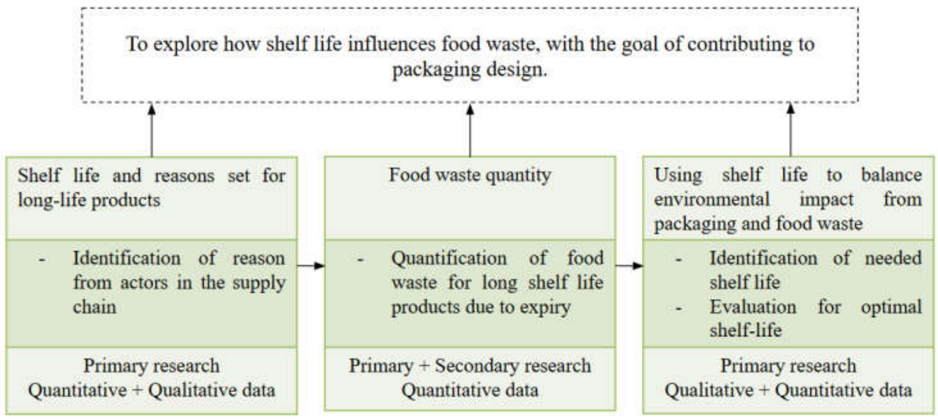

Figure 5 Linking data to study propositions

3.2 Product selection

This section explains the rationale for choosing UHT plant-based beverages as a product case. A UHT beverage was selected because it achieves extended shelf life through processing and packaging rather than product formulation, allowing the study to focus on the impact of packaging on shelf life and food waste. Plant-based beverages were chosen due to their increasing popularity and environmental sustainability compared to conventional cow's milk (Grant & Hicks, 2018). The aim is to contribute to the packaging design of an already environmentally sustainable alternative. Furthermore, the current studies have significant gaps on the relationship between shelf life and food waste for plant-based beverages.

3.3 Data collection and analysis

To achieve the objectives of this thesis, a combination of qualitative and quantitative data were gathered using both secondary and primary data collection methods.

Literature review and database searches were used for secondary data. Whereas for primary data, semi-structured interviews were conducted.

3.3.1 Literature review

A comprehensive literature review was conducted on the relationship between shelf life, food waste and food packaging at the beginning and during the research. A funnel approach was employed, starting with a broad overview of the topics to understand the concepts of food packaging, aseptic packaging, food waste, and long-life products (Newcastle University, n.d.). A theoretical basis was established and gaps in current research were identified to further frame the study. As the review progressed, more specific keywords were used to delve into the subject of packed beverages, particularly plant-based beverages. Additionally, various tools were explored to find a suitable framework for analyzing the data collected in Section 4. The literature review later supplemented information for the research questions posed. The key words used can be seen in Table 1.

Google Scholar and LUBsearch were used to gather published articles. The contents of the relevant papers were skimmed through to identify pertinent data. Forward and backward reference searches were conducted to uncover further relevant literature.

Table 1 List of keywords used for literature review

Topic	***Keywords***
General overview of the topic	Food packaging, aseptic packaging, food waste, long-life products
RQ 1: Shelf life requirements and reasons	Shelf life requirements, shelf life regulation, maximum shelf life
RQ 2: Food waste quantity for long-life beverage	Food waste ambient milk, plant based milk/beverage, oat/soy/coconut/almond milk LCAs
RQ 3: Optimal shelf life/packaging	Optimal shelf life/packaging framework, optimal shelf life/packaging for ambient milk

3.3.2 Semi-structured interviews

Conducting semi-structured interviews was selected as a data collection method due to its low barrier access to gain insights from the interviewees. They offer flexibility, allowing for pre-planned questions while also enabling adjustments based on the flow of conversation. This approach fosters candid exchanges, facilitating the exploration of diverse perspectives and the thorough examination of complex issues (Naz et al., 2022).

The semi-structured interviews were divided into two groups summarized in Table 2 for easy categorization. Group A included various supply chain representatives from packaging producer to retail organization at management levels with the aim of gaining in-depth information on why a certain shelf life is set for UHT plant-based beverages, food waste rates at each supply chain level, and the time taken for stock to move through the supply chain. Group B consisted of retail store staff with the aim of gathering quantitative data from real-life scenarios on food waste due to expiry in the UHT beverage category, as well as information on replenishment, order strategies, and turnover rates.

Table 2 Division of interview groups and purposes

Group	*Description*	*Number of interviewees*	*Purpose*
A	Supply chain representatives from packaging producer, food manufacturer and retailer at management levels	4	To understand the shelf life requirements and rationale, food waste rates, and the time taken for stock to move through the supply chain.
B	Retail staff including store managers, supervisors and floor staff	11	To obtain quantitative data on food waste due to expiry in retail, replenishment and order

For Group A, four representatives agreed to participate in the interviews. The online interviews were conducted via Microsoft Teams or Google Meet, while the in-person interviews took place at Lund University. The interviews lasted 30 minutes to an hour. Appendix A contains the set of guiding questions used during the interviews. A summary of the stakeholders interviewed is provided in Table 3.

Subsequently, the interviews were transcribed and analyzed using the Nvivo software. The quantitative data was extracted to address shelf life requirements, food waste rates, and time taken for stock to move through the supply chain. Following the steps shared by Adu (2019), the qualitative data was coded to develop relevant themes to answer the question regarding the rationale behind setting specific shelf life requirements.

Table 3 Details of actors that participated in the semi-structured interviews

Supply chain actor	***Name***	***Position***	***Date***
Packaging producer: Tetra Pak	Cena, A.	Global accounts manager for Danone	15/04/24
	Henriksson, L.	Early innovation leader	24/05/24
Food manufacturer: Sproud	Göransson, M.	Sustainability and Quality Manager	05/02/24
Retailer: British multinational retailer	P.E.	Lead packaging manager	15/04/24

For Group B, empirical data was gathered from 11 retail stores whose representatives agreed to the interviews. Quantitative insights were derived from responses given by floor staff, store supervisors, and managers, drawing from their speculation and experience. The guide for these interviews with retail staff is provided in Appendix B. The list of stores, location and personnel interviewed can be seen in Table 4.

Table 4 Details of stores surveyed

Retail store	***Location***	***Person interviewed***
COOP	Lomma, Sweden	Category manager
ICA Kvantum Malmborg	Lund, Sweden	Floor staff
ICA Kvantum Mobilia	Lund, Sweden	Floor staff
ICA Supermarket	Lund, Sweden	Floor staff in charge of ambient milk category
ICA Supermarket	Lomma, Sweden	Supervisor
Lidl	Bexleyheath, U.K.	Second manager
Lidl	Lund, Sweden	Store manager
Sainsbury	Bexleyheath, U.K.	Store manager
Willys	Lund, Sweden	Floor staff in charge of ambient milk category
Willys	Lomma, Sweden	Supervisor
Willys Hemma	Lund, Sweden	Supervisor

3.4 Research quality

Ensuring the quality of research is crucial for obtaining reliable and valid results. This section outlines the steps taken to maintain the validity and reliability of the study, along with addressing potential limitations.

To ensure validity, data was gathered from multiple sources to achieve a holistic view of the research topic. Data was collected from a combination of literature review and interviews to explore RQs 1 and 2. The interview results were reviewed by the interviewees to ensure the information conveyed is accurate.

Reliability was enhanced by following the case study protocol outlined by Yin (2009). The semi-structured interviews adhered to the objectives stated in the interview guides in Appendix A and B. Interviews from Group A were recorded and transcribed to maintain accuracy, while interviews from Group B were recorded in note form during and immediately after the sessions, since they were shorter. Informed consent was obtained from all interview participants.

Maintaining the relevance and comprehensiveness of the literature review was a continuous process. Regular dialogues with supervisors played a crucial role in keeping the research focused. These discussions also provided valuable guidance on exploring new pathways for literature by using different terms and methodologies.

While the findings provide insights into the shelf life and food waste of UHT plant-based beverages in Sweden and the U.K., they are not intended for generalization to other regions or product categories.

Several limitations should also be noted and will be discussed in chapter 6.

By implementing these measures, the research aim to ensure high standards of validity, reliability, and ethical considerations, providing a robust foundation for understanding the relationship between shelf life and food waste in UHT plant-based beverages.

4 Results

This chapter presents the findings of the research. It is presented in three main sections based on the research questions developed. The first part consists of the findings on shelf life requirement and rationale set by the industry; the second part presents the findings on food waste quantity due to expiry in long-life foods; and the third part assesses the balance of environmental impact through food waste and optimal shelf life.

4.1 Shelf life requirement and rationale

To answer RQ1: What are the shelf life requirements set by various stakeholders in the supply chain, and what are the rationales for these requirements, observations in retail settings and insights from plant-based beverage manufacturers like Danone, Sproud, and Oatly were obtained.

Interviews conducted with representatives from various levels of the supply chain offered a multi-perspective understanding around the meaning of shelf life, the requirements for UHT plant-based beverages, and the rationale behind setting these standards. It is found that UHT plant-based beverages typically have a minimum total shelf life of 12 months (Cena, interview, 2024; Göransson, interview, 2024; Oatly, n.d.).

All interviewees concurred that shelf-life represents the maximum duration a food product can maintain its quality before consumption. The criteria for defining "good quality" are internally determined by the company. For a food manufacturer like Sproud, shelf life refers to the duration during which the product maintains its intended quality (Göransson, interview, 2024), aligning with Nicoli's (2012) definition. Sproud ensures that all their products are designed to maintain quality for at least 12 months. However, exceeding this timeframe does not necessarily render the product unsafe for consumption; instead, indicators like sedimentation may signal a decline in quality. Göransson (interview, 2024) also noted that retailers hold influence by specifying the required shelf life for products. To remain competitive, companies should align their product's shelf life with that of other products in the same category.

From a commercial standpoint, shelf life can serve as a bargaining chip within the supply chain (Cena, interview, 2024; P. E, interview 2024). In the EU, there are no known regulations regarding the minimum shelf life required for UHT beverages. However, the USDA Commercial Item Description for Plant-Based Non-Dairy Beverages (2023) mandates a minimum shelf life of six months. The establishment of remaining shelf life (as explained in Section 2.3.3) rules varies across supply chain partners and countries, with Swedish retailers requiring 75% remaining shelf life (Göransson, interview, 2024). Some European distributors may follow the "one-third-one third-one-third rule," ensuring that a product spends equal thirds of its shelf life at the manufacturer, distribution center, and retail store, respectively (Akkas & Honhon, 2023; Santos et al., 2022). In this situation, an extended shelf life can provide greater flexibility and convenience for each stakeholder in the supply chain, particularly retailers, allowing more time for product sales (P. E, interview, 2024).

When asked about how retailers set their shelf life requirements, P.E from a multinational British retailer (interview, 2024) suggested that historical precedents play a role. These practices have been maintained over the years, although modern trade has significantly reduced the time taken for products to travel from food manufacturers to retailers (Henriksson, interview, 2024). Another factor to consider is the presumption about consumer behavior, where consumers are believed to demand UHT beverages with very long shelf lives for stockpiling purposes, prompting retailers to supply products that meet this expectation (P. E, interview, 2024).

The key reasons for setting shelf life for food manufacturers and retailers are illustrated in Figure 6.

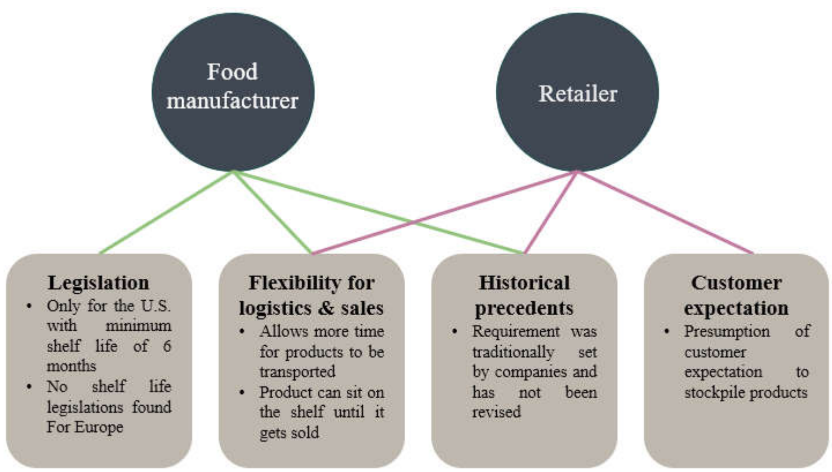

Figure 6 Rationale for setting shelf life from food manufacturer and retailer's perspective

4.2 Food waste quantity due to expiry

To answer RQ2: How much food waste is found for long-life foods due to expiry, data was collected through database searches and interviews with one food manufacturer and several retail stores.

A significant portion of research on food waste in retail primarily concentrates on perishable items like fruits, vegetables, dairy products, meat, and bread. Cicatiello's (2017) analysis of 16 papers related to food waste in retail revealed that only five of them included non-perishable categories.

While some data exists on the quantity of food waste for long-life products, and some studies have investigated food waste resulting from product expiry, none have specifically focused on food waste from the expiry of long-life products. The waste rates and reasons of food products with long shelf life obtained from secondary research is tabulated in Table 5. The reasons for this food waste include packaging damage, inaccurate promotional forecast, and rarely, approaching end of shelf life.

Table 5 Long-life food waste from previous studies

Food item	*Food waste rate (%)*	*Shelf-life*	*Reason*	*Source*
Oil	<7	12-18 months	Fragile packaging	Mena et al., 2011
Frozen food	<1	>6 months	Inaccurate promotional forecast packaging/product damage	Mena et al., 2011
Canned products	<7	>12 months	Packaging defects Sometimes but rarely approaching end of shelf-life	Cicatiello, 2017
Dry rice, pasta	<5	>12 months	Packaging defects Sometimes but rarely approaching end of shelf-life	Cicatiello, 2017

Given the sensitive nature of food waste data, the information collected relied on verbal surveys conducted with retail staff, drawing from their speculation and experience within the category. Across the 11 stores surveyed, the level of food waste experienced is below 0.5%. The primary reason for UHT beverage waste was attributed to packaging damage. Almost no product was wasted due to expiry, indicating that product hardly surpass its 'best by' date and become unsellable.

Food waste at the wholesale level due to expiry was also explored with the case of Sproud. Göransson (interview, 2024) shared that product returns from customers were less than 0.1%, primarily due to pallet or packaging damage, with no returns due to expired products. Sproud typically puts products on promotion when there is between six and one month of remaining shelf life, which occurs only a few times a year and represents a negligible amount for the business.

In summary, food waste due to expiry for UHT beverages is insignificant and has not been an area of concern.

4.3 Balancing environmental impact from packaging and food waste through optimal shelf life

To answer RQ3: How can optimal shelf life balance the environmental impact from packaging material and food waste, information was gathered from supply chain actors on the time stock takes to move between stakeholders and the duration it stays at each stage. The information is combined with the amount of food waste generated due to expiry to suggest an optimal shelf life.

After manufacturing, the products are transferred to central distribution and/or retail distribution centers before arriving at retail stores. The duration spent in central and retail distribution centers varies, depending upon factors such as demand rate and logistical considerations. Nonetheless, the product typically reaches retail stores within one month (Cena, interview, 2024; Göransson, interview, 2024). Cena (2024) further elaborated that a buffer period of three months is allocated for potential supply chain disruptions.

On the retail level, analysis of replenishment and turnover data from retail stores provided insights into the retail shelf life of UHT beverages. The findings indicate a consistent pattern of replenishment and rotation, with products promptly restocked upon delivery, aligning with order receiving days. Many stores utilize automatic ordering systems, placing orders based on the previous week's sales data. This system helps to reduce holding inventory at the retailers and do away with backrooms, as backrooms were found to cause poor replenishment processes (Bixler & Honhon, 2021; Myers et al., 2000).

The replenishment rate ranges from daily to monthly intervals depending on demand, as detailed in Table 6. which highlights the short retail shelf life of these products. Turnover rate was obtained from three stores. During the interview with Cena (2024), it was noted that products failing to rotate on shelves within six months are considered unsuccessful and may face discontinuation.

Table 6 Turnover and replenishment rate data obtained from retail stores

Retail store	***Location***	***Replenishment rate (times per week)***	***Turnover rate (cartons per week)***
COOP	Lomma, Sweden	1	
ICA Kvantum Malmborg	Lund, Sweden	2	High volume: Family pack: 200 Portion pack: 60 Low volume: Family pack: 2 Portion pack: 4
ICA Kvantum Mobilia	Lund, Sweden	1	
ICA Supermarket	Lund, Sweden	3	Low volume: Family pack: 2 Portion pack: 2 Low volume product can take up to 60 days
ICA Supermarket	Lomma, Sweden	1	
Lidl	Bexleyheath, U.K.	7	
Lidl	Lund, Sweden	1	
Sainsbury	Bexleyheath, U.K.	3	
Willys	Lund, Sweden	7	
Willys	Lomma, Sweden	0.5	
Willys Hemma	Lund, Sweden	1	

Based on the data provided, the information is plotted into a supply chain map as shown in Figure 7. The total shelf life starts with 12 months upon manufacturing. While it typically takes one month for products to arrive at retail stores, the worst case scenario was accounted for hence three months is designated to the timeline. Consequently, the product remains on the retail shelf for nine months to be sold. In the case of ICA Supermarket, a slow moving product has a turnover rate of up to 60 days (round off to two months), leaving an additional seven months of shelf life to be used by the consumer.

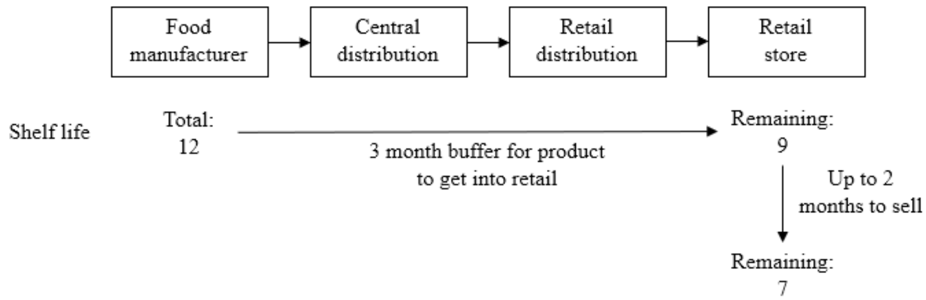

Figure 7 Supply chain map with remaining shelf life

As the scope of this research does not cover the consumer level, and there is currently no found studies on how long consumers store their UHT beverages before consuming, this study will assume a three months storage time at consumers' homes before consumption. This assumption is based off Oatly's two-month total shelf life of a refrigerated plant-based milk, with an additional buffer of a month. (Oatly, n.d.).

This assumption leaves a four month gap of shelf life that remains unused. Based on this, the shelf life required by a UHT plant-based milk is nine months, while still experiencing no food waste due to expiry. If the required shelf life is nine months, there is a potential that adding more packaging material that provides extended shelf life can result in hitting a tipping point that goes the other way around as being overpacked.

Hence, an optimal shelf life could be used as an indicator to balance the negative impact from food waste and packaging. The implications of different consumer behaviours are further discussed in section 5.2.

5 Discussion

This chapter discusses the results presented in chapter 4.

5.1 Redefining the optimal shelf life

Results revealed the required shelf life today for UHT plant-based beverages is set to be 12 months. Flexibility is the most frequently mentioned reason by interviewees which is aligned with what was found in literature (Parfitt et al., 2016; Njoman, 2021; Santos et al., 2022). The most valuable insight is that flexibility is presumed necessary due to long supply chain durations or consumer needs. This required shelf life, historically established, needs critical reassessment as it has been largely overlooked, driven by results in section 4.3, which suggests that the required shelf life is nine months.

This finding underpins the proposal put forward by Akkas & Honhon (2023), which advocates for a re-evaluation of industry practices. It emphasizes the importance of considering factors such as product demand, logistical timelines, waste quantity, and consumer behaviour when establishing the minimum remaining shelf life for products.

There is very limited quantitative data on food waste due to expiry found from secondary research, especially for specific long shelf life foods. This may stem from the higher waste rates associated with perishable items compared to non-perishables, hence, the non-perishable category receives less attention. The empirical data, however, indicates consistent responses of low waste rates, from both independent sources, namely the food manufacturer and retail stores. The low waste rate found can be attributed to the product's sufficiently long shelf life, ensuring that it is typically sold well before reaching its expiration. Although such occurrences are rare, retailers have ample time to initiate promotions as the product nears its 'best by' date. These rare situations typically arise from order errors leading to oversupply, from products falling behind shelves, or being misplaced by customers in less frequently rotated areas of the store.

The study fits the findings that a long shelf life product does indeed result in very low food waste, at least up until the retail level, as indicated by Spada et al. (2018)'s inverse model (mentioned in section 2.3.4). However, it becomes more complicated when it comes to balancing the negative impact from the packaging that provides the extended shelf life.

5.2 Role of the consumer

While the scope of this thesis focuses only up to the retail level, it is clear that understanding the full picture of how shelf life is utilized requires studying the role of the consumer. Consumers influence shelf life through their purchasing decisions and impact food waste through their consumption behavior. However, understanding consumers is challenging due to the many aspects that affect their influence on shelf life and food waste.

Purchasing decision influencing shelf life can be illustrated between two examples. First, consumers decide between regular purchases consumed within a shorter period and emergency purchases consumed within a longer period. Emergency purchases are intended to be used during crises that cause food shortages like the recent COVID-19 pandemic (Amaral et al., 2022; Ahmadi et al., 2022). To address the different requirements of shelf life and to adhere to the PPWR, potentially different packaging materials providing different shelf lives can be used. For example, portion packs could benefit from the new packaging as it is more likely to be purchased for regular consumption.

Second, consumers could be influenced to stockpile products when they are on promotion, especially long-life products because they have the flexibility to store it before the quality deteriorates.

On the other hand, consumption behaviours influencing food waste can also be viewed through two examples. According to Wansink et al. (2000), products that are not immediately used after purchase are often pushed to the back of the shelf and later forgotten. Regardless of the remaining shelf life, consumers tend to discard these forgotten products if they remain unused for five months after purchase (Wansink et al., 2000). Therefore, extending the shelf life beyond the optimal level suggested in section 4.3, may not be necessary to minimize food waste at the consumer level.

One retailer interviewed also highlighted consumer confusion regarding long shelf life beverages. Consumers often believe that these products remain good to drink until the end of the 'best by' date even after opening. However, the aseptic technology only maintains product quality as long as it remains unopened, after which it should be consumed within a few days. This misunderstanding leads to food waste, as consumers may not finish the opened UHT beverages before they spoil.

The wide range of consumer influence makes it difficult to cover during the period of this research project.

5.3 Relationship between shelf life and food waste

The two consumption behaviours identified in section 5.2 can be illustrated using the Innventia AB model (Figure 8) where excessive packaging that provides an extended shelf life, increases the negative environmental impact through packaging material, and also eventually leading to food waste at the consumer's end.

The relationship between the model by Spada et al. (2018) and the model by Innventia AB are further evaluated. The former explains longer shelf life leads to less food waste. The latter explains there is an optimal level of packaging where underpackaging leads to more food waste and overpackaging leads to packaging waste. In Figure 8, when superimposing the models, it is possible to identify the minimum shelf life that meets the optimal packaging material usage. At this level, the benefits are gained from the positive environmental impact on reduced food waste and reduced packaging.

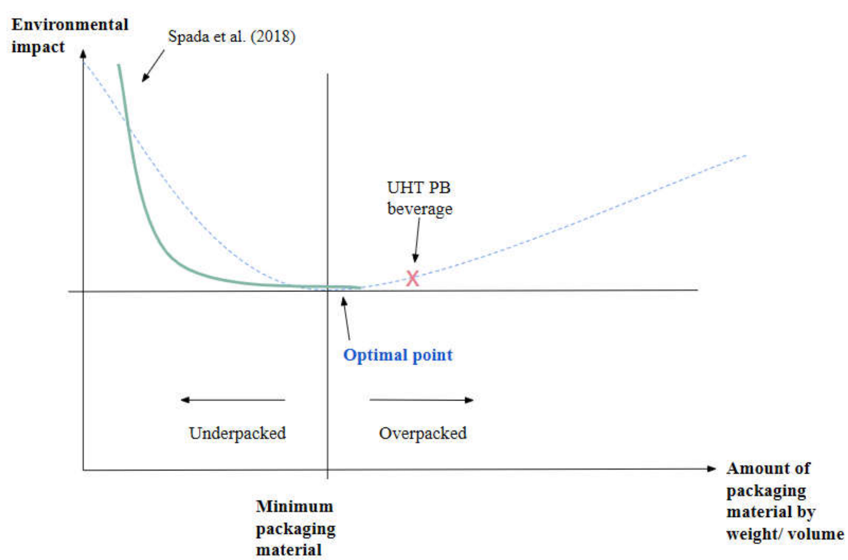

Figure 8 Combining Spada's inverse model with Innventia AB model

6 Conclusions, limitations and recommendations

This chapter presents the conclusions of this research paper. The methods used to obtain the results are critically assessed and future recommendations are presented.

6.1 Conclusions

The goal of this research is to study the relationship between shelf life and food waste to inform a more optimal packaging design. The relationship between shelf life and food waste of UHT plant-based beverage was explored through three RQs. The study focused on the case of UHT plant-based beverages through an exploratory approach, using data from a combination of literature review and semi-structured interviews with different actors in the supply chain. They are summarized and concluded below:

1. **What are the shelf life requirements set by various stakeholders in the supply chain, and what are the rationales for these requirements?**
   The required total shelf life for UHT plant-based beverages today is set to be 12 months. The required remaining shelf life set by retailers in Europe and the U.S. varies between 67 to 80% of total shelf life. For the specific case study of Sproud in Sweden, it is set at 75%. The main rationale for setting these long shelf life requirements include allowing flexibility for logistics and sales, and historical precedents, which indicates that the required shelf life needs to be updated and set intentionally.

2. **How much food waste is found for long-life foods due to expiry?**
   There is insignificant food waste due to expiry found for UHT plant-based beverages at the food manufacturer and retail level. There is also very little food waste data available from secondary sources for long-life foods.

3. **How can optimal shelf life balance the environmental impact from packaging material and food waste?**

The remaining shelf life analysis revealed that the current 12 months total shelf life is not fully utilized, suggesting that the current product is overpacked. Limitations are noted and detailed in section 6.2. When the needed shelf life is understood, the right packaging materials can be used to provide the sufficient amount of protection and shelf life without inducing an increase in product waste.

In conclusion, this study contributes to the existing literature by finding that there is insignificant food waste due to expiry at the food manufacturer and retail levels for the UHT plant-based beverage category. Additionally, the study suggests that some of the provided shelf life remains unused, indicating potential overpackaging. Food and packaging companies can consider introducing new barrier materials that produces lower carbon emissions for this category. Although these materials might reduce shelf life, they are unlikely to significantly impact food waste, at least up to the retail level. Packaging design and materials should be chosen to accommodate the necessary shelf life to balance the environmental impact of both packaging and food waste, rather than extending shelf life as much as possible.

6.2 Limitations and recommendations for future research

There are several limitations that can be addressed for this study.

Firstly, using Sproud as a single wholesaler case limits the ability to generalize findings across the industry. The company's success in achieving minimal waste may be attributed to its excellent management, which could be easier to achieve in a smaller organization. Nonetheless, Sproud's case study contributes significantly because it uses the same packaging material as other UHT plant-based beverages on the market. It is recommended to conduct more case studies on different organizations to enhance generalizability.

Secondly, regarding data obtained from retail staff, bias in responses is expected. As the results demonstrate almost perfect no wastage due to expiry, the extremity of this should be considered in further detail. Retail staff responses may be influenced by factors such as product performance and management practices that affect their perception. Additionally, during interviews, retail staff often do not refer to recorded data, suggesting that responses are based on personal experience rather than concrete evidence, leading to potential underestimation. It is recommended to use recorded quantitative food waste data to improve reliability and accuracy of results. Applying anonymity to responses can mitigate biases.

Thirdly, data was not obtained from other key stakeholders such as warehouse and distribution actors, while consumers were not in the scope of the research. Data from these actors would provide a clearer picture of the relationship between food waste and shelf life. Future research should incorporate data from these stakeholders.

Lastly, the ability to generalize the findings is constrained by geography. This research is limited to two locations: Lund, Sweden, and Bexleyheath, U.K. Geographic diversity is important because different regions may have varying supply chain practices, consumption patterns, and weather conditions. It is recommended to include different geographical locations in future studies.

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Appendix A: Interview guides for food manufacturers

Supply chain map and timeline

1. What is the general supply chain map?
2. Where does the product go after production?
3. Starting from processing, how long does it take to go from production to storage, to distribution etc.?
4. What is the RSL required from retailers?
5. How does this compare to chilled milk production?

Waste and returns

1. Food waste levels and return rates? What are the reasons?
2. Do you reimburse the returned products?
3. Are there any returns due to expiry?
4. Is it possible to obtain quantitative data?

If yes,

5. What are the measures taken to reduce the waste?
6. What do you do with the returned products?

If no due to products being promotion,

7. How much remaining shelf-life before they go on promotion?
8. How often do they go on promotion? How many % of products in a year go on promotion due to approaching RSL? Why?

Shelf-life

1. Why set a *xx* month shelf-life?
2. Do you think you will have less food waste/promotion if you had a longer shelf-life? Or will you experience the same cost for storage?

Appendix B: Interview guides for retailers

Supply chain map and timeline

1. Where does the product get delivered from?
2. Any storage in stores? How long?

Waste and returns

Waste is considered products you will have to throw away because you cannot sell them.

1. Food waste levels or return rates
2. What are the reasons?
3. What happens to the product you throw out?
4. How much is due to expired products?
5. Reasons for expired shelf life?

Turnovers and replenishment

1. Turnover rate/frequency/volume of sales
2. Replenishment procedure and strategies of products? How often?

Shelf-life and promotion

1. How much shelf-life left on shelves before they go on promotion?
2. Main reasons for products reaching near expiration (and need to go on promotion)?
3. How often do they put products on promotion?
4. Procedure to weed out expired or near expired products?
5. Do you think you will have less food waste/promotion if you had a longer shelf-life? Or will you experience the same cost for storage?
6. What will the impact be on the supply chain if the shelf-life is reduced by 2 months?