The biodegradable straw

Investigating how enzymes can be used to enhance desired product qualities of drinking devices.

Charlotte Parnefjord Gustafsson and Hanna Liang

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MASTER THESIS

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Abstract

The increasing production of single-use plastics negatively affects the climate. The resulting plastic ocean debris has fatal consequences to marine life. As a result, the European Parliament has placed a ban on single-use plastics by 2021, making it essential to study sustainable materials for single-use products such as straws. Previous research has investigated how enzymes can be used to catalyse reactions in food processing. However, little research has explored the use of enzymes to biodegrade the material of single-use straws or drinking devices. This thesis aims to investigate how different designs and material combinations using enzymes can enhance both the environmental profile and user experience of drinking devices.

Interviews with 24 experts at Tetra Pak Packaging Solutions AB and the Division of Biotechnology at Lund University were conducted to gain insights into industry needs and material development. Moreover, a questionnaire based on Kano Analysis was performed to study consumer preferences regarding features of drinking devices. Statistical methods were used to analyse the results from the 308 respondents and target specifications were established for the product development.

Based on a literature study, interviews and consumer preferences, multiple material combinations and designs were developed and evaluated. The final recommendation is a fibre-based drinking device with a PHB surface treatment with encapsulated enzyme. The purpose of surface treatment is to improve the moisture resistance and mouthfeeling. Furthermore, the role of the enzyme is to increase the biodegradation rate of the PHB. The suggested design is an ergonomically shaped mouthpiece for increased stability and control, reducing potential spilling. A theoretical multiple linear regression model is developed as a proposal for evaluating the biodegradation of the bioplastic surface treatment. Further experimental testing is needed with the material combination, prototyping of the final product design as well as the theoretical biodegradation model.

Keywords: *biodegradable, bioplastics, drinking devices, enzymes, fibre material, PHA, product design, statistical analysis, straws.*

Sammanfattning

Den ökande produktionsvolymen av engångsplaster har negativ påverkan på klimatet. De resulterande havsplastföroreningarna har omfattande konsekvenser för marint liv. Som ett resultat har Europaparlamentet infört ett förbud mot engångsplaster till år 2021, vilket gör att det av grundläggande betydelse att studera alternativa och hållbara material för engångsprodukter som sugrör. Tidigare forskning har undersökt hur enzymer kan användas för att katalysera reaktioner i livsmedelsbearbetning. Däremot finns det mindre forskning om hur enzymer kan användas för att bryta ner material för engångsbruk. Detta examensarbete har som syfte att undersöka hur olika designs och materialkombinationer med enzymer kan förbättra både sugrörens miljöprofil samt användarupplevelse.

Intervjuer med 24 experter genomfördes på Tetra Pak Packaging Solutions AB och avdelningen för bioteknik vid Lunds universitet för att få insikt om branschens behov och om materialutveckling. Dessutom togs ett frågeformulär fram baserat på Kano-analys för att studera konsumenternas preferenser gällande sugrörs olika funktioner. Statistiska metoder användes sedan för att analysera resultaten från de 308 respondenterna och därefter fastställdes målspecifikationer för produktutvecklingen.

Baserat på litteraturstudie, intervjuer och konsumenternas behov, utvecklades och utvärderades flera lösningar. Den slutliga rekommendationen består av ett fiberbaserat sugrör och en PHB-ytbehandling med inkapslat enzym. Syftet med ytbehandlingen är att förbättra fuktbeständigheten och munkänslan. Enzymets roll är att öka den biologiska nedbrytningshastigheten för PHB. Den föreslagna designen är ett ergonomiskt format munstycke för ökad stabilitet och kontroll, vilket minskar potentiellt spill. En teoretisk multipel linjär regressionsmodell föreslås utvecklas för att göra en utvärdering av biologisk nedbrytning av den bioplastiska ytbehandlingen. Ytterligare experimentella tester behövs gällande materialkombinationen, prototyputveckling av den slutliga produktdesignen samt den teoretiska biologiska nedbrytningsmodellen.

Nyckelord: *biologisk nedbrytbarhet, bioplaster, enzymer, fibermaterial, PHA, produktutveckling, statistisk analys, sugrör.*

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This master's thesis was conducted in collaboration with the department New Materials for Openings and Closures at Tetra Pak Packaging Solutions AB and Lund University Faculty of Engineering. The project provided us with invaluable experience in project management, material development and innovation. We are truly grateful for everything we have learnt during this time.

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Thank you!

Lund, June 2020

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Hanna Liang

The biodegradable straw - Investigating how enzymes can be used to enhance desired product qualities of drinking devices.

The increasing ocean debris from single-use plastics has fatal consequences to marine life. As a response, the European Parliament imposed a ban on single-use products, such as straws, by 2021. The new regulations are making it essential to study alternative sustainable materials. Although paper straws have become a popular substitute, product qualities such as sogginess are reducing consumer satisfaction. Furthermore, little research has identified how enzymes can be used to enhance the desired qualities of straws. In this thesis, the possibilities of using enzymes to create a biodegradable and user-friendly straw are investigated.

Through interviews with experts in the packaging industry and biotechnology, challenges and opportunities in utilising enzymes for drinking devices are discussed. Mainly, the analysis suggests that there is a potential for using bioplastics as a surface treatment to a paper-based drinking device. Current paper straws quickly become soft and wet during use and a bioplastic surface treatment is a potential solution. Bioplastics have similar properties to fossil-based plastics but also offer additional advantages as they are biodegradable and biobased. A potential to utilise encapsulated enzymes in the surface treatment was identified to increase the rate of biodegradation before recycling.

To identify consumers' preferences about drinking devices, a survey was conducted with 308 respondents. Safety, moisture resistance and flavourless were identified as the most important features of a drinking device. In addition, recyclability and biodegradability are shown to be of high importance according to the respondents.

Based on the interviews and the survey responses, several designs and material proposals for environmentally- and user-friendly drinking devices are suggested and discussed. A theoretical mathematical model is developed as a proposal for how to model the biodegradation rate of the material combination. An outline is also given for how to use a mathematical model for analysing how much an enzyme can speed up the biodegradation process.

The study identifies the potential of using a PHB surface treatment on a fibre-based drinking device with encapsulated enzymes, see Figure 1. The suggested drinking device design is an ergonomic mouthpiece that creates control during use to prevent spillage. Once the drinking device touches the liquid, the encapsulated enzymes will start to biodegrade the bioplastic surface treatment.

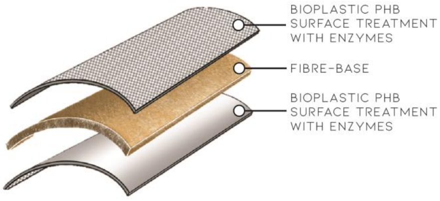

Figure 1. Final design proposal for the biodegradable drinking device

Popular scientific summary of the master's thesis The biodegradable straw – Investigating how enzymes can be used to enhance desired product qualities of drinking devices. *Charlotte Parnefjord Gustafsson and Hanna Liang, 2020.*

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List of acronyms and abbreviations

A	anti-feature
BIC	bayesian information criterion
D	desired
E	exciter/delighter
F	frequent user
I	infrequent user
M	mid-frequent user
MLR	multiple linear regression
N	neutral
PHA	polyhydroxyalkanoates
PHB	polyhydroxybutyrate
PHBH	poly(hydroxybutyrate-co-hydroxyhexanoate)
PHBV	poly(hydroxybutyrate-co-hydroxyvalerate)
PP	polypropylene
Q	questionable
R	required
UX	user experience

1 Introduction

What are the challenges of creating an environmentally and user-friendly drinking device? This chapter presents the background for the new material development of drinking devices in single-use packaging as well as the research gap, purpose, research questions, delimitations and finally the outline for the thesis.

1.1 Background

The production of plastics, particularly single-use plastics, does not only clog landfills and threaten marine life but also accelerates climate change (WWF, 2019). Most plastic materials are derived from fossil fuels and the process of extracting, transporting and manufacturing plastics creates millions of tonnes of greenhouse gas emissions each year (WWF, 2019). In response to this problem, the European Parliament introduced new regulations in March 2019 to ban single-use plastic products such as plastic straws by 2021 (Europarl.europa.eu, 2019). As a global producer of food- and beverage packages, Tetra Pak has a key role in reducing the amount of plastic waste from packages. Not only are regulations coming from the European Parliament, but consumers are also demanding more sustainable packaging (Gutierrez, Royals, Jameel, Venditti & Pal, 2019; Tetra Pak, 2019a). Therefore, there is a growing need to study sustainable alternatives to single-use packaging materials.

To reduce plastic consumption and waste production, Tetra Pak has increasingly studied alternative packaging materials, such as fibre-based materials and different kinds of natural polymers. The challenge with these materials is to create a sustainable and feasible product solution which consumers will want to use. At the same time, the material of the package must ensure food safety. “Protects what’s good” is still the number one priority of Tetra Pak (2020a). Furthermore, there is a strong interest from Tetra Pak to develop biodegradable packaging materials (Tetra Pak, 2019b).

When it comes to single-use products, a lot of media attention has focused on plastic straws. Although this is only a small part of the plastic waste caused by single-use products, it is a start. While there are numerous straws of alternative materials on the market, consumer satisfaction and functionality of these straws can be improved.

In the scope of this study, drinking devices are tools for consuming liquid from packages. This study is particularly looking at developing a drinking device for a single-use package such as Tetra Pak’s Tetra Brik® Aseptic 200 Base package (see Figure 1.1).

Enzymes have long been used in other industries for desired functions, such as in medicine or dairy production (Homaei, Sariri, Vianello & Stevanato, 2013). There is hence an interest from the packaging industry to study how enzymes can be used to create more environmentally friendly packaging materials. However, in the packaging industry enzymes have yet to be introduced on a large scale. The hypothesis is that materials combined with designed enzymes, i.e. enzymes developed for a particular purpose, can improve desired qualities like biodegradation of packaging material. The role of the enzyme will thus be to facilitate biodegradation of the materials.

Figure 1.1 Tetra Pak Tetra Brik® Aseptic 200 Base package

1.2 Research Gap

Paper straws have become a popular substitute to plastic straws (Gutierrez et al., 2019). Previous research has studied the challenges of paper compared to plastic straws, where the main challenge being that paper straws become soggy after a short time of use (Gutierrez et al., 2019; Tetra Pak, 2019). There are studies looking into alternative materials such as bamboo straws, starch, glass and metal. Many of these alternatives are good substitutes for plastics straws. However, for single-use packaging it is not preferable to use more expensive and reusable straws made of metal or glass. Additionally, the more natural alternatives like starch and bamboo can be harder to biodegrade and process than paper. Additionally, more research is needed to investigate how enzymes can be used to help the biodegradation of alternative materials. Therefore, this research aims to investigate how enzymes can be used to improve desired product qualities of fibre-based drinking devices. The final recommendations from this master thesis will be valuable for the packaging industry as well as academia and important in the development of environmentally friendly drinking devices.

1.3 Purpose

The purpose of this thesis is to design both a user- and environmentally friendly drinking device for Tetra Pak's Aseptic single-use packaging. Both a material combination and a final design will be suggested. Additionally, this thesis investigates how regression models can be used to evaluate the biodegradation rate of the material combination.

1.4 Research questions

The research questions of this thesis are the following:

1. What are the main opportunities and challenges in industry and academia for developing biodegradable drinking devices utilising enzymes?
2. What are the principal consumer needs in designing a commercially viable drinking device?
3. How can the rate of biodegradation of alternative materials be modelled using linear regression?
4. What are some alternative material combinations and designs that would fulfil consumer and industry needs?

1.5 Delimitations

Firstly, the research is limited to the use of fibre materials and their possible treatments with enzymes. Although alternative materials such as algae, starch etc. are known, the research will mainly focus on fibre-based drinking devices. The reason being that fibre materials are natural and widely accessible with extensive previous knowledge of its uses in the packaging industry.

Secondly, the research will not focus on the production process of such a material or drinking device. The limitations imposed by existing production lines and machines will not be considered at this stage.

Thirdly, since this thesis has an explorative approach with the aim to inspire the development of biodegradable materials, the focus of the research is on the material itself and not on the cost to produce it.

Lastly, due to external circumstances, such as Covid-19, experimental testing of enzymes and biodegradation are not conducted.

1.6 Outline of the Thesis

The remainder of this thesis is organised into the following chapters:

Chapter 2. **Method –** Firstly, the research approach is outlined describing the Two-Track Unified Approach through a Technical track and Design track, analysing both the material development and the design features for the drinking device. Secondly, the data collection and analysis methods in the form of interviews and questionnaires are presented. Lastly, the validity and reliability of the study are discussed.

Chapter 3. Theory – In this chapter an introduction to fibre-based materials is outlined. The definitions and differences between biobased, disintegration, biodegradation and compostability are presented along with a brief understanding of how various polymers can be used as surface treatment. In addition, an introduction to the industrial uses of enzymes is offered. Lastly, the theory of Kano Analysis, the statistical hypothesis testing and multiple linear regression is described.

Chapter 4. Industry needs and considerations – This chapter presents the results from 24 interviews with specialists from the packaging industry and scientists in biotechnology. Mainly, the opportunities and challenges of developing an environmentally friendly drinking device are discussed.

Chapter 5. Mapping consumer-needs – This chapter presents the results and statistical analysis of the responses to the Kano questionnaire. In addition, consumer ideas for the product development of drinking devices are reviewed.

Chapter 6. Targets and Requirements – In this chapter, the main challenges and opportunities from the industry and academia are summarised. Furthermore, consumer-needs regarding the design features are specified and ranked based on importance scores and preferences. These lead to the target specifications for the final development of the drinking device.

Chapter 7. Technical and material development – This chapter presents the potential material combinations based on the previous chapters and suggests one combination for further development. A theoretical multiple linear regression model is developed as a suggestion for how to evaluate the biodegradation rate of this material combination.

Chapter 8. Design development – This chapter outlines the mood board for the drinking device. Furthermore, seven design concepts are presented with advantages and disadvantages. In addition, feedback from the packaging industry for the design concepts are discussed and ranked on a three-point scale. Lastly, the final design concept is presented.

Chapter 9. Discussion and conclusion – This chapter discusses the process, findings and limitations of this thesis by answering the research questions. Finally, recommendations for future research are outlined.

2 Method

This chapter describes the methodology for the product development process using a Two-Track Unified Process with consideration of both design and technical aspects. The research approach, data collection and analysis methods are described along with the validity and reliability of the research.

2.1 Research Approach

The approach of this thesis was a problem-solving study (Höst, Regnell & Runeson, 2006) to find a solution for creating a user and environmentally friendly drinking device for single-use beverage packaging by utilising enzymes. Firstly, literature reviews were conducted to identify findings from already established research in the fields of packaging materials and enzyme technology. To better suit the problem-solving study and create structure in the research process, a customised model was developed by the authors. The reason being that the problem statement required a two-track solution, looking both at the material combination as well as the product design. Therefore, a Two-Track Unified Process was used as the general approach for this study (see Figure 2.1). In the product development process of the drinking device, two main tracks were identified in need of consideration: the material considerations (*Technical track*) and the overall product design (*Design track*).

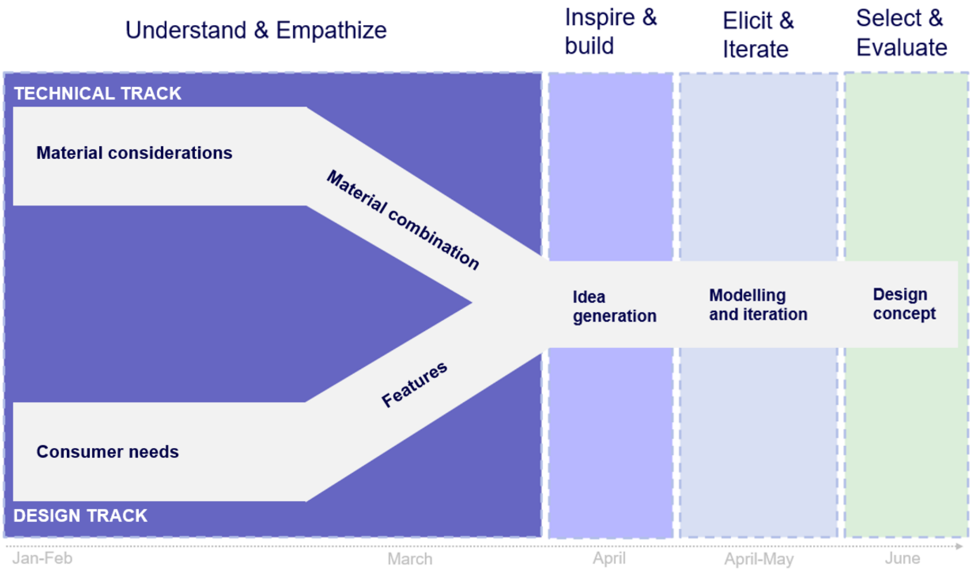


Figure 2.1 Two-Track Unified Process for the development of a fibre-based drinking device. Design thinking model made by authors, inspired by Interaction Design Foundation (2020) and Tetra Pak (2020).

The *Technical track* offered insight into what was physically feasible and relevant for the packaging industry. Qualitative data was gathered from semi-formal exploratory interviews with a range of professionals at Tetra Pak and researchers in biotechnology. The main purpose was to gain an understanding of current opportunities and challenges in the material development of the biodegradable drinking device. The *Design track* contributed to insights about consumer attitudes towards the product features. A questionnaire based on a Kano Analysis (see Ch. 3.2) was used to identify the desired features from a user-experience (UX) perspective. The results from the questionnaire were analysed using statistical tests: binomial, Kruskal-Wallis and Wilcoxon rank-sum tests.

The two tracks led to target specifications for the product features and potential materials of the drinking device. Material combinations were proposed and evaluated. Furthermore, a multiple linear regression model was discussed for further analysis of the biodegradation of the material combinations. The proposed model was based on a literature review of applications of multiple linear regression models on experimental data and discussions with statistical experts at Tetra Pak. Moreover, several design proposals were generated and evaluated on a three-point scale based on the target specifications. Feedback was received from development engineers at Tetra Pak to improve and iterate the design of the drinking device. Lastly, the authors gave suggestions for designs and recommendations for future development.

2.2 Data Collection and Analysis Methods

The study was initiated by gathering secondary data from a literature review to build the research on already available knowledge, minimising the risk of overlooking pre-existing knowledge (Sekaran & Bougie, 2016; Höst et al., 2006). After an initial literature study, interviews and questionnaires were conducted for the data collection following the next two sections.

2.2.1 **Interviews**

Primary data was gathered through a qualitative pre-study in the form of interviews. The interviews were conducted with a semi-structured format with flexible diversions where deemed fit (Martin & Hanington, 2012). The main purpose of conducting interviews was to gather information about material development and product design to understand the opportunities and limitations of developing a biodegradable drinking device. There are several benefits for conducting interviews. Firstly, the interviews support the explorative approach where the interviewers can adapt the questions and clarify any doubts (Sekaran & Bougie, 2016). Secondly, interviews offer experts' perspectives of the topic and nuances are easier to notice compared to other methods, e.g. surveys (Martin & Hanington, 2012). Thirdly, it offers new insights and gives possibilities to receive contact details to additional relevant specialists who could help in the data collection.

Interviews were conducted with 24 specialists in academia and industry with various expertise (see Appendix B Table B.1). The interviewees were chosen based on their field of specialisation and were often recommended to the authors by previous contacts or supervisors. As preparation for each interview, a meeting agenda was created with a few main themes, normally consisting of around 3-5 questions or topics. The interviews lasted between 30-60 minutes each, primarily with one note-taker and one interviewer. The interviews were conducted either in person or on a video call. During some of the interviews, more than one specialist was being interviewed.

After each of the interviews, the meeting notes were directly transcribed into a collective document. Additionally, the authors debriefed after each meeting and compiled ideas and suggestions for further research. After all the interviews had been held, the main topics were identified in the form of challenges and opportunities for the material development of the drinking device. The main topics were chosen based on relevance and the number of times they had been mentioned by various experts.

2.2.2 **Questionnaire**

A questionnaire was constructed to gather data on consumer needs and preferences of features of drinking devices (see Appendix C.1). The questionnaire gathered information on the consumers' side to understand which product traits of a drinking device were desirable. The benefits of a using a questionnaire are primarily that it enables gathering large quantities of data in a limited time frame (Martin & Hanington, 2012; Ejvegård, 2012). Secondly, since all respondents answer the same questions, it enables the comparison of the answers from a statistical approach (Ejvegård, 2012). Thirdly, a questionnaire is beneficial when looking for data regarding people's attitudes, thoughts and opinions (Martin & Hanington, 2012; Ejvegård, 2012) which was valuable in the product development process.

The questionnaire was based on a Kano Analysis study (see Ch. 3.1.1). Kano Analysis was chosen since it can be used to determine in what way product features generate consumer satisfaction and which features have the greatest impact (Martin & Hanington, 2012). The questionnaire included six parts (see Appendix C.1):

(1) Demographics

(2) UX for straws

(3) Kano: physical features

(4) Kano: Surface feeling

(5) Kano: Environmental and material aspects

(6) Ideas and suggestions.

Where parts (1) and (2) gathered information about the respondents' habits and parts (3), (4) and (5) collected data for the Kano analysis, identifying the respondents' preferences for specific features. Specifically, 12 main features were analysed, chosen based on literature reviews and discussions with experts in design thinking and packaging materials. The 12 main features included in the questionnaire were: *bendable*, *biodegradable*, *flavourless*, *recyclable*, *reusable*, *safe*, *separate*, *smooth*, *soft*, *soggy*, *stiff* and *wrapped*. The last part of the questionnaire, part (6), allowed the respondents to give suggestions of features and feedback on the survey itself.

Four pilot tests were conducted with chosen respondents before sending out the questionnaire to a larger sample. The pilot tests offered the opportunity to receive feedback and comments on the precision and relevance of the questions in the questionnaire. The pilot tests were also conducted to ensure that the questionnaire was well understood by respondents (Sekaran & Bougie, 2016). The target group of the questionnaire was a wide range of people within various professions, ages and locations. The main forum used to send out the questionnaire were different Facebook groups, LinkedIn and through a network of connections.

Once the data had been gathered, the primary analysis was made based on continuous Kano Analysis (see Ch. 3.1.1.), giving an overview of the categorisation of features and the spread of the responses. To gain further insight, the data was split into different demographics based on how frequently the respondents used straws: Frequent users (F), Mid-frequent users (M) and Infrequent users (I). From a product development perspective, it is important to find the most important features of the targeted demographic. In this case, all three groups were targeted and common important features were of special interest to design an appealing drinking device to all groups. Statistical tests were used to study differences between the demographics, which led to the selection of features to include in the product development. The advantage with using statistical analysis is that it gives more robustness to the analysis compared to simple visual analysis or tallying. It also allows a product development process to be based on quantitative analysis as a complement to qualitative analysis. The computer program R was used in all statistical analysis of the questionnaire. The detailed explanation of the statistical tests is given in Ch. 3.2.2.

2.3 Validity and reliability

To ensure that information from the interviews had not been misinterpreted, the analysis of the interviews was sent for review to three selected interviewees from Table B.1 in Appendix B. To further gain reliability, statements from the interviews were cross-referenced with literature or other experts in the same field.

Regarding the questionnaire, conducting a user-experience questionnaire online does not give the same value as conducting in-person user testing. The respondents may have answered some questions too quickly without fully considering how they would feel using the product. To prevent this issue, clarifications of the answer options and terms in the questions were provided.

3 Theory

This chapter describes the theoretical frameworks and concepts in the product development process for the biodegradable drinking device. The technical track includes the description of the material side of the development and how multiple linear regression can be used to evaluate the biodegradability of materials. The design track describes the Kano Analysis and the statistical methods used to evaluate the questionnaire.

3.1 Technical track

3.1.1 **An introduction to fibre-based materials**

Paper can be described as a network of natural fibres (Persson, 1996). A fibre is a single elongated part of a given material that has an approximately round cross-section and is often twisted with other fibres to form a thread. In the processing of paper for product development, the reactions between fibres and water are essential (Persson, 1996). The extent to which the fibre can absorb water can be affected through chemical and mechanical processing (Persson, 1996). The water absorbance of the fibres affects the moisture resistance as well as the ability to laminate the surface.

The hydrophobic properties of a fibre material are dependent on the amount of air in the pores between the fibres (Kungliga Tekniska Högskolan, 1992). The water can partially penetrate the fibres and partly fill the pores (Kungliga Tekniska Högskolan, 1992). If fibres are not fully saturated with water, they are normally highly hygroscopic, meaning they easily attract water molecules (Kungliga Tekniska Högskolan, 1992). For products used in liquids, such as straws, the effect can quickly turn the products soggy (wet and soft) during use.

Surface treatment can be added to prevent the absorption of liquids and to alter the surface qualities of the paper, such as glossiness and smoothness. When treating fibre-materials, the surface of the fibre-material is pressed together with a liquid substance and then dried. Technically, any application to a paper surface can be considered a surface treatment. Surface treatments tend to fill the void and hollow areas of the paper, thus preventing water absorption (Smook, 1982), see Figure 3.1.

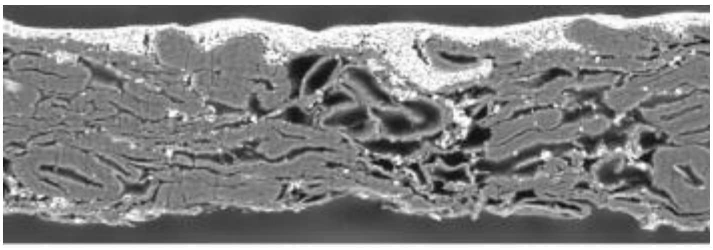


Figure 3.1 Visualisation of the surface treatment of fibre material, where the treatment layer appear as bright material (Dahlström, 2012)

3.1.2 Biodegradation of biopolymer surface treatment

Paper can be treated by a mixture of materials or polymers to improve certain surface qualities. The environmental profile of polymer alternatives should be considered when selecting a surface treatment. To improve the conventional plastic straws, biobased and biodegradable alternatives are of interest. However, the terms biobased, disintegration, biodegradation and compostability can easily be mixed up. Therefore, it is important to first distinguish between the definitions of these terms.

A material is biobased if it is made from renewable biological sources. The sources can be of agricultural origin, plant, animal, fungi, microorganisms, marine or forestry materials living in a natural environment in equilibrium with the atmosphere (Narayan, 2016). Moreover, fossil-based materials are not included in the definition of biobased material. One important consideration is that a biobased material is not necessarily biodegradable or compostable within a reasonable timeframe (Narayan, 2016). Disintegration refers to whether a material falls apart over time and is therefore strongly linked to the thickness and density of the material (OWS, 2020).

Biodegradation is the chemical process in which materials break down into the natural elements water, carbon dioxide and biomass with the help of microorganisms (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016). Biodegradation can be facilitated by enzymatic and/or fungal activity (Deconinck & De Wilde, 2013). Furthermore, the biodegradability of a material does not depend on its origin, but rather on its chemical structure (European-bioplastics, 2016). Technically, all materials can biodegrade, the difference is at what rate and in which environments. The distinctions and connections between conventional, bio-based and biodegradable polymers or plastics can be seen in Figure 3.2.

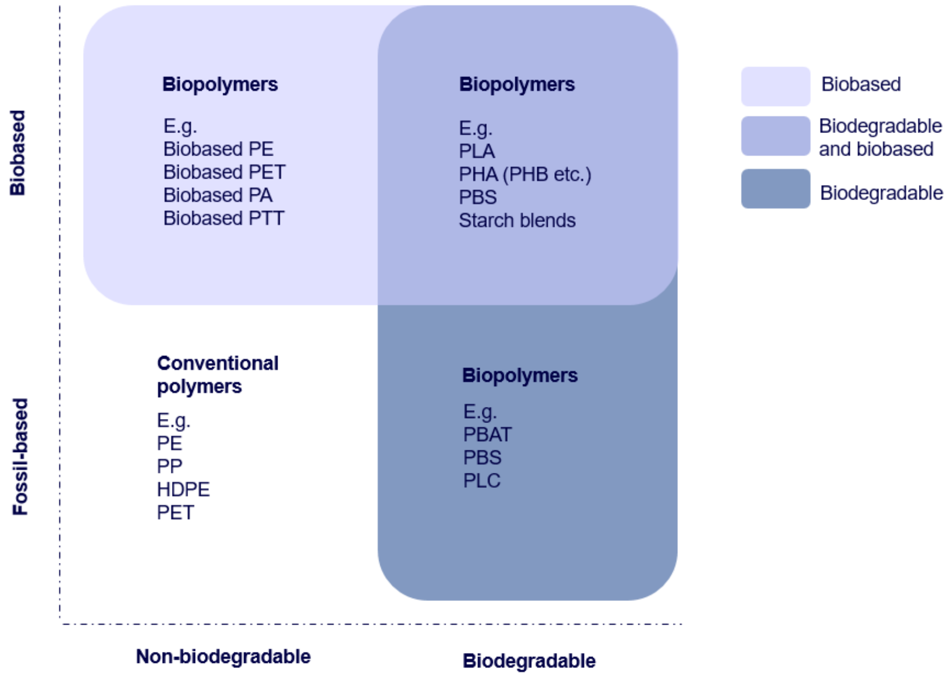


Figure 3.2 The distinctions and connections between conventional, bio-based and biodegradable plastics. Figure is made by authors and inspired by European-bioplastics (2019).

Bioplastics are a type of biopolymers and are plastic materials that are derived from biological substances rather than petroleum. They are either biobased, biodegradable or both (European-bioplastics, 2020). Bioplastics have the same properties as conventional plastics (e.g. PE, PP, HDPE and PET) and offer additional advantages such as reduced carbon footprint and alternative waste management options such as composting. Biobased biopolymers (e.g. biobased PE, biobased PET, biobased PA and biobased PTT) offer identical properties to their fossil-based counterparts but with reduced carbon footprint and can be mechanically recycled in existing recycling streams. Alternative materials such as PHA, PLA cellulose or starch-based materials offer completely new functionalities, for example biodegradability and compostability and in some cases optimised barrier properties (European-bioplastics, 2019).

Regarding the general biodegradation process of biopolymers in room conditions, the aerobic degradation process should be considered. The process is called aerobic if oxygen is present. In this process, the carbon is converted into carbon dioxide (CO_2) and water (H_2O). Some of the carbon from the sample (C_{sample}) will remain as residuals ($C_{residuals}$) whereas some will become biomass ($C_{biomass}$), as shown in Equation (3.1) (Deconinck & De Wilde, 2013).

$$C_{sample} + O_2 \longrightarrow CO_2 + H_2O + C_{residual} + C_{biomass} \quad (3.1)$$

The difference between a compostable- and biodegradable material is that a compostable material biodegrades within a certain time frame and under certain environmental conditions, e.g. temperature and pH (European-bioplastics, 2016). The time frame and environmental conditions are specified by international standards and certifications for compostability. Hence, compostable material is always biodegradable. However, biodegradable material is not necessarily compostable (Deconinck & De Wilde, 2013).

There are several internationally recognised standards and certifications for biodegradability and compostability. Most of the widely accepted international certifications are based on the European standard EN 13432 "Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for the final acceptance of packaging". According to EN 13432, a material is industrially compostable and hence biodegradable if the following requirements are fulfilled (European Committee for Standardization, 2000).

- Biodegradation: In maximum 6 months, at least relative 90% of the material must have been broken down to carbon dioxide.
- Disintegration: after 12 weeks, no more than 10% of the original dry weight can remain when the remaining residuals are sieved through a 2.0 mm sieve.
- Additionally, tests for ecotoxicity and heavy metals content must be performed.

Materials can be certified to be biodegradable in three main environments: soil, water or marine (Tuv-at.be, 2020). To fulfil the certification for soil environments the product must be guaranteed to completely biodegrade in the soil without adversely affecting the environment (Tuv-at.be, 2020). Water biodegradation guarantees biodegradation in a natural freshwater environment and contributes to the reduction of waste in rivers, lakes or any natural freshwater. Lastly, marine biodegradation ensures that the product can biodegrade in sea waters (Tuv-at.be, 2020).

3.1.3 **Enzymes**

Enzymes are used in the food, agricultural, cosmetic, pharmaceutical and other industries to speed up and control reactions (Sepmag, 2020). For example, enzymes are crucial to making cheese, brewing beer, extracting fruit juice etc (Sepmag, 2020). Enzymes can accelerate the reaction rate of cellular metabolism of living microorganisms. Therefore, it is of interest to study the contribution of enzymes in the biodegradation of biopolymers (Jayan, Moses, & Anandharamakrishnan, 2018; Sepmag, 2020; Banerjee, Chatterjee, & Madras, 2014).

During the biodegradation of polymers in a solution with an enzyme, firstly the enzyme diffuses from the solution to the surface of the polymeric material. Then the enzyme gets adsorbed on the surface and catalyses the biodegradation reaction. Lastly, the products of the biodegradation reaction are released into the solution. Banerjee et al. (2014) argue that studying the biodegradation kinetics helps to better understand the biodegradation mechanism to predict the performance of the polymer degradation by a specific enzyme. To biodegrade the polymer, the enzyme needs to interact with the material. Therefore, a material can be biodegraded better with higher permeability i.e. higher levels of water uptake (Banerjee et al., 2014). The rate of biodegradation can be measured in multiple ways, such as weight loss or the production of CO_2 (Shah, Hasan, Hameed, & Ahmed, 2008).

3.1.4 **Multiple linear regression**

Multiple linear regression models (MLR) can be utilised to understand how biodegradation of biopolymers are simultaneously influenced by multiple experimental conditions, e.g. temperature or pH (Tang, Qi & Krieger-Brockett, 2005; Gordon, Huang, Burns, French & Bruckman, 2018). MLR can give information about whether there is a significant association between the rate of biodegradation and an experimental condition. Additionally, MLR can be used to determine which experimental condition has the greatest influence on the rate of biodegradation. This section gives a brief theoretical background on MLR, how non-linear data trends can be modelled with splines and how to evaluate the quality of the model. For more detailed information see James, Witten, Hastie & Tibshirani (2014) or Hastie, Tibshirani & Friedman (2017).

As shown in Equation (3.2), MLR assumes there is a linear relationship between a response variable Y and explanatory variables $X = X_1, \ldots, X_p$.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \varepsilon, \quad \varepsilon \sim N(0, \sigma^2) \qquad (3.2)$$

In this context, the response variable is the biodegradation rate of biopolymer and the explanatory variables are the experimental conditions. The model coefficients $\beta = \beta_1, \ldots, \beta_p$ quantify the association between the explanatory variables X and the response variable Y. The interpretation of a coefficient β_j is the average change in Y for one unit increase in X_j, when all other explanatory variables are constant. The variable ε is the random deviation assumed to have a normal distribution with standard deviation σ. Furthermore, ε_i is assumed to be independent and identically distributed. Given experimental data $(y_i,\ x_{i1}, \ldots, x_{ip})$, the coefficients are estimated by the least-squares method. This is equivalent to minimising the residual sum of squares (RSS), defined by:

$$RSS = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2, \; i = 1, \dots, n, \qquad (3.3)$$

where n is the total number of data points. Furthermore, $\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_{i1} + \hat{\beta}_2 x_{i2} + \cdots + \hat{\beta}_p x_{ip}$ is the predicted value of y_i and $\hat{\beta}_j$ is an estimation of β_j.

A hypothesis test can be used to determine if there is a significant association between the response and the explanatory variables. If there is no association between the variables, $\beta_1, \dots, \beta_p$ will be 0. For an introduction about hypothesis testing, see Ch. 3.2.2. The null- and alternative hypothesis are given by:

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_p = 0, \; H_A: \text{at least one } \beta_j \neq 0 \qquad (3.4)$$

This hypothesis test is performed by computing the *F*-statistic, given by:

$$F = \frac{(TSS - RSS) \,/\, p}{RSS / \,(n - p - 1)} \qquad (3.5)$$

where *TSS* is the total sum of squares $\sum_{i=1}^{n} (y_i - \bar{y})^2$. Under the null hypothesis, the *F*-statistic is assumed to have a $F_{p,n-p-1}$ distribution. Knowing the $F_{p,n-p-1}$, the p-value can be calculated and H_0 can be accepted or rejected in favour of H_A.

Often, the true underlying relationship between *Y* and *X* is not linear. For example, the biodegradation rate can be very slow for low temperatures and increase rapidly for high temperatures. Using a purely linear model would lead to poor explanatory and predictive power. To solve these issues, the MLR model needs to be extended with non-linear regression methods. A common method is spline regression. The approach is to split *X* into different regions and fit polynomials of different degrees, basis functions, on each region. The breakpoints between the regions are called knots and *K* is the number of knots. Spline regression allows an MLR model to include flexible non-linear patterns in the data and is widely applicable in regression modelling (Perperglou, Sauerbrei, Abrahamowicz & Schmid, 2019). For example, Gordon et al. (2018) use splines when modelling the influence of photodose on the degradation of colour, gloss and haze in Polyethylene terephthalate (PET). A regression model with one explanatory variable, X, and splines can be represented by:

$$Y = \sum_{q=0}^{Q} \alpha_q h_q(X) = \alpha_0 + \alpha_1 h_1(X) + \alpha_2 h_2(X) + \dots + \alpha_Q h_Q(X). \qquad (3.6)$$

Where $h_1(\cdot), \dots, h_Q(\cdot)$ are basis functions, $\alpha_0, \dots, \alpha_Q$ are the associated spline coefficients and Q is the number of basis functions. There are several options for the choice of basis functions. A popular option is natural cubic splines which have the basis functions:

$$
\begin{aligned}
h_1(X) &= 1 \\
h_2(X) &= X \\
h_3(X) &= X^2 \\
h_4(X) &= X^3 \\
h_{k+3}(X) &= (X - \tau_k)_+^3, \ k = 1, \ldots, K,
\end{aligned} \tag{3.7}
$$

where τ_k is a knot and $(X - \tau_k)_+^3 = (X - \tau_k)^3$ if $X > \tau_k$ and 0 otherwise. Using the same format as in Equation (3.6), and assuming there are three knots (τ_1, τ_2, τ_3), a regression model with natural cubic splines looks like the following:

$$
\begin{aligned}
Y = {} & \alpha_0 + \alpha_1 X + \alpha_2 X^2 + \alpha_3 X^3 + \alpha_4 (X - \tau_1)_+^3 + \alpha_5 (X - \tau_2)_+^3 + \\
& \alpha_6 (X - \tau_3)_+^3
\end{aligned} \tag{3.8}
$$

The natural cubic spline imposes constraints, not only on the continuity between the breakpoints, but also linearity beyond the boundary knots. This produces estimates with less variation, making natural cubic splines a favourable choice of basis functions.

To evaluate how well the model fits the data, there are various methods and criteria. Every model criterion has its advantages and drawbacks, and no single criterion should be relied on solely by itself. From literature study, common model criteria are Bayesian information criterion (BIC), R_{adj}^2 and cross-validation. BIC and R_{adj}^2 are favourable to use since they are easily interpreted. For example, the model with the lowest BIC should be chosen when assessing if an additional explanatory variable improves the model.

$$
BIC(p) = n \log(\textstyle\sum_{i=1}^{n} (y_i - \hat{y}_i)^2 / n) + \log(n)(p + 1). \tag{3.9}
$$

Meanwhile, R_{adj}^2 gives a proportion between 0 and 1 for how much of the variance in the data is described by the model. Hence, a high R_{adj}^2 value is desired.

$$
R_{adj}^2 = 1 - \frac{RSS/(n - p - 1)}{TSS/(n - 1)} \tag{3.10}
$$

Both BIC and R_{adj}^2 penalizes the inclusion of many variables in the model to avoid a very complex model with poor predictive capabilities, i.e. overfitting. To gain direct insight into the predictive capabilities of a model, cross-validation is favourable to use, even though it is computationally intensive. Cross-validation works by splitting the data into a training- and test set. The model is then fitted on the training set and predicted on the test set. The idea is to see how well the model can predict on data it has never seen before. When the set of observations are divided into *k* groups or folds of approximately equal size, the method is called *k*-fold cross-validation. The first fold is used as a test set and the model is fitted on the remaining *k-1* folds. The Mean Square Error (MSE) given by Equation (3.11) is then calculated. This is repeated k times with a different group of observations used as a test set each time. Typically, k is chosen to be 5 or 10 to have a reasonable computational time.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2. \tag{3.11}$$

$CV_{(k)}$, which is the average MSE can then be calculated by:

$$CV_{(k)} = \frac{1}{k} \sum_{i=1}^{k} MSE_i \tag{3.12}$$

When comparing models using cross-validation, the model with the lowest $CV_{(k)}$ should be chosen.

3.2 Design track

3.2.1 **Kano Analysis**

To understand the consumer needs for product development, a Kano Analysis was carried out to evaluate which features of a drinking device has the greatest impact on consumer satisfaction (Martin & Hanington, 2012). This is done by assigning each feature to five main categories: Required, Desired, Exciter/delighter, Neutral and Anti-feature (Martin & Hanington, 2012).

- **Required features** are baseline features that must be included in the design of the product. Features in this category may not necessarily increase consumer satisfaction, however, its absence will have a negative impact.
- **Desired features**, also called One-dimensional features, have a linear relationship with consumer satisfaction. When the feature is included the perceived value will go up, if absent the perceived value will go down.
- **Exciter/delighters** will generate consumer satisfaction by fulfilling unspoken consumer needs and desires. However, unlike the Required features and Desired features, its absence will not create a negative impact on consumer satisfaction.
- **Neutral features** will neither impact consumer satisfaction positively nor negatively.
- **Anti-features** negatively impact consumer satisfaction and should actively be prevented in the design of the product.

An overview of the Kano Model and its categories is displayed in Figure 3.3 (Borgianni, 2018; Jen & Bueso, 2010; Martin & Hanington, 2012; Pheng & Rui, 2016).

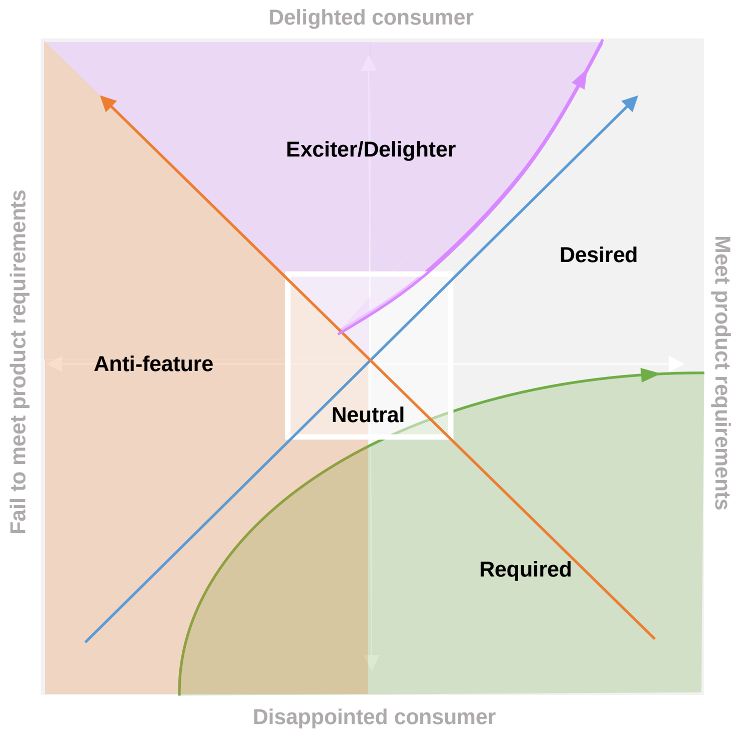


Figure 3.3 Displays the Kano Analysis and how attributes can be divided into five categories Required, Desired, Exciter/Delighter, Neutral and Anti-feature. The figure is made by the authors, based on the theory of the Kano Model from Martin and Hanington (2012).

The features are divided into the five categories based on consumer responses on how they feel if the feature was present or not present. This was done by asking a **functional** and a **dysfunctional** question. For example, a **functional question** is "If the drinking device is *bendable*, how would you feel?". While a **dysfunctional question** is "If the drinking device is not *bendable* (i.e. straight), how would you feel?". For both the functional and the dysfunctional question, the participant can choose between the following answers (Borgianni, 2018; Jen & Bueso, 2010; Pheng & Rui, 2016):

- I really like it
- It must be this way
- I don't care/ I am neutral
- I can tolerate this/ I can live with it
- I dislike it

For each feature, the combined answers of the functional and dysfunctional question place the feature in one of the five categories as shown in Table 3.1 (Borgianni, 2018; Pheng & Rui, 2016). Additionally, to get a better overview of the spread in the responses from a Kano Analysis, a continuous approach can be taken where the answers are scored according to Table 3.1.

Table 3.1 Categorization of a feature according to answer options to functional and dysfunctional questions. The answer options are scored based on DuMouchel (1993).

		DYSFUNCTIONAL				
		Like (-2)	**Must be (-1)**	**Neutral (0)**	**Live with (2)**	**Dislike (4)**
FUNCTIONAL	**Like (4)**	Questionable	Exciter/ delighter	Exciter/ delighter	Exciter/ delighter	Desired
	Must be (2)	Anti-feature	Neutral	Neutral	Neutral	Required
	Neutral (0)	Anti-feature	Neutral	Neutral	Neutral	Required
	Live with (-1)	Anti-feature	Neutral	Neutral	Neutral	Required
	Dislike (-2)	Anti-feature	Anti-feature	Anti-feature	Anti-feature	Questionable

Note that in Table 3.1 and in Figure 3.4, a Questionable category has been added. A response is categorised as Questionable if it implies the respondent has not understood the question or the definition of the feature (Borgianni, 2018). For example, if the respondent answers “I really like it” to both the functional and dysfunctional question, there is a contradiction and the response is categorized as Questionable.

Based on the scored answers, the mean ($\bar{x}$) and standard deviation (σ) of the functional and dysfunctional questions can be calculated for each feature according to (Körner & Wahlgren, 2010):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{3.13}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}, \tag{3.14}$$

where n is the total number of respondents and x_i is the answer score (-2, -1, 0, 2, 4). By calculating means and standard deviations, a measure of spread in the answers can be obtained. An advantage of using a continuous approach is that it allows for an easier graphical presentation (DuMouchel, 1993).

In addition to the functional and dysfunctional questions, a third question for the feature can be asked weighing the perceived importance (DuMouchel, 1993). The importance question asks the respondents to rank the feature on a Likert scale, where

1 is unimportant and 7 is very important. The importance score represents how important it is for the respondent that the feature is included in the product (DuMouchel, 1993). It can be used to compare the relative importance of features which have the same category (DuMouchel, 1993).

From the mean scores, a Kano Analysis can be graphically visualised into a grid representing the categories Desired, Exciter/delighter, Neutral, Anti-feature as shown in Figure 3.4 (DuMouchel, 1993). The diameters of the circles are proportional to the mean importance score of the features.

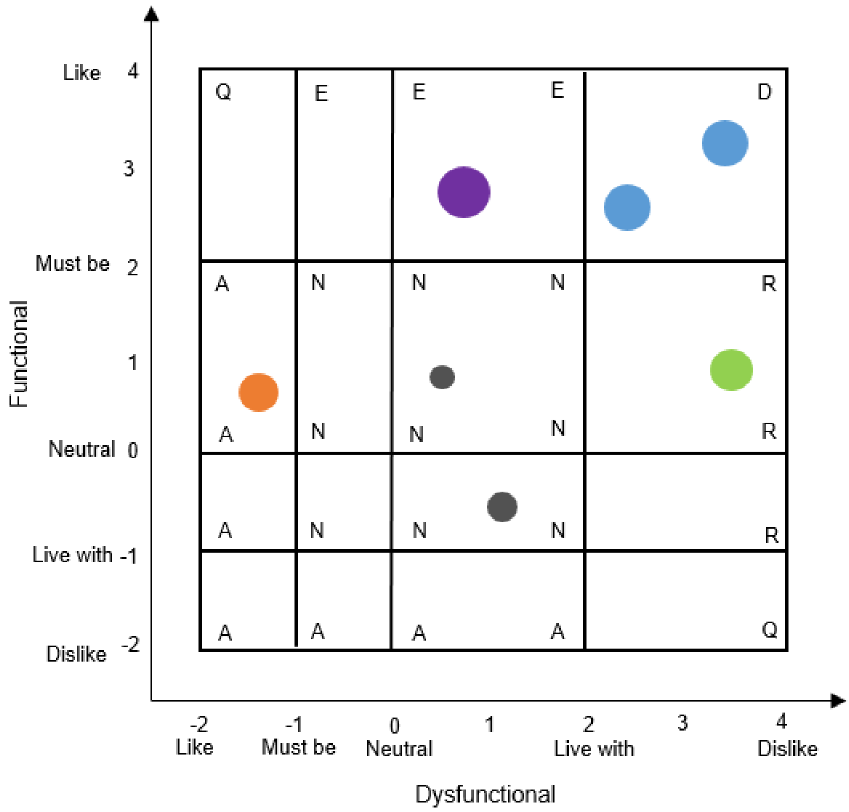


Figure 3.4 Each feature in the Kano Analysis is plotted in the grid according to its mean functional and dysfunctional score. The features are colour coded according to the five different categories: Desired (D), Exciter/delighter (E), Neutral (N), Anti-feature (A) and Questionable (Q). The diameter of each circle represents the mean importance score for that feature. The features in this figure are examples. The figure is made by the authors based on DuMouchel (1993).

3.2.2 **Statistical analysis**

To gain deeper insight into the responses to a Kano questionnaire, statistical methods can be used. The following section gives the theoretical background for statistical significance testing: the binomial test, Kruskal-Wallis test, Wilcoxon rank-sum test and Bonferroni correction.

3.2.2.1 Statistical significance testing

In this section, a theoretical background of the statistical analysis methods will be given. For more detailed information, we refer to Körner and Wahlgren (2010) and Yepez and Gagnuer (2020). To test if two distributions of random variables are different, various significance tests, also called hypothesis tests, can be conducted. These methods can confirm with a certain level of statistical confidence whether there is a significant difference in the data. They can also be used to test many other observations in data, for example whether the mean of a dataset is equal to a certain value. The results from significance tests can aid in the decision of which features to include in the development of a new product. All of them rely on the same core concepts of formulating a null hypothesis H_0, an alternative hypothesis H_A and computing the p-value. Typically, a null hypothesis H_0 is the assumption that there is no difference between two measured phenomena, or there is no association among groups. The alternative hypothesis is the opposite of the null hypothesis, i.e. there is a significant difference or association. Under the null hypothesis $H_{0,}$ a test statistics T, e.g. the mean or median of a data set, follows a certain distribution $P(T|\, H_0)$.

The p-value is the probability that the test statistics T would be the same as or more extreme, i.e. either larger or smaller, than the observed results T_{obs} under the null hypothesis H_0. For sufficiently small p-values, the null hypothesis is said to be rejected in favour for the alternative hypothesis H_A and the p-value is said to be significant. In most literature, the null hypothesis is rejected at a significance level of $\alpha = 0.05$, corresponding to a 5% significance level. The significance level is the probability of rejecting the null hypothesis when it is true. Hence, if the p-value < 0.05, the null hypothesis is rejected and the smaller the p-value is, the greater the support for the alternative hypothesis. For a two-tailed event, i.e. the test statistic T can be either larger or smaller than the observed result T_{obs}, the p-value is defined by (Yepez & Gagnuer, 2020):

$$p\text{-}value = 2min\{P(T \leq T_{obs}|\, H_0), P(T \geq T_{obs}|\, H_0)\} \tag{3.15}$$

3.2.2.2 Binomial test

The binomial test is used when there are two possible outcomes from an experiment, the typical example being success or failure. It is used to test the null hypothesis, H_0, that the observed probability of success π differs from the expected probability of success π_0. In the analysis of categorization of features in a Kano Analysis, the two outcomes can be the number of votes for category1 and votes for category2. Category1 is the category which received the most votes from all respondents and category2 has the second-highest number of votes. Using the binomial test, it can be determined if the number of votes for category1 is significantly different from category2. This is of interest when the number of votes for the two categories are close. The null hypothesis H_0 and the alternative hypothesis H_A are given by:

$$H_0 : \pi = \pi_0 \, , \; H_A : \pi \neq \pi_0. \tag{3.16}$$

For analysing categories, the expected probability π_0 corresponds to the fraction of votes for category1 out of the total number of votes for category1 and category2. If there is no significant difference between the number of votes for the two categories, the fraction for category1 is 0.5. Hence, π_0 is set to 0.5. Under the null hypothesis, it is assumed the number of votes for category1 follows a binomial distribution. The p-value can be calculated according to Equation (3.15) by calculating the probability:

$$P(X = x) = \binom{n}{x} \pi^x (1-\pi)^{n-x} \tag{3.17}$$

Where n is the total number of experiments or trials, in this context the total number of votes for the two most popular categories. X is the number of votes for category1 and π is the proportion of votes for category1.

3.2.2.3 Kruskal-Wallis test

The Kruskal-Wallis test is used to test if there is a difference in the distribution of k samples of data, $n_1 + n_2 + \cdots + n_k = n$, $k \geq 3$. The number of data points in a sample i is n_i and the total number of data points is n. The Kruskal-Wallis test is non-parametric; hence, it does not require the distribution of the data to be known. What the test does assume, is that the k samples of data are independent of each other. Furthermore, the data is assumed to be ordinal, meaning there is a ranking in the data. Due to these characteristics, it is a suitable test to use for analysing importance scores from a questionnaire. Since the test allows for comparisons between multiple groups, it is suitable for analysing responses which are divided into demographics. In this case, Frequent, Mid-frequent and Infrequent user. The null hypothesis H_0 of the Kruskal-Wallis test is given by:

$$H_0 : \textit{The } k \textit{ data samples have the same distribution} \tag{3.18}$$

$$H_A : \textit{At least one data sample does not have the same distribution}$$

As explained above, the null hypothesis is rejected for a p-value < 0.05 in favour of an alternative hypothesis H_A. The test works by first ranking all the observations. For each sample of data, the sum of the ranks R_i is calculated. The total sum of ranks for all samples is then given by:

$$\sum_{i=1}^{k} R_i = \frac{n(1+n)}{2} \tag{3.19}$$

Previously, the notation *T* was used for the test statistic. The test statistic for the Kruskal-Wallis test is denoted *H* and is given by:

$$H = \frac{12}{n(n+1)} \sum \frac{R_i^2}{n_i} - 3(n+1). \tag{3.20}$$

Under the null hypothesis, *H* is assumed to be approximately χ^2-distributed with k - 1 degrees of freedom and the p-value can be calculated according to Equation (3.15). A significant p-value (< 0.05) from a Kruskal-Wallis test does not tell which data samples have significantly different distributions. It only tells the data sets do not have the same distributions. Therefore, further pairwise comparisons of data samples are needed.

3.2.2.4 Wilcoxon rank-sum test

The Wilcoxon rank-sum test, also called the Mann- Whitney U test works the same way as the Kruskal-Wallis test. It has the same assumptions as the Kruskal- Wallis test. However, it only allows for comparisons between two groups of data, $X = \{x_1, x_2, \ldots, x_{n_x}\}$ and $Y = \{y_1, y_2, \ldots, y_{n_y}\}$. The null and alternative hypothesis of the Wilcoxon rank-sum test are given by:

$$H_0: \mathrm{P}(X > Y) = \mathrm{P}(Y > X), \; H_A: \mathrm{P}(X > Y) \neq \mathrm{P}(Y > X). \tag{3.22}$$

In other words, the null hypothesis means that both data sets have the same distributions with the same median. The alternative hypothesis is that the distributions of both populations are not equal and do not have the same median. Like the Kruskal-Wallis test, the Wilcoxon rank-sum test begins with ranking all the observed values from the two data sets. In the Wilcoxon rank-sum test, the test statistic is denoted *U* and is defined as:

$$U = min\,\{U_x, U_y\} \tag{3.23}$$

where U_x is defined as:

$$U_x = R_x - \frac{n_x(n_x+1)}{2}. \tag{3.22}$$

R_x is the sum of the ranks of the x_i's and n_x is the number of observations in the set *X*. The definition of U_y is analogous to U_x. Under the null hypothesis, the expected value and variance of *U* are:

$$E(U) = \frac{n_x n_y}{2}, \quad (3.24)$$

$$Var(U) = \frac{(n_x n_y)(n_x + n_y + 1)}{2}, \quad (3.25)$$

For large numbers of n_x and n_y, U is approximately normally distributed with $E(U)$ and standard deviation $\sqrt{Var(U)}$. The p-value can then be calculated according to Equation (3.15), assuming that U is normally distributed under the null hypothesis.

3.2.2.5 Bonferroni correction

In the analysis of importance scores, the scores for the same feature will be tested against multiple other features to see if there is a significant difference between the distributions. When multiple significance tests are performed simultaneously, the probability of obtaining significant results due to chance will increase (Goldman, 2008). To adjust for this problem, the significance level α can be corrected to α/n, n being the total number of tests which are conducted (Goldman, 2008).

4 Industry needs and considerations

This chapter presents the findings from 24 interviews with specialists in packaging material, fibre material, food safety and biotechnology. The opportunities and challenges for developing a user- and environmentally friendly material for drinking devices are discussed. The key challenges and opportunities are summarised in Table 6.1.

4.1 Fibre-based straws

During the interviews, discussions were held on the main challenges for paper-straws. Specialists in fibre-materials indicated that the main challenge for using fibre-based materials in drinking devices is to improve water resistance while keeping the fibre susceptible to adhesives in the production process (Tetra Pak, 2020b-v). They argue that for the material to be water-resistant, it needs to be hydrophobic. However, adhesion requires the fibre- material to be susceptible to liquids, which conflicts with the desired qualities of waterproofing the material. Additionally, the hydrophobic property can hinder the separation of fibres during repulping. Hence, a balance between air, glue, hydrophobia and repulpability is desired in the development process of drinking devices (Tetra Pak, 2020b-v).

To enhance the product qualities of the drinking device, especially regarding water resistance, it would be beneficial to create a double-sided surface treatment, both on the outside and inside of the drinking device (Tetra Pak, 2020b-v). The interviews with specialists from Tetra Pak strongly indicated that a drinking device with fibre material and bioplastic surface treatment was an area of great interest. In the development of surface treatment on a paper straw, experts listed six desired criteria to be met by Tetra Pak (Tetra Pak, 2020b-v):

1) Food contact approved
2) Does not hinder paper recyclability
3) Hinders water absorption of paper
4) [Bio]degradable in all environments
5) Has good adhesion to paper
6) Enables sealing

The requirements act as guidelines to consider when adding a surface treatment to a fibre-based drinking device. The three first requirements 1) – 3) refers to that the device should be safe when in contact with food, it should not prevent or reduce the recyclability of fibres and the material should not easily get soggy and absorb too much water during use. Requirement number 4) refers to the ability for the material to biodegrade in soil, water and marine environments, see Ch. 3.1.2. Tetra Pak (2020b-v) particularly mentioned that it would be beneficial to create a drinking device that is biodegradable in marine environment while simultaneously not hindering recycling. Marine biodegradation is generally considered the most difficult environment to achieve biodegradation in (Tetra Pak, 2020b-v). Regarding requirement number 5), adhesion refers to the ability of dissimilar particles or surfaces to cling to one another i.e. the surface treatment and fibre-based material should be able to attach. The sealing requirements, number 6), refers to enable sealing without wet glue. In this context, sealing refers to how straws made out of paper strips are glued together using winding machines. The reason for wanting to replace wet glue is to make the straw production faster and simpler as well to increase the positive environmental profile by reducing the mix and types of materials used (Tetra Pak, 2020b-v).

4.2 PHB as a surface treatment

In selecting a surface treatment, it was of interest to choose a bioplastic for their biodegradable and biobased properties, see Ch. 3.1.2. The fibre- and biotechnology specialist indicated that PHA (Polyhydroxyalkanoates), a group of bioplastics, could be a good option for surface treating a fibre-based drinking device, since PHA is known to be naturally biodegradable (Lund University Faculty of Engineering, 2020a-b; Tetra Pak, 2020b-v; Shah et al., 2008). Although other alternatives for both biodegradable and biobased biopolymers exist, the extensive research into PHAs and their biodegradation as well as interest from the packaging industry made it the most interesting option for this study.

PHAs are biocompatible materials, i.e. do not produce a harmful effect when it comes into contact with a living system (Vert et al., 2012). The specialists suggested that, although PHA biodegrades in all environments, it biodegrades rather slowly in water and marine environment (Tetra Pak, 2020b-v). Therefore, it would be highly advantageous to study how to increase the speed of biodegradation of the surface treatment in these environments (Tetra Pak, 2020b-v). The biocompatibility and mechanical properties of PHA can be changed by blending and modifying the PHA with enzymes, inorganic materials and other natural or synthetic polymers (Banerjee et al., 2014; Michael, 2004).

Among the different PHAs, scientists particularly mentioned the bioplastic Polyhydroxybutyrate (PHB) and the two subgroups PHBV poly(hydroxybutyrate-co-hydroxyvalerate) and PHBH poly(hydroxybutyrate-co-hydroxyhexanoate). While both options are noteworthy, this study chooses to discuss the overarching group of PHB as the main option. As PHB has similar properties to commonly used fossil-based plastics such as polypropylene (PP), it makes it a favourable option as surface treatment (Lund University Faculty of Engineering, 2020a-b; Tetra Pak, 2020b-v). Table 4.1 shows the comparison of the properties between the synthetic polymer PP and the biopolymer PHB.

Table 4.1 Comparison between the material properties of PHB and PP (Markl, Grünbichler & Lackner, 2018).

Property	PHB	PP
Crystalline Melting point (°C)	175	176
Degradation temperature (°C)	220	328
Crystallinity (%)	80	70
Molecular Weight (Daltons)	5×10^5	2×10^5
Glass transition temperature (°C)	4	-10
Density (g/cm3)	1.250	0.905
Flexural modulus (Gpa)	4	1.7
Tensile strength (Mpa)	40	38
Extension to break (%)	6	400
Ultraviolet resistance	Good	Poor
Solvent resistance	Poor	Good

Unlike PP, PHB has been shown to biodegrade within months and can also biodegrade in a marine environment (Bhatt, Patel, & Trivedi, 2011; Markl, Grünbichler, & Lackner, 2018). On the other hand, the challenges in processing PHB into thin films is the main prevention for widespread application (Anbukarasu, Sauvageau & Elias, 2015). It can be a challenge to use PHB as a surface treatment on top of fibre materials due to challenges in achieving adhesion, getting the surface treatment to attach to the base material (Tetra Pak, 2020b-v). This is because adhesion requires heat, which may become a problem for bioplastics like PHB. The high melting point (~175 °C) and low degradation temperature (~220 °C) limit the possibility of thermal processing (Anbukarasu et al., 2015). To improve the thermal processability there are possibilities to use heat treatment and co-polymerisation. Through these treatments, PHB can be extruded, rolled or pressed to films with good mechanical properties (Anbukarasu et al., 2015).

4.3 Enzymes catalysing biodegradation of PHB

In the packaging industry, there is a curiosity to investigate how enzymes can be used as a treatment for materials. Biotechnology researchers were positive to the idea of testing if an enzyme in the PHB surface treatment can increase biodegradability (Lund University Faculty of Engineering, 2020a-b).

The benefit of PHB is that it can be broken down by enzymes known as PHB depolymerases. A variety of enzymes over a broad range of temperatures can biodegrade pure PHB with non-toxic degradation products. This makes PHB a food safe alternative to fossil-based polymers. (Anbukarasu et al., 2015). Enzymes can accelerate the biodegradation by reducing polymers to monomers through depolymerisation and hydrolysation. The building blocks are then converted to CO_2 and H_2O (Lund University Faculty of Engineering, 2020a-b).

Numerous enzymes (PHB depolymerase) which are secreted by microorganisms have been identified in nature (Shah et al., 2008). How much the PHB is biodegraded depends on the environmental conditions and the number and types of microorganisms involved in the biodegradation process (Bhatt et al., 2011). Biotechnology researchers speculated that the biodegradation speed could be increased more than double, depending on several factors and properties. Properties in the environment that could affect the biodegradation are temperature, pH, humidity, oxygen level, nutrients presence of inhibitors etc. (Bhatt et al., 2011; Lund University Faculty of Engineering, 2020a-b). Material properties like porosity, permeability, hydrophobicity, surface characteristics as well as the enzyme stability etc. can also affect the biodegradability (Bhatt et al., 2011; Lund University Faculty of Engineering, 2020a-b). Furthermore, the researchers argued that these factors will need to be tested experimentally for the application of PHB as a surface treatment (Lund University Faculty of Engineering, 2020a-b).

To utilise enzymes in the packaging industry and particularly for fibre-based drinking devices, it is of interest to look at commercial enzymes such as lipase (Lund University Faculty of Engineering, 2020a-b). Although the interest is to use enzymes for biodegrading a PHB surface treatment, it can also hydrolyse the fibre-base. In other words, there is a chance the enzymes will also attack the fibre-base which is not desired if the goal is to recycle the fibres. A more effectful approach is to develop enzymes specifically for the biodegradation of fibre-based drinking devices with PHB surface treatment (Lund University Faculty of Engineering, 2020a-b). The authors identified a few challenges and opportunities for utilising enzymes to increase the biodegradation of a bioplastic surface treatment. Apart from the above-mentioned suggestions, the following sections outline the main considerations for the utilisation of enzymes as part of surface treatment of drinking devices.

4.3.1 Activation on-demand

Biotechnology researchers described that enzymes are inactive if they are dry, hence, a solution can be to activate the enzymes when they are inserted into the liquid (Lund University Faculty of Engineering, 2020a-b; Bologna University, 2020). In this case, the main challenge is to enable activation on-demand, i.e. preventing the enzymes from activating too early or too late in the process of using the drinking device (Lund University Faculty of Engineering, 2020a-b).

4.3.2 Effects of pH on enzymes

Enzymatic activity and biodegradation are affected by pH level. When the enzymes are in contact with the liquid, the reaction starts immediately (Lund University Faculty of Engineering, 2020a-b). If the enzymatic reaction is to be activated when they are placed in a liquid, i.e. a beverage, the pH level of the beverage would play a role in the biodegradation (Lund University Faculty of Engineering, 2020a-b). For example, fruit juice typically has a lower pH compared to water (Lund University Faculty of Engineering, 2020a-b). The biotechnology researchers suggested that different pH level should be used when testing the reaction speed of the enzymes. Currently, researchers at Bologna University are doing a comparison study where they used simple test conditions by incubating each enzyme in its optimal pH and temperatures (Bologna University, 2020).

4.3.3 Survival of enzymes in a surface treatment

Enzymes are sensitive molecules. To include the enzymes inside a surface treatment, biotechnology researchers suggested encapsulating the enzymes (Lund University Faculty of Engineering, 2020a-b). Encapsulation is an enzyme immobilization technique which improves the stability of an enzyme and as a consequence maintains their activity (Homaei, Sariri, Vianello, & Stevanato, 2013). Immobilised enzymes are more robust and resistant to environmental changes compared to free enzymes in a solution (Homaei et al., 2013). The researchers suggested that some additives, e.g. chemicals, will be needed to activate the enzymes after encapsulation (Lund University Faculty of Engineering, 2020a-b). Also, they suggested that it would be of interest to test if, and how long, enzymes can keep activity in surface treatment. The researchers described that they were working on the development of a method to protect the enzymes during the preparation of multi-layered packaging material (Bologna University, 2020). The main issues are to protect the enzymes from thermal shocks during the lamination process and from contact with organic solvents (Bologna University, 2020). The primary risk is that the enzymes do not react in the material since it is not the optimal conditions (Lund University Faculty of Engineering, 2020a-b).

4.3.4 **Effects of temperature on enzymes**

Biotechnology researchers also indicated that enzymes are highly affected by temperature. In room temperature, around 20°C, the activity of enzymes is relatively slow (Lund University Faculty of Engineering, 2020a-b). When the temperature increases, the enzyme might break or be activated (Lund University Faculty of Engineering, 2020a-b; Tetra Pak, 2020b-v). Besides, when laminating the packaging material or drinking device with PHB, the temperature will have to be increased to 175 – 220°C during around 40-45 s (Tetra Pak, 2020b-v). Scientists argued that this temperature range is too high since even thermostable enzymes from thermostable microorganisms can resist only up to 100°C (Lund University Faculty of Engineering, 2020a-b). Hence, either enzymes would need to be developed to handle higher temperatures or a process to add enzymes after laminating would be needed. The researchers mentioned that microorganisms can be sourced from 'extreme' environments such as hot springs, which is naturally more stable compared to other microorganisms or enzymes (Lund University Faculty of Engineering, 2020a-b). The scientists described that by studying the genes of the enzymes, they could find possibilities to modify the enzyme and optimise its activity (Lund University Faculty of Engineering, 2020a-b).

4.4 How the material affects recyclability and safety

From a recycling point of view, Tetra Pak specialists (2020b-v) argue that the best alternative is for the product to be made of only one material, i.e. mono-material. Even when only a fibre material is used, repulping remains a challenge (Tetra Pak, 2020b-v). Thus, the challenges of applying a PHB surface treatment, or any treatment, to a fibre material is that the surface treatment may pollute the recycling stream (Tetra Pak, 2020b-v). In addition, usually polymer-based glue is used during adhesion which also can cause harm to the recycling stream. One of the main goals is to be able to recycle the fibres fully in paper recycling without any adverse effect from the surface treatment (Tetra Pak, 2020b-v). Alternatively, Tetra Pak specialists (2020b-v) argue that the amount of bioplastic used as surface treatment should be reduced as much as possible before recycling. In this case, the thickness of the surface treatment is an important factor to consider. To apply a thinner surface treatment can be a challenge in production, but better for the biodegradation since less material will need to biodegrade (Tetra Pak, 2020b-v). However, if recycling is considered instead, a too thin surface treatment cannot be recycled separately from the fibre-base and will pollute the recycling stream (Tetra Pak, 2020b-v). While marine biodegradation is of strong interest from Tetra Pak, it is emphasized that biodegradability should not hinder recyclability (Tetra Pak, 2020b-v). Tetra Pak (2020b-v) aims to maximise the fibre-content in their packages, thus making the package as recyclable as possible.

The use of enzymes in a surface treatment could further pollute the recycling of the fibre material (Tetra Pak, 2020b-v). Experts from Tetra Pak and researchers in biotechnology discussed how instead of being a hinder, the enzymes can be an aid in recycling. A separate idea is to use an additive in the recycling stream, for example a chemical to activate the enzyme to separate a surface treatment from a fibre-material (Lund University Faculty of Engineering, 2020a-b). For recycling purposes, the enzymes can also be activated by adding water (Lund University Faculty of Engineering, 2020a-b). The best option is to develop a recycling bioreactor, where most conditions, e.g. temperature, moisture and pH can be controlled (Lund University Faculty of Engineering, 2020a-b). Alternatively, the enzymes could aid in recycling by increasing the rate of biodegradation of the surface treatment, leaving only the fibre material to be recycled. Consequently, researchers are looking into how enzymes can be used not only to biodegrade bioplastic but also help in the recycling process of packaging materials (Lund University Faculty of Engineering, 2020a-b; Bologna University, 2020).

Another issue is that the by-products of biodegradation with enzymes can be toxic (Lund University Faculty of Engineering, 2020a-b). When breaking down bioplastics there may be smaller residues left behind that can cause harm to users of the drinking device. Researchers in biotechnology suggested that some in the industry may prefer non-biodegradable plastics for safety reasons since there would be no residues from the material in the beverages (Lund University Faculty of Engineering, 2020a-b).

Microbiologist experts raised the importance of keeping the drinking device hygienic and preventing the beverage from getting spoiled when in contact with the drinking device (Tetra Pak, 2020b-v). The materials themselves need to fulfil certain microbiologist standards and they cannot cause any harm to the consumer. More specifically, the experts are concerned that the material of a drinking device releases substances into the beverage, i.e. migration. However, there can be an extent of harmless spoil of the product, in other words a certain amount of substance migration from the packaging or drinking device to the beverage is allowed if it is not harmful to the consumer (Tetra Pak, 2020b-v). The amount of substance migration per gram of material needs to be tested before the safety can be guaranteed (Tetra Pak, 2020b-v). Food safety specialists mentioned that a drinking device does not necessarily need to have as stringent requirements for food safety as a food package, since a drinking device may not be in contact with the liquid content during shelf-life (Tetra Pak, 2020b-v).

Among the interviews, it was also particularly emphasised that the drinking device should be safe and easy to use for a multitude of people (Tetra Pak, 2020b-v). Inclusive design of features was of great interest for Tetra Pak, meaning the features of the drinking device would be comfortable and safe to use for not only adults but also children, elderly people and people with disabilities (Tetra Pak, 2020b-v).

5 Mapping consumer needs

This chapter includes the results from the Kano questionnaire and statistical analysis of the categorisation and importance scores of the features. Additionally, a summary of consumers' ideas and feedback about drinking devices is given.

The Kano Analysis questionnaire received in total 308 responses. The detailed survey questions can be seen in Appendix C.1. Around 66% of the respondents were female and around 74% of the respondents were in the age between 18 and 34 years old. Most of the respondents were either working professionals, 46%, or students, also 46%. Figure 5.1 shows the responses to the question “How often do you drink liquids using a straw?”. Both the mode and the median answer are “Every 2-3 months”. Figure 5.2 shows the number of respondents per answer option to the question “On average, for how long do you usually use your straw?”. Only 7% of the respondents answer an option greater than 1 hour and both the mode and the median answer are “30 minutes”. Thus, a requirement of the drinking device can be that it needs to last at least 30 minutes in the liquid before starting to become wet. The respondents are divided into three different demographic groups, Frequent user, Mid- frequent user and Infrequent user, based on how often they use straws, as shown in Figure 5.1.

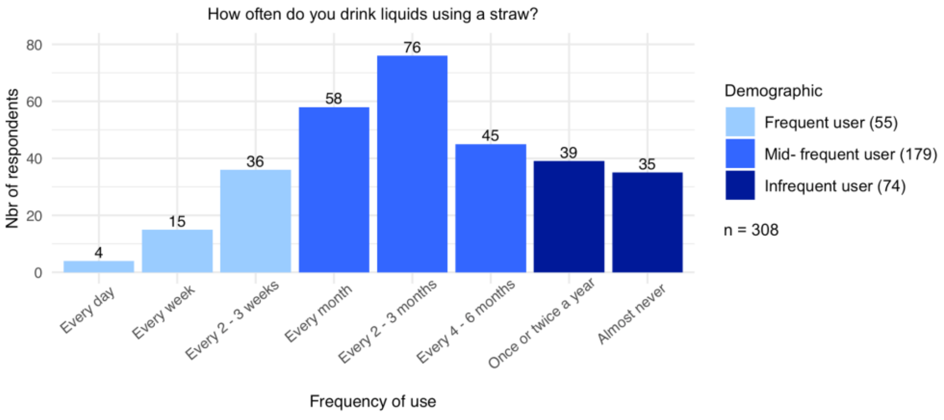


Figure 5.1 How frequently respondents use straws.

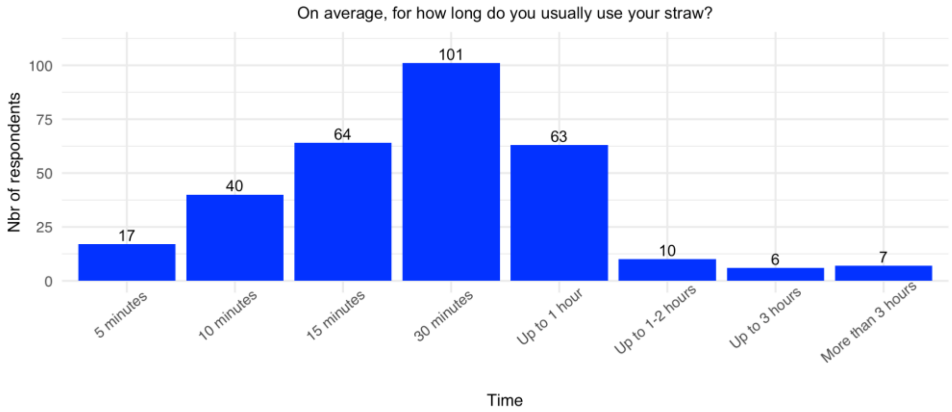


Figure 5.2 How long respondents use straws.

5.1 Categorisation of features

Through literature study and discussions with experts in packaging material and design, 12 features were chosen to be included in the Kano questionnaire: *bendable*, *biodegradable*, *flavourless*, *recyclable*, *reusable*, *safe*, *separate*, *smooth*, *soft*, *soggy*, *stiff* and *wrapped.* The twelve features were categorised as Required, Desired, Exciter/delighter, Neutral, Anti- feature based on the continuous Kano Analysis (see Ch. 3.2.1). Figure 5.3 a) displays the result of this categorisation. Each feature is plotted in the grid according to its mean functional and dysfunctional score. The diameter of the data points corresponds to the mean importance score of the features, i.e. how important it is for the respondents to have the feature included in the drinking device. Figure 5.3 b) shows the standard deviations in the functional and dysfunctional scores, represented as error bars.

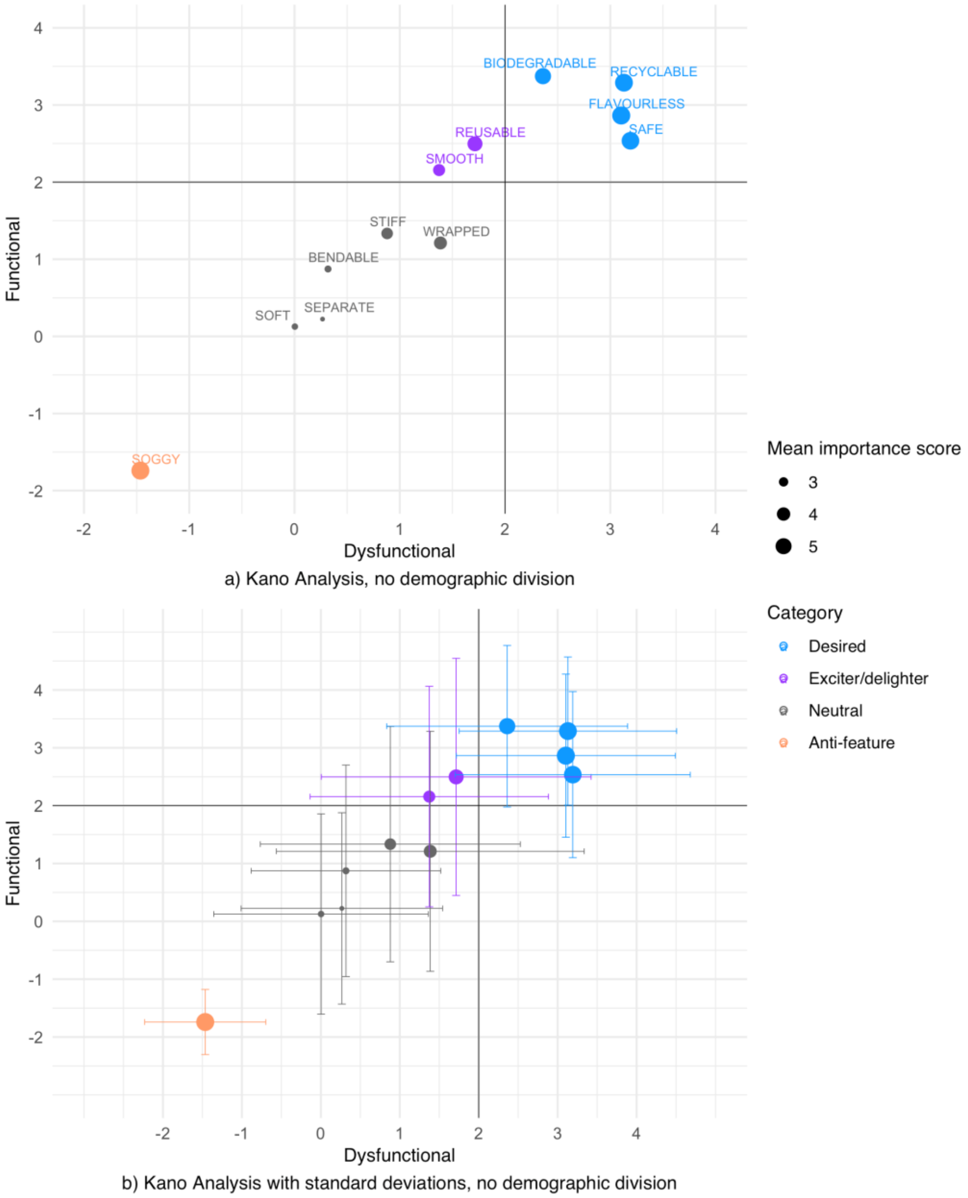


Figure 5.3 a) – b) Displays the results from the Kano questionnaire when there was no demographic division of the respondents. Each feature is plotted in the grid according to its mean functional and dysfunctional score. The features are colour coded according to the four different categories: Desired, Exciter/delighter, Neutral and Anti-feature. The diameter of each circle represents the mean importance score for that feature.

Studying Figure 5.3 a), no feature is analysed to be a Required feature. The large standard deviations in Figure 5.3 b) indicate a large spread in the distribution of the functional and dysfunctional answer scores. The error bars overlap to other categories. Suggesting a need for further analysis into the categorisation of the features. From a product development perspective, there shoul be no contradiction between the categorisation of the features. Figure 5.4 shows the total number of respondents per category for each feature. Note that in Figure 5.3 and 5.4, the responses categorised as Questionable are excluded, however, they can be viewed in Table C.1 in Appendix C. The highest number of Questionable responses are 5 for the feature *separate*. Most other features have 3 or fewer Questionable answers. The low numbers of Questionable responses suggest that the questionnaire was well understood by the respondents. Figure 5.4 gives a more exact overview of how the responses are spread out between the different categories. When the number of responses for the two highest categories were close, binomial tests were used to determine if there was a significant difference. The p-values for the binomial tests are presented in Table C.2 in Appendix C.

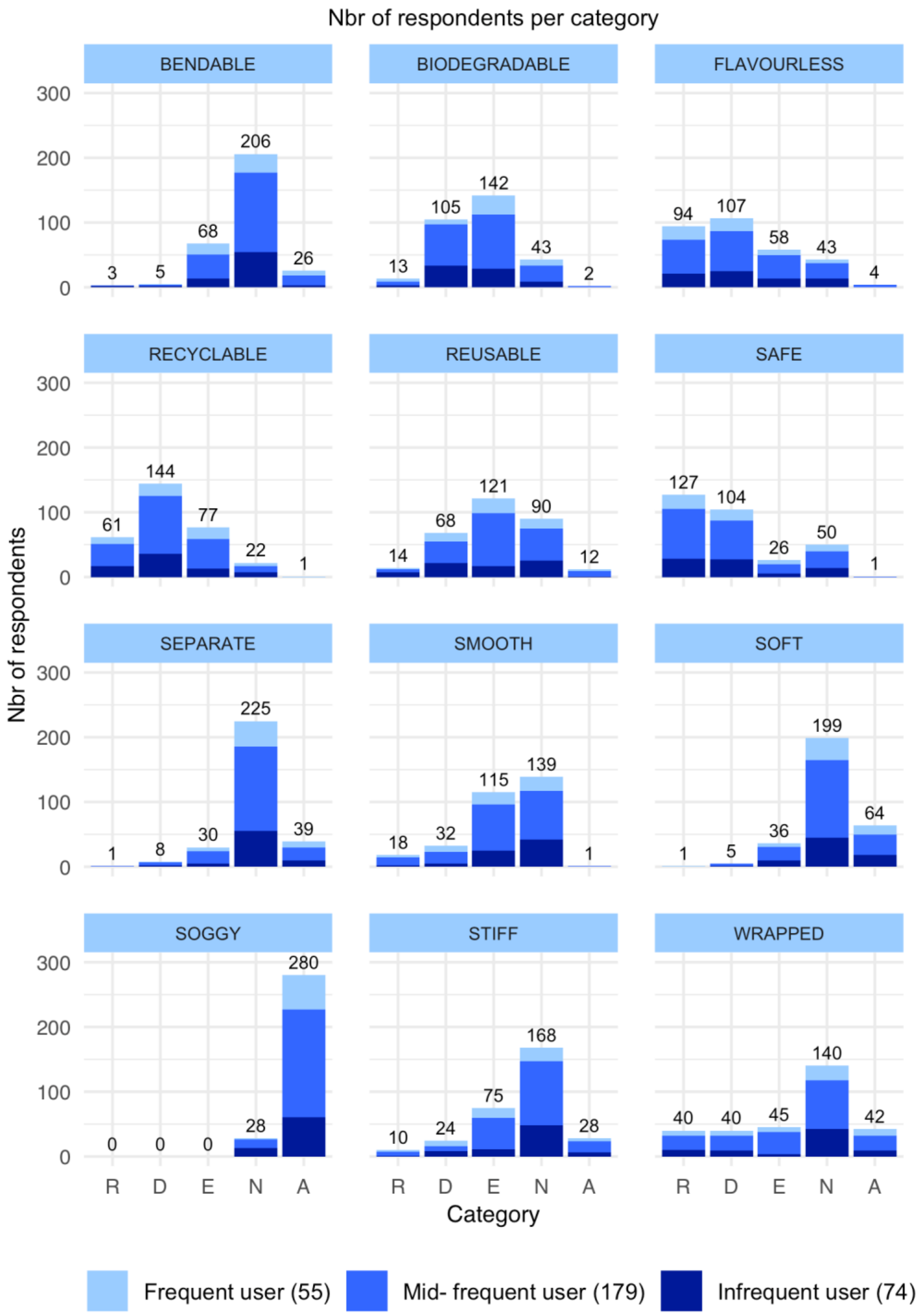


Figure 5.4. The number of respondents per category, for each feature demographic group. R: Required, D: Desired, E: Exciter/delighter, N: Neutral, A: Anti-feature.

Although no feature is categorised as Required in Figure 5.3, as seen in Figure 5.4, the majority in all demographic groups voted for the feature *safe* to be Required. As the second most popular category was Desired, together with the rest of the votes, the mean value still concluded the feature to be Desired. For both *safe* and *flavourless*, the number of votes for Required and Desired are close in all three demographics. The results from the binomial tests are insignificant (p-value > 0.05), i.e. there is no significant difference between the number of responses for Required and Desired. Hence, it is inconclusive whether the features *safe* and *flavourless* should be categorised as Required or Desired.

For the feature *biodegradable*, Frequent users differ from Mid- and Infrequent users by having a clear majority for Exciter/delighter. For Mid- and Infrequent users there is a similar number of votes between Desired and Exciter/delighter. Comparing the tallied responses, the binomial test gives a significant p-value (< 0.05). Hence, *biodegradable* can be concluded to be an Exciter/delighter. *Recyclable* has a clear majority of votes for Desired, although there are many votes in Required and Exciter/delighter as well. *Reusable* has most votes for Exciter/delighter, but all three demographics also have many votes to Neutral. From the binomial test, it is concluded that the number of votes for Exciter/delighter is significantly different from Neutral.

The results from the binomial tests gives inconclusive results for whether *smooth* should be classified as Neutral or Exciter/delighter. The features *bendable*, *separate*, *soft*, *stiff*, and *wrapped* all have a clear majority of votes for the features to be categorised as Neutral, in all three demographics. What should be noted is that *bendable*, and *stiff* also have a large proportion of voters in Exciter/delighter. For children, elderly and disabled people, the feature *bendable* is important for functionality. The majority of the respondents to the questionnaire is not in any of these groups. If the goal is to develop an inclusive drinking device, it can be worth to consider including *bendable* despite its main category as a Neutral feature. Tetra Pak has the aim to reduce littering from single-use packaging (Tetra Pak b-v, 2020). One way to reduce littering is by using a non-detachable drinking device to the beverage package, i.e. the drinking device is *not separate*. Consequently, *separate* should *not* be included in the product features. Only in the feature *soft* is the category with the second highest votes Anti- feature. *Soft* can be therefore concluded to be an unnecessary feature to include in the design of a drinking device.

Soggy has an overwhelming consensus as an Anti-feature in all three demographics, corresponding with Figure 5.3 a)-b). Comparing the error bars in Figure 5.3 b) for *soggy* to the other features, *soggy* also has smaller standard deviations in the functional and dysfunctional scores.

5.2 Importance scores of features

The Kruskal-Wallis test, Wilcoxon rank-sum test along with the boxplots in Figure 5.5 gives further insight into which features are more important to one demographic group compared to the other groups. They also allow for comparison between the importance of features which have the same categorisation. The most important insights are given in this chapter. The more detailed analysis can be viewed in Appendix C. The p-values from the Kruskal-Wallis and Wilcoxon rank-sum tests are presented in Table C.3 and C.4, Appendix C. Note that unless otherwise specified, the median scores in the analysis are presented in the order of Frequent user, Mid- frequent user and Infrequent user.

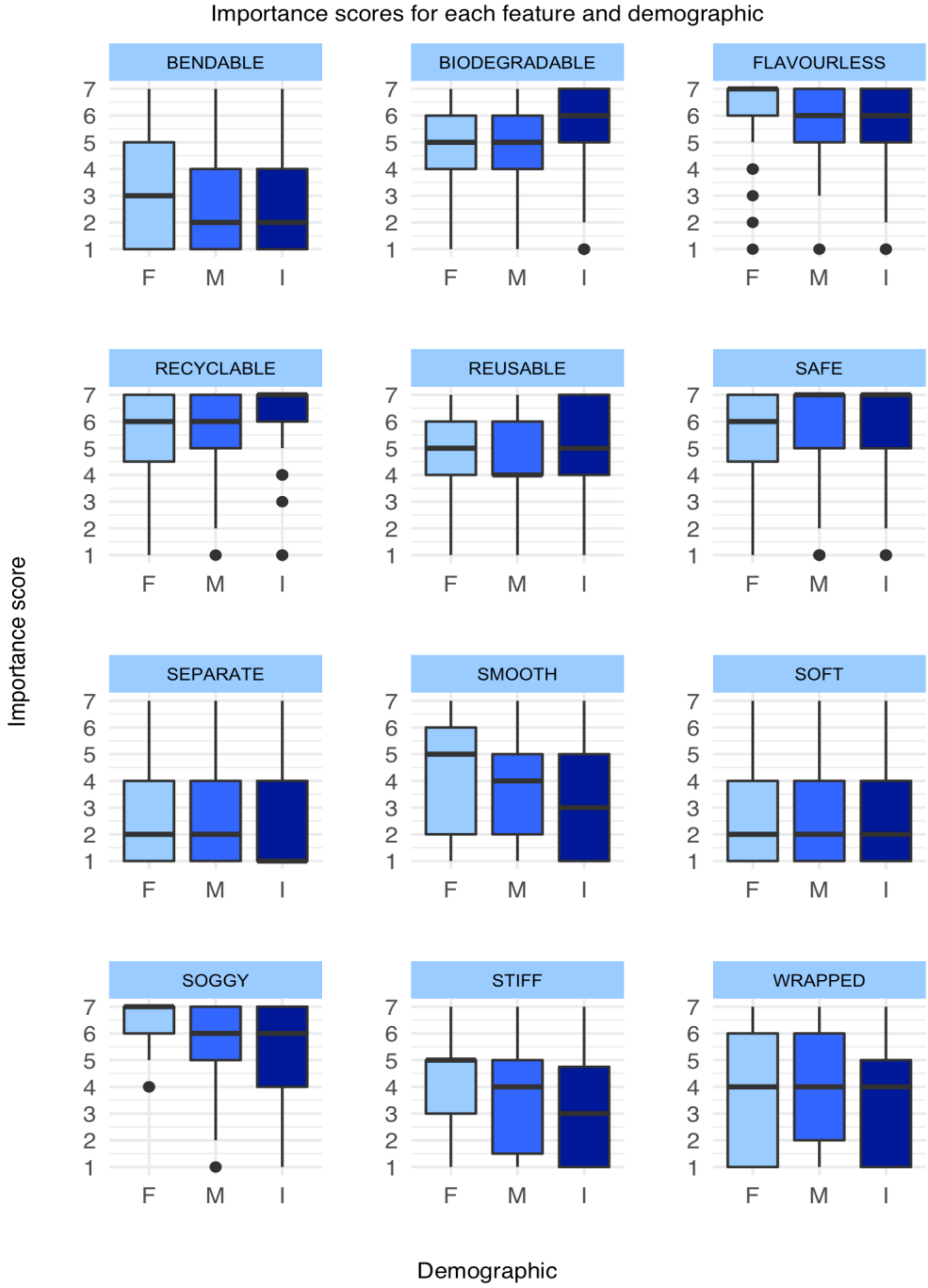


Figure 5.5. Boxplots of the importance scores for each feature and demographic. F: Frequent user (55 respondents), M: Mid-frequent user (179 respondents) and I: Infrequent user (74 respondents).

From the Kruskal-Wallis tests, the features *flavourless, reusable, safe, separate, soft* and *wrapped* have insignificant p-values (> 0.05). Meaning there is no significant difference in the importance scores between the three demographics for these features. Studying the boxplots, the scores are also quite unanimous between the demographics. For the features which have significant p-values (< 0.05), *bendable*, *biodegradable*, *recyclable*, *smooth*, *soggy* and *stiff*, further pairwise Wilcoxon rank-sum tests were performed. Note that the importance scores for the feature *soggy* was from the question: "How important is it for you that the drinking device does *not* become soggy (wet and soft) during use?". In the Wilcoxon rank-sum tests, only tests between Frequent user and Infrequent user have significant differences. The importance scores of Mid-frequent users do not differ significantly from neither Frequent nor Infrequent users for any feature. Studying the boxplots, it is mostly Frequent users which have higher importance scores in the features with significant p-values from the Wilcoxon rank-sum tests. A conclusion is that Frequent users place higher importance scores on the features, *(not) soggy, flavourless*, *stiff* and *smooth*, compared to Infrequent users.

All three demographics rank the features *safe, (not) soggy* and *flavourless* highly with median importance scores 6 or 7, see Figure 5.5. Generally, the environmental features *biodegradable*, *recyclable* and *reusable* all show high median importance scores between 4 and 7, see Figure 5.5. Interestingly, for *biodegradable* and *recyclable*, the Wilcoxon rank-sum tests with Infrequent users gives significant p-values (< 0.05), meaning the importance scores for Infrequent users differs significantly from Frequent users. The boxplots reveal that the importance scores are considerably higher for Infrequent users. Another noteworthy observation is that in all three demographics, the median scores for *recyclable* (6, 6, 7) are higher than for *biodegradable* (5, 5, 6) and *reusable* (5, 4, 5). Further analysis reveals that all three demographic groups have significantly higher importance scores for *recyclability* than *biodegradable* and *reusable*, see Table C.6 in Appendix C.

The features *bendable*, *stiff*, *smooth* and *wrapped* all have median importance scores between 2 and 5. Worth considering is the relatively large spread in the importance scores in all three demographics for these features. The features *separate* and *soft* both give insignificant p-values (> 0.05). The boxplots showed the distributions between the demographics are very similar for both features with low median importance scores. For the feature *separate* the medians are 2, 2 and 1 and for *soft* the median is 2 for all groups.

5.3 Consumer ideas

To gather further ideas and suggestions for the design, the respondents could answer the optional question “What features would you like a drinking device to have?”. 132 responses were received for specific desires surrounding features of drinking devices, see Appendix C.3. Firstly, the most mentioned feature is to prevent the sogginess of drinking devices (26 mentions). Secondly, where it was assumed the respondents meant reusable drinking devices, it is highly desired to make them easy to clean and wash (22 mentions). Other interesting features mentioned are that the drinking device should not have any harsh material such as metal or glass (11 mentions) and that the drinking device should be adjusted in size depending on the beverage (10 mentions). There are also quite a few responses arguing that straws are unnecessary (9 mentions) and that the drinking device could be built into the packaging itself (3 mentions). Another idea is to make the drinking device temperature regulating (5 mentions).

6 Targets and requirements

This chapter describes and summarises the needs and target specifications for the drinking device based on the analysis of the literature reviews, the Kano questionnaire and interviews with the packaging industry and academia. The requirements is used as a basis for the material and design development of the drinking device.

6.1 Consumer and industry needs

From the conducted interviews, the main challenge identified in using fibre-based materials is the balance between keeping the material susceptible to adhesion while still enabling moisture resistance during use. A solution to this is to treat the fibres with a bioplastic surface treatment made of PHA, specifically a thin PHB film. To increase the biodegradability of the surface treatment, encapsulated enzymes can be mixed in the surface treatment. There is a potential for the enzymes to be activated when the material absorbs liquid. The main challenges with utilising enzymes in this manner are to create activation on demand, determining what effect the pH of the liquid and temperature has on the enzymes as well as how the enzymes can survive in the surface treatment. The material combination and design must not affect the recycling stream negatively. Besides, it is essential to study the safety regarding food contact and the by-products of the biodegraded bioplastics with enzymes. The main challenges and opportunities are summarised in Table 6.1.

Table 6.1 Summary of the main challenges and opportunities for developing a drinking device for single-use packaging, identified from interviews with the packaging industry and academia. In this table, challenges are defined as obstacles needed to be overcome in the development process. Opportunities refer to the possibilities of development or solving any of the raised challenges.

Topic	Challenges	Opportunities
Fibre-materials	Making the fibres moisture resistant Making the fibres susceptible to adhesives	Treating the fibres with double-sided surface treatment
Surface treatment	Adhesion between material layers Does not hinder paper recyclability Biodegradability	Biobased and biodegradable biopolymers
Biopolymers	Temperature-sensitive	Biobased and/or biodegradable Similar properties to fossil-based polymers PHA and particularly PHB is of interest due to material properties
Enzymes	Activation on demand Effect of temperature and pH on enzymes Survival of enzymes in a surface treatment Enzymes can cause hydrolysis of cellulose fibres	Increase biodegradation of biopolymers Commercial enzymes such as lipase Designed enzymes for biodegradation of PHB Encapsulated enzymes
Recycling	Preferably mono-material in the recycling process Repulping after recycling The surface treatment and enzymes may pollute the recycling stream	Maximising the fibre content Thin surface treatment can be reduced with the help of enzymes before the recycling process starts Utilising enzymes in a recycling process to separate the material layers
Safety	Migration of particles from material to beverage Inclusive design that does not harm children, disabled or elderly people if used wrong.	Fully wrapped drinking device before use Drinking device is not in contact with liquid before use

Table 6.2 summarises the results from the analysis of the Kano questionnaire and consumer preferences. Features that the authors decide to not include in the design due to low importance or contradiction with other features are summarised in Table 6.3. Specifically, the feature *reusable* is not included since the drinking device cannot be *reusable* and *biodegradable* simultaneously.

Table 6.2 Summary of features from the analysed consumer insights in Ch. 5 to include in the development of a drinking device, in order of importance. Note that the importance scores for *soggy* were asked using "*not soggy*".

Feature	Category	Importance – median values of importance (F, M, I)
SAFE	Required or Desired	High (6, 7, 7)
(NOT) SOGGY	Anti- feature	High (7, 6, 6)
FLAVOURLESS	Required or Desired	High (7, 6, 6)
RECYCLABLE	Desired	High (6, 6, 7)
BIODEGRADABLE	Exciter/delighter	High (5, 5, 6)
SMOOTH	Neutral or Exciter/ delighter	Mid (5, 4, 3)
STIFF	Neutral	Mid (5, 4, 3)
WRAPPED	Neutral	Mid (4, 4, 4)
BENDABLE	Neutral	Mid (3, 2, 2)

Table 6.3 Summary of features from the analysed consumer insights in Ch. 5 to *not* include in the development of a drinking device. *Reusable* is a contradiction to *biodegradable*, and hence it was decided to not be included.

Feature	Category	Importance – median values of importance (F, M, I)
REUSABLE	Exciter/ delighter	High (5, 4, 5)
SOFT	Neutral	Low (2, 2, 1)
SEPARATE	Neutral	Low (2, 2, 2)

6.2 Target specifications

Based on the user-experience from the Kano analysis, consumer ideas (see Appendix C.3) and industry needs, the following target specifications are summarised, see Table 6.4.

Table 6.4 Target specifications for the drinking device.

Need no.	Product requirements	Specification
1	Recyclable	The solution does not negatively hinder or pollute the recycling stream
2	Biodegradable	The solution has the potential to biodegrade in the marine environment
3	Moisture resistant	The solution reduces the risk for the drinking device to become soggy during use
4	Prevent spillage	The solution minimises the risk for spillage
5	Reduced littering	The solution prevents littering of separate parts
6	Ease of use	The solution offers an inclusive design that can be used by a multitude of people and is child- and disability friendly
7	Hygienic	The solution prevents dirt and keeps the device sterile throughout shelf-life
8	Keeps shape	The design and shape of the device is sturdy and fulfils its purpose throughout use
9	Ergonomic	The solution provides the consumers with a comfortable mouth contact
10	Food safe	The solution minimises the risk of migration from the material to the beverage

7 Technical and material development

This chapter presents and discusses the suggested material combinations for the drinking device. A multiple linear regression model is described for evaluating the proposed material combination.

7.1 Material combinations

Based on the literature study, compiled consumer needs and the recommendations from the packaging industry and biotechnology experts, proposals of material combinations were developed. From the *technical track*, the suggested material combinations are based on the requirements aiming to improve recycling and biodegradation of the generic plastic straw. From the *design track*, considerations are mainly taken into how the material combination can improve the surface qualities and prevent sogginess of the popular paper straw. The proposed material combinations are presented in Figure 7.1.

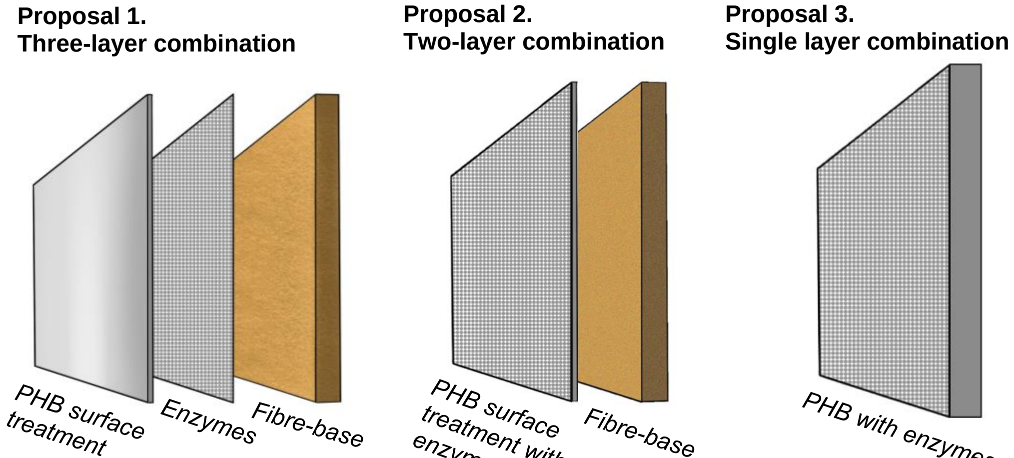


Figure 7.1 Suggestions for material combinations.

The first proposal is a three-layered material combination, see Figure 7.1 Proposal 1. The main interior is a fibre-based material, followed by a middle layer of enzymes and the outer layer of PHB surface treatment. The purpose of the PHB surface treatment is to improve product traits such as smooth mouth feeling and moisture resistance. The role of the enzyme layer is to tackle the issue of biodegrading and recycling PHB surface treatment. The idea is that the enzymes will be able to activate and increase biodegradation of the PHB surface treatment to prevent the bioplastic from hindering or polluting the recycling stream, see Figure 7.2.

Figure 7.2 Concept illustration of the biodegradation of the PHB surface treatment with enzymes on a fibre-based drinking device.

The remaining material would be the fibre interior for which there is extensive previous knowledge to recycle. While the aim of the development process is for the drinking device to be biodegradable, it was clear from discussions with experts in the packaging industry that recyclability is still a desired quality and should not be compromised by biodegradability. The enzymes are inactive in dry conditions and would activate when the drinking device absorbs liquid from the beverage it is immersed in. The PHB is slowing down the rate of moisture absorption from the beverage, thus delaying the biodegradation process until after use. The advantage of such a material combination would be that it can be used to improve product qualities like smoothness, recycling and biodegradation. The paper experts raised the difficulties with achieving adhesion between different layers of material. Furthermore, scientists in enzyme technology raised the issue that the enzymes may be sensitive to the high temperatures in the adhesion process.

These issues lead to the development of a second proposal, see Figure 7.1, Proposal 2. Instead of including the enzymes in the material combination as a separate layer, the enzymes can be encapsulated in the PHB surface treatment. Not only is the number of material layers reduced, but the enzymes can also be better protected against denaturation by high temperatures if encapsulated. From a food safety perspective, encapsulating enzymes in the PHB surface treatment could hinder migration of the enzymes into the food product. The challenge is to encapsulate the enzyme well enough to handle a production process of the drinking device, but not well enough that it prevents activation when it comes into contact with liquid.

As the main challenge with fibre-based materials is sogginess, another possibility is to replace the fibre material entirely by PHB. The third proposal is a drinking device consisting of a single layer of PHB mixed with enzymes. This eliminates the need for adhesion. However, a drinking device made of solely PHB is significantly thicker than a surface treatment made of PHB, resulting in more material to biodegrade.

While biodegradation is a desirable product quality, there can still be residual compounds left from the biodegradation process (see Ch. 3.1.2). This may pose a problem regardless of which option is chosen. Secondly, the environment in which the drinking device will be discarded should be considered. While Tetra Pak has requested marine biodegradation, most drinking devices would probably end up in a trash bin. Although, the biodegradation is supposed to be activated by the enzymes coming into contact with the liquid beverage, the environment in a trash bin needs to be considered.

The idea which the authors find has the most potential is the second proposal. Encapsulated enzymes will be more favourable since issues with adhesion will be reduced. It is also a more favourable option from food safety considerations. Thin surface treatment is easier to biodegrade compared to a drinking device made entirely out of PHB. Figure 7.3 shows the second proposal with the PHB surface treatment with encapsulated enzymes on both sides of the fibre-based interior. The interior layer with encapsulated enzymes will be activated by the pH of the beverage in the drink, consequently, the exterior layer will be activated by the surrounding beverage and saliva from the consumer's mouth during use.

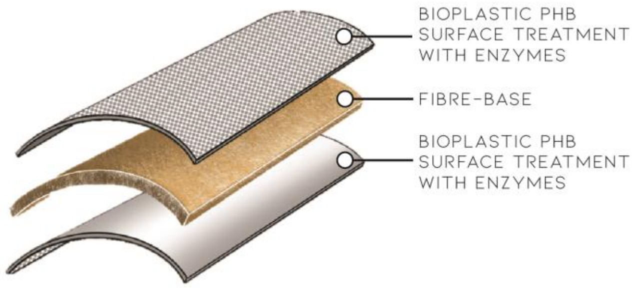


Figure 7.3 Second proposal using a fibre-based interior treated with PHB. The figure illustrates a two-sided PHB and enzyme surface treatment. The enzyme is encapsulated in the PHB surface treatment.

7.2 Material evaluation using multiple linear regression

To evaluate the biodegradation rate of the suggested material combinations, experiments need to be conducted in controlled lab environments. In this section, an outline is given for possible experiments and methods to analyse the results using multiple linear regression (MLR).

The material combination can be evaluated by continuously measuring the biodegradation of PHB films with encapsulated enzymes. The experimental conditions are the temperature, pH of the beverage, time length of the experiment and the initial thickness of the sample. These factors are of interest as they have a high impact on the biodegradation of the drinking device. As suggested by the biotechnology researchers, see Ch. 4.1.2, designed enzymes can be developed specifically for this study. Alternatively, known commercial PHB depolymerises such as lipase could be tested.

Biodegradation is a complex chemical process and even more so when enzymes are involved. There are mainly two approaches to modelling chemical processes. Firstly, a model can be based on chemical reactions when there are sufficient information and knowledge about the underlying process (Hong, Duan, Meeker, Stanley & Gu, 2015). For instance, using the Arrhenius equation the effect of temperature on the reaction rate can be modelled (Hong et al., 2018; Tetra Pak, 2020w-x). Secondly, a statistical and data-driven approach can be used which is not constrained by physical phenomena (Hong et al., 2018; Sauerbrei et al., 2020). This method is more flexible to describe a dataset or phenomenon of interest (Hong et al., 2018; Sauerbrei et al., 2020).

Since MLR models the association between explanatory variables and a response variable, it is a suitable statistical approach for modelling biodegradability (Blockeel et al., 1999). In this context, the goal of using an MLR model is to predict if the proposed material combination will biodegrade within a certain time frame. Biodegradation tests are generally being performed by recognised companies that issue international certificates for biodegradation. This is an extremely time consuming and costly procedure. To be able to estimate the biodegradation rate using predictive modelling would allow the packaging industry to save a large amount of resources and time. Furthermore, a trustworthy MLR model can help in the product development process. For example, the material proposal can be modified by quantifying how the biodegradation rate is affected by the thickness of the PHB surface treatment. Moreover, there is interest from Tetra Pak to study how utilising enzymes can speed up the biodegradation rate of PHB (Tetra Pak, 2020b-v). The increase in biodegradation rate from the enzyme can also be assessed using

MLR. Therefore, modelling is beneficial in the design of experiments for further studies of a biodegradable drinking device.

A common way of measuring biodegradation is to measure the percentage of weight loss over time. This is also the desired response in the regression model, allowing easy interpretation and comparison. Therefore, the regression model should predict values between 0 and 1. To bound the prediction range of the model, the data can be transformed using a logit function, see Equation (7.1). The logit function transforms values, y_i, between 0 and 1 to the real value scale (- ∞, ∞),

$$logit(y_i) = log(\frac{y_i}{1-y_i}) \tag{7.1}$$

and the inverse transformation is given by

$$sigmoid(\hat{y}_i) = \frac{e^{\hat{y}_i}}{e^{\hat{y}_i} + 1} \tag{7.2}$$

The predicted values of weight loss, $\hat{y}_i$, are transformed back to the 0-1 scale using the sigmoid function.

For the same set of experimental conditions, control experiments will have to be conducted without the enzyme in the PHB film. The presence of an enzyme can be included in the model by adding a categorical variable x which is equal to 1 when the enzyme is added and 0 when it is not. The effect of the enzyme can be determined by assessing the significance of the coefficient for the categorical variable. The multiple regression model of interest to fit on the data is given by:

$$logit(y_i) = b_0 + b_1 x_{i1} + b_2 x_{i2} + b_3 x_{i3} + b_4 x_{i4} + b_5 x_{i5} \tag{7.3}$$

where y_i is the weight loss, the b variables are the regression coefficients for the different explanatory variables $x_{i1}, \ldots, x_{i5}$ and $i = 1, \ldots, n$ are the data points corresponding to different experiments. The resulting coefficients would give information on how the percentage weight loss of the PHB film changes when there is a change in one of the variables, provided all other factors are constant.

The assumption of a linear relationship may be an oversimplification for some variables. Thus, the model needs to be extended with non-linear regression methods. To find out which variables have non-linear relations, exploratory data analysis can be conducted. Another approach is to consult experts in enzymatic biodegradation in what relations can be expected from the experimental variables (Tetra Pak, 2020w-x). Plots with residuals $y_i - \hat{y}_i$ versus predicted values $\hat{y}_i$ can also be used to gauge whether non-linearity is necessary or not. If a discernible pattern can be detected, it suggests non-linear terms need to be added into the model (James et al., 2014). A non-linear regression method, which allows for great model flexibility, is spline regression (see Ch.3.1.4). In Equation (7.4), an example is given for how the model looks using natural splines for the variable x_3:

$$logit(y_i) = b_0 + b_1 x_{i1} + b_2 x_{i2} + \sum_{q=1}^{Q} h_{q3}\, b_{q3}\, x_{i3} + b_4 x_{i4} + b_5 x_{i5} \qquad (7.4)$$

Where $h_{qj}, q = 1, 2, \dots, Q$ are the basis functions (see Ch. 3.1.4) of the natural cubic spline for x_{i3}. The knot positions can be optimised by minimising the cross-validation residual sum of squares (RSS).

It should also be investigated if there are significant interaction effects, i.e. if there are synergistic effects from two explanatory variables on the response. Multiple interaction terms can be included in the model and the significance of their corresponding coefficients should be tested. Interaction terms can also be included based on knowledge about which synergistic effects can be expected from the experimental conditions (Gordon et al., 2018; Tetra Pak, 2020w-x). Equation (7.5) shows how the MLR model would look with one interaction term between e.g. time length of the experiment and the use of an enzyme, $x_{i1}x_{i5}$:

$$logit(y_i) = b_0 + b_1 x_{i1} + b_2 x_{i2} + \sum_{q=1}^{Q} h_{q3}\, b_{q3}\, x_{i3} + b_4 x_{i4} + b_5 x_{i5} + b_6 x_{i1} x_{i5}, \qquad (7.5)$$

where b_6 is the additional coefficient describing the association between $logit(y_i)$ and the synergistic effect from $x_{i1}x_{i5}$. To assess how well the model captures the relation between the predictors and responses, analysis of RSS and R^2_{adj} can be conducted. Furthermore, to evaluate whether an additional interaction term in the model results in a better fit to the data, BIC can be used. Regardless of which modelling technique is used, prediction outside the range of data is always a challenge (Tetra Pak, 2020w-x). However, *k*-fold cross-validation can determine the predictive capabilities within the range of available data. Predictions outside the range of data should be compared with further experimental studies.

The effect of the enzyme can be determined by assessing the significance of the b_6 coefficient in Equation (7.5). Figure 7.4 illustrates how to interpret the coefficient. The two lines represent different slopes for the data points with (triangle) and without (circle) enzyme. The coefficient b_6 is the difference between these two slopes and can be interpreted as the difference in percentage weight loss per day for experiments with and without enzyme.

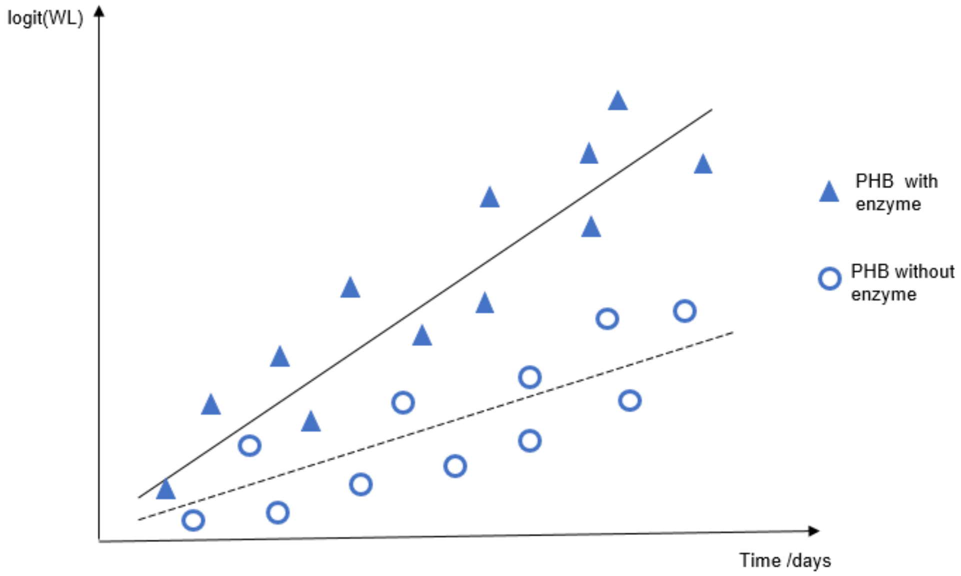


Figure 7.4 An illustration made by the authors for interpreting the coefficient b_6. The two lines represent different slopes for the data points with (triangle) and without (circle) enzyme. The coefficient b_6 is the difference between these two slopes and can be interpreted as the difference in percentage weight loss per day for experiments with and without enzyme.

8 Design concepts

This chapter outlines the mood board for product development and design suggestions. The suggestions are evaluated based on the target specifications and material combination in Ch. 6.2 and Ch. 7.1 respectively. Iterations on the chosen designs are made and a final design suggestion is proposed.

8.1 Mood board

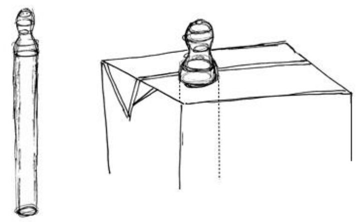
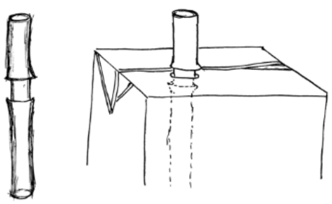
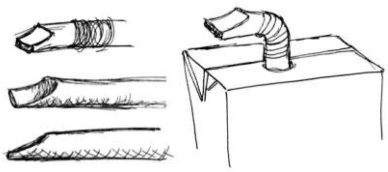
The mood board in Figure 8.1 presents the inspiration for the potential physical features of the drinking device. Inspiration is taken from various mouthpieces with different uses and applications: inhalers, whistles, e-cigarettes, musical instruments, baby bottles and dental equipment. From the idea generation process, using the mood board and several brainstorming sessions, the primary design concepts are created (see Table 8.1).

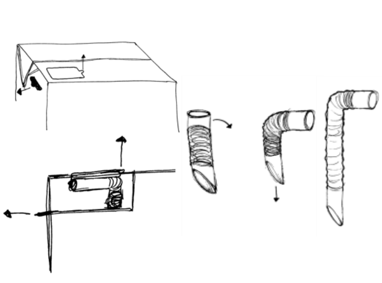
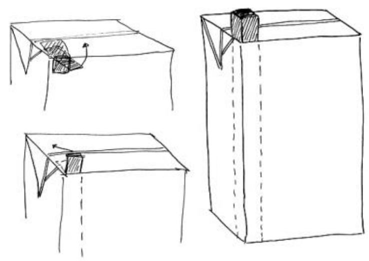
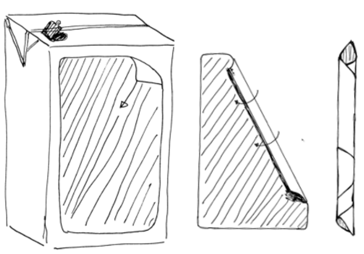
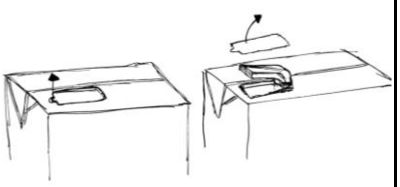
Figure 8.1 Mood board for the development of a biodegradable drinking device.

8.2 Design concepts

From a *design track* perspective, the overall appearance and physical features of the drinking device are considered in alignment with the material combination. Various design concepts are developed based on the user needs and preferences, see Table 8.1. The design concepts are specifically aiming to solve some of the main concerns detailed under target specifications (see Ch. 6.2).

Table 8.1 Design ideas, sketches and their respective advantages and disadvantages.

Idea	***Sketch***	***Advantages and disadvantages***
A. Bottle drinking device ***A straw shaped device with a feeding bottle mouthpiece that prevents the liquid from spilling.***		***Advantages:*** Preventing spillage and ease of use. ***Disadvantages:*** adults may be sceptical towards using a baby bottle drinking device. Difficulties in constructing the bottle shape and functionality with fibre-materials.
B. The double stopper drinking device ***The drinking device can easily be inserted in the packaging. However, the stoppers prevent it to be removed or fall into the package once inserted.***		***Advantages:*** Keeps the drinking device in place. Bendability function can be added. ***Disadvantages:*** Can be removed using force.
C. Ergonomic mouthpiece ***A shaped mouthpiece inspired by musical instruments for controlled sipping. Bendable functionality is optional.***		***Advantages:*** Bendable and comfortable mouth contact with the drinking device. Intuitive and easy to use. ***Disadvantages:*** Challenges in construction and technical properties with a fibre-base.

D. 'Pop-up' drinking device ***Once the user pulls the two tabs, the drinking device will pop down, to access the liquid and pop up to reveal the drinking device for the user.***		***Advantages:*** Fun user experience. The device is completely wrapped, bendable and stays in place. ***Disadvantages:*** Complex to use and construct. Difficulties to corrugate the whole drinking device using fibre-materials. Loose tabs are bad for littering.
E. Hidden drinking device ***Peel the wrapping and pull up the drinking device into a squared shape. The drinking device is on the inside of the package.***		***Advantages:*** The drinking device is wrapped, attached to the package and easy to use. ***Disadvantages:*** The opening process may not be intuitive and easy to use. Enzymes may be activated in advance as the drinking device is immersed in the liquid from the start.
F. Burrito drinking device ***Peel off the rectangle from the outside of the package and roll it into your drinking device.***		***Advantages:*** Less glue makes it easier to biodegrade. Effective for stacking and production purposes. Can be wrapped through an exterior film that can be peeled off. ***Disadvantages:*** Hard to prevent spillage, increased complexity to use and is not bendable. Hygiene challenges when rolling with fingers.
G. Peel and reveal drinking device ***Peel away the wrapping and lift the drinking device. The mouthpiece is connected to a drinking device inside the package.***		***Advantages:*** Wrapped, bendable and keeps the drinking device in place. ***Disadvantages:*** does not prevent spillage and there are challenges in construction. Enzymes activated in advance.

8.1 Discussion and improvements of design concepts

Based on feedback from Tetra Pak colleagues in the department of New Materials for Openings and Closures (see Appendix B, Table B.2), the advantages, disadvantages and ideas for improvements of the design concepts are reviewed. The following sections presents the evaluation of the design concepts based on the feedback together with the authors' own assessments.

Concept A: Bottle drinking device

The two main benefits of the drinking device are the ergonomically shaped top and prevention of spillage. The appearance of the drinking device is more targeted towards small children or babies, rather than adults. This may affect the attractiveness of using the product for grown-ups. In addition, the small opening of this design can make it tougher to drink thicker liquids like smoothies. To attend to these concerns, it would be beneficial to increase the size of the opening of the drinking device.

Considering the material combination, a fibre-material with bioplastic surface treatment can be a challenging material for this design concept. Instead, the shaft could be developed using pure fibre-material while the mouthpiece could be produced entirely in bioplastics. With this modification, the separation process during recycling is simplified. In this case, the attachment of the parts is an important consideration. Either the mouthpiece can be attached during production to the drinking device, or it can be an addition where the consumers apply the mouthpiece themselves to the drinking device during use. This type of mouthpiece can be created as a reusable tip for all types of straws. Furthermore, the user may need to bite the mouthpiece to sip liquid and hence the material needs to be sturdy enough to handle that.

A suggestion for technical improvement is to make the profile of the mouthpiece lower, i.e. for improved fit placing the curved outline further down. Furthermore, other non-return valve mechanisms can be added to ensure the liquid does not come out of the drinking device. However, such a mechanism can restrict the flow of the liquid. Another idea was that the mouthpiece can have a lid that can be opened and closed, like a water bottle. In this case, it is important to consider how this device would sit on the package and if there is be a risk that it would break off. Lastly, to further attend to the target group of babies and small children, the idea can be combined with concept B: Double stopper drinking device to also keep the drinking device in place.

Concept B: Double stopper drinking device

The main benefit of the design concept is that the drinking device can be discarded together with the package, effectively reducing littering. To reduce littering by attaching the drinking device to the package is a highly desired feature in the packaging industry. Furthermore, the double stopper prevents the drinking device from falling into the package before the consumer has finished the beverage. The simple design is easy to use and keeps its shape throughout use. This design concept is also simple to make bendable by corrugating the drinking device at the top section. An issue is to make the stoppers stick to the drinking device while still making the drinking device aesthetically pleasing for the consumers.

The disadvantage of stoppers is that users cannot easily move the drinking device around in the package. Besides, keeping the drinking device in the opening raises concerns about how users can empty the package from beverage before recycling. A suggestion is to make the stop function flexible or longer. So that consumers can push down the drinking device to reach all corners in the bottom of the package. The drinking device can also be combined with a telescopic straw, making it possible to increase the length to reach all corners of the packaging. To improve the user experience, the drinking device could click with a satisfying sound when inserted in the package.

The material combination would work well with this design. The sole consideration is the material and construction of the stoppers. If extrusion is used, it is not easy to deform the drinking device to create stoppers. The drinking device could come with a separate part with the stopping function to be attached by the consumers. In this case, it is essential to make it intuitive for the consumers how and why they should attach the stoppers and prevent them from throwing them away and littering.

Concept C: Ergonomic mouthpiece

The shaped mouthpiece was appreciated by Tetra Pak employees, particularly with the bendable functionality. The main benefits are the reduced risk of spillage, the ergonomic shape and possibility to use the material combination. On the other hand, many colleagues argue that the solution restricts the flow on an already small diameter, particularly for thick liquid products. A suggestion is to make the opening of the drinking device an oval or round shape for a better drinking experience. Another suggestion was to make the top a separate and reusable part of the drinking device that can be applied to any straw. However, the intricate shape is challenging to produce using a fibre-base material. Further improvements could be made by making the shaft purely fibre-based and the top purely in bioplastic with enzymes or simplifying the top section of the design concept.

Concept D: Pop-up drinking device

According to Tetra Pak employees, the idea was an innovative and intriguing solution that had not been seen in the context of drinking devices before. In addition, the solution would ensure a safely enclosed and hygienic drinking device. The integrated drinking device solution is also beneficial for stacking the packages. If the functionality is feasible, it is a surprising and delightful solution. On the other hand, the idea is complex both for manufacturing and for the user. It is also harder to use a corrugated drinking device to reach all the corners of the package due to the bendable properties. Furthermore, there are difficulties in making a fibre-based drinking device sturdy enough to enable a pop-up effect. Also, a tight chamber is needed for the drinking device to be able to pop open. Tetra Pak's Aseptic package is sensitive to have integrated parts in the package; thus, a chamber will be disadvantageous during construction. Tetra Pak's concern is that too many things can go wrong in the popping functionality. Lastly, it is important to consider whether the tabs are still attached or if they are to be separately disposed of.

Concept E: Hidden drinking device

The benefit of this concept is that there are no external parts that can get lost, reducing littering. In addition, it is easy to empty the package when the drinking device is fixed in a corner. According to feedback, the squared shape is interesting. However, Tetra Pak engineers are not sure if the shape would be positive or negative for the mouthfeel compared to a round drinking device. A disadvantage with a drinking device fixed in a corner is that it prevents the consumer from reaching another corner and sip the last drops of the beverage. In addition, having the drinking device on the inside can be complicated for an Aseptic package.

Regarding the material combination with enzymes, the challenge is to prevent the encapsulated enzymes from reacting during shelf-life. Furthermore, since the device is in contact with the liquid throughout shelf-life, food safety requirements will be much higher. In this case, an enzyme combination to increase biodegradation is not optimal. A suggestion for improvement is to integrate the drinking device on the outside of the package. In this case, one would still need to insert it in the package. But the issue of integration and more stringent food safety requirements are removed. Moreover, it should be considered how the final squared shape can be made robust enough to avoid it becoming flat again. This design would also be interesting to test with a round or oval-shaped drinking device. Furthermore, to prevent vacuum while drinking, another idea was to incorporate a small puncture next to the drinking device sprout to allow for air to flow.

Concept F: Burrito drinking device

This design concept offers a do-it-yourself solution and provides benefits through saving space when stacking packages. The solution provides a unique and fun user experience compared to other drinking device solutions. The challenges are that it adds complexity for the user, particularly for children. The solution requires two hands to roll the drinking device which makes it less practical compared to a classic drinking device. Also, there are hygienic trade-offs since the consumer needs to roll the drinking device with their fingers. Furthermore, issues with sealing and leaking will likely become an issue when the consumers roll the drinking device themselves.

From a material perspective, the shape is highly beneficial for the biodegradation of the drinking device. If the drinking device is thrown away, the thin rectangle shape aids the process to biodegrade the material. However, once the consumers have rolled the drinking device it will be slightly thicker and take more time to biodegrade. To improve the design, it would be beneficial to simplify the rolling procedure for the consumers. In addition, very clear instructions are needed to avoid consumers from failing to roll the drinking devices. It is also essential to consider who is responsible if the drinking device fails. The user journey would need to be described; how to open, prepare and drink with the drinking device. An idea is to create an internal rolling mechanism which allows the drinking device to be rolled together when the consumer pulls on the string. In this case, the consumers only need to place the rolled drinking device in the package.

Concept G: Peel and reveal

According to development engineers in the packaging industry, integrated spouts like this design concept are very appreciated in theory. The design concept covers and protects the drinking device before use, thus enabling wrapping and improved hygiene. The concept is a stealthy solution that also minimises waste. The main dislike for this concept is the removable tab since it creates a risk of littering. Thus, to improve the design the tab should not be removable from the package. As for the material combination, a bioplastic solution could work for this design. However, to integrate the enzymes, the drinking device should not be in contact with the liquid before use. There are two main options for the construction of the concept. Either the drinking device consists of only the mouthpiece attached to the top of the package, or it is attached to a straw that is inside the package. In the first case, it needs to be ensured that the sides of the drinking device do not leak if the package is tilted by the consumers to drink the beverage. In the latter case, a suggestion is to place it in a corner to make it easier to empty the package. Additionally, it would be beneficial to attach the drinking device to the outside of the package to avoid contact with the liquid during shelf life. In either case, a small hole is needed next to the device to prevent vacuum while drinking.

8.2 Target evaluation

Table 8.2 presents the evaluation of the design concepts based on the target specifications (see Table 6.4). The authors ranked each concept based on their potential to fulfil the target requirements by carefully considering the feedback and discussions in Ch. 8.1. A scale of 1-3 is used to determine whether each concept fulfils each the target specification where the ratings are defined as follows; 1 = Poor potential to fulfil target specification, 2 = May fulfil target specification and 3= Good potential to fulfil target specification.

Table 8.2 Evaluation of the design concepts A-G. The design concepts are scored on a three-point scale where 1= Poor potential to fulfil target specification, 2=May fulfil the target and 3=Good potential to fulfil target specification. The total scores of the design concepts are tallied.

Target specification	A	B	C	D	E	F	G
1. Recycling	2	2	2	2	3	3	3
2. Biodegradation	3	1	3	1	1	3	1
3. Moisture resistance	1	2	2	2	1	3	2
4. Spillage	3	2	3	2	2	1	2
5. Reduced littering	1	3	1	2	3	1	2
6. Ease of use	2	3	2	1	2	1	2
7. Hygiene	2	2	2	3	2	1	3
8. Keeps shape	1	3	2	1	1	1	2
9. Ergonomic	3	2	3	1	2	1	2
10. Food safety	2	2	2	2	1	1	1
Total score	**20**	**22**	**22**	**17**	**18**	**16**	**20**

Based on the rating in Table 8.2, concepts B and C received the highest scores. Firstly, concept B: Double-stopper drinking device is determined to be an interesting solution after discussions at Tetra Pak. Secondly, concept C: Ergonomic mouthpiece is the other most popular proposal. The latter can be combined with concept A: Bottle drinking device to give additional benefits. Thus, two concepts were further developed concept B and a combination of concepts A and C.

8.3 Design iterations

Iterations of the double stopper drinking device (concept B) are firstly brainstormed as seen in Figure 8.2. The ideas include various types of stoppers and additional features such as it being bendable or having a telescope function to extend the drinking device. The main purpose is to prevent the drinking device from falling into the package before the consumers have finished their drink, and to prevent consumers from littering by keeping the drinking device attached to the package.

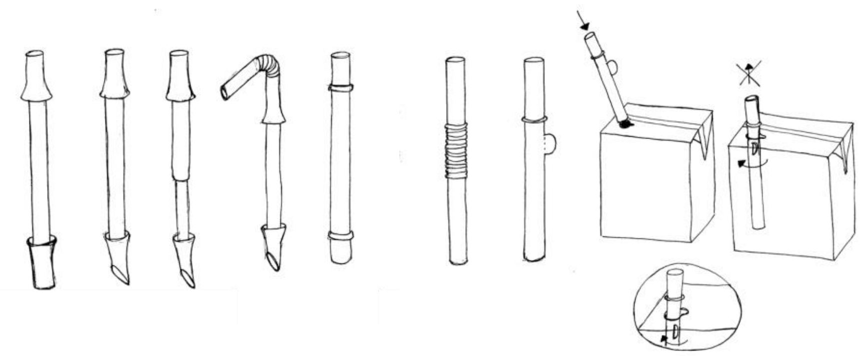


Figure 8.2 Iterations of design concept B. Double stopper drinking device.

Furthermore, ergonomic designs aiming to prevent spillage based on concepts A and C are brainstormed as seen in Figure 8.3. Various ergonomic mouthpieces are developed as well as different types of lids. A more complex solution is also considered in Figure 8.3 on the right. Here a valve mechanism is added, the consumer can push the side of the drinking device to allow for the liquid to pass through.

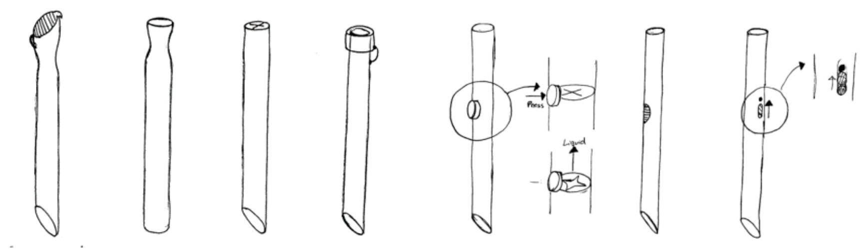


Figure 8.3 Iterations of designs concept A. Bottle drinking device and concept C. Ergonomic mouthpiece.

The straw on the Aseptic packaging is very small, thus it is challenging to create complicated valve mechanisms and buttons. Although these suggestions open a range of interesting solutions, anything added to a single-use drinking device must be minimal and easy to produce. As the material combination tackles the issues of biodegradation, recycling and moisture resistance, the design of the drinking device can complement the material combination by addressing other product requirements. concept B mainly eliminates littering and it is, therefore, an interesting idea for a non-biodegradable, fossil-based drinking device. The combination of concepts A and C, on the other hand, complements the biodegradable material combination through other user-friendly qualities such as ergonomic use and reduced spillage. Spilling is mostly connected to the feeling of control and knowing when the liquid reaches the mouth, thus by increasing the control of the drinking device the consumers can also reduce spillage. After careful consideration, the combination of concepts A and C has the greatest potential to fulfil consumer needs while being a good complementation to the biodegradable material combination.

8.4 Result and final design proposal

Based on discussions with Tetra Pak, the final design proposal is an hourglass ergonomic mouthpiece for improved mouth control. The top of the mouthpiece has a round opening to increase the flow of liquid. The bottom of the drinking device is angled to easier push the drinking device into the package. The mouthpiece is designed to feel comfortable in the mouth and reduce the risk of spilling (see Figure 8.4).

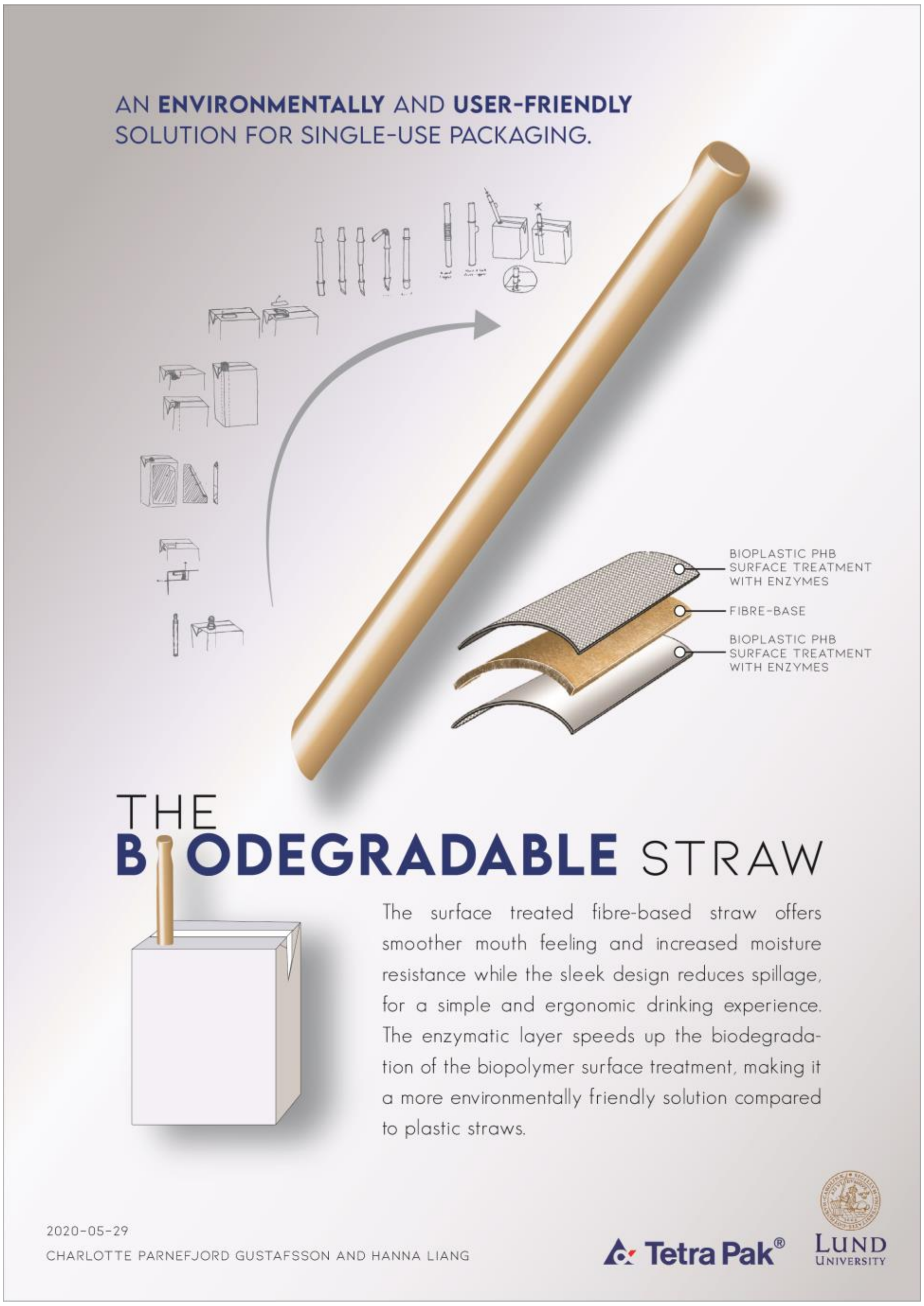


Figure 8.4 Poster of the final design proposal and material combination.

9 Discussion and conclusion

The methods, results and limitations to each research question of the thesis are discussed in this chapter. The conclusions of the thesis are presented along with the final recommendation. Lastly, suggestions for further research are given.

9.1 Discussion

A *Technical* and *Design track* perspective was used to identify the main opportunities and challenges in developing an environmentally and user-friendly drinking device for a Tetra Brik® Aseptic 200 single-use packaging. Based on a literature review, the utilisation of enzymes has been explored to increase the rate of biodegradation of biopolymer surface treatment. Furthermore, through a Kano Analysis, the most important features of a drinking device from the consumer's perspective were analysed. Based on the study, suggestions of material combinations were recommended. A proposal was given of how multiple linear regression can be used to study the biodegradation rate of the suggested material combination. Furthermore, design concepts were developed and evaluated based on the target specifications and lastly a final design was proposed. The following sections summarise and discuss the findings to each of the four research questions.

1. *What are the main opportunities and challenges in industry and academia for developing biodegradable drinking devices utilising enzymes?*

The authors identified the opportunity to create a fibre-based drinking device treated with biopolymers to address the challenge of moisture resistance. The bioplastic PHB was categorised as an interesting prospect for the surface treatment due to its similar material qualities to PP and the extensive previous research on enzymatic biodegradation of PHB. The benefits of using a surface treated fibre-based drinking device are to keep the material as naturally biodegradable as possible while still attending to the needs of the consumers, such as moisture resistance and smooth mouth feeling.

To simultaneously enable laminating the fibres with a PHB surface treatment while still minimising the intake of moisture, the fibres need to be susceptible to adhesives. The adhesives, usually a polymer-based glue, may affect the recycling stream negatively. These adhesives are usually not biodegradable. A solution to minimise the contamination of the fibres with the biopolymers is to use an enzyme to biodegrade the surface treatment in advance of the recycling of the drinking device. In other words, the biodegradation of the biopolymer surface treatment can be started after the drinking device has been placed in the liquid, utilising enzymes as a catalyst for the reaction.

Enzymes are inactivated in dry conditions; thus, a solution would be to encapsulate the enzymes in the biopolymer surface treatment. Commercial enzymes such as lipase can be used, however, a better option is to develop an enzyme specific for the use of PHB surface treatment. A designed enzyme can be modified to be more robust towards high temperatures. There are four main challenges identified in the process of using enzymes. Firstly, it is challenging to activate the enzymes on-demand after the drinking device has been placed in the liquid. The process should neither begin during shelf-life nor use. The goal is to start the process directly once the consumer has finished the beverage, or once it is thrown in a recycling- or trash bin. Secondly, as drinking devices will be used in various types of beverages, e.g. milk, juice and alcoholic beverages, the various pH of the beverages will affect the rate of reaction of the enzymes. Thirdly, not only do the enzymes need to be encapsulated but also reactivated in the liquid. This can be a challenge as not all the enzymes will be able to reactivate after being encapsulated. Fourthly, the temperature and environmental conditions such as humidity may affect how the enzymes react with the bioplastic.

Another challenge with utilising enzymes in a drinking device is being able to create a product that is both biodegradable and recyclable. The by-products of the biodegradation should not affect the recycling stream negatively. Repulping the fibres can be a challenge in and of itself; the surface treatment makes it more challenging to recycle the fibres. Therefore, a potential is if the by-products of the biodegraded biopolymer and enzymes can be separated in the chemical process of the recycling stream. Additionally, it is important to consider the safety of consumers. There cannot be any dangerous levels of migration to the beverage from the material of the drinking device. On the other hand, since the drinking device is not immersed in the beverage during shelf life, there are less stringent requirements on the levels of migration.

Conducting the interviews with specialists in the packaging industry gave valuable insights into the priorities and points of interest in the development of a new biodegradable drinking device. However, there are a few limitations to consider. Firstly, a limited number of experts were interviewed and most of them were professionals from Tetra Pak. Their suggestions and expertise may have been biased towards Tetra Pak's or their preferences. On the other hand, the findings from the interviews became more targeted towards the needs and challenges experienced by Tetra Pak. For this reason, it would be of interest to also investigate the needs and preferences of other product stakeholders such as customers of Tetra Pak machines. Secondly, access to raw data about the biodegradation rate of bioplastics was extremely limited, which restricted the extent of data-driven evaluation for the material combination. Although biodegradation tests had been made by partner companies to Tetra Pak, the data was limited to photographs or a single data point which were insufficient for a thorough quantitative analysis. Thirdly, most attention of which bioplastic can be suitable as a surface treatment was given to PHB. However, there are many other biobased and biodegradable polymers which also should more deeply be considered as potential surface treatments for the biodegradable drinking device.

2. *What are the principal consumer needs in designing a commercially viable drinking device?*

From the literature review, the authors found that Kano Analysis applies to a wide range of products and industries. A questionnaire based on Kano Analysis was used to gain the general attitudes from consumers to 12 selected features. The features in the questionnaire were: *bendable*, *biodegradable*, *flavourless*, *recyclable*, *reusable*, *safe*, *separate*, *smooth*, *soft*, *soggy*, *stiff* and *wrapped*. They were selected through literature review and discussions with experts in the packaging industry. The 308 respondents were divided into the demographic groups; Frequent user, Mid-frequent user and Infrequent user, depending on how often they use straws. The responses were analysed using the statistical methods of binomial tests, Kruskal-Wallis tests and Wilcoxon rank-sum tests. The use of statistical significance testing allowed robustness and precision in the analysis of the responses, which simple visual analysis or tallying would have lacked. The results from the statistical analysis were used to decide which features were important to include in the product development of a drinking device. The most important features were *safe*, *(not) soggy* and *flavourless*. The environmental features *biodegradable*, *recyclable* and *reusable* also received high importance scores. Kruskal-Wallis and Wilcoxon rank-sum tests revealed that all three demographic groups placed higher importance scores on *recyclable* than *biodegradable* and *reusable*. Furthermore, Infrequent users ranked the features *biodegradable* and *recyclable* higher than Frequent users. Interestingly, Frequent users placed higher importance scores on the features, *soggy*, *flavourless*, *stiff* and *smooth*, compared to Infrequent users.

Binomial tests showed that some features had inconclusive categorisation between the two categories with the highest number of votes. This may suggest the respondents did not clearly understand the answer options to the questionnaire. In the feedback section of the questionnaire, some respondents stated they did not fully understand the options “It must be this way” compared to “I really like it”. The difference was explained in the top section of each of the sections in the questionnaire. However, many respondents can easily have missed this text. This can explain why the categorisation was inconclusive for the features *safe* and *flavourless* even though the expected categorisation for at least *safe* is Required. On the other hand, the low number of Questionable answers for each feature suggests the questionnaire was well understood by the respondents. More importantly, the availability and the limited number of respondents to the questionnaire should be considered. Since the questionnaire was sent out to the authors' network, which included professionals from the packaging industry, there may have been biasing created by them. On the other hand, the questionnaire is a time-efficient way to gather a large amount of data about consumer preferences. A disadvantage with the questionnaire is that it does not ask the respondents to rank the importance of the features against other features. This is relevant if a limited number of features can be developed due to cost or production considerations and the features will need to be prioritized. However, cost and production considerations were in delimitations. Hence, including one feature in the development process did not necessarily mean another feature could not be included. Furthermore, except for the frequency of use, another statistical analysis of consumer preference based on e.g. gender, age or occupation was not conducted. Lastly, the questionnaire included a selected number of features and there are other possible features which may have been relevant to include. This issue was however partly solved at the end of the questionnaire where respondents could propose their ideas and thoughts about drinking devices.

3. *How can the rate of biodegradation of alternative materials be modelled using linear regression?*

The limited access to raw data about the rate of biodegradation of PHB leads to the development of a theoretical model and the experiments that should be conducted. The biodegradation rate of PHB films with encapsulated enzymes should be studied in controlled lab environments. A multiple linear regression model can quantify the influence of time, temperature, pH and thickness on the biodegradation rate of a PHB film. Biodegradation rate can be measured as percentage weight loss and this would also be the response variable in the model, while the experimental conditions are the explanatory variables. For the same set of experimental conditions, control experiments without the enzyme should be performed. The model can assess the influence of using the enzyme to increase the rate of biodegradation by including a categorical variable. A trustworthy model can also be used to predict if the PHB will biodegrade within a certain timeframe under set experimental conditions. Thus, aiding in the design of further experiments and saving resources.

Prediction is always a complex task and there are of countless ways to build a statistical model. Although the described model is not applied to data, certain aspects can still be discussed. Firstly, the selected experimental factors as explanatory variables are not all-encompassing. There are various material properties and environmental factors which can affect biodegradability, for example, permeability. On the other hand, the proposed modelling technique allows for easy addition of new variables of interest. However, the statistical significance of additional variables would have to be tested. Secondly, a multiple linear regression model assumes a linear relationship between the response and explanatory variables. However, the actual relationship is unknown, and the true underlying relation is rarely linear. For example, there could be exponential or polynomial trends in the data. By incorporating splines in the model, considerations to non-linearity have been included in the model. The suggestion of using natural cubic splines is one of many methods to model non-linear relations. How suitable natural cubic splines are to model biodegradation needs to be evaluated by applying the model on actual data. However, natural cubic splines are a favourable beginning since its requirements for continuity and linearity at the boundaries allow for more robust estimates.

4. *What are some alternative material combinations and designs that would fulfil consumer and industry needs?*

This thesis mainly proposes the material combination of a fibre-based drinking device and a PHB surface treatment with embedded enzymes. This is a theoretical solution that should be further investigated. Other alternative material combinations are a three-layered solution where the enzymes are not encapsulated in the PHB treatment. However, this solution creates the challenge of preventing the enzymes to instantly biodegrade the drinking device after production, which is not beneficial. Furthermore, a pure bioplastic PHB drinking device can be created utilising encapsulated enzymes. In this case, it will take slightly longer to biodegrade due to increased thickness. From an environmental perspective, it would be more beneficial to make the drinking device in a mono-material to prevent contamination in the recycling stream of the interior fibre material. Encapsulating enzymes could however make sure the PHB surface treatment is biodegraded before the drinking device reaches the recycling state. If the drinking device ends up in nature, the drinking device should still biodegrade since fibre material is naturally biodegradable. Another alternative approach is to use enzymes in the recycling process to separate the layers of the drinking device. Utilising enzymes in the recycling stream have potential, but it still does not address the problem of plastic pollution in marine environments. The advantage of utilising encapsulated enzymes in a bioplastic surface treatment is that the drinking device can be biodegradable and simultaneously not hinder recycling.

This research evaluated seven different design concepts aiming to solve the identified target specifications for consumer needs. Mainly, the material combination aimed to target the features of *recycling, biodegradation* and *moisture resistance.* The goal of the design was to complement the features to attend to some of the other user concerns and preferences. Based on the target specification, a combination of design concept A: Bottle drinking device and concept C: Ergonomic mouthpiece were used for the final design. The final design is a straight drinking device with an ergonomically shaped mouthpiece to improve mouth feeling and control of the device to reduce spilling. However, further user and prototype tests need to be conducted to confirm the potential of reduced spilling. The bottom of the drinking device is angled to ensure that it can be pushed into the package. The authors are satisfied with the results of the material and design suggestion and received positive feedback and great interest from Tetra Pak's side. There is also potential to further develop another of the seven concepts listed under Ch 8.2. The concepts need to be tested both regarding construction as well as with user-testing before being used for commercial purpose. Additionally, both cost of development and production needs to be considered. Overall, the authors believe the result is a great start on the way to develop a user- and environmentally friendly drinking device. Furthermore, there is also further potential of using the material combination with enzyme technology for other packaging materials in the industry.

9.2 Conclusion

The purpose of this thesis was to suggest a design and material proposal for developing a user-and environmentally friendly drinking device utilizing enzymes. Through literature review, interviews with experts in packaging material and biotechnology, and a Kano Analysis, a material suggestion was developed. A proposal was given for how this material suggestion could be tested experimentally and how the experimental results could be evaluated using multiple linear regression. Lastly, design suggestions were developed based on the mapped requirements from industry and consumers.

The final recommendation is a fibre-based drinking device with a surface treatment of PHB and encapsulated enzymes. The similar properties of PHB to conventional PP plastic makes it a preferable material to use as a surface treatment. The surface treatment would improve product qualities such as moisture resistance and smooth mouth feeling. The encapsulated enzymes would begin to catalyse the biodegradation process of the PHB treatment when the drinking device is placed in a beverage package. The surface treatment targets one of the principal needs for consumers, to prevent the drinking device from becoming soggy. Therefore, the greatest challenge in utilising enzymes is to ensure that the biodegradation process is activated after the consumer has used the drinking device. The final design concept recommended is an ergonomic mouthpiece that prevents spilling and is easy for consumers to use. The recommended material combination needs further experimental testing as well as user testing with a prototype of the final design.

9.3 Future research

Further research is needed in developing designed enzymes for biodegrading a PHB surface treatment. Additionally, commercial enzymes should be mapped and tested for the same purpose. Furthermore, the proposed material combination needs to be evaluated through physical prototypes. Specifically, the rate of biodegradation should be tested when the drinking device is immersed in liquids with various pH and temperatures. Moreover, the suggested multiple linear regression model should be applied to real data to evaluate and improve its predictive capabilities. Finally, user tests with the proposed design suggestion should be made to further develop the ergonomic mouthpiece.

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Appendix A Work distribution and time plan

Appendix A describes the distribution of work between the two master thesis students, in addition, the time plan for the thesis project is described.

A.1 Work distribution

The work distribution was distributed evenly between the authors throughout the whole process of the master thesis project. Both students were involved in all parts of the thesis. However, each student had extra responsibility for their respective fields, mathematical statistics and design sciences. The statistical analysis of the Kano questionnaire and the outline of using multiple linear regression were mainly researched and investigated by Hanna. Meanwhile, the suggested design concepts and their evaluations were mainly developed by Charlotte.

A.2 Project plan and outcome

The initial time plan set at the beginning of the thesis project is displayed in Figure A.1. The results for the time plan, after changes and modifications to surrounding circumstances, is displayed in Figure A.2. Overall, the time plan was followed with a relatively high success rate, where the alterations in the time plan did not affect the overarching goal of the thesis. Due to external circumstances like Covid-19, plans of activities, such as physical enzyme development and physical product testing at Tetra Pak facilities, needed to be cancelled. It was particularly challenging for the authors to limit the scope of the thesis since there were plenty of intriguing side-tracks to explore. However, with the help of supervisors and colleagues, the authors stayed on track. The study has provided the authors with invaluable experience in time-management, flexibility and refocusing the aim to manageable goals.

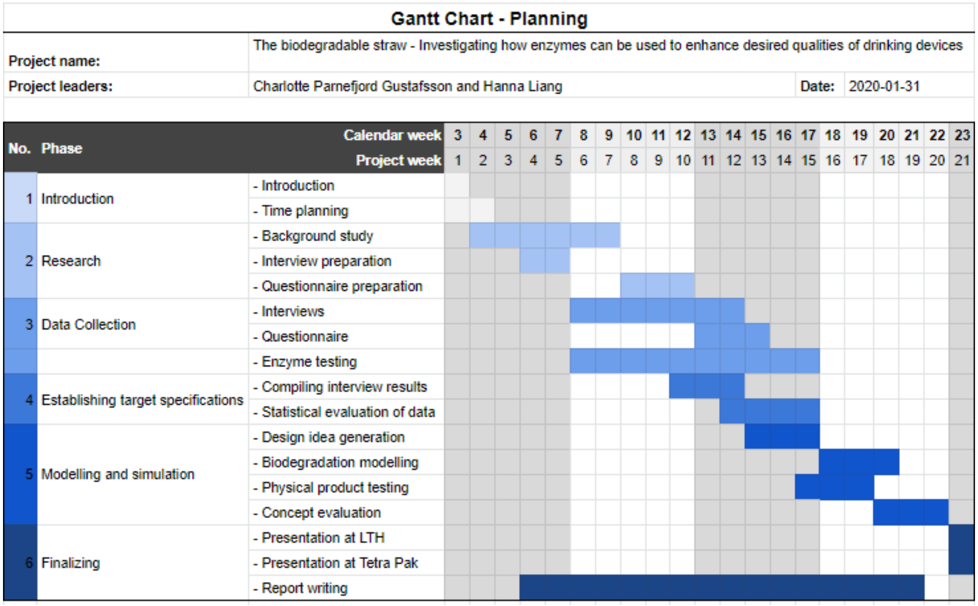

Figure A.1. Initial time pan of the thesis between January-June 2020.

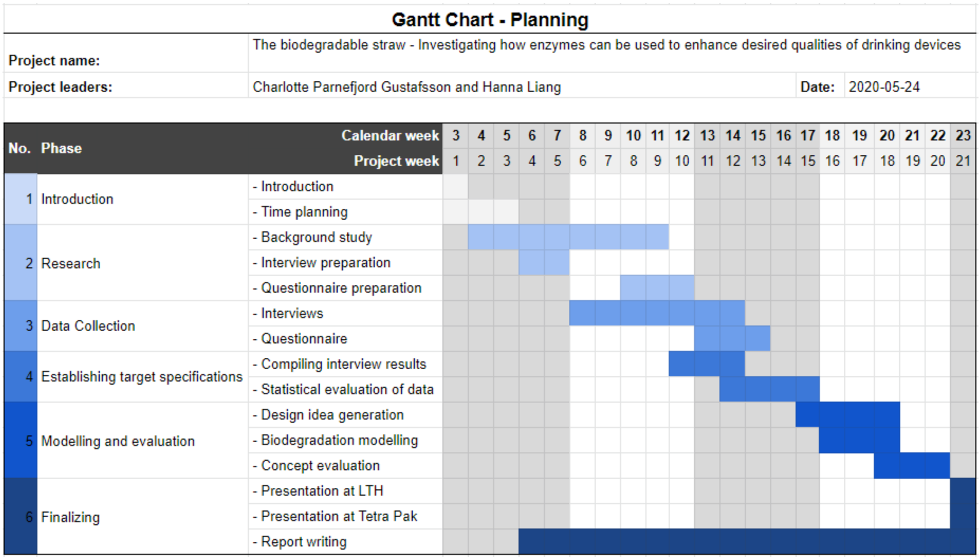

Figure A.2. Final time plan of the thesis between January-June 2020.

Appendix B Interviewees and contacts

Appendix B outlines the interviewees and contacts for the qualitative pre-study and design iterations. Table B.1 presents the participants of the interviews, while Table B.2 displays the Tetra Pak colleagues providing feedback for the iterations of the design concepts.

Table B.1 The table outlines the types of experts and specialists interviewed during the qualitative pre-study. The name, professional title, location of work and date of interview are displayed in the table.

Name	Professional title	Location	Date
Dzina Kleshchanok	Technology Specialist B	Lund, Sweden	2020-01-15
Åsa Olsson	Technology Specialist B	Lund, Sweden	2020-02-03
Anonymous	Technology Specialist B	Lund, Sweden	2020-02-06
Lisa Albe	Food Safety Early Phase Development and Customer Communication	Stuttgart, Germany	2020-02-11
Ingemar Jacobsson	Manager Next Generation & Sustainable Materials	Lund, Sweden	2020-02-12
Katarina Jonasson	Technology Specialist A	Lund, Sweden	2020-02-13
Patrick Adlercreutz	Professor in Biotechnology	Lund, Sweden	2020-02-20
Filip Henrikson	Development Engineer B	Lund, Sweden	2020-02-24
Anonymous	Associate professor at Biotechnology	Bologna, Italy	2020-02-24
Mikael Hamskog	Recycling Specialist	Lund, Sweden	2020-02-26
Ulf Nyman	Technology Specialist A	Lund, Sweden	2020-02-26
Martina Ambrogi	Development Engineer	Lund, Sweden	2020-02-26

Eskil Andreasson	Technology Specialist B	Lund, Sweden	2020-02-27
Sazyia Parveen	Technology Specialist B	Lund, Sweden	2020-02-27
Caroline Malm	Test Factory Expert	Lund, Sweden	2020-02-27
Anonymous	Manager Microbiology	Stuttgart, Germany	2020-02-27
Franziska Breitenwieser	Technology Specialist B	Stuttgart, Germany	2020-02-27
Mikael Berlin	Technology Specialist A	Lund, Sweden	2020-03-02
Andreas Hein	Laboratory Engineer A	Lund, Sweden	2020-03-02
Oskar Thornqvist	Development Engineer	Lund, Sweden	2020-03-06
Tommy Sandevi	Development Engineer Consultant	Lund, Sweden	Continuous
Javier Linares-Pastén	Senior lecturer at Biotechnology	Lund, Sweden	Continuous
Anonymous	Statistical Engineering Expert	Lund, Sweden	Continuous
Anonymous	Development Engineer A	Lund, Sweden	Continuous

Table B.2 The table displays the Tetra Pak colleagues providing feedback for the iterations of the design concepts. The name, professional title, location of work and date of received feedback are displayed in the table.

Name	**Professional title**	**Location**	**Date**
Joachim Bjurenheim	Development Engineer	Lund, Sweden	2020-05-20
Filip Henrikson	Development Engineer B	Lund, Sweden	2020-05-20
Jakob Udesen	Associate Business Developer	Lund, Sweden	2020-05-20
Tina Jacobsson	Development Engineer A	Lund, Sweden	2020-05-20
Tommy Sandevi	Development Engineer Consultant	Lund, Sweden	2020-05-20
Oskar Thornqvist	Development Engineer	Lund, Sweden	2020-05-20
Martina Ambrogi	Development Engineer	Lund, Sweden	2020-05-20

Appendix C Questionnaire

This appendix includes the questionnaire used to gather data about consumer preferences of features of drinking devices. The p-values from the binomial tests and Wilcoxon rank-sum tests are also presented along with additional analysis. Lastly, this chapter includes specific consumer ideas and suggestions for drinking devices.

C.1 Questionnaire

User-experience of Drinking Devices

In this questionnaire, you will answer questions regarding preferences and user-experiences surrounding drinking devices. Drinking devices in this context are defined as appliances which transfers liquid from a package to the mouth. An example of drinking devices are straws.

Any information derived from this questionnaire will only be used by the researchers, Charlotte and Hanna, and for research purposes only. The researchers are master thesis students at The Faculty of Engineering at Lund University (LTH) within the degrees Mechanical Engineering with Industrial Design and Engineering Physics.

If you have any additional requests for the handling of the information you give in this questionnaire or any further questions, please contact either of the researchers at charnapg@gmail.com or hanna.liang@outlook.com.

The questionnaire takes no more than 10 minutes to fill out, and you can cancel your participation at any time by closing the browser.

Thank you for participating!

A brief background about the structure of the questionnaire: this questionnaire is based on the Kano model. The Kano model investigates the role and importance of various features of a new product in the perception of the consumer. If you want to read more about the Kano model, you can find information here: https://en.wikipedia.org/wiki/Kano_model
*Obligatorisk

1. What is your occupation? *

Markera endast en oval.

- Student
- Working
- Unemployed
- Retired
- Part-time employed
- In parental leave
- Övrigt: ____________

2. What is your gender? *

Markera endast en oval.

- Female
- Male
- Other/I do not want to answer

3. What is your age? *

Markera endast en oval.

- Under 12 years old
- 12-17 years old
- 18-24 years old
- 25-34 years old
- 35-44 years old
- 45-54 years old
- 55-64 years old
- 65-74 years old
- 75 years or older

Consumer experience - straws

The following section asks questions about your experiences of straws and various straw materials.

4. How often do you drink liquids using a straw? *

Markera endast en oval.

- ◯ Every day
- ◯ Every week
- ◯ Every 2 - 3 weeks
- ◯ Every month
- ◯ Every 2 - 3 months
- ◯ Every 4 - 6 months
- ◯ Once or twice a year
- ◯ Almost never

5. On average, for how long do you usually use your straw? From placing the straw in the drink to discarding the package/cup. *

Markera endast en oval.

- ◯ 5 minutes
- ◯ 10 minutes
- ◯ 15 minutes
- ◯ 30 minutes
- ◯ Up to 1 hour
- ◯ Up to 1-2 hours
- ◯ Up to 3 hours
- ◯ More than 3 hours

8. When you use a straw, what type of liquids do you usually drink? *

Markera alla som gäller.

- ☐ Milk
- ☐ Juice
- ☐ Water
- ☐ Coffee
- ☐ Tea
- ☐ Alcoholic drinks
- ☐ Soda
- ☐ Smoothies
- ☐ Milkshakes
- Övrigt: ☐ ____________

9. Where and in what situations do you usually use straws? *

Markera alla som gäller.

- ☐ Home
- ☐ Cafés/restaurants
- ☐ Bars/nightclubs
- ☐ Outdoors
- ☐ Sports/exercising
- ☐ At the hospital
- ☐ Traveling by airplane/train/car
- ☐ At work
- Övrigt: ☐ ____________

10. How do you usually discard straws after use? *

Markera alla som gäller.

- ☐ Into the mixed waste bin (without sorting it).
- ☐ Into a recycle bin (e.g. plastic recyling bin).
- ☐ In the nature/outdoors.
- ☐ I don't, I use a reusable straw.

6. Which types of straws have you heard of before? *

Markera alla som gäller.

- ☐ Plastic straws
- ☐ Paper straws
- ☐ Metal or stainless steel straws
- ☐ Pasta straws
- ☐ Bamboo straws
- ☐ Silicone straws
- ☐ Hard plastic straws (reusable)
- ☐ Glass straws
- Övrigt: ☐ ____________

7. Which types of straws have you used? *

Markera alla som gäller.

- ☐ Plastic straws
- ☐ Paper straws
- ☐ Metal or stainless steel straws
- ☐ Pasta straws
- ☐ Bamboo straws
- ☐ Silicone straws
- ☐ Hard plastic straws
- ☐ Glass straws
- Övrigt: ☐ ____________

How would you feel? Section 1.

In this section you will be asked questions about your experiences of various features of drinking devices. Drinking devices in this context are defined as appliances which transfer liquid from a package to the mouth. An example of drinking devices are straws.

I really like it = you really appreciate this feature.
It must be this way = the drinking device must have this feature, otherwise you will be unsatisfied.
I don't care/I am neutral = you don't care about whether this feature is there or not.
I can tolerate this/I can live with it = it is alright but you don't prefer this feature.
I dislike it = you don't like this feature.

Note: although it may feel like the same question is being asked several times, all questions have a purpose.

11. Do you prefer larger or smaller inner diameter of straws? *

Markera endast en oval.

- ◯ I prefer when the diameter is larger (e.g. bubble tea straws)
- ◯ I prefer when the diameter is smaller (e.g. old fashioned thin straws, straws in portion sized juice packages)
- ◯ I prefer an average diameter of the straw (about 0.6 cm)
- ◯ I don't care

12. If the top part of the drinking device is bendable, how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

13. If the top part of the drinking device is NOT bendable (i.e. straight), how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

14. How important is it for you that the top part of the drinking device is bendable? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

15. If the drinking device is attached to the package (not a loose part of the package), how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

16. If the drinking device is NOT attached to the package (i.e. it is a loose part of the package), how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

17. How important is it for you that the drinking device is a separate part of the package? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

18. If the drinking device is sealed or wrapped before use, how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

19. If the drinking device is NOT sealed or wrapped before use, how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

20. How important is it for you that the drinking device is sealed or wrapped before use? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

How would you feel? Section 2.

In this section you will be asked questions about your experiences of various features of drinking devices. Drinking devices in this context are defined as appliances which transfer liquid from a package to the mouth. An example of drinking devices are straws.

I really like it = you really appreciate this feature.
It must be this way = the drinking device must have this feature, otherwise you will be unsatisfied.
I don't care/I am neutral = you don't care about whether this feature is there or not.
I can tolerate this/I can live with it = it is alright but you don't prefer this feature.
I dislike it = you don't like this feature.

Note: although it may feel like the same question is being asked several times, all questions have a purpose.

21. If the drinking device is sturdy/stiff (the diameter of the straw cannot easily be deformed), how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

22. If the drinking device is NOT sturdy/stiff (the diameter of the straw can easily be deformed), how would you feel? *

Markera endast en oval.

- ◯ I really like it
- ◯ It must be this way
- ◯ I don't care/I am neutral
- ◯ I can tolerate this/I can live with it
- ◯ I dislike it

23. How important is it for you that the drinking device is sturdy/stiff (the diameter of the straw cannot easily be deformed)? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

24. If the drinking device is soft and can be squeezed, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

25. If the drinking device is NOT soft nor can be squeezed, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

26. How important is it for you that the drinking device is soft and can be squeezed? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

27. If the surface of the drinking device is as smooth as a plastic straw, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

28. If the surface of the drinking device is NOT as smooth as a plastic straw, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

29. How important is it for you that the surface of the drinking device is as smooth as a plastic straw? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

30. If the drinking device becomes soggy (wet and soft) during use, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

31. If the drinking device does NOT become soggy (wet and soft) during use, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

32. How important is it for you that the drinking device does NOT become soggy (wet and soft) during use? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

33. If the drinking device is flavourless, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

34. If the drinking device is NOT flavourless (i.e. it has a slight unintended flavour from the material), how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

35. How important is it for you that the drinking device is flavourless? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant	◯	◯	◯	◯	◯	◯	◯	Very important

How would you feel? Section 3.

In this section you will be asked questions about your experiences of various features of drinking devices. Drinking devices in this context are defined as appliances which transfer liquid from a package to the mouth. An example of drinking devices are straws.

I really like it = you really appreciate this feature.
It must be this way = the drinking device must have this feature, otherwise you will be unsatisfied.
I don't care/I am neutral = you don't care about whether this feature is there or not.
I can tolerate this/I can live with it = it is alright but you don't prefer this feature.
I dislike it = you don't like this feature.

Note: although it may feel like the same question is being asked several times, all questions have a purpose.

36. If the drinking device is biodegradable, how would you feel? (Biodegradable means it can be broken down by living organisms such as bacteria, e.g. in the soil.) *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

37. If the drinking device is NOT biodegradable, how would you feel? (Biodegradable means it can be broken down by living organisms such as bacteria, e.g. in the soil.) *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

41. How important is it for you that the drinking device is recyclable? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant								Very important

42. If the drinking device is reusable, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

43. If the drinking device is NOT reusable, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

44. How important is it for you that the drinking device is reusable? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant								Very important

38. How important is it for you that the drinking device is biodegradable? (Biodegradable means it can be broken down by living organisms such as bacteria, e.g. in the soil.) *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant								Very important

39. If the drinking device is recyclable, how would you feel? (Recyclable means the material of the drinking device can be used again for other purposes after the recycling process) *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

40. If the drinking device is NOT recyclable, how would you feel? (Recyclable means the material of the drinking device can be used again for other purposes after the recycling process) *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

45. If the drinking device is safe to use according to EU regulations, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

46. If the drinking device is NOT safe to use according to EU regulations, how would you feel? *

Markera endast en oval.

- I really like it
- It must be this way
- I don't care/I am neutral
- I can tolerate this/I can live with it
- I dislike it

47. How important is it for you that the drinking device is safe according to EU regulations? *

Markera endast en oval.

	1	2	3	4	5	6	7	
Unimportant								Very important

Thoughts and ideas

In this section you have the possibility to share your thoughts and ideas about what you wish to improve in today's drinking devices and/or straws. Feel free to be imaginative and bring up any innovative or crazy ideas that you have. Additionally, we welcome all feedback about the questionnaire itself.

48. What features would you like a drinking device to have?

49. Do you have any feedback about the questionnaire?

Det här innehållet har varken skapats eller godkänts av Google.

Google Formulär

C.2 Statistical analysis

The highest number of Questionable responses for a feature are 5 out of the 308 responses. Most features have 3 or fewer Questionable responses. Table C.1 displays the tallied number of responses categorised as Questionable.

Table C.1 The number of Questionable responses per feature, no demographic division

Feature	Nbr of Questionable responses
BENDABLE	0
BIODEGRADABLE	3
FLAVOURLESS	2
RECYCLABLE	3
REUSABLE	3
SAFE	0
SEPARATE	5
SMOOTH	3
SOFT	3
SOGGY	0
STIFF	3
WRAPPED	1

When the number of responses for the two highest categories were close, binomial tests were used to determine if there was a significant difference. Table C.2 presents the p-values from the binomial tests. The null hypothesis was set to that the fraction of responses for Category1, is equal to 0.5.

Table C.2. The p-values from binomial tests, which compares the number of votes for the two most popular categories. The p-values are presented with four decimal points.

Feature	(Category1, Count)	(Category2, Count)	p-value
BIODEGRADABLE	(Exciter/delighter, 142)	(Desired, 105)	0.0218
FLAVOURLESS	(Desired, 107)	(Required, 94)	0.3974
REUSABLE	(Exciter/delighter, 121)	(Neutral, 90)	0.0386
SMOOTH	(Neutral, 139)	(Exciter/delighter, 115)	0.1488
SAFE	(Required, 127)	(Desired, 104)	0.1475

The p-values show that the null hypothesis is rejected for *biodegradable* and *reusable*, i.e. the proportion of votes for Exciter/delighter are significantly different from 0.5. The categorisation of the other features *flavourless*, *smooth* and *safe* remains inconclusive between their two most popular categories.

Kruskal-Wallis and Wilcoxon rank-sum tests are used to gain further insight into how the importance scores of the demographics differ for each feature. Table C.3 and C.4 presents the p-values from the Kruskal-Wallis tests and Wilcoxon rank-sum tests. The three demographic groups do not have a significant difference between their importance scores for *flavourless*, *reusable*, *safe*, *separate*, *soft* and *wrapped*.

Table C.3 The p-values from the Kruskal Wallis tests, which compares the importance scores of each feature and demographic. The p-values are presented with four decimal points.

Feature	p-value
BENDABLE	0.0419
BIODEGRADABLE	0.0120
FLAVOURLESS	0.2300
RECYCLABLE	0.0084
REUSABLE	0.2008
SAFE	0.4697
SEPARATE	0.3433
SMOOTH	0.0234
SOFT	0.8861
SOGGY	0.0121
STIFF	0.0090
WRAPPED	0.2857

For the features which had significant p-values (< 0.05), *bendable*, *biodegradable*, *recyclable*, *smooth*, *soggy* and *stiff* further pairwise Wilcoxon rank-sum tests were performed. Only tests between Frequent users and Infrequent users were significant.

Table C.4 The p-values from the Wilcoxon rank-sum tests, which compares the importance scores of each feature and demographic. Bonferroni correction is used. The p-values are presented with four decimal points.

Demographic1	**Demographic2**	**Feature**	**p-value**
Frequent	Mid-frequent	BENDABLE	0.4416
Frequent	Infrequent	BENDABLE	0.0515
Mid-frequent	Infrequent	BENDABLE	0.2661
Frequent	Mid-frequent	BIODEGRADABLE	0.3432
Frequent	Infrequent	BIODEGRADABLE	0.0138
Mid-frequent	Infrequent	BIODEGRADABLE	0.1113
Frequent	Mid-frequent	RECYCLABLE	0.0537
Frequent	Infrequent	RECYCLABLE	0.0126
Mid-frequent	Infrequent	RECYCLABLE	0.3984
Frequent	Mid-frequent	SMOOTH	0.1422
Frequent	Infrequent	SMOOTH	0.0324
Mid-frequent	Infrequent	SMOOTH	0.4179
Frequent	Mid-frequent	SOGGY	0.6786
Frequent	Infrequent	SOGGY	0.0192
Mid-frequent	Infrequent	SOGGY	0.0573
Frequent	Mid-frequent	STIFF	0.0699
Frequent	Infrequent	STIFF	0.0069
Mid-frequent	Infrequent	STIFF	0.4872

Visual analysis of boxplots shows that *recyclable* has higher median scores of importance than *biodegradable* and *reusable* in all demographic groups. To study how the importance scores for *biodegradable*, *recyclable* and *reusable* differs for each demographic group, further Kruskal-Wallis and Wilcoxon rank-sum tests are conducted. The p-values are presented in Table C.5 and C.6.

Table C.5 The p-values from the Kruskal-Wallis tests, which compares the importance scores for *biodegradable*, *recyclable* and *reusable* within each demographic. The p-values are presented with four decimal points.

Demographic	**p-value**
Frequent	0.0263
Mid-frequent	0.0000
Infrequent	0.0000

Table C.6 The p-values from the Wilcoxon rank-sum tests, which compares the importance scores for *biodegradable*, *recyclable* and *reusable* within each demographic. Bonferroni correction is used. The p-values are presented with four decimal points.

Demographic	**Feature1**	**Feature2**	**p-value**
Frequent	BIODEGRADABLE	RECYCLABLE	0.0560
Frequent	BIODEGRADABLE	REUSABLE	1.0000
Frequent	RECYCLABLE	REUSABLE	0.0620

Mid-frequent	BIODEGRADABLE	RECYCLABLE	0.0000
Mid-frequent	BIODEGRADABLE	REUSABLE	0.0011
Mid-frequent	RECYCLABLE	REUSABLE	0.0000
Infrequent	BIODEGRADABLE	RECYCLABLE	0.0064
Infrequent	BIODEGRADABLE	REUSABLE	0.1908
Infrequent	RECYCLABLE	REUSABLE	0.0001

From Table C.6, all tests involving *recyclable* had significant p-values. Together with the visual analysis, this suggested all demographics gave higher importance scores to *recyclable* compared to *biodegradable* and *reusable*. Mid- frequent users placed higher importance scores on *biodegradable* than on *reusable*. For Frequent and Infrequent users, the importance scores for *biodegradable* and *reusable* did not differ significantly.

C.3 Consumer ideas

From the open question at the end of the questionnaire, the researchers received 132 responses with specific preferences of features. The comments are divided into umbrella terms of mentioned features and **selected** comments of interest are displayed in Table C.7. Furthermore, the number of people who mentioned the feature is summed.

Table C.7 The table displays the mentioned features and some comments from the respondents. The features are ordered based on the no. of respondents describing the feature in the question.

Mentioned feature	**Selected comment**	**Nbr. respondents**
Not soggy	“When I use a straw, it is usually threaded through a plastic lid and where the lid pushes against the straw tends to get mushed and after a while, it collapses and becomes unusable as a straw. “	26
Easy to wash or clean	[Assuming reusable drinking devices] “Easy to wash or clean even after milkshake clumps have dried inside... “	22
No taste	“*Flavourless* and no strange taste.”	18
Reusable	“The ones I use at home should be reusable”	14
Biodegradable or compostable	“It's great if it's *biodegradable* since people can't be trusted to recycle plastic.”	12
Recyclable	“Recyclable due to the environment.”	12
Environmentally friendly	“Minimum of material used”	11

Safe – No harsh material	"A metal straw is very, very dangerous if you accidentally push it into your throat. It could easily pierce you. Glass could splinter and injure you."	11
Adjustable size depending on the drink	"Diameter according to the thickness of the liquid. Long enough to touch the bottom of the container and that it has enough length above the container so that the container does not touch my face. Dishwasher safe if reusable."	10
No spillage	"A stop so that it will not drip/spill juice if you accidentally pinch the package, but still be able to drink like normal"	10
Easy to use	"Simple to use, functional.", "Easy to suck up the liquid."	10
No straw at all	"For me, the big question is – can you not just drink directly from the packaging in most cases. This is about changing behaviours". "Do all containers have to have straws? Can they not fold up into glasses? Does a straw have to be a "pipe"? How about a more "sponge-like" material in the core?"	9
Easy to suck up the liquid	"Easy to suck up the liquid" "It should fill its purpose to get the liquid out"	7
Aesthetics	"Sleek, simple and the visual appearance should communicate where it should be disposed."	7
Easily transportable	"should not break when transported in a bag"	6
Smooth surface	"It should feel like a regular plastic straw."	5
Fairly sturdy	"No deformation"	5
Temperature regulating	"Temperature resilience, I don't want to be burnt or iced by the device. It should transfer heat/cold from the body of the beverage before touching my mouth."	5
Hard straws or metal straws	"I use straws of hard plastics and can, therefore, reuse them. I like them because they are hard and does not become soggy and does not taste like paper (like *biodegradable* paper straws can when they get soggy). The ultimate would be if the straws were hard, *reusable* and *biodegradable*!"	4
Bendable	"*Bendable* to suit my drinking position. Preferably bent at the top but can be "pre-bent" without being adjustable."	4
Comfortable drinking experience	"Comfortable during drinking experience"	4
Not transportable	"I don't want to be carrying around a straw, it's not hygienic and I wouldn't use it that often."	4
Not easy to break	"Not break after a few minutes."	3
Eatable	"If it has a good flavour it could be eatable."	3
Choice of colour	"Fun colours! That can brighten up the beverage."	3

Preferably attached to package	Suggestion: “A refillable water bottle with a straw attached to the lid”	3
Well wrapped	“It is preferable if the straw is wrapped somehow due to hygiene”	2
Does not blow away or disappears into the packaging	“Maybe be extra heavy at the bottom so it doesn’t easily blow away in the wind and makes it feel better in the hand. Could also help with mixing the drink if needed.” “Not too slidable onto the drinking package”	2
Outliers	“It should be sentient and change colours according to my political views.” “More outside the box feature: you know when you reach the bottom of the drink and you tilt the glass forward, and the straw is in your mouth, so it points to the wrong half of the bottom... I'd like a feature that solves this!”	7