Concept development and evaluation of a fibre-based packaging for ready-meals

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FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2024

MASTER THESIS

FIPDes
Food Innovation & Product Design

This Master's thesis has been done within the Erasmus Mundus Joint Master Degree FIPDes, Food Innovation and Product Design.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

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A Concept Packaging Design Project for Micvac

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Published by
Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Food Packaging Design (MTTM01)
Division: Packaging Logistics
Academic Supervisor: Klas Hjort
Company Supervisor: Uli Nicol Hosse Pastor
Examiner: Fredrik Nilsson

Abstract

This report details the development and evaluation of fibre-based primary packaging concepts for the growing ready-meals category, focusing on a concept packaging design project for Micvac AB. The research methodology employed the Double Diamond of Design Thinking as an innovation model. The project encompassed an assessment of the desirability, feasibility, and viability of fiber-based packaging. Subsequently, a product design specification (PDS) was formulated. Based on the PDS, various concepts were generated and evaluated, culminating in the selection of two concepts for the prototyping phase. The two selected concepts use fibre moulding technology and the inclusion of a plastic liner to improve barrier properties. The liner design is adaptable to allow vacuum or keep a headspace.

Keywords: Fibre, Moulding, Ready Meals, Packaging Development, Sustainability

Acknowledgments

I would like to express my gratitude to the FIPDes consortium for allowing me to be part of this life-changing program and to the Erasmus+ Programme of the European Union for granting me a full scholarship.

I want to thank my supervisors, Klas Hjort (Lund University) and Uli Hosse (Product Manager at Micvac), for their support, time, and valuable feedback while developing this research. I would also like to express my appreciation to Robert Albino (Innovation Director) and the Customer Acquisition team at Micvac for their insights and contributions to this project. I thank Michael Bogdanski (CEO of Micvac) for the opportunity to carry out this project in this exceptional company.

I want to thank Erik Andersson and Jenny Schelin for their support and guidance during my studies at Lund University. I also want to thank Fredrik Nilsson for agreeing to be my examiner.

Lastly, I want to express my heartfelt thanks and dedication to my family, especially my mother, father, and sister. Thank you for your love, support, and encouragement, which have helped me achieve all my dreams.

Paris, Dublin, Lund, and Gothenburg—what a journey! I am grateful for all the wonderful moments I shared with everyone I met on this ride. I will cherish these memories forever!

Thank you, God!

Göteborg, May 2024

Leonardo VILLEGAS

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List of acronyms and abbreviations

RQ	Research Question
PDS	Product Design Specification
PPWR	Packaging And Packaging Waste Regulation (EU)
EPR	Extended Producer Responsibility
OTR	Oxygen Transmission Rate
WVTR	Water Vapor Transfer Rate
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PET	Polyethylene Terephthalate
EVOH	Ethylene Vinyl Alcohol
PP	Polypropylene
PLA	Polylactic Acid
PHB	Polyhydroxybutyrate
CNF	Cellulose Nanofibres
CNC	Cellulose Nanocyrstalls

1 Introduction

This section elaborates on the background, research questions, and project scope. An outline of the project is presented.

"Because we don't think about future generations, they will never forget us"
-Henrik Tikkanen.

1.1 Background

The demand for plastic materials is on the rise due to their unique properties such as excellent barrier properties, malleability, low cost, and aesthetic appeal. However, the increase in demand has caused a significant amount of plastic waste (McKinsey & Company, 2022). According to BCG (2019), mankind has produced over nine billion tons of plastics in the last century; out of that, seven billion tons have been wasted.

The UN estimates that 36% of all plastics are used in packaging, including single-use packaging for food and beverages. However, 85% of these plastics end up in landfills and unregulated waste. In addition, 98% are made from virgin materials (UN Environment Programme, 2024).

Most plastics are not biodegradable and can decompose for up to a thousand years (UN Environment Programme, 2023). However, the root of the problem is not the material's biodegradability. Rather, poor waste management causes pollution, affecting oceans, soil, groundwater, atmosphere, and human health (BCG, 2019; UN Environment Programme, 2023).

Therefore, it is important to have a structured and holistic method for managing plastic waste (McKinsey & Company, 2022). Policymakers are implementing new regulations to address the issue of plastic waste. These regulations include banning plastic from landfills, limiting the use of single-use plastic products, introducing taxes, and implementing extended producer responsibility, among other initiatives (BCG, 2019; Rabobank, 2024).

Today, many companies are tackling the problem of plastic waste by implementing measures such as designing recyclable packaging, using materials more efficiently, and avoiding the use of plastics wherever possible. As part of these efforts, the industry is exploring alternatives to plastic packaging materials, such as paper and fibre-based options. However, these alternatives raise concerns about their ecological, safety, and potential business impacts. Therefore, it is important to thoroughly evaluate these implications before implementing any new solution.

Micvac is an innovative food processing and packaging solutions company for ready-meals products. The company is strongly committed to sustainability and has implemented policies to minimize any negative environmental impact caused by its operations. Micvac promotes sustainable development by prioritizing environmental sustainability as a driver of its innovation portfolio.

In a previous study, Micvac researched sustainable packaging material concepts that could be implemented in their innovation roadmap. This research focused on evaluating fibres as a material for ready-meals packaging.

1.2 Purpose and research questions

1.2.1 Purpose

The project aims to develop a fibre-based packaging concept for the ready meals category compatible with Micvac's in-pack microwave pasteurization technology. It will assess fiber technology's feasibility, desirability, and viability as a primary packaging solution.

1.2.2 Research questions

To succeed in the objective, the following research questions (RQs) have been set:

RQ1: Is fibre-based technology feasible, desirable, and viable as a primary packaging solution for ready meals?

> (a): What is the business outlook for adopting fibre technology as a packaging solution in the ready meals industry?
>
> (b): Is fibre-based packaging a desired solution for ready-meals producers?
>
> (c): Is fibre-based packaging technically possible in the foreseeable future?

RQ2: What are the requirements for designing a fibre-based package compatible with Micvac technology?

RQ3: Among different fibre packaging concepts, what is the most suitable option for Micvac's technology?

> (a) From the selected concept, is it possible to create a prototype?

1.3 Research limitations

The following limitations have been set for the project:

- The study uses a Double Diamond as an innovation model reference but does not fully adhere to the Design Thinking methodology.
- The study is limited to primary packaging for ready meals.
- The DVF research concentrates on Europe, emphasizing nine specific countries: Sweden, Finland, Norway, the UK, Belgium, Netherlands, France, Spain, and Italy.
- The desirability assessment due to time constructions is based on interviews with Micvac employers who have direct contact with clients and secondary sources.
- The technical assessment focused on explaining currently available commercial fibre-based packaging technologies and their scientific bases.
- The prototyping stage does not involve a laboratory characterization.

1.4 Structure of the report

This project is structured into 10 chapters and presented as:

Chapter 1: *Introduction*. It describes the background and motivation of the study, the research questions, and limitations.

Chapter 2: *Frame of reference*. It provides an outline to understand relevant concepts for the project.

Chapter 3: *Methodology*. It describes the research approach and methodologies to answer the research questions.

---Results and discussions---

Chapter 4: *Discover: Viability.* It discusses the business environment of using fibre-based technology as a packaging solution.

Chapter 5: *Discover: Desirability.* It delves into the attractiveness potential of fibre-based packaging for potential customers.

Chapter 6: *Discover: Feasibility*. It analyses the technological outline of fibre-based packaging as a solution.

Chapter 7: *Define: Product Design Specification.* It outlines the requirements for designing a fibre-based concept tray compatible with Micvac technology.

Chapter 8: *Develop: Concept generation and evaluation*. It describes the generated concepts and their evaluation.

Chapter 9: *Deliver: Prototype.* A preliminary solution is presented.

---End of results and discussions---

Chapter 10: *Conclusions and suggestions for further research.*

2 Frame of reference

This section provides an outline to understand relevant concepts for the project.

> "What is the calculus of innovation? The calculus of innovation is really quite simple: knowledge drives innovation, innovation drives productivity, productivity drives economic growth"- William Brody.

2.1 Structure

The chapter's content is outlined in Figure 1. First, it defines ready meals, in-pack microwave pasteurization, and the Micvac method with requirements. Next, it discusses packaging functions and their relationship to sustainability. Then, it presents some key concepts related to fiber-based technology. Finally, it presents the design thinking approach as a packaging innovation model.

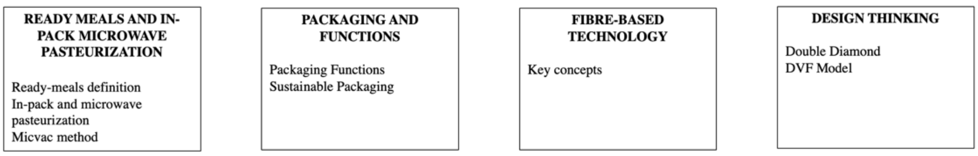

Figure 1. Structure of the frame of reference.

2.2 Ready meals and in-pack microwave pasteurization

According to Remnant & Adams (2015), ready meals are pre-prepared foods that can be reheated in their packaging and do not require any additional ingredients, only a little preparation before eating.

2.2.1 In-package microwave pasteurization

Microwave pasteurization uses electromagnetic waves that are absorbed by the molecules of food, such as water, proteins, and fats. This causes them to vibrate, allowing the heat to cook the food even at cooler points (Whirlpool, n.d.).

In-package microwave pasteurization involves placing food packed in trays or pouches into a microwave tunnel. The food is heated by microwave and boiled for the desired time. Finally, the containers are cooled down (Stanley & Petersen, 2017).

Microwave pasteurization has several advantages. It reduces processing time and is suitable for heat-sensitive or multicomponent foods (Tang et al., 2018).

2.2.2 Micvac technology

Micvac is a Swedish food packaging and processing company. Its technology offers in-pack microwave pasteurization, which turns raw food into fully cooked food in 7 minutes and has a shelf life of more than 45 days. The technology can be explained in the unique package design and the microwave tunnel.

The original process begins by filling a plastic tray with raw ingredients. Then, the tray is sealed with a layer film, and a hole is punched in the lid. A valve is applied to cover the hole. The food is then heated in a microwave tunnel, which causes expansion in the tray's headspace. The internal pressure opens the valve and expels the steam and air. After heating, the valve closes and creates a vacuum (Micvac, n.d.).

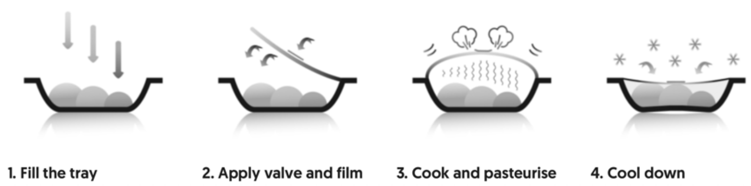

Figure 2. Micvac original method (Micvac, n.d.).

Nevertheless, Micvac is a FoodTech company characterized by innovation and scientific values. The company recently developed a new method for creating sustainable packaging called Micvac FlexProcess®. This method differs from the traditional method in that the valve is applied after pasteurization.

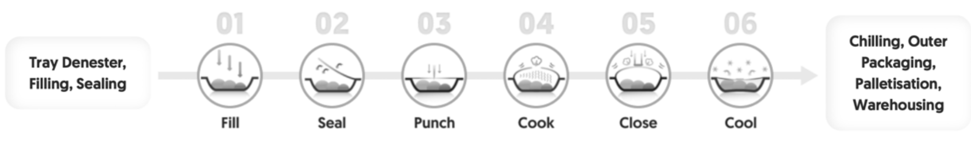

Figure 3. Micvac FlexProcess® (Micvac, n.d.).

2.2.2.1 Value proposition

Among the benefits of using Micvac technology for ready meals are 45 days of shelf life without any preservatives, automation in the production line, fast microwave cooking and pasteurization, natural vacuum, guaranteed food safety, and preservation of flavors and nutritional (vitamins) profiles.

2.2.2.2 Requirements

Using the technology requires a cold chain to keep the products safe, special materials and packaging design patented by Micvac, and a microwave tunnel or steam oven for cooking and pasteurization.

2.3 Packaging and functions

According to Paine (1981), packaging can be defined as a system composed of materials that serve different functions, such as containing, protecting, transporting, handling, distributing, delivering, and presenting products. It ensures a safe delivery while achieving good techno-economic effectiveness.

Hellström et al. (2016) defined seven functions that packaging must comply with:

1. Containment: To hold the content and keep it secure.
2. Protection: To safeguard the content from external factors.
3. Apportionment: To give the right amount of content for proper use.
4. Unitization: To make the handling more efficient by modularizing.
5. Convenience: To make the packaging and content easy to use.
6. Information: To provide data between the product and logistics.
7. Communication: To link between the brand and the consumer.

2.3.1 Sustainable Packaging Development

Three factors can be used to define sustainability: the environment, the economy, and human well-being (David Ibrahim et al., 2022). Packaging design should positively impact all sustainability dimensions. Different packaging development models have been developed to achieve this goal. Hellström et al. (2016) proposed six approaches to attain sustainable packaging:

1. Increase the **filling rate** to reduce the impact of transportation.
2. Ensure product **protection** to prevent food waste.
3. Use an adequate amount of **material** to avoid over and underpackaging.
4. Increase **user-friendliness** to tackle product waste.
5. Efficient **communication** throughout the supply chain to optimize resource usage.
6. Provide correct **apportionment** by manageable sizes.

This project is linked to packaging materials and their efficient usage. Material sustainability requires the consideration of various actors, ranging from economic to environmental aspects. Although there is no widely accepted definition of sustainable packaging materials, David Ibrahim et al. (2022) define them as materials that come from renewable sources or tend to reduce the use of virgin resources and can be recycled or reused at the end of their useful life.

2.4 Fibre-based technology and key definitions

Key terms associated with fibre-based technology are presented to enhance the understanding of the following chapters.

Table 1. Fibre-based technology and key definitions.

Keyword	Definition
Paper-based packaging	Flat and sheet-like products like cardboard, paperboard, shipping sacks, and paper bags. It is made from renewable resources (American Forest & Paper Association, n.d.; Kóczán & Pásztory, 2024).
Fibre-based packaging	Thicker, shaped products with a 3D design. It is made of natural fibres from growing plants like trees, wheat, and sugarcane (Kóczán & Pásztory, 2024).
Moulded- fibre packaging	3D dimensional package, made of fibres from wood or other sources. The forming process involves pressure and high temperature (Didone et al., 2017).
Composite material	Type of materials made up of phases of different materials in form or layer or dispersions in a matrix. It cannot be speared by hand (Mattox, 2010; Näringslivets Producentansvar, 2024).
Laminate material	Material made by sticking two or more layers together. It can be separated either by consumers or in the recycling process (Näringslivets Producentansvar, 2024).
Coating	Layer applied to the outer surface to improve the barrier properties of fibre-based packaging (dos Santos et al., 2022).
Lining	Layer that covers the inner surface of the packaging to improve its barrier properties (dos Santos et al., 2022).
Varnish	Unpigmented system that are added to the enhance the visual appeal of a printed surface (4evergreen, n.d.)

Sustainable packaging	Packaging that in comparison to the conventional packaging has higher environmental, economic, and social standards, and better performance and quality features (Kozik, 2020)
Bio-based material	Consists of substances derived from biomass and are produced naturally or synthesized (EPA United States Environmental Protection Agency, 2011)
Compostable packaging	It can be decomposed into compost without releasing toxic residues into the surrounding environment (Matt Dobson, 2024)
Recyclable packaging	Promotes the reuse of materials to manufacture new products (Matt Dobson, 2024).
Single-use plastics	They are used once, for a short period of time, before disposal (European Commission, n.d.)

2.5 Design thinking as an innovation process

Design thinking is an innovation and problem-solving approach with a human-centered core. It analyses what is humanly desirable with what is technologically possible and business profitable (IDEO, n.d.).

The principles of design thinking consist of (Design Council UK, 2024a):

1. People first: Understand people's needs, strengths, and aspirations.
2. Communicate visually and inclusively: Visually share an understanding of the problem and ideas.
3. Collaborate and co-create: Work with and be inspired by what others are doing.
4. Iterate: Catch mistakes early, reduce risks, and create confidence in your ideas.

2.5.1 Double Diamond

The Double Diamond is a comprehensive and visual description of the design thinking process. It is represented by two diamonds that embody a process of broad and deep exploration (divergent thinking) and then the adoption of specific steps (convergent thinking) (Design Council UK, 2024a).

The Double Diamond is structured in four stages (Design Council UK, 2024b):

I. Discover or research: Understanding the problem.
II. Define or synthesize: The area or problem to focus on.

III. Develop or ideation: Explore potential solutions.
IV. Deliver or implementation: A solution that works.

Figure 4 graphically exemplifies the design thinking process using the double-diamond approach and some frameworks for each stage.

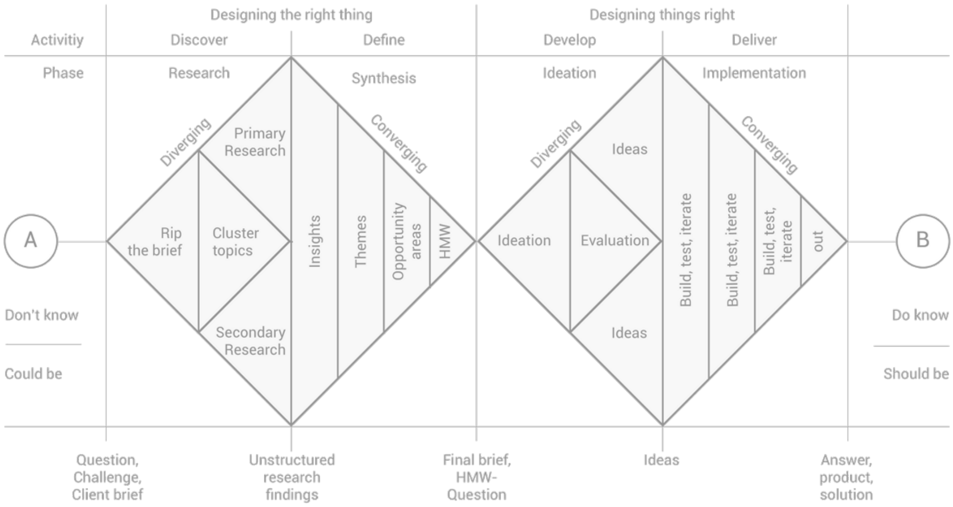

Figure 4. Design Thinking: Double Diamond (UX Collective, 2018).

2.5.2 DVF Model

Design thinking evaluates the desirability, feasibility, and viability of a problem or an idea. Desirability refers to understanding the wants and needs of people or customers; feasibility examines the potential for business profitability, while feasibility involves assessing the technological aspects necessary for implementation (UX Design Institute, 2022).

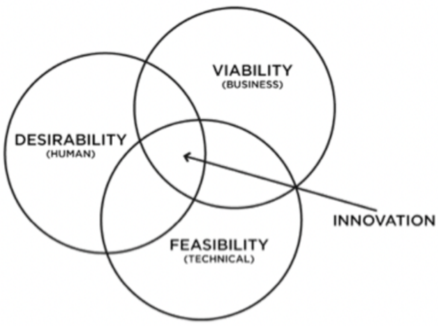

Figure 5. DVF Model (IDEO, n.d).

3 Methodology

This section presents the research approach and methodologies to answer the research questions.

"A pile of rocks ceases to be a rock pile when somebody contemplates it with the idea of a cathedral in mind" —Antoine de Saint-Exupéry.

3.1 Research design and approach

The project aims to develop a fibre-based packaging concept for the ready meals category compatible with Micvac's in-pack microwave pasteurization technology. The Packaging Innovation research model selected for this project was the Double Diamond of Design Thinking.

This method was chosen since the project is currently in the early stages of the innovation process. In this phase, it is essential to thoroughly evaluate the technology and develop initial packaging concepts. Furthermore, this method evaluates the feasibility of the innovation from different perspectives: technical, business, and clients. By examining these three areas, the method guarantees a thorough comprehension of the innovation's potential and challenges. This approach is important since it enhances the opportunity for a successful market entry and adoption.

3.1.1 Overview of the Double Diamond Design Process

This methodology comprises four stages, as introduced in the framework of reference (Design Council UK, 2024b; IDEO, n.d.):

1. Discover or research. The stage aims to gather insights about the problem to solve and/ or technology to assess.
2. Define or synthesize. This involves defining the requirements for the product or service based on the knowledge from the discovery phase.

3. Develop or ideation. This stage aims to generate concepts, evaluate them, and select the best ideas.
4. Deliver or implementation. This involves creating, testing, and refining prototypes to ensure they meet requirements and are viable for implementation.

Figure 6 illustrates how the Double Diamond was adjusted as a model to investigate packaging innovation and address the RQs outlined in Chapter 1. The following sections of this chapter describe the research approach used at each stage.

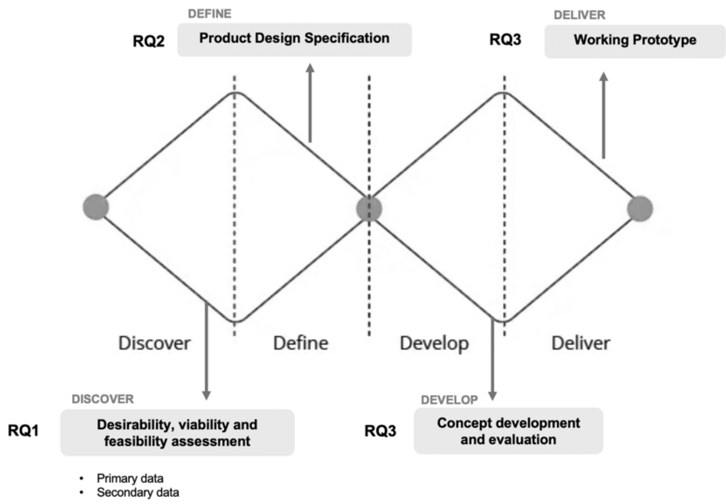

Figure 6. Layout of the research study.

3.2 Discover

During the Discover stage, the DVF framework was implemented. This framework evaluates the viability (business), desirability (consumer), and feasibility (technical) of fibre-based packaging in the ready-meals industry. This stage involves extensive research, during which primary and secondary data were collected to thoroughly research and assess RQs.

3.2.1 Data collection

Data collection is the process of gathering information for a specific purpose. It can be classified mainly into primary and secondary data, which can be qualitative or quantitative (Wagh, 2024).

1. *Primary data* is defined as the collected directly by the researcher.
2. *Secondary data* is defined as the collected by another organization or researcher (UNSW Sydney, 2024).

Figure 7 shows the methods of data gathering for the project.

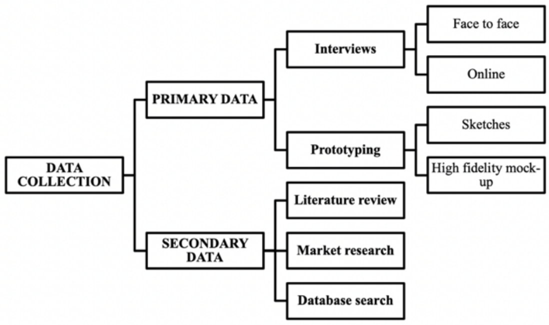

Figure 7. Data collection methods.

3.2.2 Data analysis

The data collected were analyzed using different frameworks applied within the double-diamond innovation process. The double diamond framework, comprising the Discover, Define, Develop, and Deliver phases, guided the methodological approach to ensure a comprehensive analysis. Specific frameworks were chosen for their relevance to address each research question and per each methodology stage. The frameworks used at each stage are described in the following sections.

3.2.3 Viability

Secondary research was conducted to assess the project's business viability. The data were organized and presented in different business analysis frameworks. The analysis was conducted on both the food category and packaging technology, using a zoom-in and zoom-out approach.

3.2.3.1 PESTLE analysis

Businesses use the PESTLE framework to evaluate and monitor the macro-environmental factors—political, Economic, Social, Technological, Legal, and Environmental—that impact an organization (Washington State University, 2023). This tool provides an overview of the factors affecting the ready meals and packaging industries, allowing for a zoom-out understanding of the market.

3.2.3.2 Market research

Market research combines consumer and economic trends analysis to assess a business industry (U.S. Small Business Administration, 2024). The present study analyses several key factors in the ready meals and packaging industry. Specifically, it examines the category's growth, the competitive landscape, consumer trends, and packaging demand and forecast.

3.2.3.3 5 Porter's forces analysis

The five forces framework classifies an industry's attractiveness by understanding the forces at work within it. The forces are competition, the power of suppliers, the power of customers, the threat of new entrants, and the ability to find substitutes (Harvard Business School, n.d.). This methodology helps to assess the actability of implementing fibre technology as a packaging solution in ready meals.

3.2.4 Desirability

To evaluate the desirability, both primary and secondary research were conducted. For primary research, interviews were conducted to gather data. For secondary research, packaging strategies and sustainability insights were collected from the public information available on the websites and sustainability reports of producers of ready meals.

3.2.4.1 Limitations

Due to time constraints, the interviews were focused on commercial experts in the customer acquisition department at the company. No interviews with ready meals producers or consumers were conducted due to the project's scope and breadth.

The reason to interview the company's commercial experts relies on their expertise in understanding the needs of the ready-meals industry. Three people were interviewed due to the small size of the team.

However, the author is aware of the limitations of a small sample of interviews and the constraint of not interviewing ready-meal producers or consumers. Therefore, the author elaborates on future recommendations for improving this.

3.2.4.2 Interviews

Three semi-structured interviews with commercial experts at Micvac, each lasting 45 minutes to 1 hour, were conducted. Each interview included 10 questions and 2 activities to encourage participation.

Table 2 summarizes and details the actors interviewed. The outline for these interviews and activities is in Appendix B.1.

Table 2. Details of the actors with which interviews were conducted.

Position	Department	Nature of the interview	Duration	Date
Sales Director	Customer Acquisition	Face-to-face	1 hour	26.02.24
Technical Sales Manager (A)	Customer Acquisition	Online	45 min	16.02.24

Technical Manager (B)	Sales	Customer Acquisition	Face-to-face	45 min	29.02.24

3.2.4.3 Interview insights

Primary interview data were collected using the Miro[1] platform. Miro facilitated the organization and storage of the information during the interviews. The data analysis was conducted in three steps:

1. *Coding*:
    1) The interview results were coded using a Miro framework, which enabled the organization of the qualitative data.
    2) The dashboard was divided into sections to organize it, and each section aimed to analyse one question separately.
    3) The main ideas of the interview were identified by question and placed on the dashboards.
2. *Patter identification*
    1) Keywords were then identified within each question to uncover possible patterns. These keywords were highlighted in the panel for easy reference.
    2) The selection of patterns was made in accordance with the authors' perspective. No special software was used due to the small sample of respondents.
3. *Synthesis of information*
    1) The identified patterns and keywords were synthesized to extract relevant insights that answered each question.
    2) The author elaborated the insight based on interviewees' shared patterns and keywords.
    3) The synthesized information was then presented in the results section, providing a clear and comprehensive overview of the findings.
    4) At the end, a summary of the interview results and suggestions on how to improve the analysis are presented.

To simplify the understanding of how the insights were encoded, Figure 8 is presented.

1 Miro is a digital platform designed to facilitate remote and distributed team communication and project management.

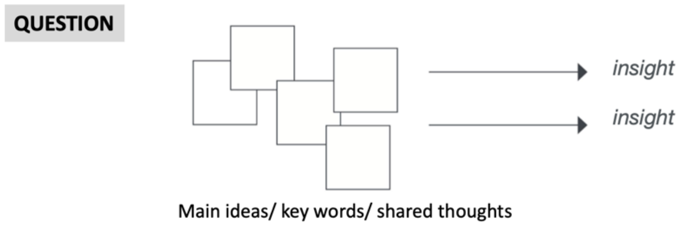

Figure 8. Insights development from interviews.

3.2.4.4 Sustainability and packaging strategy of ready-meals producers

Secondary data collection of ready-meal producers' packaging and sustainability strategy complemented the desirability study. The data were analysed and summarized in a table, briefly describing each producer's packaging strategy.

3.2.5 Feasibility

A literature review was conducted to assess the technical feasibility of the project. It is defined as academic writing that explains the academic literature on a specific topic. It synthesizes the sources into a summary with a purpose.

The University of Arizona states that there are four steps to writing a literature review (University of Arizona, 2024). This approach was selected for this research.

1) Define the research scope: Identify the research question the literature will help answer.
2) Identify the literature: It requires different sources like books, journals, articles, and/ or dissertations.
3) Critically analyse the literature: Analyse the sources critically, making connections and identifying gaps.
4) Categorize the resources: Divide the findings into categories to address the research questions.

3.3 Define

3.3.1 Data synthesis

The insights gathered during the discovery phase were translated into a Product Design Specification (PDS). The discovery phase is critical in the innovation process, as it involves extensive research and exploration of the needs, market trends, and potential technological opportunities. The information obtained in this phase served as the basis for the definition phase. This was supplemented by the findings of Hosse's (2021) thesis, which offered additional data and insights that enhanced the comprehension of the crucial factors impacting the packaging design.

3.3.2 Product Design Specification

Kent (2016) defines a Product Design Specification (PDS) as the essential requirements of a product. The PDS contains the requirements a product must meet before the design work begins and does not include the final design.

There is no general format for a PDS, and it will be different for different projects. Although one person may initially draft the PDS, it should be reviewed and agreed upon by the entire project team. Therefore, the PDS was verified by the Product Manager at Micvac.

Kent (2016) listed criteria that should be included in the PDS, but it depends on the product's goal. The criteria selected for this project were:

1) Definition
2) Performance
3) Application
4) Design
5) Cost
6) Size
7) Material and material performance
8) Manufacturing
9) Safety
10) Sustainability
11) Storage

To ensure a better understanding of the requirements in the Micvac Development Process, Hosse, (2021) classified them into three stakeholders. These actors were considered when designing the PDS. An additional stakeholder was included to gain a comprehensive understanding of the needs.

1) Manufacturing
2) Production
3) Customer
4) Product

3.4 Develop

The development stage aimed to generate various concepts for the fibre tray. This was achieved through ideation, followed by an evaluation.

3.4.1 Idea Generation

3.4.1.1 Five step method

The Five-Step Method of Ulrich et al., (2020) was adopted as an idea generation approach. This method focuses on developing concepts for new products. It involves 5 steps:

1) Clarify the problem: Understand the problem and the requirements.
2) Search externally: Collect data from the market, literature, experts, etc.
3) Search internally: Gather information from experts within the organization.

4) Explore systematically: Classify the concepts in a tree model.
5) Reflect on the solutions and the process: Identify opportunities for improvement and iterations.

For step 3, insights from the Innovation Director and Product Manager at Micvac were collected.

3.4.1.2 Concept Definition

The concepts were systematically classified using Ulrich et al.'s (2020) methodology and organized in a classification tree. In addition, the generated concepts were illustrated using sketches.

3.4.1.2.1 Sketching

For the creation of the sketches, only paper and colors were used. The author of the thesis illustrated the drawings by hand. Once the drawings were complete, they were digitized using a high-resolution scanner.

3.4.2 Concept Evaluation and Selection

3.4.2.1 Concept Scoring Matrix

Concept scoring is used when to evaluate and differentiate generated concepts. It involves listing the criteria and assigning a weight to each criterion. The following steps can be followed to implement this framework (Ulrich et al., 2020):

1) Prepare the selection matrix.
2) Rate the concepts.
3) Rank the concepts.
4) Combine and improve the concepts.
5) Select one or more concepts.

The criteria were chosen based on both internal parameters and some external elements from the Environmental Evaluation for Food Packaging (EEFP) by Molina-Besch & Pålsson (2020).The criteria have been divided into four areas: sustainability, food waste, technical feasibility, and business criteria. The first two areas were based on the EEFP tool, but some modifications were made to tailor it and the levels to the project's specific needs. Appendix B.2 shows the evaluation tool levels used for the matrix.

From the EEFP tool, the sustainability (separation and sorting) and food waste (appealing appearance and shelf-life) criteria were selected. However, the evaluation levels for appealing appearance were customized for the assessment.

It was agreed that each criterion would have the same weight, as shown in Appendix B.3.

3.5 Deliver

3.5.1 Prototype

Prototypes are created in the final stage of Design Thinking. They transform ideas into tangible products, allowing for feedback and improvement with minimal investment. Prototypes can be divided into two categories (Interaction Design Foundation, 2022):

1. *Low-fidelity* involves testing basic models. These models are inexpensive and easily made, such as by sketching or storyboarding. However, they lack realism, and the feedback can be inaccurate.
2. *High-fidelity* looks and functions closer to the finished product. These models enable data collection with a high level of validity and applicability. Nevertheless, they are more time-consuming to build and not as cheap as low fidelity.

Due to the nature of the project, a high-fidelity prototype was built to gain more significant insights and guidance on moving forward.

To prototype the selected concepts, six suppliers were contacted to evaluate potential collaboration and provide different samples of fibre trays. Upon receiving the samples, an evaluation was conducted based on technical specifications, sustainability information, and feasibility to fit the different conceptual designs. This evaluation served as the basis for selecting the suppliers to undergo testing with the Micvac method.

3.5.2 Prototype evaluation

The fibre trays were tested and tailored according to the selected concepts at the Pilot Plant at Micvac in Gothenburg, Sweden.

The trays were tested using a process designed to simulate the current Micvac process:

1. Assemble the ingredients in the tray.
2. Seal the trays with the help of a griddle.
3. Microwave at 440kW for 7min.
4. Allow to cool.

3.6 Ethical considerations

3.6.1 Ethics and consent

The primary information used comes from interviews with Micvac's commercial experts and is governed by the company's confidentiality agreement. To ensure the confidentiality of the interviewees' information, only their positions within the company were provided, and their names were not disclosed. The company reviewed and approved the information used in this report.

3.6.2 Confidentiality

In order not to disclose confidential information, the report was reviewed by the company.

3.7 Resources

The resources needed for this master's thesis included access to databases for collecting information. The company allocated a physical space at its office for the student to work on the master's degree project. Furthermore, the company provided access to the pilot plant for the prototyping and testing phase.

3.8 Summary

The research framework chosen for this packaging concept innovation project was the double diamond model, which is well suited for exploratory and early-stage innovation. This model consists of four distinct stages, each with a specific objective that guides the innovation process from initial exploration to final implementation. This method facilitated the exploration of fiber technology for ready-meals packaging and the definition of packaging design concepts by enhancing creativity and practical validation.

4 Discover: Viability

This section discusses the business environment of using fibre-based technology as a packaging solution for ready meals.

"Don't chase the market; create it"- The Blue Ocean Strategy.

4.1 Structure

This chapter addresses RQ1 (a): *What is the business outlook for adopting fibre technology as a packaging solution in the ready meals industry?*

A comprehensive analysis framework was used to examine the factors contributing to the growth of fibre technology as a packaging solution for ready meals. A thorough analysis was conducted on both the food category and packaging technology, using a zoom-in and zoom-out approach. Figure 9 outlines the methodology employed to address the RQ1 (a).

Figure 9. Viability assessment methodology.

4.2 Results

4.2.1 Industry PESTLE Analysis

A PESTLE analysis was conducted to understand the factors that influence the ready-meals category and the packaging industry in Europe. Table 3 highlights important touchpoints to consider when evaluating a new technology for this segment.

Table 3. Ready-meals and packaging PESTLE analysis in Europe.

Top Trends	Industry Implication
POLITICAL	
1. Trade disruption from the war in Ukraine	1. Ukraine is a key food and agriculture raw materials supplier (Euronews, 2023).
2. Plastic tax for some EU members	2. EU members will contribute financially based on the quantity of plastic packaging waste that is not recycled (KPMG, 2021).
3. Producer responsibility for packaging in Sweden	3. Financial responsibility by ensuring the collection and recycling of packaging materials (Näringslivets Producentansvar i Sverige AB, 2024).
ECONOMIC	
1. Food pricing inflation	1. Main drivers: increment of energy costs and reduction of key agricultural materials (fertilizers, animal feed, etc.) (Euronews, 2023).
2. Ready meals, a dynamic category with high revenue and growth	2. Global CAGR (2022-2028) in revenue terms is expected to increase +5.7% (Mordor Intelligence, 2024; Statista, 2023a).
SOCIAL	
1. Reduction of meat consumption	1. 23% of the UK ready-meals consumers are interested in plant-based ingredients as replacement of animal proteins (Mintel, 2023a).
2. Convenience as top purchasing factor	2. 34% of Sweden consumers consider "easy-to-prepare" as a key factor when buying a product (Statista, 2023c).
3. Demand for healthy ready meals	3. Awareness about healthy foods, functional ingredients, clean-label, and preservatives-free products (Mordor Intelligence, 2024).

TECHNOLOGICAL	
1. R&D on new materials to replace single-use plastics	1. Fibre-based and bioplastics materials development for food packaging.
2. Tech & Data	2. Offers more sustainable operations. E.g., RFID, GPS, and MES. Important to profit e-commerce and delivery opportunities (McKinsey, 2022).
3. Nanotechnology	3. Improves material performance to prolong the food products shelf-life (Ashfaq et al., 2022)
LEGAL	
1. EU Green Deal	1. It serves as a basis for the Form to Fork Strategy, Chemical Strategy for Sustainability, and Circular Economy Action Plan
2. Restrictions roadmap under chemicals strategy for sustainability	2. Regulation regarding PFAS, PVC, bisphenols, and toxic chemicals.
3. EU legislation on packaging and packaging waste (PPWR)	3. Reduction of packaging waste and the need for virgin materials. Improvement in the quality of recycling. All the packaging should be fully recyclable by 2030.
ENVIRONMENTAL	
1. Consumers seek for more environmentally friendly packaging	1. 38% of new ready meals launches claim to be packaged in recyclable materials (2022-2023) (Mintel, 2023a)
2. Tackle the food waste	2. 1/3 of the food produced is wasted globally. 61% comes from households, 26% from food service and 13% from retail (EUFIC, 2021)
3. Improvement consumer communication	3. Certification orgs help companies promote sustainability efforts to consumers. E.g., Plastic-free or Papercycle Certification.

Several factors may impact the ready-meals category, including commercial growth, regulation, and evolving consumer preferences.

The ready-meal segment is rapidly growing due to consumers' busy lifestyles. However, they are also becoming more health and environmentally conscious, preferring clean-label products and sustainable packaging. Therefore, finding a balance between convenience and healthfulness in the products is important. Furthermore, the EU is revising its packaging regulations to promote sustainability in the food packaging industry. The introduction of the PPWR could be the most important packaging regulation ever implemented in EU history.

4.2.1.1 Regulatory Overview

Some European governments intend to restrict the use of single-use plastics in the food industry. Consequently, new policies have been introduced to support this plan. Table 6 provides an overview of the regulatory framework in the EU.

Table 4. Regulatory Overview in Europe.

Country	Regulatory Overview
Sweden	*National Plastic Action Plan*: 50% reduction in the consumption of single-use plastic cups and food containers by 2026 (United Nations, 2022)
	Extended producer responsibility for packaging (Fee 2024 SEK/kg): Plastic packaging not compatible with material recycling: 5.00 vs paper partially or not compatible with material recycling: 1.50 (Näringslivets Producentansvar i Sverige AB, 2024)
Finland	*Plastic Roadmap for Finland 2.0*: Avoids unnecessary consumption, enhances recycling, and finds alternative materials (Ministry of the Environment of Finland, n.d.)
UK	*Plastic Packaging Tax:* This applies to plastic packaging components with less than 30% recycled plastics (£200 per tonne). Effective date: April 2022 (KPMG, n.d.)
Spain	*Tax on non-reusable plastic packaging:* EUR 0.45 per kilogram. Effective date: January 2023 (KPMG, n.d.)
Italy	*Plastic tax on single-use plastic products:* EUR 0.45 per kilogram. Effective date: July 2024 (expected) (KPMG, n.d.)

European countries have taken measures to adhere to global and regional agreements to address plastic pollution. For instance, countries like the United Kingdom and

Spain have implemented plastic taxes, and Italy is also expected to implement taxes soon. Additionally, countries like Sweden have proactively adopted the Extended Producer Responsibility (EPR) and imposed higher tariffs on plastic packaging than alternate materials such as paper.

4.2.2 Ready meals market research

4.2.2.1 Chilled Ready Meals

The chilled ready meals category is experiencing growing demand, making it an attractive market for innovation. Figure 10 illustrates a comparison of sales and category growth across different EU countries.

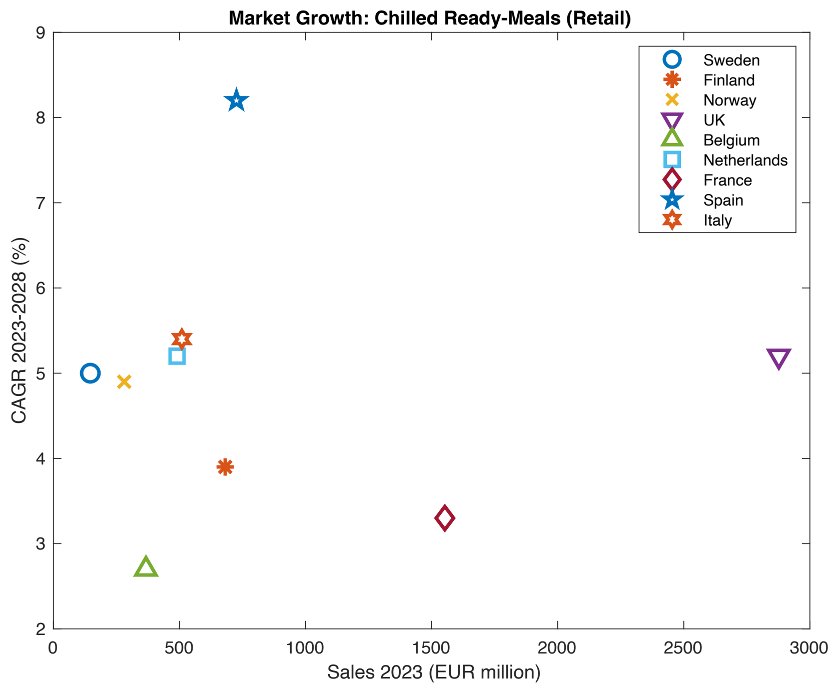

Figure 10. Market growth: Ready meals in the EU. Source: Euromonitor, 2024.

Spain is projected to have the highest growth rate at 8.2%, followed by Italy at 5.4%. However, the UK holds the largest market, with sales of 2,876 million euros in 2023 and a projected growth of 5.2%. The Nordic countries do not have a market size like the UK, but they all have a growth rate higher than 4%. For example, Sweden is expected to grow by 5.0%. The smallest growth rate is for Belgium at 2.7% and France at 3.3%. Nevertheless, France had sales of 1,552 million (second place) in 2023.

Two perspectives were taken to gain market insights: the UK, which has high sales, and Sweden, which has a Nordic focus, as Micvac is based there.

A. Nordic perspective: Sweden

Swedish consumers increasingly opt for ready meals due to their busy lifestyles and need for convenience (Euromonitor International, 2023). When buying food products, 34% of Swedish consumers consider "easy-to-prepare" as an important purchasing factor. Additionally, 22% of the consumers reported that they consume ready meals regularly (Statista, 2023b).

In 2023, sales of chilled ready meals reached EUR 146 million, and Euromonitor International projects a 5.0% CAGR from 2023 to 2028 (2023b).

In 2023, per capita consumption averaged 16.4kg. By 2028, it is estimated to increase to 18.3kg (Statista, 2023b).

The competitive landscape is dominated by Orkla Foods with an 18% market share. It is closely followed by Dafgård AB with 13% and ICA Sverige with 8.7% (Euromonitor International, 2023).

The new product launch strategy has been focused on promoting health and wellness, minimizing ecological impact, and exploring new cuisines for a variety of flavours (Euromonitor International, 2023b). Statista (2023b) states that 22% of Swedish consumers avoid purchasing plastic-packaged foods to minimize their ecological footprint.

This coincides with what is happening in the region. Mintel (2023) states that 42% of ready-meal consumers in Ireland are concerned about the effects of packaging on the environment. In Europe, between July 2022 and June 2023, 45% of new product launches claimed to have an "environmentally friendly package," while 38% claimed to be "recyclable."

B. Leader perspective: The UK

There are two growth opportunities in the category: health and wellness, and affordability.

UK consumers are demanding organic and plant-based options in their ready meals, with a strong focus on prioritizing nutrition (Euromonitor International, 2023a). Additionally, the UK government plans to establish a new regulatory framework by October 2025 to prohibit medium and large retailers from promoting HFSS foods (high in saturated fat, salt, and sugar). Increasing the availability of healthier options will help balance the impact of restrictions on prepared meal promotions and meet consumer demands (Mintel, 2023b).

Regarding affordability, 31% of home cooks would choose chilled ready meals due to the cost-saving opportunity they offer (Mintel, 2023b). However, this driver is polarized, as some consumers value affordability, and others are willing to spend on premium meals (Euromonitor International, 2023a).

In 2023, the sales of chilled ready meals reached EUR 2,876 million, projecting a 5.2% CAGR from 2023 to 2028 (Euromonitor International, 2023c).

The per capita consumption averaged 16.8kg in 2023. By 2028, it is estimated to increase to 17.1kg (Statista, 2023b).

Tesco leads the category market (14.3%), followed by Sainsbury's (9.8%) and Asda (8.2%) (Euromonitor International, 2023c).

According to a survey conducted by Mintel in 2023 on people's attitudes towards food packaging, 53% of respondents believed that it should be sustainable, while 49% felt that it should keep the food fresh for a longer period. When it comes to the materials used for packaging, 63% of the respondents believed packaging should avoid plastic, and 59% be recyclable.

4.2.2.2 Ready meals packaging

Figure 11 shows the demand for ready-meal trays. It counts items made from different materials such as plastics, composite materials, paper, etc.

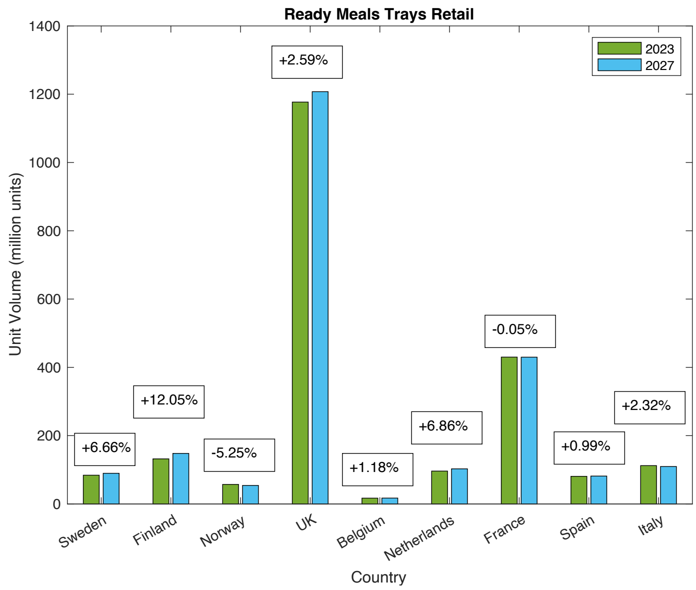

Figure 11. Ready meals trays placed in the European market. Source: Euromonitor International, 2024.

There is an increasing demand for ready meal trays in most European countries, except for Norway. Finland (12.0%), Sweden (6.6%), and the United Kingdom (2.6%) are projected to have the highest demand for these trays. The UK has placed the most trays on the market, followed by France. This information is consistent with sales records, as the UK and France are the largest markets for ready meals products.

As regulators and consumers place increasing emphasis on sustainable food products and packaging, the food industry is actively seeking materials that can be recycled more efficiently. As a result, it is no surprise that demand for paper trays is on the rise. Figure 12 illustrates the demand for paper tray packaging, including fibre-based packaging and cartons.

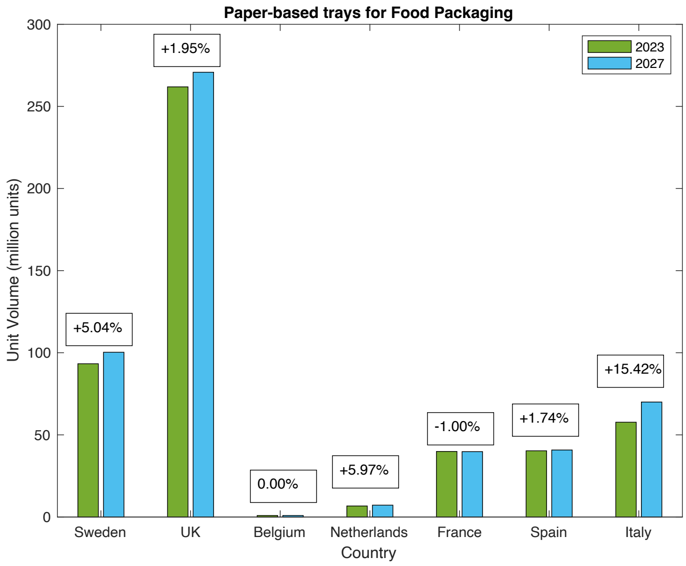

Figure 12. Paper-based food packaging placed in the European market. Source: Euromonitor International, 2024.

Italy is set to experience the greatest growth in demand for paper trays. This change is likely due to the upcoming plastic tax that will be implemented in mid-2024. On the other hand, the Netherlands and Sweden are also expected to increase in demand for paper trays, which can be attributed to consumer demands and preferences.

4.2.3 Fibre-based packaging market outlook

Global growth for moulded fibre pulp packaging is projected to increase by 5.4% between the years 2024 to 2034. The increase in demand is a result of manufacturers seeking a substitute for plastics, which are now subject to new regulations in different countries (Future Market Insights, 2024).

Mordor Intelligence (2024) envisions this technology to be cheaper than petroleum solutions due to the wide availability and affordability of natural fibres.

4.2.3.1 Benchmark

Fibre moulding provides an opportunity for sustainable packaging design. Therefore, this technology has seen significant innovation with many new launches embracing it in recent years. Table 5 showcases some applications of fibre-based technology as a packaging solution

Table 5. Benchmark, products with fibre-based packaging.

Product	**Plant-based spread**	**Conditioner**
Picture		
Brand/ company	Flora, Upfield®	Lenor, P&G®
Claims/ description	Packaging made from paper	Made with a paper structure and recycled plastic

Product	**Bean Enchiladas**	**Beef Bolognese**
Picture		
Brand/ company	Freasy®	Waitrose®
Claims/ description	Packaging completely free from plastic	Home compostable ready meal packaging

Note: All rights belong to the companies and brands aforementioned.

The major challenge in using fibre-based packaging is its limited barrier properties. However, recent examples have shown significant improvements in technology, making it possible to use it with frozen or cold chain food products, as well as liquids in the consumer goods industry.

While some new launches use plastic linings to improve the water, oxygen, and grease barriers, most of them are designed to be recycled in the paper recycling stream.

4.2.3.2 Key players

There is a growing demand for packaging made from natural fibres, which has led to an increase in the number of players in the market. To meet this demand, science-based start-ups have emerged. In addition, global corporations have partnered with them to expand their portfolio and invested in coating research to promote the adoption of the technology. Table 6 shows some key market players that Micvac could partner with.

Table 6. Paper and fibre-moulded technology key players.

Company	Overview
Yangi AB®	State-of-the-art technology for dry moulding
Huhtamaki®	Packaging solutions for sustainable food products
Stora Enso®	Fibre sustainable solutions to replace single-use plastic packaging
Pulpac®	State-of-the-art technology for dry moulding
Rottneros®	Fibre packaging solutions

Note: All rights belong to the companies aforementioned.

4.2.4 Porter’s 5 Forces analysis

Finally, to assess the overall competitive landscape of the ready meals industry and the attractiveness of fibre technology for this category, Porter's 5 forces analysis was performed, and the results are summarized in Table 7.

Table 7. Five forces of fibre-based packaging for ready meals.

Force	Evaluation	Overview
New entrants	Medium	• PPWR regulation is the most important packaging regulation set in the EU history, which is part of the EU Green Deal, aiming for more efficient use of raw materials. • Taxes regulation for plastic has been implementing in countries like the UK, Spain, and Italy.
Substitute product/ services	Low- medium	• Consumers are increasingly aware of sustainability and may perceive fibre-based solutions as an eco-friendlier packaging option. • Microwave pasteurization offers flexibility since it can be used with a wider range of packaging materials than other methods like conventional pasteurization, retort, HPP, etc.
Power of suppliers	High	• Science-based start-ups are utilizing innovative technologies to improve and boost the use of paper and fibre materials available through licenses and IP protection. • Global packaging companies partner with start-ups and invest in research to meet demand. • Each supplier offers a different degree of innovation and has different business models.
Power of buyers	Low- medium	• The demand for fibre packaging has increased due to changing consumer preferences and new regulatory frameworks. • As part of their sustainability strategy, companies are now seeking to reduce their use of plastic materials in their packaging portfolio while improving their recyclability and reusability.
Competitor	Low	• There is currently no fibre-based packaging solution that can extend the shelf life of ready meals. • Global growth in ready meals is forecast at 5.7% and fibre packaging at 5.4%.

4.3 Main remarks of the chapter

- The ready meals category is growing due to consumers' hectic and rapid lifestyles. The global CAGR (2022-2028) of the category is +5.7%. Spain and Italy are projected to grow the highest, while the UK and France had the largest market in 2023.
- There is an increase in awareness and demand for healthier and more sustainable ready meals. Sustainability is mainly linked to packaging.
- Two factors are driving the limitation of plastics as packaging material: increased sustainability awareness among consumers and new regulatory frameworks, such as taxes and the incoming PPWR.
- Fibre materials offer a window as a substitute for plastics. However, suppliers with cutting-edge solutions have high power as their technology is protected by intellectual property.

5 Discover: Desirability

This section delves into the needs and wants of potential customers concerning fibre-based packaging.

"If I had asked people what they wanted, they would have said faster horses"- Henry Ford.

5.1 Structure

This chapter addresses RQ1 (b): *Is fibre-based packaging a desired solution for ready-meals producers?*

Interviews were conducted to Micvac commercial experts to determine if fibre materials are a suitable packaging solution for ready-meal producers. This information was supplemented by analysing the sustainability and packaging roadmaps shared by producers in their public annual sustainability reports and websites.

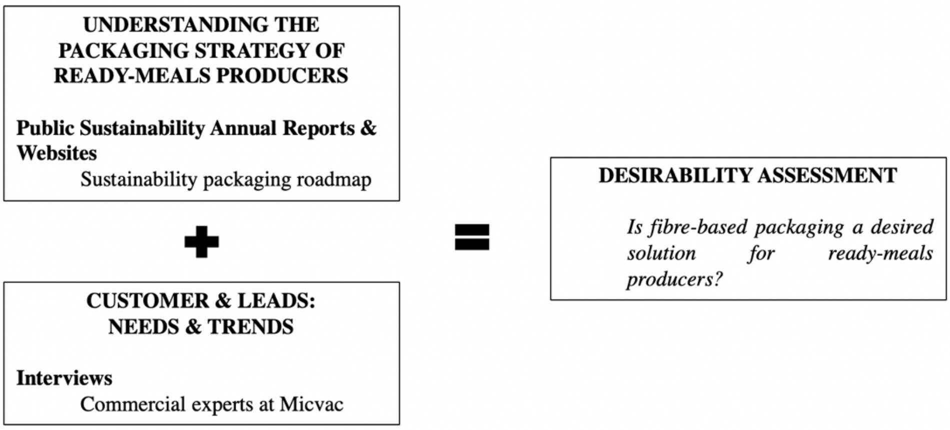

Figure 13. Viability assessment methodology.

5.2 Results

5.2.1 Interviews insights

The following section presents the main highlights of the interviews:

- Effectively communicating the value proposition of Micvac technology to ready-meal producers is a challenge in the sales process.
- Producers value Micvac technology because it increases products' shelf life, enhances automation, ensures sustainability, and is cost-effective.
- Producers often overlook the value proposition of automation and labour cost reduction until they experience the benefits in their factory plants.
- So far, the customers who have shown interest in Micvac technology have not expressed any concerns about using plastics as a solution.
- The commercial team envisions a fibre-based solution opportunity to meet customer-driven sustainability demands and to be the first company to use this technology in synergy with Micvac.
- Pricing should be cost-effective; otherwise, it will only be affordable for premium products.

5.2.1.1 Requirements to implement a new packaging solution in the ready-meals category

Figure 14. Requirements to implement a new packaging solution in the ready-meal category.

During interviews with Micvac's business experts, it was agreed that compliance with regulatory and food safety frameworks is key to evaluating a new solution. In addition, increasing the shelf life of products while maintaining cost-effectiveness is also important. Finally, discussions highlighted the growing importance of incorporating sustainable and recycling practices in the industry to minimize its environmental impact.

5.2.1.2 Discussion

Current and potential Micvac customers appreciate the technology's ability to prolong the shelf life of their products and automate their production lines by reducing the labour force. Therefore, adding these features to the fiber packaging solution would make it more attractive for ready-meal producers to implement. In addition, one of the motivations for the producers to adopt this solution is to support their sustainability strategy in packaging, but the offer must be cost-effective to increase the chances of adoption.

The information collected is limited and does not provide detailed information. Therefore, it was supplemented with secondary data from sustainability reports. Due to time limitations and the project's scope, the research focused on commercial experts at Micvac. However, it is recommended that more interviews be conducted in the future, especially with ready-meal producers and consumers. Moreover, when conducting qualitative research with consumers, it is advisable to inquire about the specific physical features that the fiber tray should possess.

5.2.2 Sustainability and packaging strategy roadmap for ready-meals producers

To understand the strategy of ready meals producers in terms of packaging innovation and sustainability, secondary research was conducted. Table 8 presents the findings of some players in the European market.

Table 8. Sustainability and packaging strategy for ready-meals producers.

Producer	Strategy
Orkla®	Efforts concentrated to reduce packaging waste by prioritizing the use of recycled and renewable plastics over virgin plastic materials (Orkla, 20222).
Atria®	Focus on the efficient use of materials, reduction of plastics, easily recyclable packaging, and food waste reduction (Atria, 2022)
HKSCAN®	Development of sustainable materials and design of recyclable packaging (HKSCAN, 2022).
Sigma Alimentos®	Reduce the use of plastics, eliminate components or layers, increase the use of recycled plastics, use biodegradable materials, and easy to recover/ recycle (Sigma, 2022).
Bakkavor®	Eliminate the unnecessary single-use packaging. Use reusable or recyclable plastic. At least 30% average recycled content in plastic packaging (BAKKAVOR, 2022)

NorgesGruppen®	To decrease the use of new fossil-based plastic in packaging. Use recycled plastic or fibres instead (Norgesgruppen, 2022).
Conagra®	Renewable, recyclable, or compostable packaging (Conagra, n.d.)
Fjordland®	Use packaging that can be recycled and provide clear communication to educate people on how to properly sort and recycle it (Fjordland, n.d.)

Many companies today are making efforts to create more sustainable packaging. While most focus on reducing the use of virgin plastics and increasing the recyclability of packaging materials, the goal is not to completely eliminate the use of it. Instead, it is to use plastic in the most efficient manner possible. However, some companies are also researching the use of renewable materials and fibres as an alternative to it.

5.3 Main remarks of the chapter

- Ready-meals producers appreciate Micvac technology for its capacity to extend the shelf-life of the products and improve automation in the production lines.
- Ready meal producers are prioritizing the efficient use of raw materials as part of their packaging strategy. Their focus is on minimizing virgin plastic consumption while promoting recyclability through packaging design. It is important to note that most producers are not aiming to completely eliminate the use of plastic. Rather, they are striving to use it in the most efficient way possible to help reduce its environmental impact.
- Fibre-based technology has not been extensively discussed in packaging strategies. This may be due to the technical challenges it presents. However, there is an increasing interest in utilizing renewable materials, and fibre materials may play a role in the future.
- Fibre-based packaging presents an opportunity for ready-meals producers to meet consumers' demands and achieve their sustainability objectives. However, it needs to demonstrate its ability to keep the product fresh and safe. Moreover, the cost-effectiveness of fibre-based packaging must be monitored to facilitate its widespread adoption. A synergy with Micvac technology would be a disruptive innovation, given its potential high value in terms of sustainability.

6 Discover: Feasibility

This section analyses the technological outline of fibre-based packaging as a solution for ready-to-eat meals.

"There's a way to do it better. Find it" –Thomas Edison.

6.1 Structure

This chapter addresses RQ1 (c): *Is fibre-based packaging technically possible in the foreseeable future?*

A literature review was conducted to explore the manufacturing process of a fibre tray. The review covers the fibre morphology and properties, the pulping methods, and the fibre moulding technologies required to manufacture a tray. It also includes exploratory research related to coatings and linings to improve the barrier properties and the challenges related to food safety and sustainability. Figure 15 outlines the technical review.

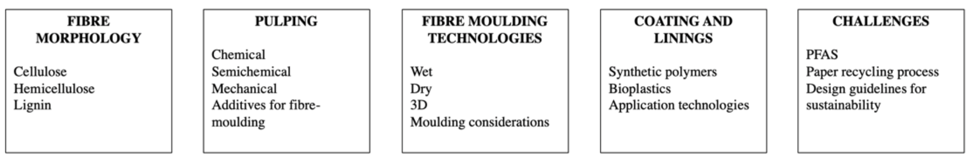

Figure 15. Technical review outlook.

6.2 Results

Fibre-based packaging has the potential to reduce environmental pollution by decreasing the use of single-use plastic packaging materials. Fibre-based packaging is an excellent choice as it can be partially and completely recyclable and biodegradable (Kóczán & Pásztory, 2024).

It is important to note that certain challenges are related to the barrier and mechanical properties of fibre-based materials for food packaging (Kóczán & Pásztory, 2024). These materials must be able to protect food products from gas, moisture, and lipid exchange (Perera et al., 2023).

It has been observed that fibre-based packaging when used without coatings has weak barriers (Kóczán & Pásztory, 2024). Therefore, it is necessary to conduct further research to enhance its protection without compromising its biodegradability and recyclability properties.

6.2.1 Fibre-based morphology

The manufacturing of fibre-based products relies on pulp as the primary raw material. "Pulp" refers to fibrous material obtained through mechanical, chemical, or combined separation processes from trees or other crops (Robertson, 2012).

Pulp can be produced from wood or non-wood sources (Kóczán & Pásztory, 2024). Currently, 97% of all paper and derivates products worldwide come from wood pulp, with 85% originating from coniferous trees such as spruces, firs, and pines (Robertson, 2012).

Fibre-based products can be produced using different types of fibres which can be classified into primary and secondary fibres. Primary fibres, also known as virgin fibres, are sourced from either wood or non-wood materials. Secondary fibres, on the other hand, are obtained from recyclable materials (Kóczán & Pásztory, 2024).

The primary components of plants are cellulose, hemicellulose, and lignin (Patel & Parsania, 2018).

6.2.1.1 Cellulose

Cellulose is the most abundant polymer on the earth (Dufresne, 2013) and the principal component of fibre-based products.

Cellulose is a linear polysaccharide composed of glucose monomers, linked by β-1,4-glycosidic bonds. It has a degree of polymerization (DP) of 3500 (Robertson, 2012). Additionally, cellulose is mainly characterized by hydroxyl groups due to the glucose molecules (Sahin & Arslan, 2008).

Its structure can be explained by two regions - crystalline and amorphous (Patel & Parsania, 2018). The β-1,4-glycosidic bonds encourage an ordered crystalline region governed by van der Waals forces and inter and intramolecular hydrogen bonds (Rajinipriya et al., 2018).

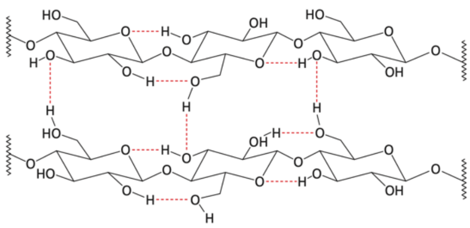

Figure 16. Cellulose with intra and intermolecular hydrogen bonds(Dufresne, 2013).

Parallel stacking is promoted by van der Waals and hydrogen bonds between polymer chains, which produces fibrils (Illera et al., 2018). Therefore, the ability to form fibres depends on cellulose chains' length and parallel arrangement (Robertson, 2012).

Cellulose is a hydrophobic molecule because of its intermolecular bonding. This bonding stops water from penetrating the cellulose (Dufresne, 2013). In paper manufacturing, a higher percentage of crystallinity reduces water absorption but, in turn, limits flexibility (Wan et al., 2011). Crystalline cellulose structures possess stronger mechanical properties than amorphous ones (Perera et al., 2023).

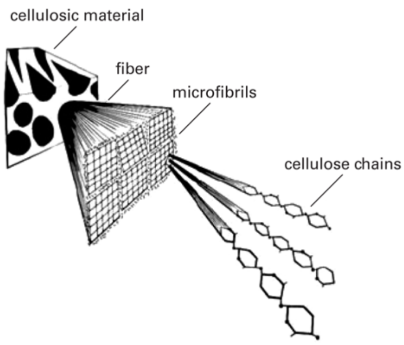

Figure 17. Representation of cellulose fibers (Dufresne, 2013).

6.2.1.2 Hemicellulose

Hemicellulose is a complex heteropolymer composed of diverse sugars, including mannose, xylose, galactose, uranic acids, and arabinose. Its DP is 15 (Robertson, 2012). It is a non-crystalline material due to its high degree of branching (Patel & Parsania, 2018).

It is widely known that hemicellulose significantly facilitates the fibrillation process (Rajinipriya et al., 2018).

Hemicellulose has important contributions to the pulping process (Hu et al., 2013). Due to its hydrophilicity (Patel & Parsania, 2018), it takes the principal role in hydration and inter-fibre bonding (Robertson, 2012), improving the tensile properties of fibre-based products (Hu et al., 2013).

If the hemicellulose content decreases, the strength does, too. One theory, among others, holds that the loss of hemicellulose reduces the hydrogen bonds between the fibres by decreasing the number of free hydroxyl groups (Hu et al., 2013).

Furthermore, hemicellulose enhances the barrier to air permeability by promoting inter-fibre hydrogen bond strength. It also improves fibre flexibility, printability, and smoother surfaces (Hu et al., 2013).

6.2.1.3 Lignin

Lignin is a highly branched polymer constituted of phenylpropane or propylbenzene units. It does not have fibre-forming properties and is mostly eliminated in pulping processing (Robertson, 2012).

It is primarily in charge of the color development of the paper. As a result, it is eliminated using different procedures (Haq et al., 2020). In addition, the retention of lignin in the pulp produces stiff fibres (Robertson, 2012).

Table 9 presents a comparison of the characteristics and properties of cellulose, hemicellulose, and lignin.

Table 9. Fibre properties.

Cellulose	Hemicellulose	Lignin
• Polymer of glucose. • Hydrophobic molecule. • The chains can form fibres due to their length and parallel arrangement. • It provides strength to the product.	• Mixed sugar-polymer. • Hydrophilic molecule. • It enhances the interbonding in the chemical pulping. • It provides flexibility, printability, and smoother surfaces.	• Branched polymer of phenylpropane or propyl benzene. • Hydrophobic molecule. • It contributes to color development. • It does not have a fibre-forming capacity. • It produces stiffer products.

6.2.2 Pulping

Pulping is the process of separating cellulosic fibre raw materials from the rest of the wood components (Robertson, 2012). Wood is composed of (i) cellulose, (ii) hemicellulose, (iii) lignin, and (iv) extractives such as resins, pectins, etc (Gibbons, 1989).

The objective of pulping is also to eliminate lignin. The lignin must be dissolved to free the cellulose and hemicellulose. If lignin remains, stiff and weak fibre products are expected. Color and strength deterioration may also occur (Robertson, 2012).

If the fibres are derived from wood, softwood is preferred due to its longer fibres, which are 2.5 times longer than those of hardwood (Gibbons, 1989; Robertson, 2012).

The pulping process produces some degree of fibre deterioration. This deterioration occurs to a greater or lesser degree depending on the type of pulping and the stage of the process (Robertson, 2012).

The pulping process can be classified into three categories: chemical, semichemical, and mechanical (Bajpai, 2018).

Table 10 summarizes the different yields and pulp properties of the different pulping processes.

Table 10. Pulp properties.

Pulping process	Yield	Pulp properties
Mechanical	Higher (90-95%)	Short, weak
Chemical	Lower (40-55%)	Long, strong
Semichemical	Medium (55-85%)	Intermediate pulp properties

6.2.2.1 Mechanical pulps

Mechanical pulps are obtained by mechanical attrition processes, with high yields typically ranging from 90% to 95% (Gibbons, 1989). However, this method has a notable drawback: it retains lignin within the pulp, resulting in fibres with lower strength due to ineffective hydrogen bonding caused by the presence of lignin (Bajpai, 2018).

In addition, mechanical pulping is characterized by considerable energy requirements, which can vary depending on factors such as the specific process employed and the properties of the raw materials used (Bajpai, 2018).

The main application of mechanical pulp is the manufacture of non-permanent products that do not require high strength, such as newsprint, tissues, or catalog paper (Gibbons, 1989).

There are three main methods: (i) refiner mechanical pulping (RPM), (ii) thermomechanical pulping (TMP) and (iii) chemithermomechanical pulping (CTMP). RPM and CTMP produce stronger pulps and TMP makes more flexible pulps (Robertson, 2012).

6.2.2.2 Chemical pulps

Chemical pulping involves cooking the fibres at high temperatures using a chemical solution. It yields approximately 40-55% and ensures high-quality fibres (Bajpai, 2018). This process gets rid of lignin, resulting in a stronger product with greater flexibility and durability (Gibbons, 1989). Because fibre release is chemical and not mechanical, the pulp contains a higher degree of long fibres (Young et al., 2003).

One of the most widely used processes is Kraft pulping. This begins with steaming the wood chips and then blending them with an alkaline solution containing sodium hydroxide and sodium sulphide. The mixture enters a digester, undergoing pressurization and cooking at temperatures ranging from 160-170°C. Lastly, the separation of pulp and cooking liquor concludes the procedure (Bajpai, 2018; Young et al., 2003)

6.2.2.3 Semichemical

It uses a combination of chemical and mechanical processes to extract the fibres (Bajpai, 2016). This method aims to improve the performance of chemical processes with better fibre strength than the mechanical method (Robertson, 2012).

6.2.2.4 Fibre properties for moulding products

When it comes to manufacturing moulded fibre packaging, there are some differences in the pulp compared to paper manufacturing. Firstly, the pulp must have a higher solids content in the fibre slurry (3-5%). Secondly, the fibres can be oriented in all directions, rather than being oriented primarily in one plane. Finally, the fibres used for moulded products are less refined than those used for printing paper (Debnath et al., 2022).

6.2.3 Additives for fibre-moulding pulp products

In addition to fibre materials, additives are used in the manufacture of paper and fibre moulding products. They can be classified into three categories: binders, hydrophobic substances, and flocculants (Debnath et al., 2022).

6.2.3.1 Binders or strength aids

Chemical additives can enhance a product's strength through various mechanisms. First, they can improve the consolidation of fibres on a structural level. Second, they may increase the bond strength between fibres. Finally, they can decrease the amount of stress within the product (Wennman, 2023).

1. Hemicellulose: Increases the bond strength by interlocking the fibre- fibre joint.
2. Carboxymethyl cellulose (CMC): Increases dry strength by enhancing fibre-fibre joints.
3. Starch: Employing this material increases hydrogen bonding due to abundant hydroxyl groups in the fibre network. Cationic starches are commonly used in pulp slurry at a dosage of 0.5-1.5% based on fibre solids.
4. Locust bean gum: The increase in strength can be attributed to the high molecular weight of the gum, which encourages attachment to the fibres.

6.2.3.2 Hydrophobic substances

They can be classified as sizing agents, lignin, and waxes (Debnath et al., 2022).

1. Sizing agents: Alkyl ketene dimer (AKD) is a sizing agent added to the pulp slurry before forming and drying the product. In the past, aluminium sulphates were used, but problems arose when recycling the fibres.
2. Lignin: It is a phenolic resin that is one of the main components of wood. It is hydrophobic and is recommended when thermoforming a moulded product.
3. Waxes and emulsions: Emulsions of fatty acids like oleic acid and abietic acid can attach to fibre surfaces, making fibre products hydrophobic.

6.2.3.3 Flocculants

Based on the fibres used, there are two types of flocculants: virgin or recycled (Debnath et al., 2022).

1. Aluminium sulphate: Mostly used for virgin fibres to improve vacuum performance and facilitate efficient drainage, aluminium sulphate is beneficial for effectively retaining fine particles.
2. Copolymers of acrylamide: It bridges the macromolecular chains of fibers in suspensions and is useful in a pH range of 7 to 8.5.

6.2.4 Fibre moulding technologies

"Moulded pulp" refers to a type of three-dimensional packaging made from cellulosic fibres (Yam, 2009). In general, the manufacturing process involves depositing fibres onto a metal mould where vacuum, pressure, and heat are applied to shape them in a specific geometry (Semple et al., 2022). There are three primary methods of fibre moulding: wet, dry, and 3D. Table 11 compares wet and dry moulding.

Table 11. Moulding technologies comparison.

Wet- moulding	Dry- moulding
• Raw material: Pulp slurry. • More freedom in the design. • Suitable for more advanced barrier needs.	• Raw material: Cardstock or paperboard. • Energy and water efficiency.

6.2.4.1 Wet moulding

Wet moulding involves utilizing a dispersion of fibres in water and some additives as raw materials. There are two main steps involved in the process. Firstly, the fibres are shaped using vacuum-forming, during which the water is removed through vacuum suction, achieving a solid content of 20-30%. In the second step, the resulting product is dried until it contains up to 92% solids, removing the remaining water. In the manufacturing process, moulding tools are tailored to the geometry of the final product to shape the desired product (Didone, 2020)

The drying process follows the formation step. This can be categorized into two methods: plain and precision moulding. In plain moulding, the products are dried in an industrial oven. In precision moulding or thermoforming, heat is applied through moulds (Didone, 2020).Thermoforming produces high-precision, smooth, and thin-walled products. This technology is the most suitable for fibre trays intended for food products (Semple et al., 2022).

The process of manufacturing thermoformed pulp products involves multiple stages (Didone et al., 2017):

1. *Mixing*: Fibres are mixed with water and additives to enhance mechanical and barrier properties.
2. *Forming*: The pulp slurry is shaped by designed metal and perforated tools (moulds). The water is expelled by vacuum suction.
3. *Pressing and drying*: The remaining water is evaporated using a heated mould. Two molds press the intended product. Vacuum and pressure are necessary for a good bond between the fibres.
4. *Trimming*: The product is trimmed, and the protruding edges are removed.

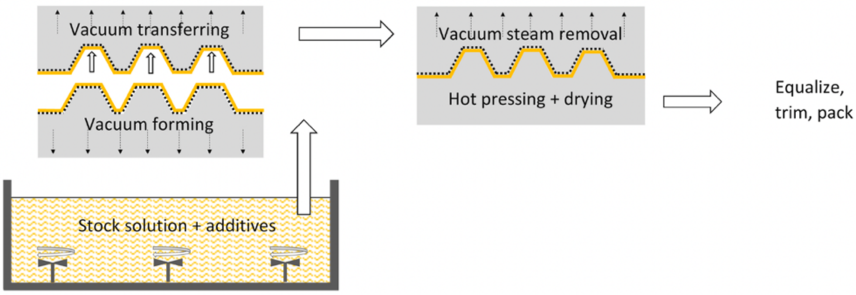

Figure 18. Wet- moulding: graphical representation of the thermoforming process (Semple et al., 2022)

6.2.4.2 Dry moulding

This method is designed to lessen the amount of water used, the drying time, and the energy consumption. It involves using defibrated cardstock or paperboard laminates as raw material. The fibres are then mechanically separated, air-laid into a pad, and sprayed with a food-grade biopolymer such as gelatine or guar gum. Then, the fibres are 3D-shaped using heat and pressure, and any excess material is removed before the final product is trimmed (Semple et al., 2022) .

The process can be described as follows (Pulpac, 2024; Yangi, 2023):

1. *Dry-raw material and defibration*: Cardstock or paperboard is used as the primary material to begin production. The material is then subjected to defibration, whereby the cellulose fibres are separated.

2. *Fibre formation*: The fibres are formed into a light and airy web by using a process called air-laid. A food-grade biopolymer can be sprayed in this step.
3. *Product forming*: The fluffy web or pad is 3D-shaped using heat and pressure to the cellulose fibres, creating the packaging product.
4. *Trimming and waste management*: The excess material is removed from the final product and reused in the process.

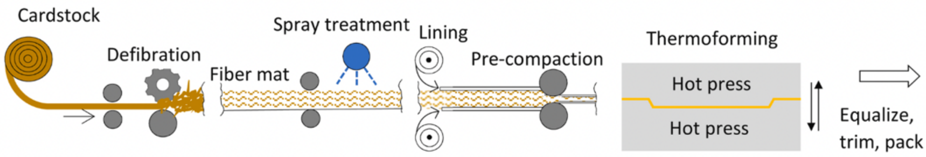

Figure 19. Dry-moulding: graphical representation of the process (Semple et al., 2022)**.**

6.2.4.3 3D printing

3D printing involves creating objects by adding layers of material based on a 3D model created using software. The raw materials used in this process are natural fibre composites, which are made by mixing natural cellulosic fibres with petroleum-based polymers or biopolymers such as PLE or PLA. These polymers need to be thermoplastics (Bi & Huang, 2022).

The addition of fibres as nucleating agents increases the rate of polymer crystallization. However, there is a challenge in achieving good bonding between the polymer and cellulosic fibres due to the difference in their affinity to water. Fibre modification is being used to enhance the bonding (Bi & Huang, 2022).

6.2.4.4 Moulding considerations

When producing a moulding pulp product, there are several factors to consider (Semple et al., 2022):

- In the wet moulding process, the length of time that the pulp is soaked in water affects the consistency and shape of the fibres. If the water retention is high, cellulose crystallinity will be lower.
- The excessive beating of the fibres can damage the fines that fill the void space in the food container. Porosity and permeability also affect barrier properties.
- The time it takes for a material to dry can impact its wall thickness and mechanical properties. If the moulding temperature is increased, the material becomes less porous because of increased crystallinity, reduced hygroscopicity, and better resistance to moisture absorption. Additionally, residual lignin can also help to reduce porosity.

6.2.5 Coating and Linings

Adding a barrier coating or lining to fibre-based packaging prevents oxygen, aromas, moisture, water, oil, and other substances from migrating into the food from the environment and vice versa.

To select the best barrier system for a food product, certain criteria must be considered: (i) understanding the stability of the food matrix is crucial in determining how a food product changes when exposed to various environmental factors such as oxygen, light, water, etc; (ii) environmental factors like temperature, light, relative humidity (RH%), storage conditions, etc; and (iii) ensure that the solution is compatible with the manufacturing process and preservation method to maintain its quality and safety (Johansson, 1993).

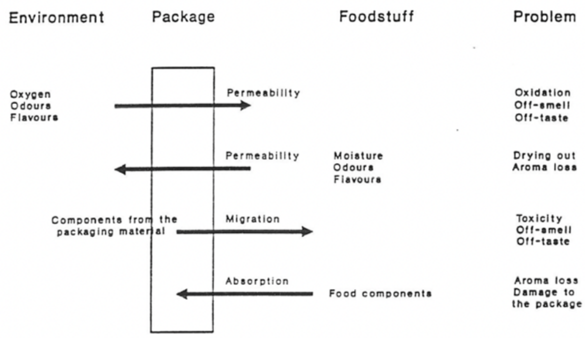

Figure 20. Interactions food product- packaging- environment (Johansson, 1993).

Ibrahiem & Khalifa (2016) categorized the barrier properties in terms of oxygen transmission rate (OTR) and water vapor transmission rate (WTRV) for food products. Table 12 summarizes the findings. This classification of barrier properties can aid food packaging manufacturers in selecting the most suitable packaging material for their products.

Table 12. Barrier classification. Adapted from (Ibrahiem & Khalifa, 2016).

Barrier classification	WVTR [$g/m^2/day$]	OTR [$cm^3/m^2/day/atm$]	Application
Low	>100	>100	Frozen foods, fruits, vegetables
Medium	6-100	6-100	Chilled foods
High	1-5	1-5	Dry Foods
Very High	<1	<1	Sensitivity products

6.2.5.1 Synthetic polymer

Petro-based polymers such as polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and polyolefins (POs) are popular due to their affordability, flexibility, and performance. These plastics are commonly applied by extrusion or lamination (Tyagi et al., 2021).

Table 13. Barrier properties of plastics. Adapted from (Tyagi et al., 2021).

Coating material	WVTR [g.mm/m^2/day]	OTR [cm^3.mm/m^2/day/atm]	Properties	Applications
HDPE	0.1-0.24	26.3-453	Humidity protection, rigid.	Moisture-sensitive products.
LDPE	0.39-0.59	98-453	Humidity protection, flexible.	Moisture-sensitive products.
PET	0.28	55	Heat resistance, grease barrier, moisture protection, and sealability.	Oven-heated trays.
EVOH	0.8-2.4	0.01.0.15	Excellent oxygen barrier and aroma protection.	Oxygen sensitive products.
PP	3.9-6.2	35-377	Heat resistance, grease barrier and moisture protection.	Microwave, oven-heated trays. For frozen foods.

A. Polyethylene (PE)

PE comes in LDPE and HDPE. LDPE is heat-sealable with a good moisture barrier, while HDPE is stronger, thicker, and less flexible. Both have poor oxygen and aroma barriers (Robertson, 2012).

B. Polypropylene (PP)

PP is highly durable and puncture resistant. It provides moderate resistance to water but a weak oxygen barrier. However, it has excellent heat and low-temperature resistance (Robertson, 2012).

C. Polyethylene terephthalate (PET)

PET has good barrier properties against lipids and water, but its oxygen barrier is lower than PE (Robertson, 2012).

D. Ethylene vinyl alcohol (EVOH)

EVOH provides excellent oxygen and carbon dioxide barrier but has weak moisture barrier (Robertson, 2012).

6.2.5.2 Bioplastics

Bioplastics have a broad definition. Those produced by renewable resources are not necessarily biodegradable, and biodegradable plastics are not necessarily made of renewable plastics (Asgher et al., 2020). Figure 21 aims to facilitate the definition of this type of material.

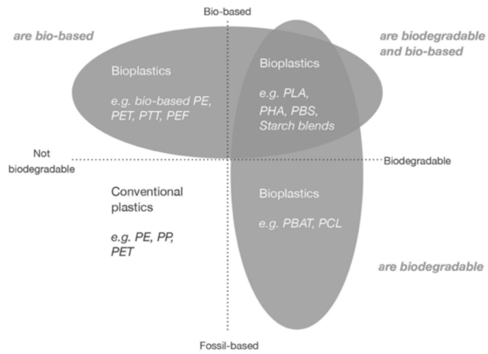

Figure 21. Bioplastics classification (European Bioplastics, 2022).

Table 14. Barrier properties of bioplastics (Tyagi et al., 2021).

Coating material	**Water Vapor Permeability [g.mm/m^2/day]**	**Oxygen Permeability [cm^3.mm/ m^2/day/atm]**	**Properties**	**Applications**
PLA	1.34	0.038-0.042	Moderate grease barrier.	Respiring products
PHB	0.23	0.42	Rigid. Good gas and moisture barrier.	Food dairy coatings
CNF	17	0.3	Good oxygen barrier.	Oxygen sensitive products.

A. Polylactic acid (PLA)

PLA is widely used because of its versatile performance. It can easily be combined with other materials, has a low cost, is transparent, and can be thermoplastic. PLA can be processed using various methods such as film casting, extrusion, thermoforming, film blowing, fibre spinning, injection moulding, and more (da Silva Pens et al., 2024).

The material is strong but lacks elasticity, which makes it prone to brittleness. It is moderately effective against oxygen (da Silva Pens et al., 2024). It has good resistance against water and oil but is sensitive to thermal degradation (Swetha et al., 2023). According to some studies, PLA may not be enough to safeguard high-oil-content products (Tyagi et al., 2021).

Due to its nature, PLA can be blended with antimicrobials, plasticizers, and other materials to improve its performance as a food packaging coating.

B. Polyhydroxybutyrate (PHA)

PHAs are hydrophobic thermoplastic polyesters produced by fermentation. PHAs have properties like LDPE in terms of barrier, printability, and heat sealability. There are more than 150 different types of PHA (Wayne-Tull, 2021).

Among PHAs, polyhydroxybutyrate (PHB) is the most representative due to its good performance as a gas barrier. PHB has better moisture and gas resistance than PP (Bulantekin & Alp, 2022).

However, PHA is characterized by being thermosensitive and brittle (Hong et al., 2021).

C. Starches

Starch is one of the most abundant and cheapest biomaterials. Mixed with a plasticizer such as glycerol, sorbitol, xylitol, etc., it improves flexibility, physical strength, oil resistance, and oxygen barrier. Since starch is sensitive to moisture, it must be modified to incorporate hydrophobic groups (Rastogi & Samyn, 2015).

D. Cellulose and derivates

Nanocellulose (NC) is obtained by chemical-mechanical modification of the cellulosic fibres. NC can be categorized as cellulose nanocrystals (CNCs) and cellulose nanofibrils (CNFs). Both CNCs and CNFs are less than or equal to 100nm in size, denser, have more crystalline regions, and are stronger than cellulose. It offers excellent mechanical and barrier properties to grease, water, gases, and volatile compounds. It is seen as a potential replacement for EVOH (Fotie et al., 2023).

6.2.5.3 Application technologies

A. Extrusion

Extrusion coating is the process by which a thermoplastic material is passed through a die to form a sheet. It can be explained in three parts: extrusion to melt the plastic, a die to form the plastic, and downstream equipment (pressure and back pressure roller) where the combination of pressure and temperature will adhere the plastic to the paper (Moody & Needles, 2004).

B. Lamination

Laminating combines two materials using an adhesive to bond them together. An adhesive must provide a strong bond, appearance, and good mechanical properties such as flexibility (if necessary). The adhesive must penetrate the material for a good bond and cover as much surface area as possible (Joshi & Butola, 2013).

C. Dispersion

Dispersion coating involves small polymer particles in water or another substance to create a coating. The liquid is applied to the surface of the paper or fibre packaging and dries to create a film that covers them. This type of technology creates a coating of less than 10% of the total weight, making the product recyclable in the paper stream (Notpla, 2023).

6.2.6 Challenges: Food safety and sustainability

3.3.6.1 PFAS

Per and polyfluoroalkylated substances (PFAS) are synthetic chemicals that have long been used in consumer products (National Institute of Environmental Health Sciences US, 2024). PFAS are used in paper food packaging to improve the barrier against moisture, water, and grease. The target applications are fatty foods and packaging that will be heated, such as popcorn, baking paper, take-out boxes, etc (OECD, 2020)

PFASs have been associated with adverse health effects, such as cancer, increased cholesterol, hormonal alterations, etc. Moreover, PFASs contaminate the food production cycle: from direct contact with food to drinking water, packaging disposal contaminating the soil, etc. This is because these molecules have strong carbon-fluorine bonds, so they are not easily degradable in the environment (Teli et al., 2020).

3.3.6.2 The recycling process of paper packaging

The paper recycling flow consists of five steps: (i) paper packaging is cut into smaller pieces; (ii) it is then mixed with water and the result is called a "dissolving drum"; (iii) the fibres are dissolved in water and separated from other materials such as plastic, adhesives, etc., (iv) the paper fibres undergo several filtration stages to purify them as much as possible and turn them into new packaging; (v) finally, the rejected goes to incineration (Näringslivets Producentansvar, 2024).

3.3.6.3 Sustainable Paper Packaging Design

Näringslivets Producentansvar (2024) has published some design guidelines to facilitate the recycling of paper containers.

1. Design packaging with easily identifiable material.
2. Use mono-material whenever possible and avoid mixing materials.

3. Avoid chemical products that modify the fibre to increase its strength or improve barrier properties.
4. Reduce or avoid the use of glues and adhesives. Use water-soluble adhesives.
5. Avoid inks with mineral oil hydrocarbons.

The World Packaging Association (WPO) has published guidelines for designing recyclable paper trays.

1. Prefer fibres from coniferous and deciduous trees. Non-wood fibres can interfere with paper recycling.
2. Uncoated and unlaminated paper is preferred. If using coated paper, only one side should be coated, and it should not exceed 15% by weight.
3. Mineral fillers like titanium dioxide and starch can be used as do not interfere in the recycling process.

6.3 Main remarks of the chapter

- Cellulose provides the strength in fibre packaging, while hemicellulose enhances interbonding between fibres, giving flexibility. Lignin can be used as a hydrophobic coating.
- There are three primary processes for pulping, which extract fibres and remove lignin. Mechanical pulping has a higher yield but produces short, weak fibres and does not remove lignin. Chemical pulping, on the other hand, produces longer and stronger fibres but has a lower yield. Semichemical pulping aims for a balance of higher yield than chemical and better fibre quality than mechanical.
- Some additives, such as binders or strength aids, hydrophobic substances, and flocculants, can improve the mechanical and barrier properties of fibre packaging.
- Fibre moulding can be classified as wet, dry, and 3D. Wet moulding uses pulp slurry as raw material, while dry moulding uses cardstock or paperboard. Among the benefits of dry moulding is better energy and water efficiency, but wet moulding provides more freedom in the packaging design.
- Coatings and liners are most often needed to ensure food safety and the long shelf life of food products. Fossil plastics perform better, while bioplastics present several technical and end-of-life limitations. If a plastic liner is used, it should be on one side only and not more than 10% of the container's weight.

7 Define: Product Design Specification

This section outlines the requirements for designing trays made of fibre that are compatible with Micvac technology.

"Design is the intermediary between information and understanding"

- Hans Hofmann.

7.1 Structure

This chapter addresses RQ2: *What are the requirements for designing a fibre-based package compatible with Micvac technology?*

The requirements were translated into a Product Design Specification (PDS) and are from or for four key actors: the fibre tray manufacturer, production, customers, and the food product itself.

To determine the requirements, insights from the Discover stage were used. This was complemented by Hosse's (2021) research thesis findings regarding requirements used during the product development process in Micvac. Figure 22 shows a better understanding of the methodology employed.

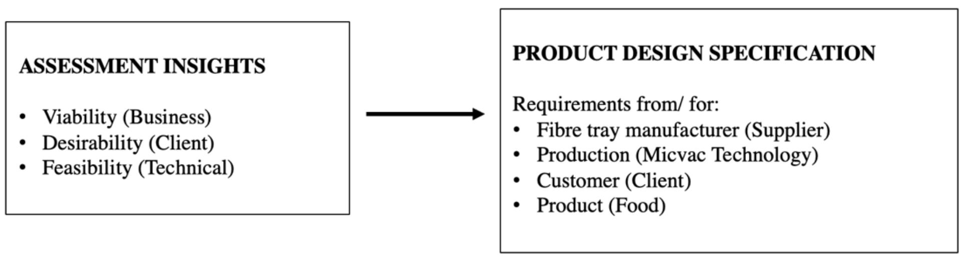

Figure 22. Outline of the PDS.

7.2 Results

Table 15. Product Design Specification.

	Requirements			
	Manufacturing	**Production**	**Customer**	**Product**
	To:		**From:**	
Definition	Fibre-tray manufacturer	Micvac technology	Food manufacturer and final consumer	Food matrix and packaging interaction
Performance	• Designed to work with the Micvac technology for in-pack microwave pasteurization. Intended to be used with a valve designed by Micvac	• Facilitates microwave pasteurization and ensure food safety	• Facilitates logistics and promotes sales. User-friendly enhancement	• Handle liquids and fatty foods • Must protect the product and avoid leaking • Increase shelf-life to at least 4-6 weeks
Application	Chilled ready- meals			
Design	• Fibre-natural color, avoid inks • Strong mechanical properties (tensile strength and elongation at break) • Tray weight: 20-30g	• Stackable • The top surface or sealing line must be flat and at least 0.5 cm wide	• The lid must be easy to peel off • Easy to grip • The surface should preferably be smooth • Designed to dining in	• Avoid sharp corners to prevent burned spots • The lid must allow the vapor release from the food

Cost	• No extra cost to final customer			
Size		• Max height: 6cm/ 2.3 inches *Recommended max height: 4cm/ 1.6inches* • Max width: 17cm/ 6.7 inches • Height should be minimized to allow cooking by microwave radiation	• Fit in storage spaces (warehouses, fridges) and shelves in supermarkets/ retail stores	• Fit in a conventional microwave and allow rotation
Material and material performance	• Pulps: Chemical or semi chemical • Linings and coatings: conventional plastics or biomaterials • Additives: comply with food and environmental regulation	• Must allow penetration of the microwaves • Both cellulose fibres and lignin/coating must withstand the temperature range (max: 121°C, min: -20°C) • Cannot get wet from the outside surface due to water vapor release in the tunnel processing	• Less amount of packaging material (if possible)	• Virgin fibres (food contact) • Effective humidity, oxygen, and grease barrier
Manufacturing	• Moulding technology: Dry or wet • Lining application: Dispersion or lamination	• It must withstand a processing time up to 10min	• Able to be reheated in a conventional microwave (up to 7min)	• Ingredients are placed raw into the tray

Safety	• PFAS Free • Regulation (EU) No 10/2011: *Plastic materials and articles intended to come into contact with food* • Regulation (EC) No 1935/2004: *Materials and articles intended to come into contact with food* • Commission Regulation (EC) No 2023/2006: *Good manufacturing practice for materials and articles intended to come into contact with food* • Council Directive 94/62/EC: *Packaging and packaging waste* • Avoid any substance declared in the REACH list			
Sustainability	• Efficient use of the resources according to internal policies	• Materials easy to identify and sort it out	• Able to be adapted to the different recycling systems in the EU. The lining could be: (i) peelable or (ii) attached to container (10% or less of plastic coating/linings)	• Avoid food waste
Storage	• Items should be stored between 5 and 35°C and protected from direct sunlight in a dry and dust-free environment		• Cold chain (0-4°C)	

As a general requirement, all the actors must comply with the food and packaging regulations and ensure food safety by avoiding the use of PFASs or any substance classified under the REACH list.

7.2.1 Fibre-tray manufacturer requirements

The manufacturer was defined as the actor responsible for producing the fibre-based tray.

The packaging design should prioritize recyclability by avoiding the use of inks, while also maintaining the natural color of the fibres. Additionally, the packaging must have strong mechanical properties to ensure the protection of the product and should not exceed a weight limit of 30g.

Options for the tray material include chemical or semi-chemical pulps, but virgin fibres must be used to ensure food safety. The tray could be manufactured using dry or wet moulding methods.

The packaging's barrier properties can be improved by incorporating coatings and liners. Furthermore, any modifications made to the fibres must comply with environmental regulations.

7.2.2 Production requirements

The production requirements were defined as the characteristics that the tray must have to operate properly with the Micvac technology components, particularly with the microwave tunnel.

The container design should enable stacking, feature a flat top surface that is at least 0.5cm wide to ensure proper sealing, and have a maximum height of 6 cm to fit in the tunnel and enable correct pasteurization. Additionally, the tray should not exceed a maximum width of 17 cm.

The cellulose fibres and coatings used in the tray must withstand a temperature range of -20°C to 121°C as the product follows a cold chain and reaches temperatures above 100°C during pasteurization. The container must be able to endure a processing time of up to 10 minutes during cooking.

7.2.3 Customer requirements

The food manufacturer and final consumer have specific requirements that aim to simplify logistics, improve sales, and ensure user-friendly use.

The tray's design should allow for easy gripping and serve as a plate. The container must fit in various storage spaces, such as warehouses, domestic refrigerators, and supermarket shelves. The lid should be easy to peel off, and the material used should be efficient and capable of withstanding microwave reheating for up to 7 minutes.

This is important as consumers need to heat the food before eating. The tray must also be able to handle cold chain temperatures to keep the food product fresh.

Regarding sustainability, the tray must be adaptable to different recycling systems. There are two options: the liner could be peelable or attached to the packaging. However, it cannot weigh more than 10% to make the fibre packaging recyclable in the paper stream. This depends on the recycling system of each country.

The final price of the tray should be comparable to the current plastic solution.

7.2.4 Product requirements

Product requirements are influenced by the food matrix and its interaction with the packaging.

It is crucial to have a tray that can handle liquid and fatty products, as many recipes include sauces or high-fat ingredients. Leakage prevention is important in such cases. One of the most significant features that Micvac customers value is the ability to extend shelf life. Therefore, the tray must contribute to increasing shelf life by at least 4-6 weeks, which requires effective barriers against moisture, oxygen, and grease.

The tray should not have sharp corners to avoid burn spots during cooking. Additionally, the lid should release steam from the food while cooking.

7.3 Main remarks of the chapter

- The tray can be made using either dry or wet moulding technologies and adding a liner to enhance its barrier properties is possible. However, the liner must meet certain requirements to ensure the tray is recyclable. Specifically, it should not weigh more than 10% of the container's total weight.
- The tray must meet certain size requirements to fit into the tunnel (Max height: 6cm/ Max width: 17cm). The top surface must be at least 0.5cm wide for proper sealing.
- The tray should not have sharp corners to avoid burn spots during cooking.
- The cellulose fibres must be virgin and able to withstand temperatures up to 120°C for food safety reasons.
- It must have excellent barrier properties against gases, humidity, and grease.
- The tray must improve the customer experience with a design that is easy to grip and eat in. It should also promote sales and logistics.
- The final price must be comparable to the current plastic solution.

8 Develop: Concept generation and evaluation

This section presents and evaluates the concepts generated using an evaluation tool.

"Design is thinking made visual" — Saul Bass.

8.1 Structure

This chapter aims to answer RQ3: *Which fibre packaging concept is most suitable for Micvac's technology?*

A product concept is the foundation of product development and includes technology, working principles, and aesthetics. It starts with target specifications and ends with selecting the best concept for a successful product (Ulrich et al., 2020). Figure 23 outlines the process carried out for this chapter.

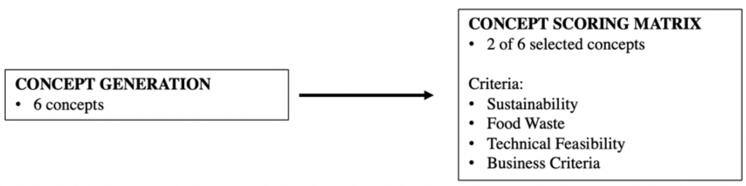

Figure 23. Concept generation and evaluation outline.

8.2 Results

8.2.1 Concept generation

8.2.1.1 Packaging concept generation

In the technical review, it was learned that one of the challenges of using fibres as a packaging material is their limited ability to act as a barrier against gases, water, and oil. Considering this, five of the six concepts generated incorporate a liner to ensure proper food handling.

This incorporation poses some challenges in its recyclability but also creates an opportunity to reduce the use of plastics in packaging solutions while still allowing the use of fibres as a material and improving sustainability.

To minimize the trade-offs between sustainability and food safety when incorporating a liner, some rules were established:

- It must not exceed 10% of the tray's weight. However, recyclability depends on each country's recycling system.
- The liner should prioritize plastics over bioplastics, as the majority of the current recycling systems in the EU cannot process some bioplastic and biodegradables.
- If an adhesive is needed, it should be water-based or compatible with the paper flow recycling system.

Furthermore, the concepts are planned to use moulding technology and virgin wood fibres as raw materials (avoiding blending with non-wood fibres) to refrain from any interference in the paper recycling process. The selection of fibre moulding technology (dry or wet) is based on the tray's ability to provide strong mechanical protection to the food product, sustainability, and cost.

Six concepts have been generated, and their definitions are summarized in Figure 24.

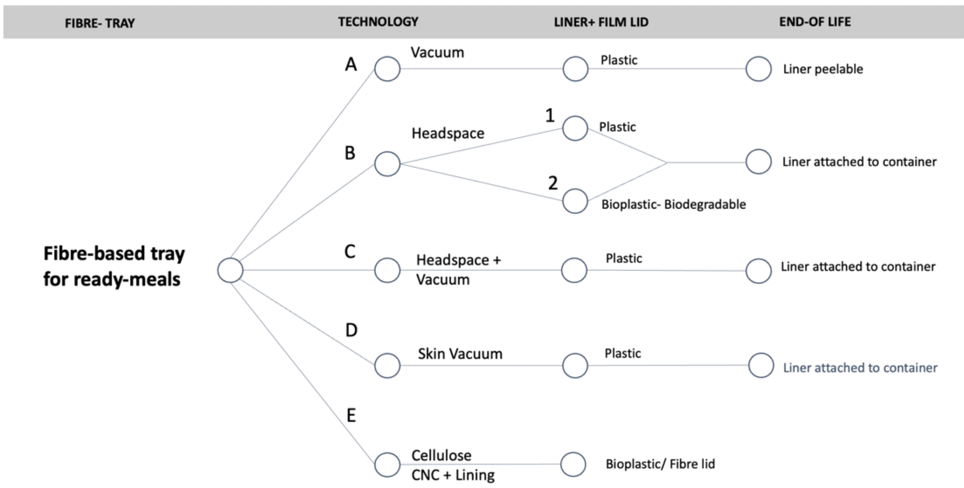

Figure 24. Concept classification tree.

1. Concept A

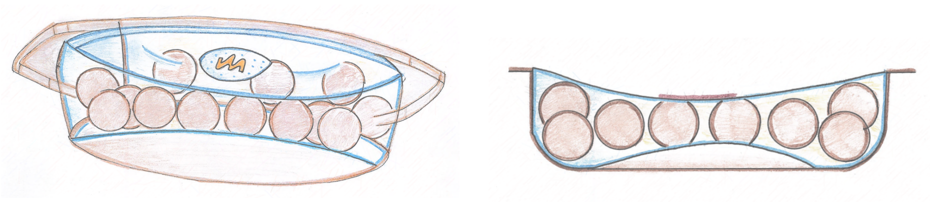

Figure 25. Fibre tray concept A.

Concept A consists of a fibre tray and a plastic liner capable of simulating a plastic bag that creates a vacuum. The idea is based on a plastic liner that is firmly attached to the walls but can be detached from the container's bottom. After pasteurization, the bottom coating will detach due to the expulsion of oxygen, creating a vacuum. The liner will be able to easily separate it from the tray. Therefore, the fibre tray should be placed in the paper bin, while the lining-bag should go in the plastics. The use of bioplastics is expected to be limited due to their flexibility constraints.

2. Concept B.1 and B.2

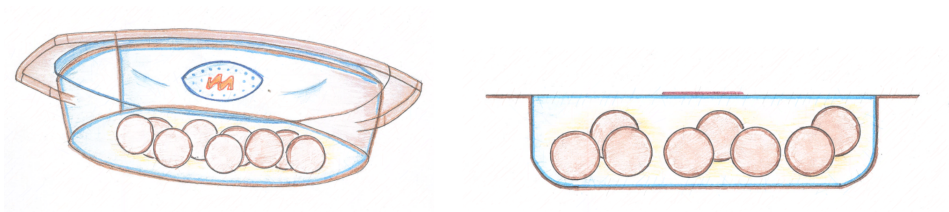

Figure 26. Fibre tray concept B.1 & B.2.

Concept B consists of a fibre tray and a plastic liner that leaves a headspace. A gas incorporation to fill the headspace is needed to reduce the rate of food spoilage reactions. The liner must be well attached to the fibre container and should not weigh more than 10% of the total weight. The lid should be easy to peel off and placed in the correct recycling bin. The plastic liner could be made of fossil plastics or bioplastics.

- **Concept B.1:** Liner made of plastics.
- **Concept B.2:** Liner made of bioplastics (biodegradable).

3. Concept C

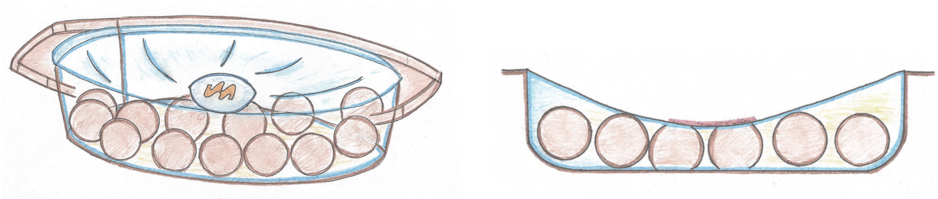

Figure 27. Fibre tray concept C.

Concept C seeks a combination of medium vacuum and headspace. The plastic liner will be adhered to the package. The lid of the film will be flexible so that when the valve is applied, it will pull down towards the food, expelling as much oxygen as possible. However, it will still maintain a minimum headspace. The liner used should not weigh more than 10% of the total weight.

4. Concept D

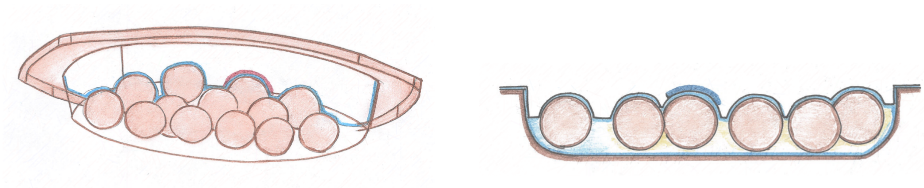

Figure 28. Fibre tray concept D.

Concept D is inspired by skin packaging technology. This means that the tray used in this concept will be shorter and only suitable for semi-solid and solid-ready meals. After pasteurization, a film lid will adhere to the food matrix, creating a vacuum.

5. Concept E

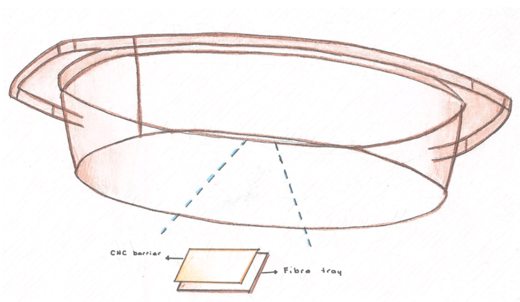

Figure 29. Fibre tray concept E.

Concept E employs cutting-edge material science to improve barrier properties with the inclusion of CNC. It eliminates the need for a plastic coating because cellulose nanocrystals provide an excellent oxygen and water barrier. This concept must be combined with either A or C.

8.2.1.2 NPD and Manufacturing Strategy

According to the viability assessment, selecting the appropriate technology supplier is important to success in the market. This is because most fibre packaging solutions are cutting-edge, with varying degrees of innovation, and are safeguarded by intellectual property. Therefore, three models were developed regarding new product development and manufacturing strategy.

	A	B	C
R&D/ Materials	Micvac	3rd party	3rd party
Tray Design	Micvac	Micvac	Micvac/ 3rd party
Machinery	3rd party	3rd party	3rd party
Manufacturing	In-house	In-house	Contract
Initial Investment	$$$	$$	$
IP	Micvac	Micvac/ 3rd party	3rd party

Figure 30. NPD and Manufacturing Scenarios.

1. **Model A**

The main advantage of this model is that Micvac will have the know-how of all aspects of packaging development, including materials, tray design, and manufacturing. Micvac can secure full intellectual property protection through various patents as the knowledge owner.

Micvac researches and selects suitable fibres and raw materials from suppliers to formulate a tray with tailored properties in this model. This allows more freedom in designing a product that is not yet supplied by third parties. However, the capital investment is high because it involves R&D consultancy, project specialists, and machinery and technology acquisition to set up the production plant. The manufacturing is in-house.

2. **Model B**

The model involves collaborating with a company that doesn't manufacture trays but has the technology and network to produce them. The goal is to minimize investment during the R&D phase (materials and machinery) and concentrate the efforts on the tray design.

Micvac will manufacture the trays and be free to design more models without relying on a third party, allowing them to expand their portfolio more easily while retaining knowledge. Another advantage is that Micvac has some degree of control over the sourcing process. Finally, in terms of initial investment, it is lower compared to model A.

3. Model C

In this model, Micvac will collaborate with a fibre expert to produce trays based on a joint design. This model requires the least capital investment compared to the other two options. However, it comes with the risk of losing significant knowledge and creates a dependency on the supplier's sourcing and services.

The key factor in choosing the right partner is not only the level of innovation in its product range, but also its co-development and technical support services, along with a dependable supply chain capable of adapting to various circumstances.

The main advantages are the technical support during the project's development and implementation at the lowest investment.

8.2.1.3 Packaging Development Economy

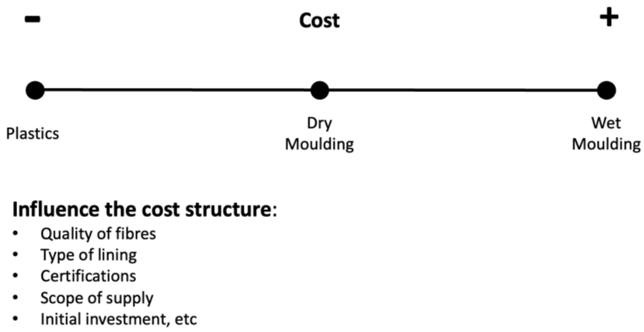

Figure 31. Moulding technology: economic comparison.

The cost of a fibre tray is determined by many factors other than the moulding technology used. The inclusion of a liner can increase it, and other components, such as the quality of raw materials, certifications, the initial investment required to manufacture the tray, etc., may also play an important role in determining the final cost. But considering that these factors will remain constant regardless of the moulding technology employed, it can be concluded that a tray manufactured with wet moulding technology will be more expensive due to energy and water consumption.

8.2.2 Concept Evaluation

Table 16. Concept evaluation.

Criteria	Weight	Concept A		Concept B.1		Concept B.2		Concept C		Concept D		Concept E	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
SUSTAINABILITY													
Separation and sorting	14.3%	4	0.568	2	0.284	1	0.142	2	0.284	2	0.284	4	0.568
FOOD WASTE													
Appealing appearance	14.3%	3	0.429	5	0.715	5	0.715	4	0.572	3	0.429	5	0.715
Shelf- life	14.3%	5	0.715	3	0.429	2	0.286	3	0.429	5	0.715	2	0.286
TECHNICAL FEASIBILITY													
Ease of manufacturate and sourcing	14.3%	3	0.429	3	0.429	2	0.286	3	0.429	3	0.429	2	0.286
Compatibility with Micvac technology	14.3%	4	0.572	3	0.429	3	0.429	3	0.429	3	0.429	3	0.429
BUSINESS CRITERIA													
Initial Invesment for Packaging Development	14.3%	3	0.429	4	0.572	2	0.286	3	0.429	3	0.429	2	0.286
Innovation & Protectable Intellectual Property	14.3%	4	0.572	2	0.286	3	0.429	3	0.429	2	0.286	4	0.572
	Total Score		3.714		3.144		2.573		3.001		3.001		3.142
	Rank	1		2		5		3		3		4	
	Continue?	Yes		Yes		No		No		No		No	

1. **Concept A**

Concept A has the highest score because of its separation and sorting benefits. Consumers will be able to easily separate the lining from the container and sort it into the correct bin. Additionally, it is expected to have a shelf life like the current Micvac solution because it is vacuumed. Furthermore, it is anticipated that only minimal modifications in the microwave tunnel will be required to make it work. Intellectual property rights can also protect the design.

2. **Concept B.1**

Concept B.1 has ranked second because it makes the food look more attractive. Additionally, this concept can be designed by a broad range of suppliers. The packaging design does not require a lot of resources for research and development, but it may require some adjustments in the microwave tunnel. The shelf life is estimated to be between 11 and 15 days (Spencer, 2005).

3. **Concept B.2**

Concept B.2 ranked the lowest due to its recyclability. This is because the concept aims to use bioplastics that are biodegradable, and most recycling systems are not able to process this type of material. This design does not allow for achieving a long shelf life and requires a high investment in the selection of the materials.

4. **Concept C**

Concept C has been ranked third. Its key feature is its improved appearance compared to other vacuum concepts. The packaging is made of composite materials, but the tray can be recycled in the paper stream. However, some modifications are required in the microwave tunnel and lid development to implement this design.

5. **Concept D**

Concepts D and C are ranked the same, but Concept D has a better shelf life despite its lack of innovation in design since similar concepts are already in the market. On the other hand, implementing Concept C requires modification in the microwave tunnel and allocation of R&D resources in the lid development.

6. **Concept E**

Concept E ranked fourth place. It is characterized by a high degree of innovation in material composition, incorporating CNC liners to avoid the use of plastic coatings. However, sourcing is risky since few companies supply this cutting-edge technology. Predicting the shelf life is quite challenging, and further evaluations are needed, as this is a novel technology.

8.3 Main remarks

- Concepts A and B.1 were selected as ideas for the next research phase. Concept A takes the vacuum as its basis, while Concept B.1 maintains the headspace with a controlled atmosphere.
- Different scenarios exist for developing and manufacturing the fibre tray, ranging from R&D of materials and in-house tray production to complete design and manufacturing outsourcing.
- Wet moulding appears to be a more expensive technology than dry moulding.

9 Deliver: Prototype

This section presents the project's practical outcome. It introduces the final prototypes and makes recommendations for scaling them up.

"An essential aspect of creativity is not being afraid to fail" - Edwin Land.

9.1 Structure

This chapter aims to answer RQ3 (a): *From the selected concepts, is it possible to create a prototype?*

Chapter 8 introduced the concept generation process and the criteria used to evaluate them. Two concepts were selected for further development. This chapter aims to create a high-fidelity prototype of the chosen concepts. To achieve this, several suppliers were contacted to learn about their commercial value proposition and obtain samples for testing. For confidentiality reasons, the names of the suppliers and a detailed evaluation of the items are not mentioned. However, some images with recommendations for scaling up the prototypes are presented in the results section.

9.2 Results

9.2.1 Concept A

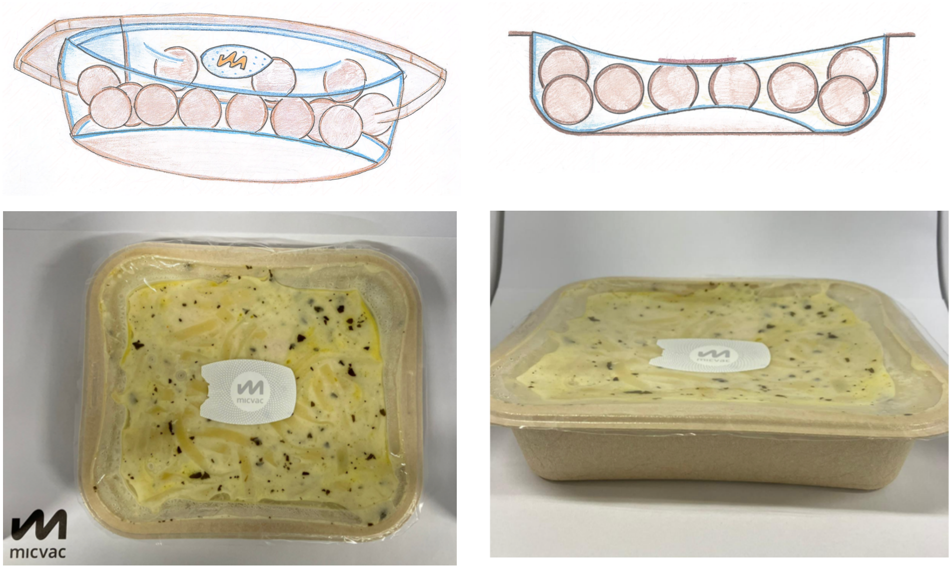

Figure 32. Prototype A.

This prototype is designed to mimic a fibre tray with a vacuum. It aims to showcase the potential of adapting the liner to enable vacuuming. The tray was manufactured using moulding technology and has demonstrated good mechanical properties through empirical testing. However, further exploration is recommended to ensure that the coating can adhere well to the walls but not to the bottom so that the vacuum can be more aesthetically pleasing.

Regarding food safety, the target microorganisms are anaerobic, with *Clostridium botulinum* being the one to be most careful with.

9.2.2 Concept B.1

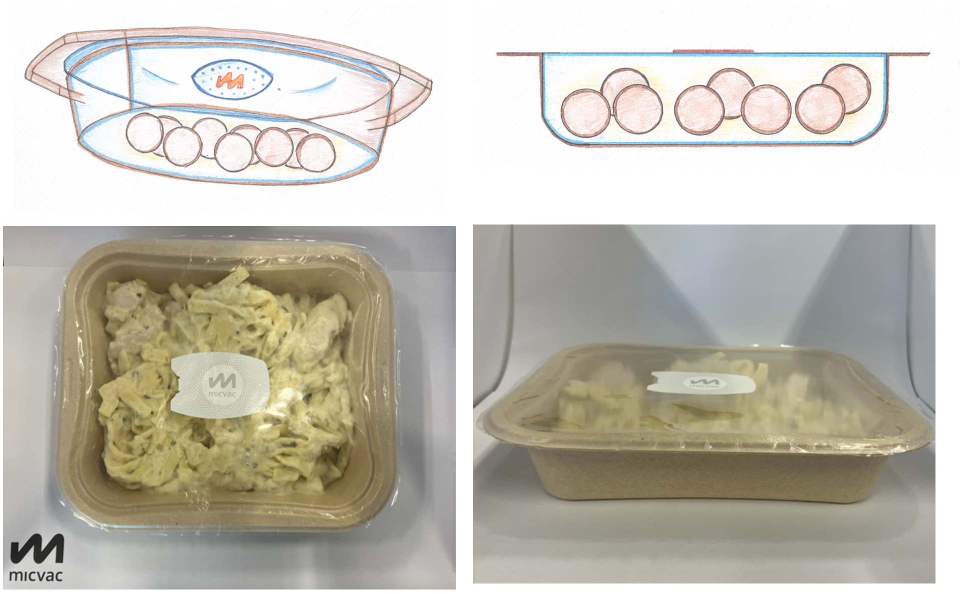

Figure 33. Fibre- tray with headspace.

This prototype is designed to simulate a fibre tray with headspace. As concept A, the fibre tray tested was manufactured with moulding technology. It is important to note that the headspace was filled with air from the atmosphere. However, to increase the shelf life of the food product, the headspace can be filled with other types of gases. The following is a summary of the different types of gases that may be used (Air Liquide, 2024):

- Nitrogen: It prevents oxidation and limits the growth of aerobic bacteria. It is an inert gas.
- Carbon dioxide: It stops the growth of most aerobic bacteria and mold. Nevertheless, CO_2 is absorbed by fats and water and becomes acidic the food.
- Oxygen: It avoids anaerobic conditions and maintains the fresh color of red meat.
- Argon. It is an inert gas and provides better control against the oxidation of flavor and color components (Spencer, 2005).

The mixture of gases is key to extending shelf life, as each has trade-offs. Some recommended gas mixes for ready meals are 30% CO_2 and 70% N_2 (Air Products and Chemicals, 2024).

Moreover, it is also important to target the spoilage microorganisms that may be presented in this concept:

- *Pseudomonas* species
- Lactic acid bacteria
- *Enterobacteriaceae*
- Yeast and mould

9.3 Main Remarks

- Two prototypes were developed and tested using Micvac technology. Positive results were obtained regarding the fibre performance.
- It was demonstrated that the liner can be adapted to achieve different designs, with or without a vacuum.

10 Conclusions

In this chapter, the study concludes by answering the research questions and elaborating recommendations for future research.

RQ1: Is fibre-based technology feasible, desirable, and viable as a primary packaging solution for ready meals?

(a): What is the business outlook for adopting fibre technology as a packaging solution in the ready meals industry?

The ready meals category is growing due to consumers' hectic and rapid lifestyles. Consumers are also increasingly aware of the importance of making healthy and sustainable food choices. Sustainability is especially linked to packaging, and consumers demand more environmentally friendly solutions. Most of them prefer plastic-free packaging. In addition, new EU regulations are being implemented to limit the use of plastic materials. Therefore, the ready meals sector represents a good opportunity to introduce innovative packaging solutions, such as fibre-based materials.

Choosing the right innovation partner and supplier for the fibre tray is critical due to the technical challenges of fibre materials. Different types of solutions have various levels of innovation, and the most innovative ones are protected by IP.

(b): Is fibre-based packaging a desired solution for ready-meals producers?

Ready-meal manufacturers are now emphasizing the efficient use of raw materials as their packaging strategy. Their main objective is to optimize the use of virgin plastic and promote recyclability through innovative packaging design. Therefore, although fibre packaging is not a top priority for producers now, it is still a potential solution that could play an important role in their medium—and long-term strategies.

Micvac's current clients and potential customers highly appreciate the technology's ability to extend the shelf life of their products and automate their production lines. Therefore, adding these features to the fibre solution would make it more attractive for ready meal producers to implement.

(c): Is fibre-based packaging technically possible in the foreseeable future?

Different fibre tray manufacturing solutions are available, such as cardboard, wet moulding, and dry moulding technologies. Each one offers different advantages in terms of price, packaging design, and sustainability. However, they all have poor barrier properties against humidity, gases, and grease. This can be improved by incorporating a liner.

There are different types of materials in terms of coating technology, such as plastics and bioplastics. Each has trade-offs, and their selection should be made according to the food matrix to be protected, the supply chain, the material's end-of-life, and its compatibility with the country's recycling system.

There is no general guideline on the maximum percentage of plastic lining to be incorporated to make the fibres recyclable, as it depends on each country. However, a good benchmark is up to 10% of the container's total weight.

Novel technologies such as CNC cellulose can be incorporated to avoid using liners.

RQ2: What are the requirements for designing a fibre-based package compatible with Micvac technology?

The requirements were classified into a Product Design Specification (PDS). Among the most important features of the tray must be the use of virgin fibres to ensure food safety and excellent barrier properties. Therefore, the incorporation of a liner is encouraged. The materials must be able to withstand temperatures up to 120°C and refrigeration temperatures. The design should avoid sharp corners to prevent burnt spots and have a flat surface on top to facilitate sealing. For the tray to fit in the microwave tunnel, it must not exceed 6cm in height and 17cm in width. The cost should be comparable to the current plastic solution.

RQ3: Among different fibre packaging concepts, what is the most suitable option for Micvac's technology?

Six concepts were generated. Concepts A and B.1 were selected. Concept A involves the adoption of a vacuum, while Concept B.1 has a headspace. Concept A scored highest due to the advantages of separation and sorting, shelf life, and higher technical feasibility of application. As for the B.1 concept, it offers a more attractive food aspect.

(a) From the selected concept, is it possible to create a prototype?

High-fidelity prototypes were built and tested under the Micvac Microwave Method.

Future research recommendations

Based on the thesis results, the following recommendations are made for investigation.

Firstly, conducting more in-depth qualitative research to assess desirability is important. Due to time constraints, the desirability assessment was based on input from commercial experts at Micvac. However, it is recommended that interviews be conducted with both ready-meal producers and consumers. In addition, it is useful to gather feedback on the concepts generated and explore ways to improve them. It is also recommended that other qualitative methodologies such as focus groups, shadowing, store checks, and so on be used.

Secondly, to ensure its efficacy, it is important to characterize and evaluate the performance of the fiber tray coating by migration analysis before and after microwave pasteurization and during shelf life. In addition, the fiber tray should be evaluated by mechanical testing to ensure product protection throughout the supply chain.

Finally, to fully assess the environmental impact of the final concept, it is essential to conduct a Life Cycle Assessment (LCA) that considers the product's entire life cycle, including raw material extraction, production, use, and disposal. This will provide valuable insight into the sustainability implications of the final concept. This must be complemented by the shelf life that the fiber packaging can provide to the food.

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Appendix A Time Plan

# Week	Month	Days	Objective	Milestone	Deadlines
1	January	15-19	A, C	Outline bibliographic research Market research on databases Bibliographic research	
2	January	22-26	A, C	Market research on databases Bibliographic research Supplier mapping Plan and outline client and stakeholders interviews	
3	January	29-02	A, C	Bibliographic research Supplier mapping and first contact Client and stakeholders interviews	
4	February	05-09	A, C	Bibliographic research Contact with suppliers Client and stakeholders interviews	
5	February	12-16	A, B, C	Summarise the findings of bibliographic, market and client research Contact with suppliers Product design specification development	Written report- Objective A and C
6	February	19-23		Product design specification development Concept development Mid- term presentation	Written report- Objective B
7	February	26-01	D	Concept development Mid- term presentation	
8	March	04-08	D	Concept development Scorecard or comparison framework development Mid- term presentation	8 March: Mid- term presentation
9	March	11-15	D	Fill out the comparison framework- Technical	
10	March	18-22	D	Fill out the comparison framework- Financial	
11	March	25-29	D	Fill out the comparison framework- Environmental	Written report- Objective D
12	April	01-05	E	Product specification development Working prototype	
13	April	08-12	E	Working prototype	
14	April	15-19	E	Working prototype	
15	April	22-26	E	Working prototype	Written report- Objective E
16	April	29-03		Final writing details for the master's thesis	
17	May	06-10		Final writing details for the master's thesis	
18	May	13-17		Potential submission final master's thesis submission	
19	May	20-24		Final presentation	
20	May	27-31		Improvement of master's thesis reports with supervisor's comments	31 May: Presentation of master's thesis- Lund

Figure A.1 Project Plan

Appendix B Methodology

B.1 Interviews outline to commercial experts at Micvac

1) Please tell me about your background (work experience) and your current position at Micvac
2) Could you tell me the main functions you perform in your current position?
3) In the sales journey, what would be the most challenging part? The easiest part?
4) What are the top 3 most common requirements/needs that a potential client looks for when evaluating a machine/ packaging solution?
5) In your opinion, what is the main challenge facing the packaging industry?
6) In a nutshell, could you tell me about the packaging strategy of your leads in terms of sustainability?
7) Have your leads shown concern about using plastic as a packaging solution? Do you know why?
8) Has any lead asked you directly for fibre-based solutions? Which ones?
9) What do you think is the most attractive feature to your leads about fibre-packaging/ more sustainable solutions?
10) Will you clients be able to pay an extra cost for a fibre-based solution for a similar performance to the current Micvac plastic solution?
11) Is there something would you like to add?

Activities

A. In this paper you will find different packaging trends. Please vote for the trends that in your perception *your leads* are following. You have 5 dot stickers to do so. You can assign 2 or more points to the same trend. It is not necessary to vote for all trends.

COST- EFFECTIVENESS	BIOPLASTICS	EDIBLE PACKAGING	COMPLIANCE WITH REGULATIONS
AI	FIBRES	INTELLIGENT AND ACTIVE PACKAGING	E-COMMERCE AND DELIVERT
DATA DIGITALIZATION FOR PACKAGING LOGISTICS	PACKAGING TO ACHIEVE CLEAN LABELS	PREMIUM AND LUXURY PACKAGING	QR & DIGITALIZATION
MONOMATERIAL DESIGN	CONVENIENCE & FUNCTIONALITY	CIRCULAR ECONOMY	MINIMALISM

B. I have 6 cards with different factors that may concern a prospective when adopting a more sustainable solution, can you rank them from the most important to the least? (Cost, regulatory framework, shelf- life & food waste, food safety, material performance, recycling performance)

COST	SHELF-LIFE & FOOD WASTE	MATERIAL PERFORMANCE
REGULATORY FRAMEWORK	FOOD SAFETY	RECYCLING PERFORMANCE

B.2 Evaluation tool

Table B.2 Evaluation tool.

AREA	CRITERIA	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Sustainability	**Separation and sorting**	Packaging consits of composite material that does not allow for material separation	Packaging consists of composite material/ several material layers that are separated in the existing recycling process	Packaging consists of several materials that consumers can easily separate before sorting (3 or more different materials)	Packaging consists of two materials that consumers can easily separate before sorting	No need for separation and sorting. Monomaterial or returnable packaging that is part of an organized deposit system
Food Waste	**Appealing appearance**	Invisible meal. The material is not transparent. The consumer cannot see what is inside	Mashed appearance with not well-defined elements	Mashed look	Restaurant plating with a mashed appearance of some elements	Restaurant plating
	Shelf- life	Less than 5 days	5-10 days	11-20 days	21-45 days	Plus 45 days
Technical feasibility	**Ease of manufacturate and sourcing**	Materials and technology are in the research phase. No commercial sourcing yet	Materials and technology are commercially available, but suppliers are limited. Product design requires R&D significant resources	Material and technology are comercially available. Product requires R&D resources	Materials and technology are widely available on the market. Product design requires minimal R&D resources	Materials and technology are widely available on the market. Product design does not require R&D resources
	Compatibility with Micvac technology	Technology needs to be redesigned.	Tunnel requires significant modification (50- 80%). Valve requires redesign.	Tunnel requires modification (20-50%). Current valve solution works for the concept	Tunnel requires modification (<20%). The current valve solution works for the concept	Concept can be scaled up by using current tunnel and valves solutions
Business criteria	**Initial Invesment**	Maximal invesment.	The concept requires packaging consultants, research and prototyping project.	The concept requires packaging consultants and a prototyping/ application development project.	The concept requires a prototype/application development project.	Minimal invesment.
	Innovation & Protectable Intellectual Property	The concept shows no degree of innovation. No protectable by IP	The concept shows incremental innovation.	The concept shows sustaining innovation.	The concept shows radical innovation.	The concept shows disruptive innovation. It is fully protectable by IP

B.3 Weight criteria

Figure B.3 Weight criteria.

Criteria	Weight
SUSTAINABILITY	
Separation and sorting	14.3%
FOOD WASTE	
Appealing appearance	14.3%
Shelf- life	14.3%
TECHNICAL FEASIBILITY	
Ease of manufacturate and sourcing	14.3%
Compatibility with Micvac technology	14.3%
BUSINESS CRITERIA	
Initial Invesment for Packaging Development	14.3%
Innovation & Protectable Intellectual Property	14.3%