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Smart sensors for food packaging and their implementation to the Swedish market

Bachelor’s thesis in Mechanical Engineering

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Abstract

Food packages are essential for the maintenance of the quality and safety of food. Controlling quality and safety has always been an essential part of our life. The first expiration date originates back in 1930 and by 1985 expiration dates became compulsory for consumable products in Sweden to ensure the safety and quality of products. Since 1930 technology has been evolving rapidly. Scientists have been working on the development of intelligent packaging since 1999. An intelligent package uses smart sensors or labels that monitor the freshness of food depending on internal and external factors. However, smart sensors are not yet seen on food packages on the Swedish market.

The objectives of this thesis were to determine why smart sensors are not on the Swedish market, what product could benefit the most from a sensor, and what could be done to implement them. Literature studies, interviews with different actors in the product chain, surveys, and sensor testing were different methods used to gain knowledge about the sensors and what specific type is most suitable for customer requirements.

The customer survey, and interviews with both retailer and sensor developer showed that meat products are in most need of sensors. The result of the literature study and interview with sensor developer showed that some smart sensors are cheap but determining the specific limit for when a product is considered spoiled is a subjective decision with no specific standard that varies from individual to individual.

In addition, the result from testing the oxygen indicator showed that reversibility is somewhat possible, however, the sensitivity is insufficient for monitoring low levels of oxygen in food packaging. The results from pH-testing showed that pH is an inefficient method for monitoring the freshness of meat because the results were contradictory to the theoretical values. Additional reasons are the high risks accompanied by having the pH sensor inside a packaging. There are many innovative sensors to monitor the quality of meat, but different products require different sensors dependent on their properties.

Keywords: ”smart sensors”, ”gas sensors”, ”food packaging”, ”smart packaging”, ”meat sensors”, ”smart sensors for food”, ”food sensors”.

Sammanfattning

Matförpackningar är avgörande för att upprätthålla kvaliteten och säkerheten för livsmedel. Att kontrollera kvalité och säkerhet har alltid varit en viktig del av vårt liv. Det första utgångsdatumet användes 1930 och 1985 blev utgångsdatum obligatoriska för förbrukningsvaror i Sverige. Sedan 1930 har tekniken utvecklats snabbt. Forskare har arbetat med utvecklingen av intelligenta förpackningar sedan 1999. En intelligent förpackning använder smarta sensorer eller etiketter som övervakar matens färskhet beroende på interna och externa faktorer. Ännu finns dock inte smarta sensorer på matförpackningar på den svenska marknaden.

Syftet med detta kandidatarbete var att undersöka varför smarta sensorer i matförpackningar inte finns på den svenska marknaden och vad som kan göras för att implementera dem. Litteraturstudier, intervjuer med olika aktörer i produktkedjan, undersökningar och sensortester var metoder som användes för att erhålla kunskap om sensorerna och vilken typ av sensor som är mest passande för kundens behov.

Kundundersökningen och intervjuer med återförsäljare och sensorutvecklare visade att köttprodukter var i störst behov av sensorer. Resultatet av litteraturstudien och intervjun med sensorutvecklare visade också att vissa smarta sensorer är billiga men att bestämma den specifika gränsen för när en produkt anses vara skämd är ett subjektivt beslut utan någon specifik standard och varierar från individ till individ.

Resultaten från testerna med syreindikatorn visade att reversibilitet är någorlunda möjligt, dock är känsligheten otillräcklig för att mäta låga syrenivåer in matförpackningar. Resultaten från pH-tester visade att pH är en ineffektiv metod för att kontrollera köttets färskhet eftersom resultaten stred mot de teoretiska värden. Ytterligare skäl är den höga risken som tillkommer med att ha pH-sensorn i en förpackning. Det finns många innovativa sensorer för att övervaka kvaliteten av köttprodukter men olika produkter kräver olika typer av sensorer beroende på dess egenskaper.

Contents

1 Introduction

The following chapter introduces the purpose and background of the bachelor thesis as well as the project's issues, limits, and implementation are presented.

1.1 Background

Smart sensors in food packaging are ”tools” that can determine various properties of perishable foods, such as storage conditions, package leaks, microbial quality, and spoilage [1]. The prospects for these sensors are significant as they can potentially extend the shelf life of foods which may also reduce overall food waste. Reducing food waste is important as it currently is one of the largest contributors to total climate impact. A study conducted by Naturvårdsverket concludes the following.

> *The production and consumption of food have an environmental impact and cause about half of the total eutrophication and 20-25 percent of the total climate impact in Sweden. Throwing away food that could have been eaten, avoidable food waste is a waste of both resources and money. Therefore, the reduction of avoidable food waste is a priority both in Sweden and internationally.* [2]

There are multiple types of sensors that fundamentally work in different ways. Among these different sensors, the most common are time-temperature indicators (TTI), oxygen & carbon dioxide monitors, pathogen indicators and lastly microbial growth and freshness indicators [3] [4]. The smart sensors used in this field are normally consisting of biological or chemical indicators that look for specific changes in the package [5].

The colour change is a typical method used by sensors to indicate fluctuation in the internal and external factors that could degenerate the quality of food, these are caused by different chemical or biological changes. The sensor reacts to the chemical or biological changes in the product that are affected by temperature, humidity, etc. Each food category has its most applicable sensor for instance, TTI is the most commonly used sensor for fruits [6].

A study carried out by the European commission in 2018 estimated that up to 10% of the 88 million tonnes of food waste generated annually in the EU are linked to date marking [7]. The food thrown away is still edible but for consumers, accurately assessing to quality of food is not always easy. The way consumers are currently able to evaluate quality of food is by signs of spoilage that occur, for example these include but are not limited to odor, changes in colours, sliminess, leaking, foam and cotton mold growth [8]. For some foods these signs are not always as apparent and it is more challenging to determine the quality of the food. Therefore, many consumers rely on the expiration date set by the manufacturer when deciding if the food is spoiled or not. This expiration date is not always accurate, even if the set date has passed, a product should still be safe and wholesome if it has been handled properly [9].

The function a smart sensor could provide to the consumer is the ability to be able to better determine the quality of their packaged food. There are developers of these sensors who have conducted independent studies on the reliability of these sensors. Despite the potential to fill a much needed role in food sustainability, they are still not available for the general market [5].

1.2 Aim

This thesis aims to examine why smart sensors are not used in food packaging on the Swedish market as of today and investigate the market for the use of sensors and look into what can be done to implement them. This can include but is not limited to, examining the sensors reliability, economic viability, and sustainability as well as the selection of a suitable sensor for a particular type of food product.

1.3 Specification of issues under investigation

To reach the aim of this thesis the following questions shall be answered:

- Why are smart sensors not used in food packaging today? What can be done to implement smart sensors in food packaging?
- What product on the market could benefit the most from the implementation of a smart sensor?
- What type of sensor is suitable for that specific product?

1.4 Limitations

During the project, only the Swedish market will be considered for smart sensors. The research will be conducted on Swedish consumers and companies. What type of product a smart sensor could be integrated into will be chosen from the research gathered. Considering the time constraints of the project, narrowing the market allows for a deeper understanding of what type of product could benefit from the implementation of smart sensors.

It also allows for more thorough research to be conducted, which will be beneficial in the decision-making regarding which product and smart sensor to focus on. Focusing solely on a singular, specific market and product will yield better and more comprehensive results for the project.

Sensors that already exist on the market that can be used for food packaging will be the main objective, there will be no attempt at making a new sensor or trying to re-create a smart sensor that can be used in packaging.

1.5 Implementation

Information will be gathered about different sensors and their functions from several different sources, both from scientific publications, articles, and dissertations but also through interviews with people in the field of research.

The next step is to determine what type of products are most in need of smart sensors. This will be done through interviews with manufacturers and retailers, but also through a consumer survey. These interviews will be conducted over the phone or e.g. Zoom due to geographical differences. Customer viewpoints will be collected through a survey to collect their opinions and views on the need for smart sensors.

By using the collected data it will be decided what kind of sensor is most suitable for the product in question. The working mechanism of a specific sensor will also be described. How the sensor can be included in food packaging will be examined. The sustainability and reliability of the sensor will be considered throughout the process.

2 Theory

The following chapter presents an overview of the theories regarding the different relevant subjects that were collected through a literature search. Examples of such subjects are the packaging, the development of smart packaging and different types of sensors and their mechanisms.

2.1 Packaging

Packaging has always been oriented towards minimizing food loss, providing safe and wholesome food and minimizing costs for all parties involved. In the pursuit of this, the area of active and intelligent packaging has gained a growing role within the industry [10].

With smart packaging, the condition of the food is monitored and information about the status of the product can be obtained when it is under transport or being stored [11]. Different examples of sensors that are integrated to the packaging include time-temperature indicators, ripeness indicators, biosensors, and radio frequency identification. These devices are usually integrated into the packaging materials, but they can also simply be attached to the inside the package [10].

There are different indicators that can be monitored to help determine the quality and freshness of food. These indicators are related to different physical and chemical characteristics for specific products, e.g changes in consistency, colour, or smell [3]. Important factors that need to be considered when monitoring the freshness of food is the humidity and temperature inside the package. For refrigerated products, how temperature changes can influence the shelf life. From the production start until the distribution and consumption of the product, changes in temperature can occur at any time [4]. Rising temperatures can contribute to both microbial growth in produce and lead to spoilage [3].

Depending on the humidity levels inside of food packaging, both the texture and condition of the product could be altered. To ensure longer shelf life these levels should be kept constant. In certain food groups, e.g. meat, dairy, and dried food, controlling the humidity inside of the packaging is crucial [4].

2.2 Food waste and health

Food waste is a problem that many countries face and it is starting to gain more attention due to the worlds exceeding population. The world is estimated to reach its population peak in 2064 with 9.7 billion [12]. Therefore, many organizations are trying to reduce the amount of food waste mainly because of its economical and ethical significance. Only two-thirds of the food produced in the world gets eaten [13]. Most of the food waste takes place in households, but it also occurs throughout the entire production cycle [13].

In addition, food waste is also correlated with global warming since food requires further handling, like transportation. Different processes in industries such as meat production are also a contributor to global warming. Livsmedelsverket states that 8-10% of the greenhouse emissions are due to food waste and the largest contributor of these emissions by a big margin is meat [14] [13]. A study from 2021 found that 57% of emissions from food production is attributed to the production of animal-based food, including livestock feed [14]. Livsmedelsverket also highlights that the estimated food waste per Swedish citizen is 19 kg per year which amounts to around 40 meals [13].

Another problem is microbial contamination which plays a significant part in food quality and nutrition. Some examples of pathogenic microorganisms that cause food-borne illnesses are Salmonella, E. coli, and Staphylococcus aureus [15]. Thus, it would be expedient to use packages that inform consumers about the quality and safety of foods as they are stored [15].

2.3 Sensors

There are different types of sensors that can be used in food packaging which can, to some degree, give information on the condition of its content. The following chapters introduce some of the more common sensors, their respective uses, and how they work.

2.3.1 Oxygen sensors

There are several different types of oxygen sensors. More conventional oxygen sensors use electrochemical methods, but in recent years there have been new developments in both methods and materials used [16].

One of the methods used to measure the gases that reside in packaged meat uses fluorescence-based sensors. The sensors consist of an active component, normally phosphorescent dye, that is embedded in a thin polymer matrix. When oxygen is present in the packaging it penetrates the layer of the matrix and reacts with the dye, causing a shift in colour, indicating the presence of oxygen [16].

To inhibit the growth and decay of micro-organisms it is important to control how both carbon dioxide, CO_2, and oxygen interact in the packaging [3]. When there is oxygen present in the package, it can cause or accelerate oxidative reactions in the food. As microbes and molds grow aerobically, oxygen is needed to fuel their growth. These reactions can cause odors, changes in flavour, colour changes, and reduced nutritional value in the food [16].

2.3.2 Time Temperature indicators

Time Temperature indicators, TTIs, are tools used to monitor the temperature of the products throughout the whole distribution chain [17]. TTIs do not depend on the nature of the food or specific metabolites, but only on the variation of the temperature [18]. The TTIs are usually designed as small labels which can easily be applied to different types of food packages to measure the temperature of a single item. These labels are relatively cheap, especially compared to other electronic temperature readers used for warehouses or transport monitoring [6].

The sensor changes colour if the food is exposed to higher than recommended temperatures for longer periods of time. The colour change is due to different chemical or biological reactions that change in the sensor by altering temperatures over time [6].

2.3.3 Humidity sensors

A low humidity level inside the packaging will cause foods with high water content, such as meat, fruits, vegetables and other fresh products, to lose moisture and dry out [15]. In contrast, foods like dried or powdered foods, which have a low water content, will absorb moisture and spoil if the packaging is too humid [15]. Therefore, monitoring the humidity inside food packaging in real-time would be beneficial.

Humidity sensors can be cheap to produce and easy to implement in packaging. An example of a low-cost humidity sensor is a planar inductor and a capacitor fixed on paper substrate. When the humidity levels increase, water is absorbed by the paper, which will cause a change in the capacitance. These sensors can often be combined with radio frequency identification tags [3].

2.3.4 Radio frequency identification

The Radio Frequency Identification tags, or RFID tags, are electromagnetic tags used to store and circulate information about a product in order to trace and identify it. Sensors using RFID technology are mainly used to track and collect data regarding the quality of products during transportation and storage [6]. Multiple parameters can be stored and monitored at the same time by using a chip. Some parameters that can be monitored are the origin of the product, parameters during the process e.g. temperature, commercial information e.g. the cost of the product [18].

2.3.5 Carbon dioxide sensors

Carbon dioxide, CO_2, is produced by bacterial mold growth in food. Detecting CO_2 levels on foods could be an indication of deterioration. As a result, these sensors are able to detect spoilage by measuring carbon dioxide levels [19].

There are two types of CO_2 sensors, Severinghaus electrode method and electrochemical. The most common of these are the Severinghaus electrode. It uses a CO_2 sensitive glass electrode in a surrounding film of bicarbonate solution covered by a thin plastic of CO_2 permeable membrane. The sensor functions on principle that in an aqueous solution, CO_2 forms carbonic acid in the solution [11]. This in turn changes the pH of the solution which can be measured by a pH meter.

2.4 Ethylene scavengers

Ethylene is a growth-stimulating hormone that causes ripening and senescence in fruits and vegetables by increasing their respiration rate hence decreasing their shelf life. Therefore, removing ethylene gas from the package prolongs shelf life by slowing down the ripening of the fruit or vegetable [20].

In the ethylene absorbing process, potassium permanganate embedded in silica is known to be the cheapest and is most widely used. By absorbing ethylene, silica turns it into ethylene glycol by oxidizing it with potassium permanganate. In addition to being kept in a sachet, the silica can be incorporated into packaging films that are highly permeable to ethylene. Due to its toxicity, potassium permanganate is not integrated onto the packaging films of food surfaces [20].

2.5 The properties of meat products

For all meat products, the high contents of fat and water in the tissue make it very susceptible to oxidation and microbial contamination during the different stages of production and distribution [21]. When meat starts to spoil, the lipids start breaking down and they form other, harmful compounds that affect the quality and freshness of the meat [22]. A change in the colour, texture or odour of the meat can be an indication that the freshness of the product has diminished [21].

For beef products, before the animal is slaughtered, the pH of the meat is around 7.1. Around 18-24 hours after the animal has been slaughtered the pH of the meat drops to 5.4-5.7. This occurs mainly because lactic acid is formed from the glycogen causing the pH to decrease. After some time, depending on how the meat is stored, the pH value will start to increase. When the pH value is around 5.8-6.2 the meat is still regarded as fresh, but once it reaches a pH above 6.5 the meat is considered spoiled [23].

2.5.1 Sensors for meat

Indicators used in smart packaging to monitor the freshness and quality of the meat include TTIs, freshness-, and integrity indicators. These all monitor different changes that happen in the product or its environment [21].

When the quality of food starts to degenerate, various harmful toxins are produced, e.g biogenic amines, sulfur compounds, volatile basic nitrogen substances [18]. Food quality or spoilage can therefore be monitored by measuring these three substances in the food. Currently, three main sensor methods has been evolved to monitor the volatile basic nitro substances such as trimethylamine (TMA), ammonia, and dimethylamine (DMA). These are developed due to the spoilage of meat but also for sea food [15].

A method to measure the quality of meat, as previously stated, was to observe the changes in the pH value. There are a number of sensors that are suitable at measuring pH in meat and among the most common is the pH-sensetive colourimetric gas sensor. The second is a semiconductor gas sensor and lastly, a metal nanoparticle plasma sensors [15]. The measurement of pH can contribute to valuable information about quality, safety, and freshness. Quality changes in food can be followed by changes in pH [21]. Meat and sea food products contain amines, the unsteady and volatile production of amines leads to an increase in pH which would result in a colour change on pH dye [23].

In addition, using a semiconductor gas sensors, amines are indirectly identified by measuring changes in the electrical conductivity of the sensor material. This is caused by changes in the electrical resistance due to amine absorption [15]. However, this method of implementing a semiconductor gas sensors on intelligent food packages is expensive [15].

Another method of measuring amines is by a metal nanoparticle plasma sensor. The metal nanoparticle plasma sensor has a modified layer that absorbs the amines which results in change of refractive index, a dimensionless number describing how fast light travels through the layer [15]. Therefore the usage of a portable optical system, such as a bar code scanner, can detect amines in a quick, simple, and economically efficient way [15].

One of the main gases released during the degradation of meat or protein-containing food such as egg and milk, is hydrogen sulfide [24]. Hydrogen sulfide contributes to an aroma that is considered unpleasant, the smell reduces the food quality and demand.

Materials for monitoring hydrogen sulfide in food packaging have recently been developed by using two main approaches for detecting hydrogen sulfide levels. The first approach is an electrochemical sensor that contains hydrogen sulfide-sensitive substances that react with hydrogen sulfide. The reaction causes changes in electrical resistance which could be visualized by using a wireless reader [25]. The second approach is by metal nanoparticle plasma sensors. The metal nanoparticle plasma sensor is made of silver particles that react with hydrogen sulfide and produce silver sulfide which contributes to the detection of hydrogen sulfide [26]. The development and formation of silver sulfide contributes to significant adjustment in the local surface plasmon resonance [15]. As a result, when a light source hits the silver sulfide layer it gets a different resonance angle and that difference is visualized by colour change. This method has been studied and utilized for the real-time monitoring of the spoilage of poultry [15].

In addition, microbial growth inside meat packages can generate carbon dioxide [11]. According to [18] researchers developed a colorimetric mixed-pH dye indicator for chicken degradation under aerobic conditions. CO_2 was used as the spoilage metabolite and it was found that the microbial growth pattern's from the colorimetric mixed-pH correlated well with the increase of CO_2 in chicken.

2.6 Mechanism of OxyEye™ sensor

In this thesis, the oxygen sensor OxyEye™ was examined. The sensor indicates the presence of oxygen by changing colour. The sensor changes colour from a bright pink when oxygen levels are below 0.01% to a purple colour when oxygen levels are above 0.01-0.05% within 30 seconds [27].

The sensor is prone to react with air which means that manufacturing and storage must take place in anaerobic conditions. After the reaction to oxygen, if the sensor is put in an oxygen-free environment the it will turn back to the pink bright colour within 3-4 hours. The sensors are designed as sticker labels and are easily applied to different food packaging [27].

2.7 Mechanism of pH instruments

The function of a pH meter is to measure the activity of hydrogen ions, [H+]. The measurements are expressed on a pH scale ranging from 0-14, where 7 is neutral. Values above 7 are considered basic and anything below 7 is acidic [28]. Certain types of food experience a change in its pH value as it progressively spoils [4].

A pH meter usually consists of several electrodes. It can have an electrode that responds to the pH, which is usually made from glass, and a reference electrode that remains unresponsive. When the instrument is used in a solution the electrodes act similarly to a battery. It is the glass electrode that responds to the activity of the [H+] and develops an electrical charge that is related to the concentration of the ions. This in turn gives a pH measurement [29].

Another way to measure pH is by using pH paper. It is a piece of paper substrate infused with a halochromic chemical compound that changes colour when exposed to either an acidic or basic substance. These are very common as they are both easy to produce and use [30]. The chemicals in the pH paper are dangerous and contaminate the food if the come in contact [31].

2.8 Laws and regulations

Currently, there are several laws in place regarding produce and how they are supposed to be labelled to ensure safe consumption. There is a requirement to mark the food with a best before date, or an expiration date [32]. The first expiration date was likely introduced first on milk bottles in 1930 [33]. However it was made a legal requirement in Sweden to have a marking showing a products expiration date in 1985, a system that has not changed since [34].

According to *article 2.2 .r in regulation (EU) number 1169/2011* a best before date marks up until when the produce is still edible, given the conditions that it has been stored properly and according to the instructions on the packaging [32]. The date should also be accompanied with either the phrase “best before” or “Best before the end of…”. For example, a packaging might say ”Best before 2022-07-06”.

Products that have passed the best before date are still allowed to be sold but the responsibility to ensure that the consumer does not fall ill is the sellers responsibility [32]. This also includes donation of food.

The expiry date marks until what date the food can still be safely consumed. This is used according to *article 24.1 in regulation (EU) number 1169/2011* for products that are easily microbiologically perishable and that can, after a short time, pose a danger to the health of the consumer. Certain produce, e.g poultry meat, must always be marked with an “expiry date” instead of a “best before-date” [32].

Similarly to the best before-date, produce should be labelled with the phrase “expiry date” accompanied with a specific date for the product. Once the expiry date of a product has passed it is seen as inedible and has to be thrown away, and can no longer be sold or donated. When the food has been marked with a date, it can no longer be changed unless the product is preserved [32].

In addition, food is protected from contamination or degradation by active packaging, either by establishing a barrier to the outside world or by controlling the atmosphere within the package, as discussed above. While in intelligent packaging, an external or internal indicator provides information about the history and/or quality of the food for instance signs of spoilage or freshness. Regulation (EC) *No 450/2009* regulates the use of active and intelligent packaging to contact food in the EU [35]. According to this regulation, active and intelligent packaging products cannot be marketed unless they contain substances listed by the European Community on its list of eligible substances.

It should be noted however that, sometimes the use of intelligent packaging involves the addition of substances. In cases where these chemicals come in contact with the food, an

EFSA review is required before the European Food Safety Authority (EFSA) can authorize the use of such substances in food packaging. These chemicals are analyzed based on how they migrate in the food, their possible reactions with the contents as well as their levels of toxicity and degradation in the environment [36].

3 Methodology

The following chapter describes the methodology and the procedures regarding the different steps taken to achieve the aim of the thesis. This includes but is not limited to the processes of a literature search, data collection, and experiments.

3.1 Literature search

In this thesis, a literature search was conducted to get an overview and gather information about some subjects such as food packaging, use of intelligent sensors and food waste work and how they might be connected. To ensure the credibility of this thesis, information was collected from databases such as Google scholar, Web of Science and Chalmers University library. Some of the keywords used to limit the searches include "*smart sensors*", "*food packaging*", "*smart packaging*", "*meat sensors*" and "*food waste*". The resulting articles and studies related to the search were analysed for relevance, reliability and credibility.

3.2 Data collection

A data collection was made in addition to the literature search to gain further insight into the current market and the developments in the field of smart sensors and intelligent packaging. The data collection was done by interviewing different concerning parties, these include grocery stores, companies developing smart sensors and researchers. A customer survey was also made to collect the consumers point of view. To ensure that only necessary information that benefits the aim of the thesis was obtained, different sets of questions were established for each respective party.

All interviews were conducted online due to geographical gaps and were recorded in order to be able to create transcripts. All questions asked are available in their respective transcripts, Appendices A, B and C.

3.2.1 Customer survey

A survey was conducted to get a better overview regarding how much food is thrown away in different household and how consumers would value the ability to monitor the freshness of the food that they buy. It was also used as a foundation to determine which food product could benefit the most from the inclusion of a smart sensor from a consumer point of view.

The customer survey was posted on several social media pages, e.g different student pages on Facebook to collect answers. People were encouraged to share the survey to their respective social groups to get wider and more accurate results. The objective was to gather as many responses as possible to get a range of opinions to ensure that enough data was collected for it to be considered reliable.

In order to get a clear image of the consumer, the survey included questions regarding the customers background e.g age and occupation. This was used to also see potential trends and biases when it came to the need or want for sensors in food packaging. The data from the customer survey was then managed in Microsoft Excel in order to divide the data and compare the responses from different age groups.

When designing the costumer survey the questions were compiled with the language used in mind. Ensuring that easy and comprehensible words were used to minimize the risk misinterpretations. To maximise the likelihood of people participating and finishing the survey, it was kept short and simple. The questions consisted of multiple choice answers that were constructed to provide insight on the following topics:

- Is there any interest in smart sensors from the consumers to monitor the freshness of the food?
- How do consumers decide when food is spoiled/inedible?
- What type of food product would customers be most interested in to measure freshness for?

3.2.2 Retail interview

A list of different grocery stores based in Sweden was curated by searching for their respective contact information online. The list included the name of the contact, their email, and phone number. Who to contact was chosen by searching for people that specifically worked with either fresh food or sustainability. Each store was then contacted through email and by phone to set up an interview.

The questions for the interview covered topics regarding the stores different policies surrounding storage of food, expiry date, waste and the possible interest and benefit of the implementation of smart sensors. The main objective was to collect information regarding what type of grocery product would be best suited for a smart sensor and what benefits grocery stores could gain from their implementation.

In order to get as many interviews as possible and to obtain reliable information, 15 different grocery stores were contacted.

3.2.3 Sensor company interview

An interview with a sensor company was conducted to gather information about the different sensors that they develop, their specific mechanism, what type of food they monitor, and how the sensor are integrated into food packaging. Other information regarding what is needed for the sensors to be implemented in the market and the different obstacles that may occur throughout the process was collected.

Searches online were conducted to find Swedish companies that work and develop sensors that monitor food freshness to interview. Manufacturers of sensors listed in different research articles about smart sensors in packaging were inspected to see if they were Swedish. The focus was solely on Swedish companies due to the supervisors advice and the limitations of the project. For the online search different keywords were used, e.g "*packaging*", "*company*", "*smart sensor*" and "*Swedish smart sensor*". An email was then sent to the contact person listed for the company.

3.2.4 Expert interview

To collect further information regarding the current development of new smart sensors, their function and their possible implementation for different food products researchers on the subject were contacted.

A list was made with the contact information for several experts on the subject of smart sensor by searching through the employees and researcher pages for different universities in Sweden. For each potential candidate found, their research was examined to establish if it was relevant for the thesis. A total of ten people were then contacted by email to set up an interview.

3.2.5 Ethical aspects

One of the most important ethical issues considered during the data collection was informed consent, respect for anonymity and confidentiality. It was imperative to ensure that the survey did not contain personal information ensuring the anonymity of the participant. However, for the interviews where the participants identity was not anonymous, verbal consent had to be given before the recording happened.

3.3 Obtaining sensors

Which food product that could benefit the most by the integration of a sensor was established by using the costumer survey, interviews and the literature search. Different companies that manufactured sensors that could be used for the product were contacted and request forms to either purchase or receive these specific sensors were submitted. Different companies were found by looking at research papers where different sensors were listed alongside their manufacturers. A total of seven different manufacturers were contacted. Some of the companies that were contacted were Mitsubishi Gas Chemical, 3M and Tempix.

Different e-commerce sites, e.g Amazon, Alibaba etc, were also used to search for the availability of different sensors that could be bought and tested. Key search words included for example "*food sensors*", "*smart sensors for food*" and "*smart sensors manufacturers*".

3.4 Testing the sensors

The function and reliability of two different sensors were tested and examined. The steps taken and the different procedures are presented below.

3.4.1 Oxygen sensor

To test the oxygen sensors, an oxygen free environment was first created to ensure the sensors did not react with the oxygen in the surrounding air. This was done by using a large, clear, plastic bag (see Figure 1a, 1b). All the equipment required to test the sensors was put in the bag beforehand. This included the sensors, scissors to open up the sensors, vials to put the sensors in, caps for the vials and a vial manual crimper to close the caps. The bag was folded over itself at a diagonal until there was only a small opening at the top where two hoses were inserted. One of which pumped in nitrogen and the other to suck out the gas with the help of a pump. The fold was taped down and the opening around the hoses was wrapped in both tape and parafilm to ensure minimal leakage of gases. All the oxygen in the bag was pumped out and then filled with nitrogen. This was repeated five times to ensure that as little oxygen as possible was still present in the plastic bag.

(a) Subjected to vacuum (b) Filled with nitrogen

Figure 1: The setup used to prepare the vials

Afterwards, some nitrogen gas was pumped out to make the bag more pliable. The oxygen sensors were cut open inside the bag using scissors. Then, a singular sensor was placed in six respective vials, and two separate vials were inserted with two sensors each. The vials were closed using caps and the manual crimper. The bag was then opened and the top of each respective vial were sealed in parafilm. See Figure 2 for the resulting vial.

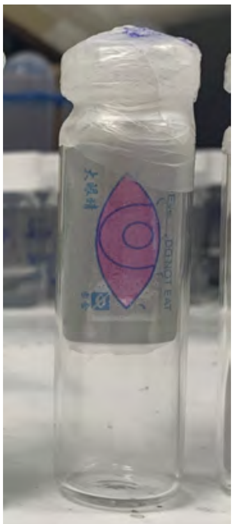

Figure 2: Test vial with sensor

Using a syringe, the vials were injected with air to see how much oxygen it would take for the sensors to react. When they were not being used, vials were then put in a vacuum chamber to ensure that no oxygen could get inside. The amount of air that had to be injected was calculated by taking the volume of the vial, 20ml, and the concentration of oxygen in air, approximately 21%, and then estimating the amount of air needed to reach a concentration of 0.01%, approximately 1ml using the calculations in Equation 1.

$$\text{Injected volume of air} = \frac{0.01 * 20ml}{0.21} = 0.95ml \quad (1)$$

The concentration of the oxygen was gradually increased in the vial by injecting more air with the help of a syringe.

To test if the sensor is reversible and could be used multiple times a vacuum chamber was used. The sensor was opened and exposed to the air. After they reacted with the oxygen and turned purple, two sensors were placed on a coverslip, next to each other. They were then put inside the vacuum chamber and the lid of the chamber was shut. A hose connected to a pump was then attached to the nozzle of the chamber and the valve was opened to allow airflow. The pump was turned on for 10 minutes to ensure a vacuum had been created and then the valve was shut to maintain it. The sensors were left in the chamber for three days which can be seen in Figure 3

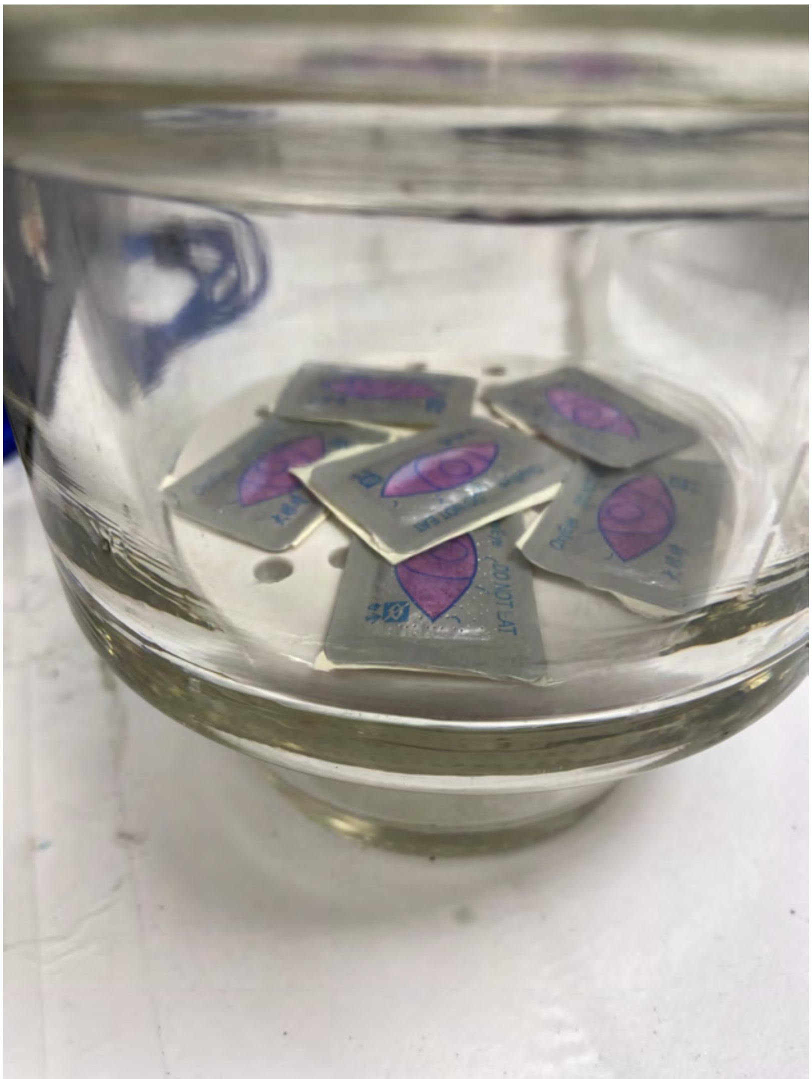

Figure 3: Vaccum chamber with sensors

3.4.2 pH sensor

A pH sensor was used to investigate whether it would be possible to detect when meat was spoiled by measuring its pH. The pH meter used was a VWR pH10 Pen which measures a pH range from 0-14, making it suitable for the purposes of this experiment.

The pH sensor was firstly calibrated by using a buffer with a pH of 7. The sensor was immersed in the buffer until it displayed a pH value of 7. It was then washed with ethanol and dried off. The pH of the meat was measured by pressing the sensor on the meat and waiting until it showed a stable value. To ensure that the measurements were as precise as possible, the pH value was measured twice each day for both the refrigerated meat and the meat in room temperature. The meat was then split into two pieces and put in two different zip lock bags. One bag was put in the fridge with a temperature of 5°C, and the other under a fume-hood in the lab with a temperature of 15-20°C. The pH of each meat was measured once a day for four consecutive days, then a final time three days after the last measurement was conducted to see how it would change over time. After each measurement, the sensor was washed with ethanol to minimize the risk of cross-contamination between the two pieces of meat.

Another method used to check the pH value of each meat was by using an indicator pH paper and dabbing it gently on each piece, enough for it to come in contact with the liquid so the paper could react.

4 Results

This chapter presents all the results that were gathered during this bachelor thesis. It covers the result of the customer survey and interviews as well as the results of testing the sensors.

4.1 Customer survey

The customer survey that was sent out got 199 responses with a majority of the people being students (60.8%), followed by employees (33.7%) and seniors (5.5%). See Figure 4 for the age groupings.

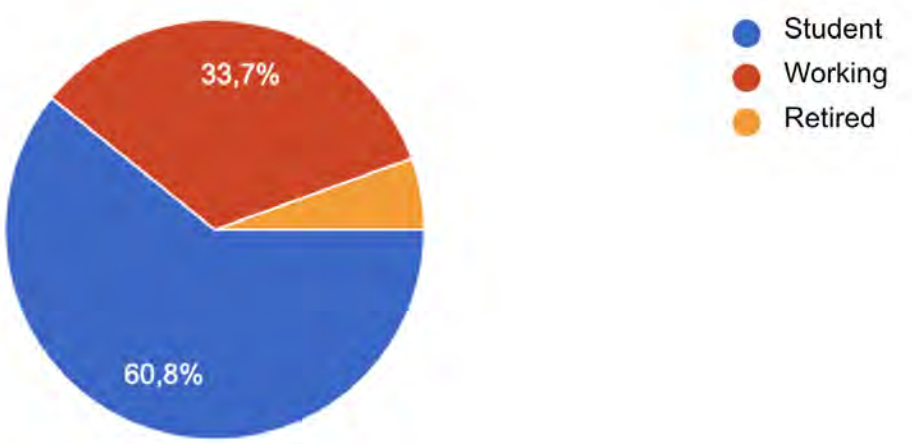

Figure 4: "What is your main occupation?"

According to the survey answers, the majority threw away at least one expired product each week, as can be seen in Figure 5. Around 24% of the respondents stated that they threw away between 10-20%. 1% of the respondents stated that they throw away 20-30% and 0.5% stated that they throw away more than 30%.

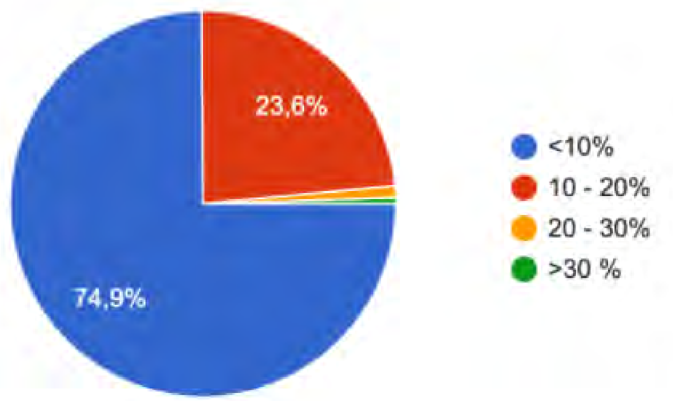

Figure 5: ”How many percent of the food in your household is thrown away?”

Regarding how people control whether their food is safe to consume or not, the most popular answer was by smelling it (179 people). Following this, the second most popular response was to visually examine the food. 113 respondents stated that they use the expiration date when they evaluate the food quality, lastly only 9 people answered that they touch their food to determine the food quality. All the responses are shown in Figure 6.

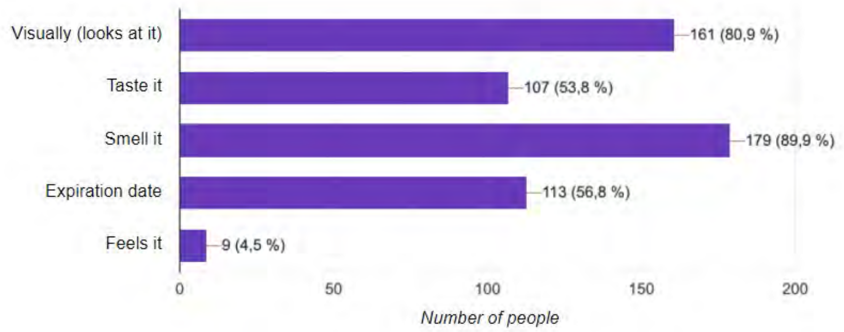

Figure 6: ”How do you examine the foods quality?”

The survey showed that the vast majority was interested in measuring the freshness of meat products with 54.3%. The second most common answer was dairy products with 29.1% and fruits and vegetables with 11.1%. The remaining miscellaneous answers were other types of food such as bread, crayfish or variations of already listed foods among the options, all of which added up to 5.5%. The graph displaying these numbers can be seen in Figure 7.

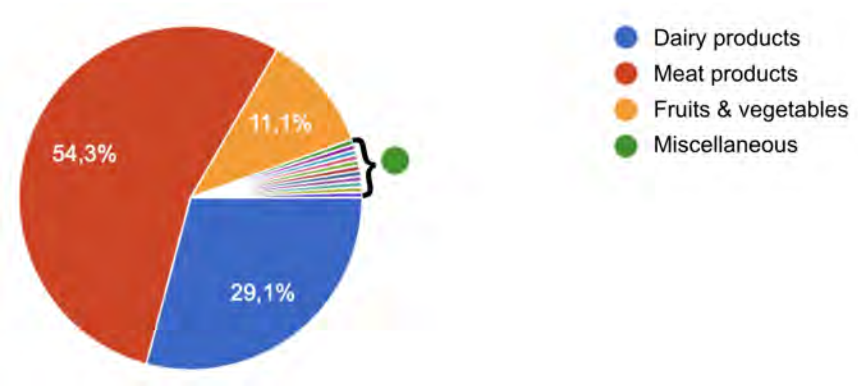

Figure 7: "If you could measure the freshness on one type of food, which would it be?"

The survey showed showed that 37.2% percent were willing to pay extra for a sensor and as seen in the graphs, a large portion of the participants were willing to pay 5% of the product's price. After dividing the responses into different age groupings, an average was calculated for each age group. For the respondents aged 18-24 the average extra they would pay is 5.63%. For the respondents aged 25-44 the average extra they would pay is 4.27%. For the respondents aged 44+ the average extra they would pay is 6.39%. See Figure 8.

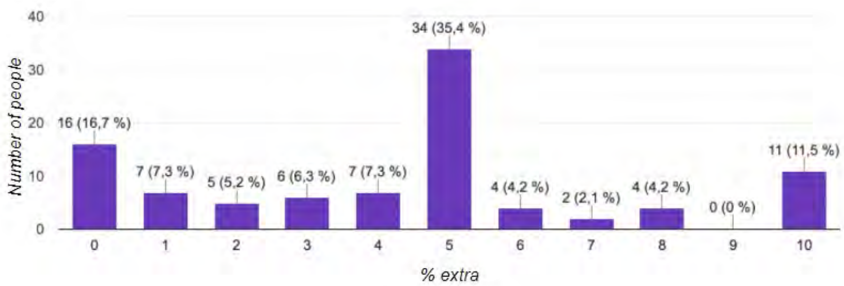

Figure 8: How many percent of a price increase of the product people were willing to pay to get package with sensor

About 50.3% of the respondent wanted to monitor their food freshness and answered either agree or strongly agree. 37.7% of the respondents did not know if they wanted to measure the freshness of the food or not. 12% of the respondents selected do not agree or strongly disagree, of which 3% selected strongly disagree. The graph showing the percentages for this question is shown in Figure 9.

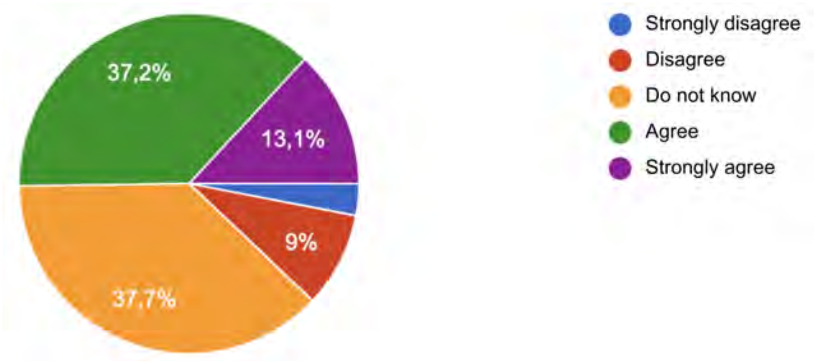

Figure 9: ”The ability to measure the food quality would be valuable to me”

There were a total of 104 responses from respondents in the age range 18-24, 35 responses from people between 25-44, and lastly 60 responses from people over the age of 44. The trends observed from the survey regarding the age groups showed how they evaluate food quality differently, which was previously shown in Figure 6.

For the age group 18-24, the answers showed that they relied more on the expiry date to evaluate food freshness compared to their elders. Another difference between the groups was that the older group (+44) used visual evaluation less in determining the food quality. Both of these examples can be seen in Figure 10.

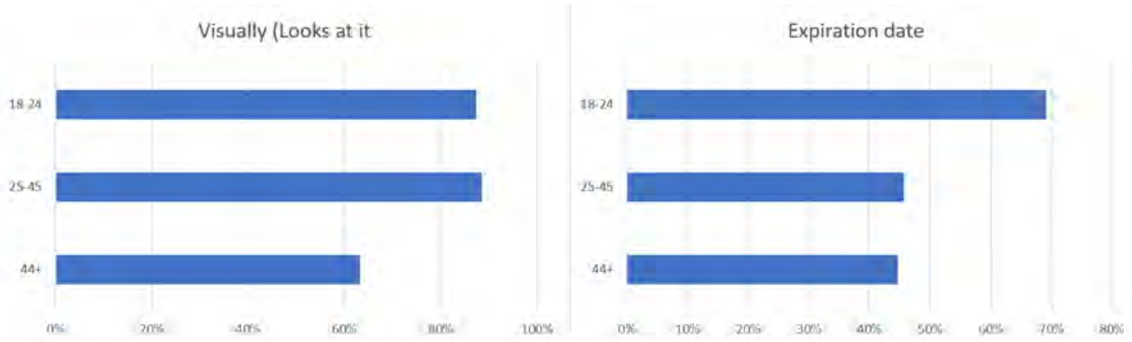

Figure 10: How different age groups answered ”How do you examine the foods quality?”

When asked what they rely most on when evaluating their food, shown in Figure 11. The younger age group was roughly twice as likely to trust the expiration date compared to the other two age groups.

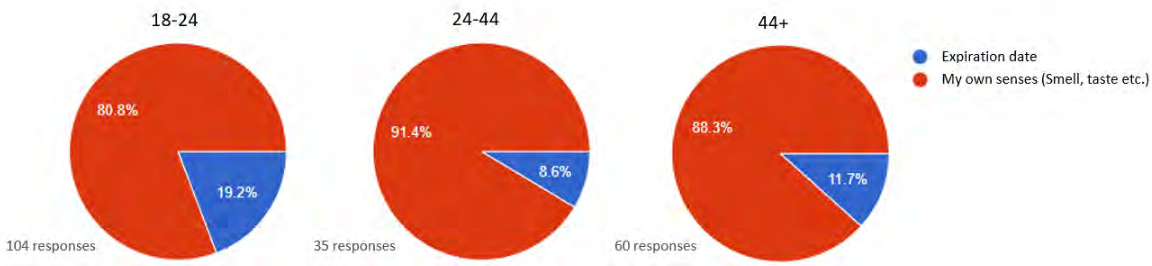

Figure 11: How the groups answered ”How do you examine the foods quality?”

For the question ”The ability to measure the food quality would be valuable to me” the differences between the 3 groups can be seen in Figure 12. Among the younger group 56.7% deemed it valuable to be able to measure food and 17.3% would strongly value it.

Strongly disagree was chosen by 2.9% and 3.8% chose disagree Among the age group of 25-44, 37.1% considered it valuable to be able to measure food quality and 5.7% of those would strongly value it. Strongly disagree was selected by 5.7%. For the age group (44+), 43% valued the ability to measure food quality with 3% strongly valuing it. Strongly disagree and disagree were chosen by 5% and 3.3% respectively.

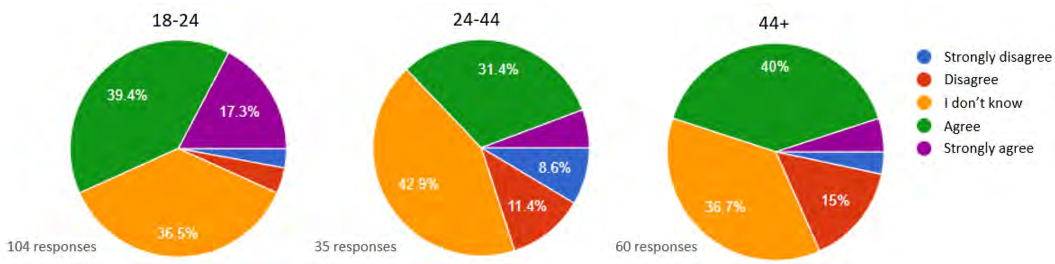

Figure 12: How the groups answered ”The ability to measure the food quality would be valuable to me”

The difference in how the groups answered the question ”Would you consider paying extra for a sensor that shows how fresh it is?”, see Figure 13, showed that the youngest group was nearly 40% more likely to answer yes compared to the other groups.

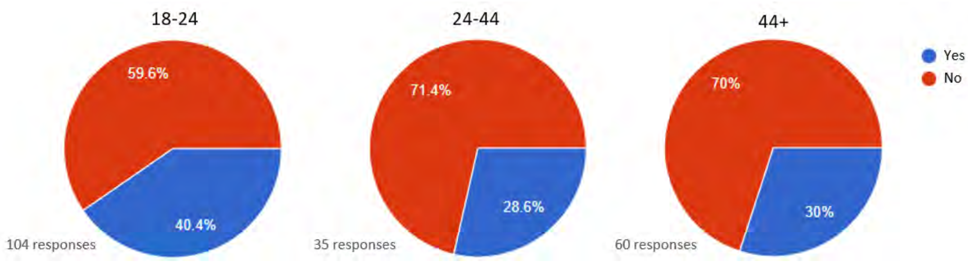

Figure 13: How the groups answered ”Would you consider paying extra for a sensor that shows how fresh it is?”

4.2 Interview with ICA Maxi Helsingborg

To ascertain the interest in smart sensors on the retail market, an interview with the sales manager for fresh products at ICA Maxi Helsingborg Marcus Adsersen was conducted. The interview transcript is available in Appendix A.

Adsersen describes in the interview that about 4-5% of packaged fresh products go to waste every week. The product that is thrown away the most of packaged products is fresh chicken. The products that are about to expire are usually reduced in price by 30% three days before the expiration date. Fresh chicken, due to the short expiration date, can only be price reduced the day before the best-before date.

To measure the quality of the food in the store Adsersen describes that first of all, they check the best-before date but also follow the cold chain of all fresh products. They measure the temperature of all in-going deliveries, if any errors occurred it is noted and the delivery company is asked to show their reports about the cold chain. Depending on how much the temperature has deviated and for how long the store decides to either keep or send back the products to the producers. Adsersen says that it is very uncommon that a whole delivery goes to waste due to these errors.

He further describes that products that have spoiled even before they have reached their expiry date are returned by the costumer. He thinks that the main reason for this is that the customers do not keep track of how long the food is out of the fridge when traveling back and forth from the store.

When it comes to smart sensors for food packaging Adsersen thinks it could benefit the customer the most, but also the entire distribution chain itself. He describes that the store has an effective way of handling fresh products and the staff has enough experience to determine when food has gone bad. The main reason why food would go to waste is the short expiration date and sometimes the customer's way of handling food.

The product in most need of a sensor, according to Adsersen is fresh chicken. He estimates that a 10 % price increase would be reasonable for meat products with a sensor.

4.3 Interview with Innoscentia

To gain more information about the specific sensors used for various food products, an interview was conducted with the chief operating officer of Innoscentia company, Pelle

Ekedahl. Innoscentia was established in Lund in 2015 with the aim of developing a new way of measuring the sustainability of food. As of today, their sensors are not on the market and according to Ekedahl, this indicates how difficult it is to develop these specific sensors. The full interview transcript is available in Appendix B.

Ekedahl states that Innoscentia has two products in its development portfolio, an analogue and a digital sensor. They are currently focusing on the analogue sensor due to the price and complexity of the digital sensor. The analogue is simpler and has a substance that changes colour as the concentration of a specific gas increases, due to bacterial growth inside the package.

According to Ekedahl, the expiration date is the only formal measurement of sustainability and it is based on estimates and is determined in the early stages of the product chain. He describes the expiration date as deficient because it ignores many factors e.g how every product will be stored. According to Ekedahl the customer does not have a source of information other than the best-before date and our own senses e.g sight, smell, and touch. He emphasized that the problem with using the senses was that they lead the customer to make inaccurate decisions about the foods quality which results in an increase of food waste. In addition, he describes that meat packages are injected with a gas that the consumer can confuse with an odor indicating spoilage, which could also result in an increase of food waste.

Both gas and TTI sensors measure the shelf life of the product in addition to showing the real-time status of the product, and helps the customer to make a well-thought decision that is to say to keep the product or throw it. Furthermore, Ekdahl states that TTI sensors are good for certain products but they lose the factors that has nothing to do with temperature in other products. Therefore, by having the analogue label (gas sensor) inside the package, variations of the initial bacteria population can be monitored. He also expressed that temperature is an important factor but it is not the whole truth. Therefore, gas sensors can be suitable for meat and TTIs can be suitable for products where temperature is the only critical factor. In addition, gas sensors have some limitations e.g it can not be applicable for vacuum-packed products because vacuum-packed products have no space where gasses could take place and trigger reaction in the label.

In the interview, Ekedahl describes that one of the obstacles they had with the gas sensor was to determine what limits there are for when a product is considered spoiled based on a bacterial level. He claimed that it is very subjective and there is no standard or government mandate for said limit. Therefore, they have to set that level on their own through extensive research and then hopefully standardize it. Ekehdal also stated that the gas sensors are not recyclable or reversible, and cost around 30 Swedish öre. He believed that most food waste happens at the end of the production cycle i.e the consumer. The reason being that the consumers do not have enough information about the packaged product, but once more information is available, they can make better decisions and reduce food waste. Ekedahl also implied that customers are used to the best-before date because they do not have a better way of measuring the shelf-life of a product.

4.4 Interview with researcher at Uppsala University

An interview was held with Dr. Hu Li, a researcher at the Department of Materials Science at Uppsala University, working in the field of gas sensors with the main focus on graphene gas sensors. The full interview transcript is available in Appendix C.

Dr. Li describes graphene as one of the simplest materials in the world with exceptional qualities. Graphene is a monolayer of carbon and has a huge surface compared to the volume as well as high conductivity and sensitivity, and is maybe one of the most sensitive materials in the world. These are some of the qualities that makes graphene a perfect candidate for gas sensor material according to Dr. Li. He also states that graphene is a very expensive material but, because of the sensitivity, only a very little amount of graphene is needed for creating a sensor. This and will lower the production costs for these types of sensors.

According to Dr. Li, there are still a lot of difficulties with graphene sensors. The main problem with graphene is the selectivity, the material can sense all molecules but cannot sense specifically which molecule is present on the surface. The selectivity is very low, and this is mainly what Dr. Li works with, to get a better selectivity for graphene. Dr. Li alongside a small group of researchers at Uppsala University is developing graphene sensors with main focus on detecting nitrogen dioxide, NO_2, and ammonia, NH_3, gases.

Lastly, Dr. Li explains that food products are quite complicated subjects to study when it comes to gases. Currently, graphene sensors cannot be used for food products but in the future, he is confident that graphene could be a possible sensor for meat and other food products. He also describes that graphene is a very toxic material and could be dangerous for humans in a large amount. Only a small amount of graphene is used in the sensor, meaning it could potentially not have a harmful effect on humans. The graphene chip is also sealed which makes him believe that graphene sensors could still be compatible with food products in the future.

4.5 Testing the sensors

The following section will describe the results of the experiments conducted with the two types of sensors that were tested, see section **??** for further discussion of the experiments and interpretation of the result.

4.5.1 Oxygen sensor

They were no observed reaction after 24 hours with a 0.01% concentration of oxygen in the vials. The results were the same with the vials containing an oxygen concentration of 0.05%.

The exact concentration needed for the sensors to react was inconclusive because the sensors had no observed colour change after inserting the specified amount of oxygen. There were still no changes in colour even when the oxygen concentration was increased gradually. The concentrations of the 6 vials which ranged from 0.5-1.2% concentration of oxygen had no change observed after 4 hours. Once left outside of the chamber, the vials reacted within 24h. The 6 sealed vials with sensors are presented in Figure 14.

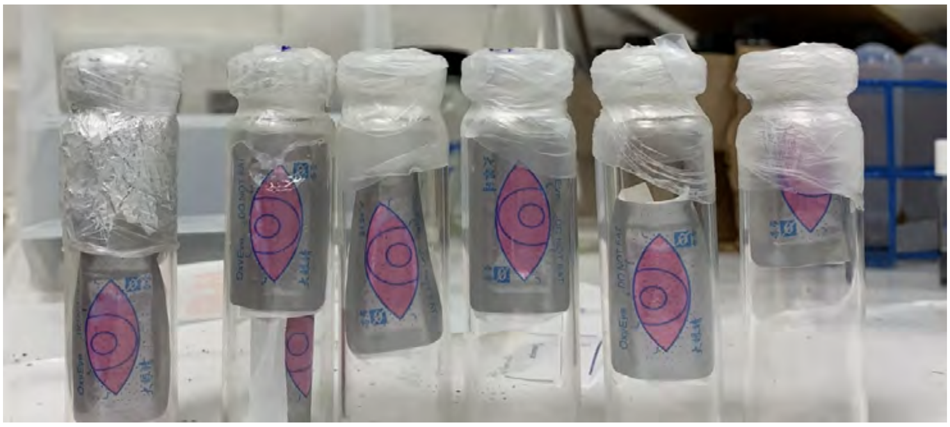

Figure 14: The 6 vials with sensors tested

After only 24 hours the OxyEye sensors had a visible change but had not yet completely reverted back, they were lighter in colour compared to the sensors left outside. The sensors had reverted back to a darker pink after two days in the vacuum chamber. There were no further changes in colour no matter the duration in the chamber.

4.5.2 pH sensor

The measured pH values for both the meat kept in the refrigerator and in room temperature are shown in Table **??**. The pH of the meat started at a value of 5.9 and increased to about 6 for both the refrigerated meat and the meat in room temperature. On the the third day, the pH decreased to about 4.6 for the refrigerated and 5.6 for the meat in room temperature. After the second day, the pH values for the refrigerated meat were lower than the values measured for the meat kept in room temperature under a fume hood. This trend continued until the end of the experiment.

The measured values are included in the Table 1 and Figure 15 was constructed using the average between the two measurements.

Table 1: Measured pH for each respective meat

Day	Refrigerated meat [pH]	Meat in room temperature [pH]
1	5.85, 5.92	5.85, 5.92
2	5.93, 6.02	5.86, 6.07
3	4.64, 4.65	5.63, 5.57
4	5.00, 5.01	5.30, 5.38
7	5.63, 5.54	6.07, 6.14

The pH values measured at each day are also presented in a plot in Figure 15.

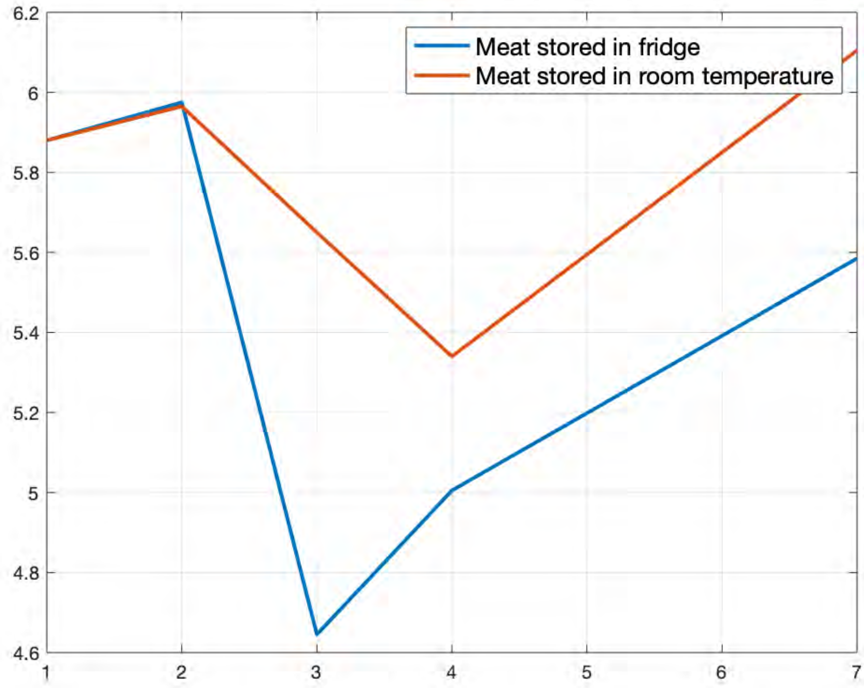

Figure 15: Plot of pH values for each day

5 Discussion

The following chapter handles the discussion of the results from the survey, literature search, interviews and testing of the sensors.

5.1 Reliability

A consistent interview structure, including background explanations and questions, was carried out to increase the reliability of the data from the interviews. The data collected from the survey and answers gathered from the interviews were compared in cases where it was possible. To ensure data from the laboratory is reliable, experiment two was designed to measure the reliability of the sensors as described above

5.2 Customer survey

The majority of the respondents were between the ages 18-24 years old. This is mainly due to the survey being published on a Facebook page for the Mechanical Engineering program at Chalmers University of Technology. Since the customer survey could not reach all age groups to the same extent, the data collected from the other age groups may not give an accurate picture due to the smaller amount of participants and opinions.

Another thing that could have affected the result of the survey is how the questions in the survey were interpreted. Misinterpretation of the questions could lead to inaccurate results.

Given the number of respondents that stated they throw away more than 10% of the food in their household. A sensor that displays the freshness of a food product, for instance, meat, could potentially reduce this number. In turn, this would contribute to minimizing its large environmental footprint.

When it comes to examining the food in a household, the most popular answer was to smell the food and visually inspect the food. These methods could generally work quite well when it comes to certain products like fruits or vegetables but for meat products, both these methods are unreliable and could be quite dangerous for the consumer. The discussion here is mainly focused on meat products due to that the majority of the respondents wanted to measure the freshness of meat products. Some bacteria in meat could give off a slight smell but many of the bacteria in meat grow unnoticeable and would therefore be impossible to detect by using the above methods.

There was a large number of participants that were willing to pay extra for a sensor in order to measure the quality and freshness of a product, specifically meat. Indicating that the implementation of sensors is not limited by an economic factor.

One thing to note was that the age group of 18-24 years old was the most likely to pay extra for food products with sensors in the packaging. However, the age group that was willing to pay the most for food products with sensors are those who are above the age of 44. The fact that the younger age group is more willing to pay extra might be due to the fact that the younger age group are more susceptible to new technology whilst the older ones have more knowledge and experience in handling food, negating the need for a sensor.

5.3 Interviews

It is important to note that the interview with ICA Maxi Helsingborg might not represent the opinions of all grocery stores since only one interview was held. Several other stores were contacted multiple times and answered positively to the request regarding an interview but were unresponsive when it came to booking a meeting and stopped replying.

The handling of food by the consumer is sometimes inadequate, and this can cause it to spoil without the consumer noticing, leading to food being thrown away when there is uncertainty. A sensor could help provide valuable information about the food quality, ensuring that food has yet to expire or spoil does not get thrown away. If sensors were to be introduced to food packages on the market, the grocery stores themselves would likely not experience any direct economic impact. In other words, there is no real downside of introducing the sensors to the market in the perspective of grocery stores.

Since the consumer would benefit the most from a sensor and not the store, implementing them could be considered difficult if there is no interest from the general public or it is deemed unnecessary from a consumer standpoint.

Innocentia was the only sensor company contacted as it was the only manufacturer found on the Swedish market. It is important to bear in mind that Innoscentia is a corporation with its own interests in mind, therefore some of the claims they make should be taken with some level of reservation.

A large obstacle to implementing the sensor was setting the spoilage limit for meat. There are currently no set laws or regulations for specific limits on bacterial activity in meat products. The current laws in place demand a best before or expiration date. For a sensor to be able to replace the need and function for these dates the laws have to be changed. Both at an international and national level.

Graphene could be used for food packaging sensors in the future, but there are still problems that remain. For this to work for food products selectivity must be increased to the point where the sensor are able to accurately measure complex gases. The question also remains regarding how safe it may be to have graphene in food products because of how toxic the material is. Even if more complex graphene gas sensors were to be developed, this could still pose a problem in the long term. Complexities such as ensuring no harmful substances migrate to food and contaminate it.

5.4 Oxygen sensor

The OxyEye™ sensor, was chosen because there were no other sensors available that could be obtained and were suitable for meat products. It was also cheap and within the budget of the thesis project. It should however be noted that an oxygen sensor is not ideal for measuring the freshness of meat.

From the results, the oxygen sensors appeared to be ineffective at detecting low concentrations of oxygen in small enclosed spaces. If used in a food package, the sensor would not be effective enough at monitoring any significant changes that could lead to spoilage. This may be due to the detection mechanism of the sensor which is a powder that changes colour as it oxidizes. For a small enclosed space with a low concentration of oxygen, the amount of oxygen present could be deficient for the powder to fully oxidize and trigger a visible colour change. Therefore in a food package with a small enclosed space, the oxygen sensor is not ideal and does not appear to be suitable sensor for its purposes.

There were obstacles during the testing of that sensors that reduces the accuracy of the results. One of the issues was ensuring that no oxygen made contact with the sensor. Both during the preparation of the vials and afterwards since they were not completely air tight. This made it difficult to maintain a constant concentration of oxygen inside the vials.

During the preparations of the vials with the sensor. When repeatedly filling the large plastic bag with nitrogen and then emptying it, small pockets of gas were still left inside each time leaving trace amounts of oxygen in the end. The bag could also be susceptible to permeation of oxygen as well as undetected potential holes or leakages allowing air to enter.

This experiment could have been improved in a number of ways. There could have been a better method of storing the sensors, to ensure that they did not react with oxygen. The optimal way of preparing the vials would have been in a glove box, to make sure there was no oxygen present when the sensors was placed in the vials.

5.5 pH-meter

The pH sensor that was tested showed results that did not align with the previous theory about pH for beef, see Section 2.5. The theory stated that the pH of the meat after slaughter should decrease to a pH around 5.4-5.7 at first and then increase as it starts to spoil. The result instead showed an increase, decrease and an increase in pH once more.

The pH of the refrigerated meat was down at about 4.6, which is too low compared to its expected value. Another thing that is inconsistent with the theory is that even after a week in room temperature the meat had still not reached a pH of 6.5, the pH for the beef when it is considered spoiled. The meat changed colour to a slightly brown hue and had a modest odor, which could also have been due to the fumed hood that the non-refrigerated beef was put under. From knowing that the meat had been out of the fridge for 7 days and visually examining it, it could be established that the meat was no longer edible. By conducting more tests on several different samples of meat may have ended in another results. Due to the lack of time, no more tests were able to be performed with the pH-meter.

One source of error that may have given incorrect results is that the pH sensor might not been calibrated correctly or that the cleaning process of the sensor was insufficient.

For the pH paper that also where tested did not give any useful results either as the paper became red from the blood of the meat. The simplest way of integrating a pH sensor would be in the form of pH paper. Since these do not give any visible results and are difficult to read, they would not be suitable to use as sensors in packaging.

5.6 Best sensor for meat

From the costumer survey, interviews, and the literature search it was concluded that the product that could benefit the most from a smart sensor are meat products.

Depending on which type of meat that needs to be monitored, different sensors could be applicable. The most important factors to monitor are temperature, humidity, and gases released from the meat. A sensor that monitors a combination of these factors would be optimal. This type of sensor would likely be more expensive than more simple variants, but this would not be a great concern due to the relatively high sales price of meat, meaning a smaller percentual price increase in relation to the product cost. This in comparison with cheaper products, like milk with a sensor having a larger percentual price increase.

When considering the current available sensors, the optimal type would most likely be a sensor that measures gases released from the meat. Knowing that when meat is starting to spoil, it releases specific gases like CO_2 and H_2S. Having a sensor that monitors the concentration of these gases would be a beneficial method. However, it is important to ensure that the sensor only measures the gas in the packaging that is released from the meat and does not pick up on gases in the surrounding environment.

Since the production of meat products already negatively impact the environment, the sensor included in the package should be biodegradable, reusable or recyclable in order to avoid worsening the environmental footprint of meat.

6 Conclusion

The purpose of this thesis was to understand why smart sensors are not on the Swedish market, find out what food product benefits the most from a smart sensor, and what type of sensor suitable for that specific product.

- As previously mentioned, one of the biggest obstacles when it comes to the potential implementation of sensors in packaging are the current laws and the available technology. Currently, there are many laws in place that prevent any other tools besides adhering to a best before or expiry date. For smart sensors to be seen as a viable option the information given by the sensors needs to be more reliable than the best before date. Considering the results of the tested sensors, further research and improvements need to be made before future implementations.
- The product with the highest demand for a smart sensors was meat according to the survey, retailers and sensor developing company. If an implementation of smart sensors in the packages of meat products could reduce the amount that is thrown away, it could have a positive impact on the environment. Consuming spoiled meat could also cause foodborne illness which could possibly be avoided by implementing smart sensors.
- The optimal sensor to use for meat products is some form of a gas sensor that can detect one or more of the gases that are released once the meat starts to deteriorate and become inedible. Gas sensors that detect CO_2 and hydrogen sulfide, H_2S, have some capability to determine the specific level of spoilage of meat.

Due to the short time frame and limited resources, the validity of the conducted experiment is limited. Therefore, the presented conclusions should be considered as recommendations based on the literature search and observed data.

Future research should aim on analyzing a much larger portion of customer survey respondents from different social groups. In addition, address the limit of spoilage and propose a standard spoilage limit depending on a specific increase of a single or multiple metabolites e.g CO_2 inside the packages.

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Appendices

A Interview with Marcus Adsersen (ICA Maxi Helsingborg)

2022-03-03 13.30
Marcus Adsersen, försäljningschef färskvaror

Ungefär hur många procent av produkter slängs i er affär skulle du säga?

- En delikatess med manuell hantering, 5,5 % av volymen där går åt. På fiskavdelningen är något högre, det är uppåt 7–8 procent som stryker med. Färdig mat och liknande, 7 % i den avdelningen. Sen har vi packade produkter som ligger stilla har vi självklart något lägre än en manuell hantering. Där är det kycklingen som är den stora boven med de korta hållbarhetstider som finns på kycklingen. Kycklingen har inget bäst före datum som har någon spelmöjlighet efter det utan det är sista förbrukning av kycklingen och därefter måste vi slänga det eller ta vara på det på annat sätt. Men det är kycklingen som är den stora boven av färskvarorna. Där ligger vi på ca 4–5 % som går åt. I våra butiker är det ganska så stora volymer trots allt för vi säljer ju mycket.

Vad gör ni för att reducera matsvinn?

- Ja nu som det ser ut så beror det ju på om det är just kyckling, kött, ost eller Chark eller vad det just ni är. Det är lite olika, några dagar innan bäst före datum som vi agerar. Är det varar som varade i flera veckor eller flera månader, veckan före bäst före då sätter vi ner vara med 30 % och säljer rullande billigare. En vecka före kan det inte vara på kyckling och färskt kött, för då hade vi fått sälja ut det direkt ju. Kyckling är ju dagen före samma dag där det sätts ner med 30%. Övriga charkprodukter, 3 dagar innan sätts det ner med 30%. Det är vi inte kan sälja undan alls det går ju till Filbornaverket och pressas och blir gas vilket är sista steget.

Hur mäter ni kvalitén på era produkter? Hur vet ni att produkter som vi fått levererande fortfarande håller sig färskt och säkert för konsumenter?

- Ja, det vi ha att förhålla oss till där är ju såklart en korrekt märkning på paketen och sedan följer ju kylkedjan att vi tar tempkontroller på ingående leveranser och bokför alla avvikelser. Har vi en avvikelse så agerar vi där och då och ber transportbolaget eller producenten att presentera deras kylkedja. Jag tycker själv att det är synd att direkt slänga allt, om en leverans som kommer ska hålla 8 grader men håller 10 då har vi aspekten tid också. Har det stigit upp till 10 grader sista halvtimman och vi ger det en kyss igen då är det ingen skada skedd men det är ju en indikation på att lastbilen har gått varm. Har det transporterats i 15 grader från Stockholm så är det inte lika trevligt som om det är sista halvtimman eller kvarten som det har gått upp i temperatur liksom. Så en tempkontroll och söka tidsspannet om det har blivit en avvikelse.

Det förekommer inte att era leverantörer har inbyggda temperatursensorer i deras lastbilar som mäter temperaturen under resan?

- Inte som presenteras till oss, men de kan ju presentera om vi kräver en avvikelserapport. Varor som transporteras långt, bananer från andra sidan jorden och övriga produkter som transporteras långt ofta via båt eller lastbil där bygger vi ibland på sensorerna som är i för det är ju billigare för dom egentligen att bra slänga i en sensor än att hämta ut dom igen så dom är ju kvar hos oss ibland så där ser man ju att det mäts där också. Men det är ju ingen data vi får tillhanda om vi inte begär ut den.

Kan det hända då ibland att det har varit för hög grad och att det har blivit att ni har fått slänga ganska mycket? Är det något som förekommer ofta eller sker det väldigt sällan?

- Det är väldigt sällan att det förekommer, det är ju ingen som vill stå för den kostnaden i kedjan. Jag tänker ju inte ta den dom den kommer till mig för varm utan då kontaktar jag ju producenten och dom får beställa nytt och hämta hem varorna. Igen i kedjan är intresserad av att betala det så det är ganska hög vikt vid att transportera i korrekta temperaturer. Så det händer väldigt sällan.

Har det hänt någon gång att man har märkt, låt säga kycklingen, att den har kanske varit i för hög temperatur eller att den har gått ut innan bäst före datum eller att ni har märkt kunder har kommit tillbaka med den eller att man har sett att den har blivit dåligt innan utgångsdatum?

- Ja det händer ju lite då och då. Vi har ju på maxi en färskvarugaranti, så är kunden inte nöjd får den 200 % tillbaka. Vi bokför ju alla dem men vi bokför ju också varför dom tycker att varan är dålig. Ofta när det gäller knycklig och färskvaror så är det nu en doft när dom öppnar paketen. Vi klandrar uu aldrig kunderna men vi har koll på våra kylkedjor och våra kylar är bevakade dygnet runt och vi kan hämta data på allting. Men ingen bevakar nu kundens bil hem i 30 grader en sommardag och dom ska bara ha en glass på kiosken så dom stannar ju där i en knapp halvtimme. Det är ju ingen som bokför det och ofta tror jag att det handlar lite grann om den hanteringen men vi tar ju tillbaka varan ändå.

Men som du säger så hamnar det på er även fast det är kunden som hanterar varan dåligt?

- Det är billig marknadsföring att ta igen mat sen handlar det ju om matsvinn och det är ju väldigt synd. Då är ju sensorerna bra i ert fall ju, många kunder tittar ju blint på datumparkeringen och vågar inte alls dricka mjölken dagen efter bäst före även fast den luktar jättegott. Eller äggen som dem till och med har i kylskåpet hemma fast den kan stå i rumstemperatur men i kylen varar den två veckor längre. Ändå så går ju åt pipan om man inte vågar använda sina sinnen.

Har du hört talas om smart sensorer innan för matförpackningar eller om du har varit i kontakt med en liknande produkt innan?

- För mig är det väl revolutionerande på ett bra sätt, det får jag väl säga. Det är välkommet och jag har faktiskt inte hört att etiketter eller liknande kan läsa av och skifta färg vid för hög grad med bakterier eller liknande. Jag tycker det är klokt. Jag har inte hört talas om det innan. Det finns massa system som övervakar datum och system för att kunderna själv ska kunna hitta datum själva i butiken och gå till en liten maskin och få priset nedsatt själv och liknande. Detta är ju en avgörande faktor; är varan bra eller dålig, skit samma vad det står på paketen. Det har jag inte hört talas om innan och tycker att det är en jättetrevlig ide. Det är bra på många aspekter, det är bra för kunden, det är bra för producenten och för alla led där emellan. Det tycker jag, för det kan gå väldigt fort med bakteriehalten när den stiger. Bara ta en Gravad lax som ofta innehåller Listeria inom riktvärdena, absolut, men kommer den gravade laxen i fel temperatur för länge så går det jättefort när Listerian växer på och man kan få sjukdomar av det ju. Det hade varit jättebra på många olika sätt.

Om du hade kunnat välja en typ av produkt som hade fått sensorer som hade kontrollerat färskheten och potentiellt kunna förlängd livslängd på vilken typ av produkt hade du valt då?

- Färsk kyckling.

Sådana här sensorer hade ju antagligen kommit med en viss prishöjning på produkten. Vilken nivå av prishöjning hade du tryckt var rimligt?

- Som priserna ser ut nu i hela världen så är det ju redan i taket men tar vi knycklig, kycklingkilot ligger på 149 kr och hade det vart 159 kr i stället så hade det vart rimligt kanske. 10 % är det ju inte, men ändå en 10 % upp då hade vi hamnat på 15 kr upp. I och försäg, nu tänker jag bara högt, är det en sån klisterlapp som ska produceras kanske 10 % kanske inte är nödvändigt ändå för kostar den 10 kr o producera så är det ju dyrt. Jag vet inte vad kostnaden för en sådan liten etikett med en lite brain men vid massproduktion av den så kommer man väl ner i pris.

Vi har gjort en undersökning med kunder där vi har nått ut till 200 människor och pratade om detta. Då kommer det fram då att det de äldre,40 plus, som verkar vara mer villiga att betala för detta. Så jag tänkte att det blivit som en sorts av certifiering med hjälp av sensorn.

- Dom är faktiskt populäraste certifieringarna. Visst är det bra för att det är MSC-certifierad fisk som är fångade i bestånd som är hållbara ASC-certifierad fisk som är uppodlade på ett bra sätt. KRAV tar ju absolut mark framför ekologiskt. Det är ju det närproducerade som nu trender skulle jag vilja säga. Men certifieringar, folk tittar på nyckelhål, folk tittar på svanen certifieringar. Det är rätt riktning ändå tror jag.

En sista fråga vi hade var också; om man hade sett dom här sensorerna på marknaden, hade du tyckt det var bäst att det sitter i paketet och man som kund kan läsa av det eller att det är något mer för er i butiken som ni kan skanna eller liknande för att kolla av. Vad tror du hade varit mest hjälpsamt.

- Det är enklast för kunden, om det står rött eller grönt liksom.

Okej så mer för att hjälpa kunden än för er i butiken?

- Ja, sen är det bra för oss också. Det underlättar ju så vi skulle kunna ta hand om produkter som har gått ut i vårt eget kök. Vi ser att det faktiskt är fullgoda livsmedel. Vårt eget svinn idag, där har vi också framsteg att göra so. Att ta hand om utgångna produkter i vårt eget kök. Vi kan ju steka upp och förlänga hållbarheten på en kycklingfilé. Men vi gör ju inte detta jättegärna för att vi står med risken. Det är den lite tråkiga biten att man måste hålla sig till att vara ”safe” liksom fast man vet att det är bra.

Ni har så pass inarbetade säkerhetsåtgärder för hållbarheten att det är mer för kundens skull man skulle ha sensorer än för butikernas skull?

- Jag tror nog att man ger större trygghet för kunden än för butiken. Jag är ingen expert över huvud taget men jag har jobbat med detta i så många år så jag tycker mig veta om en vara är bra eller dålig. För kunden vill man ha enkla och snabba svar. Jag tror det gynnar kunden mest men även butik och producentkedjan också. Våga förlänga hållbarhetsstämplarna något som producent.

Precis, men bra det var alla frågor vi hade. Tack för att du tog dig tiden att var med på denna intervju

B Interview with Pelle Ekedahl (Innoscentia)

Hej, jag vill börja med att tacka dig för att du gav oss möjligheten till ha intervju med dig. Lite kort info, mitt namn är David Hermez och jag sitter här med Egil Hultén. Vi är del av en grupp som skriver ett kandidatarbete om smart sensorer till livsmedel och vi hittade innocentia när vi sökte runt på internet. Ni specialiserar er på dessa typer av sensorer så vi skulle vilja ställa några frågor till er.
Är det ok om vi spelar in den här intervjun?

kan ni berätta lite kort om innoscentia oc**h era produkte**r?

-Grundades i Lund 2015 och har haft som mål att utveckla nytt sätt att mäta hållbarheten på mat. Och det har vi försökt göra genom att utveckla Kemisk tekniska sensor etiketter. Vi är fortfarande inte ute på marknaden, så det fortsatt produktutveckling som pågår och det säger väl någonting om hur hur svårt det här området är, hur komplicerat det är att försöka ha en sån här produkt till att vi hållit på i över 6 år. Vårt fokus har också skiftat genom åren. Vi har 2 produkter i vår utvecklingsportfölj. En digital etikett och en analog etikett.

Den digitala enkäten var det vi kom på först och även det som vi bekämpade med de första åren. Den är ganska komplex. Den bygger på tryckt elektronik och är ganska svår att få ihop, ganska dyr vilket är lite problematiskt när man ska sätta en sån här etikett på på varje förpackning efter ett tag började vi kika på en enklare sensor som fyller ungefär samma syfte som ett första steg in på marknaden. Då kom man på det som vi jobbar mycket med idag, analoga etiketten. Den är ju mycket simplare i att den egentligen har ett bläck som skiftar färg när när gaser utvecklas av bakterietillväxten inuti förpackningen. Det är de 2 etiketterna vi har. Vi jobbar fortfarande med digitala men i lite mer lågintensivt fram tills att vi har lanserat den analoga. Målet har hela tiden varit att komma på ett sätt att skapa en mer precis mätning av hållbarhet möter och framför allt kött då som är den första applikationen och jobba med för att kunna stötta minskningen av matsvinn och skapa mer effektivt matsystem.

vilka är fördelarna med att ha er produkt. Vissa säger att om man har till exempel kött i kylskåpet, så kommer det inte hända någonting.Varför ska jag behöva en sensor om man har en frukt man kan känna eller lukta på den? Hur hade ni svarat på dem eller övertygat dem?

-Jag tror inte vi motsätter oss där, utan det är. Vi vill verkligen att man ska förvara sina matprodukter, oavsett om det är frukt eller kött så hållbarhet stöttande som möjligt och där är temperaturen väldigt viktig faktor att att hålla den i kontroll och liksom ge produkten så bra förutsättningar som möjligt att vara hållbar över tid. Idag så finns det egentligen bara utgångsdatumet som det enda formella måttet på hållbarheten och utgångsdatum sätter man ju väldigt tidigt i värdekedjan, alltså i stort sett när den här produkten förpackas.Vilket också och det baserar gissningar på hur länge den här produkten kommer hålla utan att veta någonting om hur länge eller hur den kommer förvaras och behandlas med resten av värdekedjan. Vi som konsumenter har ingen annan informationskälla än det datumet och våra egna sinnen och när vi kommer till sinnena så är man ju lite begränsad, framför allt när det kommer till köttprodukter. Vi kan ju inte smaka på en rå kött produkt till exempel. Man kan dofta, men doftsinnet är liksom dels ingenting som yngre generationer som som våra generationer anser särskilt mycket av. Plus att det är ganska klurigt. För att förpackningar innehåller livsmedelsgaser som som sprutas in för att produkten ska hålla längre. Därför så vet inte kunden vad det är hen känner. Är det livsmedels gaserna eller är det maten som har blivit dålig? Därför vill vi skapa något ett bättre sätt att mäta hållbarheten på mat som mäter inuti förpackningen för just den produktens förutsättningar och realtids status. Dessutom kunna stötta slutkonsument i att ta ett väl överlagt och informerat beslut som inte baseras på den här gissningen som gjordes tidigt av producenten utan på vad som har hänt den här produkten och vad den faktiskt har för status just vid det tillfället.

vad för typ av sensor använder ni? för att känna av bakterier. Är det någon specifik gas ni letar efter?Som det här då färgen reagerar på.

-Ja, det är den kedjan vi vill knyta ihop. Det finns olika bakterier som växer inuti livsmedel överlag och kött. ;an kan dela in dem i 2 olika områden. Det finns försämring bakterier som försämrar kvaliteten över tid och patogena bakterier. Patogena är ju de som är hälsofarliga och de växer inte på samma sätt över tid utan.Antingen så så finns de där och har förmodligen då tillförts i uppförandet eller produktionen pga dålig hygien eller så finns dem inte där. I Sverige så har vi så pass välvårdade produktionskedjor att det det är väldigt sällan det förekommer patogena bakterier. De har inte samma tillväxt beteende så växer inte över tid och de släpper inte heller ifrån sig några gaser så de de mäter inte vi, utan det ligger på producenten att se till att det inte finns några partierna bakterier där. Men däremot försämring bakterierna som gör att produktens kvalitet blir sämre över tid, oavsett hur väl man behandlar den. De har ett beteende i att de efter ett tag så börjar de liksom föröka sig väldigt kraftig i produkten. I takt med att de gör det då släpper de ifrån sig vissa gaser. Gaser som som vi kan bygga en korrelation mellan, bakterietillväxt, gasutvecklingen och då reaktionen på etiketten. Exakt vilken gas det är kan vi inte svara på, utan vi har ett antal olika kandidater som vi håller på att bevisa. Bevisa handlar om att bevisa att det går att bygga en korrelationen. De går under begreppet volatila organiska gaser eller biosis. Vilket egentligen betyder bara att det är en gas som kommer av en organisk process.

-Det är det här bläcket som som innehåller en reaktiv komponent som reagerar med de här gaserna. När det blir tillräckligt mycket gas inuti förpackningen då ändrar den färg. Och det blir indikation för slutkonsumenen.

Det finns företag som gör TTI för att se om det har varit dålig förvaring. Är TTI något ni sysslar med?

Nej, inte i dagsläget. TTI är ett annat sätt att applicera samma problem.Det som man går miste om då är ju allting som inte har med temperatur att göra. Det blir en mycket mer precis mätning än vad datumet blir. Men man missar ett gäng faktorer för att kunna säga någonting om fallet om produktens totala kvalitet. Däremot när man är inuti förpackningen som i vår etikett så kan vi fånga upp även saker som variationer i den ingångsvärdet i antalet bakterier som påverkar produktens hållbarhet. Dålig hygien i produktionen kommer påverka längden hållbarhets längden på produkten. Temperatur är en väldigt viktig faktor. Men det är inte hela sanningen. Därför är gas sensoriken viktigare.

Vi ser ju väldigt viktig rörelse generellt att man i branschen börjar ifrågasätta varför man ska använda sig av utgångsdatum som ju är ett otroligt ineffektivt system att mäta hållbarhet på mat. Man har varit tvungen att förlita sig på för att den funnits bättre alternativ.

Det är bra att det finns TTI men vi ser att när det kommer till mer känsliga produkter tex kött tror vi att det kommer krävas en gas sensor för för att bygga tillräckligt mycket trovärdighet och tillförlitlighet gentemot slutkunden i sista ledet.

Men det är väl lite samma slutsats vi har dragit efter att vi har forskat lite i detta. TTI är bra, men det ger ett hum om produkten är bra eller dålig. Tex om du har en produkt i en kyl kylskåp hela tiden så kan den visa grönt, trots att maten är dåligt.

Det finns en anledning att kämpa vidare med gasen sensor istället för att gå över till TTI. Vi som bolag har som vision att bli en en aktör som som kan fylla olika behov när det kommer til dynamisk hållbarhetstid. Det finns ju begränsningar i gas sensoriken också för att vi behöver en inre miljö i förpackningen där gaserna kan ta plats och triggar den här reaktionen i etiketten. Till exempel vakuumförpackat, har inte den gas till tillväxten på samma sätt. Så där är ju liksom en en TTI då ett väldigt bra alternativ och det det utesluter inte att vi att det kommer utveckla eller tillstånd av produkter i vår produktportfölj längre fram också.

Hur pålitliga är era sensorer?

Vi fortfarande är i utvecklingsskede. Vi ser att när bakterierna växer till sig inne till produkten så följer färgen med. Men det är den där precisionen som vi fortfarande kämpar med och bevisföringen också att det som det som vi säger ska ske, det vill säga bakterier, växer till sig, det bildas gaser och det triggar en reaktion. Det är den vi kämpar fortfarande med att verkligen kunna bevisa det. För att livsmedelsbranschen är en ganska konservativ bransch som det ändå är också med lite försiktig också ska vara vilja att hoppa på ett sånt här väldigt innovativt och nytt tåg så behöver vi vara starka i vår bevisföring. Målet är ju att kunna vara oerhört precis. Och det, det tror vi att vi kan ta oss, men vi inte riktigt där än.

Det finns ett bolag i Norge som heter Keep it teknology som gör TTI och har funnits på marknaden ganska länge. De har en variation på ett dygn. Ett dygn är ganska mycket, vår ambition ligger betydligt lägre, dvs nära tröskel gränsen.

Hur avgörande den här tröskeln? Hur vet man när man när en viss bakterie population är för stor f**ör det känns som att vi måste vara väldigt svår**t att kunna avgöra det?

Det är inte så svartvitt. I datumsystemet har man midnatt gräns efter 12 slaget kan du inte inte äta din produkt om det där datumet stod på förpackningen. Vår ambition där är ju att bygga ett pussel av dels mikrobiologiska tester då där vi kollar på de bakterier grupper som vi vet är mest för försämrande och kvalitets förstörande och och det finns ju vissa tröskelnivåer man har gjort liksom studier på det här över tid där man vet att den nu är det där är liksom inte längre bra.Att kunna att kunna liksom bygga ihop den sidan med också då det som kallas sensoriska tester som inte alls har någonting med den här sen så ni gör det utan där man.Kolla på hur konsumenter alltså såna som vi upplever en produkt vid en viss bakterie nivå utifrån luft, lukt och smak och liksom utseende för det är ju liksom det är det som är grejen, att det som precis som ni säger det är inte objektivt ja eller nej, utan det är ganska mycket subjektivt inblandad i det här.När man som konsument anser att en produkt inte längre är tjänlig eller acceptera bara att konsumera. Det är egentligen där man drar gränsen just eftersom det inte heller har att göra med hälsofarliga bakterier så så är det ju liksom.Bara kan du ju bygga härligt egentligen till att konsumenter tycker att det är gott eller inte?Så att vi måste ju på något sätt försöka standardisera det här måttet och vi. Jag tror att vi har goda förutsättningar att göra det, men det blir nog upp till oss lite att sätta den gränsen. Det finns inget tydligt så myndighetsstöd att luta sig mot eller sådär utan det blir upp till oss och det är en utmaning också att.Sätta den gränsen, men en tydlig hypotes där som vi som vi har med oss.

Datum systemet som används idag är konservativt satta, det vill säga att det finns några dagar efteråt. Datumet i sig är ju ett mått på vad konsumenterna i alla fall kan tänka sig att äta produkten så vi kommer utgå mycket från det i våra tester. Tex vad är bakterie nivån, på bäst-före datumet? Vad är den 2 dagar efter och vad är den 4 dagar efter på något sätt navigerar utifrån det tillsammans med sensor i resultaten.

Tillverkar innoscentia sensorerna? eller tillverkaren ni också förpackningen eller köper ni den, av vem i så fall eller?

Nej förpackningen är ingenting som vi tar ansvar för utan vi utvecklar de här etiketterna och har för avsikt att sälja etiketterna till varumärkes ägarna, det vill säga de som tar beslut om hur förpackningen ska se ut och vad den ska innehålla och och och så vidare. Men sen så är det ju helt rätt att etiketterna kommer ju behöva appliceras i samband med förpacknings processen. Så att det det är väl egentligen så det hänger ihop att vi vi tänker vi sälja en etikettrulle som antingen för appliceras på tråg filmen, alltså plastfilmen som sen försluter tråget. Det kommer nog vara vår applicering,eller, integrationslösning i ett första skede för då kan vi egentligen bara sälja liksom eller leverera hela topp filmrullen med etiketterna på det finns en volymbegränsning där vi kan inte göra det för allt för.Liksom.Förpacknings livet som ett vägledd av alltför höga volymer i hur snabbt dom producerar och eller paketerar och så vidare. Så att på längre sikt så ser vi snarare som att vi kommer ha den här etiketten rullen och att den etiketten appliceras på insidan, vara på plasten när den har rullats ut för att sedan ta sig in i trågförslutare maskinen.

Den den har någon form av klister är någonting som man sätter på insidan av det här tråget.

Ja exakt det den kommer ha liksom ett lim lager som det översta lagret så att det. Vanligtvis är limlagret underst. Men vi kommer ha limlagret överst.

Vad är det största hindret med implementation av sensorerna. Du har redan gått in lite i det om det här med forskningen att det inte är så exakt än om ni inte har kan backa upp allting helt enkelt.

Ja, men det beror lite på vad man zoomar in på. Bevisföringen av våran teknologi så finns det några utmaningar, men när det kommer till implementationen så tror jag att det handlar om att få branschen att vara med på hela förändringen. Vi har ju mycket liksom många megatrender med oss i ryggen i form av hållbarhet och matsvinn. Vi är beroende av att producent, handlare och slutkonsument är med på i leken för att vi ska lyckas så det där kommer vara en utmaning och på sikt att då få det att lyfta. Vi behöver se till att alla upplever värdet av etiketterna gentemot det nuvarande systemet som ju som jag varit inne på är ineffektivt.

Vi har vant oss vid datumsystemet och det är egentligen ingen som upplever jättestora problem kopplade till datumet mer än på makronivå och att vi svinar väldigt mycket mat som hade kunnat konsumeras. Det är utmaningen att få dem att känna att det här är Need to have inte nice to have.

Tror ni att det hade varit dyrt att implementera sensorerna?

Ja, en av förutsättning är att det inte blir för dyrt. Där har vi en väldigt styrka i vår analoga etikett att den den går att producerar billigt. Sen kommer inte bli lika billigt som en datum etikett. Det är ju mer komplex, men vi kommer ändå komma ner på nivåer tror vi som är acceptabla för branschen att hantera.Och sen när det kommer till själva implementationen, så. Om man kollar på de 2 scenarierna, antingen att den är för applicerad på på topp filmen eller att den har en etikettapplikator i förpackning slidan så det senare kommer bli. Det kommer ju kräva en maskinell investering helt enkelt från våra kunder, men vi tror inte heller att den behöver bli särskilt stor. Och ja, det är ju lite från fall till fall. Men det är inte vår största utmaning i nuläget i alla fall. Men nej, ni ska inte bli för dyrt. Det är det är målet och ambitionen och tron

Har du någon uppskattning på vad en enhet kan ligga på för pris?

Det beror på lite på hur vi bygger upp affärsmodellen. Och på vad vi lägger vår prispunkt. Men om man kollar på produktionskostnaden så så tror vi väl att vid hyfsade volymer så kan vi få ner den till 30 öre .Sen är det också som sagt, det är fortfarande under utveckling och det kan hända saker med komponenterna som kan påverka det viset. Men det är någonstans dit vi siktar liksom att kunna ändå producera så pass billigt och sen så lägga på marginal som gör att vi blir livskraftiga bolag också.

Sen kollar man ju om man kollar på den digitala så är vi absolut det där. Den analoga är inte mycket mer komplicerat än att vi har ett plats uppdraget, vårt bläck och ett limlager. Det här är riktigt simpel produkt som levererar en en väldigt klurigt värde.

Går det att återvinna den här typen utav sensorer eller går det att återanvända dem?

-Nej, återvända kan vi inte göra för att bläcket är irreversibelt på så sätt att det när det väl har reagerat så kommer inte gå tillbaka till det kan vi inte göra på det sättet. Återvinnings aspekten är egentligen ganska lik en vanlig etikett. I och med att du har tryckt bläck på kommer du aldrig kunna återvinna hela materialet som ett mono material. Det förhåller sig ungefär likadant som en vanlig etikett egentligen ifrån att återvinnings perspektiv, det vill säga att man kan liksom inte ska säga på detaljnivå.

Innehåller etiketten några hälsofarliga kemikalier?

-Jo, men det finns ju lite komplexitet kopplade till etiketter, men inte för något återvinnings perspektiv utan snarare från livsmedel säkerhetsperspektiv. Det är klurigt när man ska placera någonting inuti en matförpackning då måste det vara jättesäkert och därför är det där är ju också någonting som vi kämpar med i produktutvecklingen nu. Att till att ingenting från blänket migrerar över till livsmedels sidan. Det är en förhållning och en reglering som vi måste förhålla oss till. Men från ett återvinning perspektiv det är precis alltså ta ett vanligt tryck bläck. Majoriteten av dem är inte heller säkra och placera inuti en packning.

Ni skriver på er hemsida att era sensorer leder till minskad matsvinn har ni data eller siffra på hur mycket matsvinn blev reducerad?

-Nej, det har vi inte ännu och det är någonting som vi håller på att skapa nu faktiskt. Dels med det här testet som jag var inne på lite förut att mäta bakterie nivå på datummärkningen 2 dagar efter och 4 dagar efter. Mycket av vår effekt på matsvinnet har att göra med, dels att vi kan liksom låsa upp fler dagar så att vi kan visa att produkten är ätbar trots att datumet har passerat.Vi vill bygga in trygghet i slutkonsumetens beslut. Det finns väldigt tydlig data på att majoriteten av matsvinnet sker hos slutkonsumenten. Vi tror att en stor faktor är för att man inte vet, och inte känner sig säker. Då tar man det säkra före det osäkra. Så vi kan leverera den informationen till konsumenten och bygga in trygghet i att äta produkten trots att datumet har passerat. Det är för tidigt att säga exakt hur mycket vi kan påverka matsvinnet för att vi inte har färdigt etiketten och därmed inte kunnat ge oss ut och testa. Men våra uppskattningar, att det finns 1 2 3 dagar att lägga till i produktens hållbarhet beroende på vilken produkt man kollar vilken produkt man kollar på. De där extra dagarna kan ha stor påverkan på att minska svinnet i konsumentledet med upp till 50 %. Lite studier som som hävdar då att så att de dagarna kan ha en så stor påverkan och. Vi har mycket kvar att bevisa där, innan vi kan med säkerhet basunera ut att det är så det ser ut.

Det är ju faktiskt en av våra största frågeställningar, men just den här typen av sensorer är ju, hur mycket kan det faktiskt reducera och vi har hittat väldigt svårt. Det är svårt att hitta datan på det och vi har gjort en del kunders alla undersökningar rätt omfattande med människor och de flesta är säger att en ganska stor majoritet luktar ju på maten och sånt innan och slänger det. Men jag tänker att det kanske är mer relevant till mjölk och sånt.För där vet ju de flesta,men till köttprodukter så tror jag att där har ju folk inte den tilliten till sina egna sinnen på samma sätt.

-Nej exakt och sen så.Det är alltid klurigt med sina konsumentundersökningar också. Vi har ju själva gjort om om man får liksom resultat om. Ja, men de är de ser lovande ut, men sen så och och jag menar man svarar en sak på etikett, men sen kan det vara liksom ett annat beteende som väl tar plats. Som vi har gjort med deras lag, var det lageransvarig eller hållbarhetsansvarig.Vi håller på och försöker få tag på så många intervjuer som möjligt. Vi kan samla lite data och bygga någon bas.Kul mycket bra.

Har ni samarbete med några företag eller vilka i så fall?

-Ja det beror på lite hur man definierar samarbete men vi har väldigt många dialoger igång och vi pratar i stort sett med med liksom alla stora livsmedelsbranschens aktörer i sverige och även utanför Kedjor då alltså ica till exempel då och så där och vi har alla stora livsmedelsbranschens aktörer i Sverige och även utanför Sverige finns det många dialoger som vi har igång och det är framför allt kött producenter och återförsäljare kedjor då alltså ica till exempel och och så där och vi har.Liksom ja vi har. Vi har väldigt många kontaktpunkter där, men vi har också svårt att liksom formalisera de här samarbetena innan vi själva har visat att etiketten fungerar som vi som vi hävdar att den ska liksom. Man kommer ofta liten. Ja, det här är superintressant, tror att det kan vara jätte relevant, men kom tillbaka när den är klar liksom.Så det är väl det är en utmaning som vi har att kunna formalisera de här samarbetena. Men å andra sidan så har vi några liksom *letter of intent*, avsiktsförklaring att ja, men när ni är klara med det här på då är vi intresserade liksom och det har vi på skrivit på lidl och COOP. Det finns bra förutsättningar när etiketten väl är klar att kunna liksom rulla ut det här.

Är era sensorer bara för kött eller vilka andra typer av mat kan man använda någon till?

-Ja, men precis vi är väldigt inriktade på kött nu, framförallt på grund av att vi vill. Vi behöver fokusera och vi behöver liksom lansera lite smalt till att börja med för att för att komma till skott med också. Vi har testat liksom bläcket då på lite olika varianter, lite olika livsmedelsprodukter, bland annat fisk och där får vi också en väldigt bra reaktion. Sen handlar det om att liksom och lära känna det är livsmedlet och förstår kemi där och vad som händer med bakterierna och gas utvecklingen och så vidare och det har vi inte den läxan har vi inte hunnit göra en.Men man kan väl säga att vi ser ju liksom inga begränsningar mer än att det måste finnas de här förpackning förutsättningar som sätter lite scopet för vad vi kan, vad vi kan applicera etiketterna på, det vill säga att det är en förpackning som präglas av en inre miljö där gaserna kan ta plats och att den är liksom försluten.Fram tills att den konsumeras då så till exempel om man tar mjölk då så har du ju en mjölkförpackning som du ofta öppnar och stänger och då då påverkar vi måste. Det är den inre miljön ganska ganska mycket och det det tror vi är krävs en del vidare produktutveckling för att kunna komma dit och där har man ett ännu större liksom. Kostnad problematiken med vatten.1 l mjölk kostar 10 spänn och då då kan inte etiketten kostar 1 kr liksom det är accepterat på den så att det. Men det är kött som gäller och sen så tror jag väl att nästa grej är fisk och därefter så så är det lite nere blurrigt vad vad det blir. Men det finns ju också en väldigt intressant framväxande kategori, liksom alternativ protein och vegetariska kött substitut.

C Interview with Dr Li

So, first question, could you tell us more about your research?

- Okay, okay. Sure, sure, sure. My main research work is about two-dimensional materials, you know, like the graphene monolayer MS too, this type of some two-dimensional kind of a semiconductor or two-dimensional semi metallic materials. And one of my research topics about the 2d materials is about sensors, you know, actually, that is mainly about graphene gas sensors, you know, do you know graphene, this new type of material?

Yes, a bit, but tell us more about it.

- Actually, it's very simple, because graphene might be one of the simplest materials in the whole world, but it's very amazing. For example, you probably know graphite right, and carbon. Graphene is a mono layer of carbon. That's very simple. Yeah. So, the amazing part of a graphene is like, it has a very, very good or very, very high conductivity. And, you know, because it is a monolayer, mono layer, atomic monolayer material, it has a huge surface. That's why graphene is a very nice candidate for sensors. You know, in the sensing in the, for example, gas sensor area, one important parameter is the surface to volume ratio, right, if you have a big surface, which means there are more sides for the gasses to attach. So it has a very high selectivity. For graphene, there is a huge surface compared to the volume. So that's why graphene is very important and also a very promising candidate for gas sensors, of course, you know, we do research because there are a lot of difficulties in graphene. One of the problems for graphene is first of all, graphene is very good in sensing. It has a very, very high, might be the highest sensitivity in the whole material family. I mean, even a single molecule that is attached to graphene, you can sense it, but the problem for graphene is like: it's true, it has a very high sensitivity, but it has no selectivity. Which means that even when there's for example, a Co molecule on the surface, or if there is an S3 molecule on the surface, we know there is a molecule on the surface, but we don't know what it is. So, this is one of the main topics I was studying. We try to maintain a good selectivity of graphene and also similar materials, or we try to improve the selectivity. So, this is yeah, this is my main job in the sensor field.

So, to figure out what type of molecule is in the air?

- Yes, yes, yeah. Or I prefer calling it like, for me i work on NO2 gas sensors, or NO2 graphene gas sensors and also NO3 graphene sensors. And, CO Graphene gas sensors and we try to understand this interaction between the molecules and graphene, of course, for, for Prestin graphene is just a pure carbon. That's extremely difficult to get a selectivity. So, we try to modify it a little bit on graphene surface. For example, let's take an NO2 sensor as one example, sorry, let's take a ammonia sensor as one example. We try to fluorinate graphene a little bit, which means that we try to put some CF bars on graphene surface, because a fluorine atom has a quite good selectivity to the NH3 molecules. So that we can really, our kind of gas sensors can really detect NH3 and then we can call it to like, Graphene, NH3 ammonia sensor. Yeah. So, because the reason really, I mean, a few months ago, we just published a paper about using graphing as ammonia sensor. So that's why.

Is that the only gas you can sense with graphene today?

- Nowadays, we mainly work on NO2 sensing and NH3 sensing. These are the two main types that we can have a good selectivity. For gas sensors there are several different parameters. The two key parameters. One is about selectivity, which means that in the cross-sensitivity measurement you can really identify which kind of molecules it is. So, this is selectivity. Sensitivity normally we characterize it by using the unit, something like ppb or ppm. Both are quite low concentration. So, currently, for our NO2 sensing our reported selectivity is something like less than 100 ppb which means that, you know, volume is only a few molecules, is extremely high also for NH3, slightly lower is something like 80, or 100 of PBB. If we can sense something like ppm value, it is already quite good. But of course, we tried to push it to the limit. So, now we are in the PBB range. Yeah.

So, I was thinking, what are some applications of having a sensor that is that sensitive.

- Okay, actually because I only work on gas sensors. But, uh, you know, if we talk about sensors, there are different types of sensors like for sensor, temperature sensor, humidity sensor, gas sensor. Everyone only focuses on their own area, small area, for example, I contribute our gas sensors. But therefore, for other things like temperature sensors, I can work a little bit, but I'm not an expert on that. There is a hot concept now, IoT, probably have heard about it. So, this means that, especially, we want every device and everything to be smart, right? Like in the car, the self-driving car, and everything must be smart. But smart normally means we should have our AI-something that can really treat the data and recruit data digitally, smartly to the data. Very, very, very smart. But first of all, you should have the data, how can we collect the data? Humans, similar to the gas sensors, our nose actually is our gas sensors, but it has a very, very low selectivity and sensitivity. In extreme cases, in the industry, sometimes it's not very useful. But we need something very selective and very, especially very sensitive to collect the data. So, sensors actually are one of the most important components in this collection process. So, this is very important. And also, for example, in my field in gas sensors, we have several collaborations with industry, you know, there's a Swedish company called Sense Air, they are selling a different type of sensor, these sensors can be used in nearly every field, in our daily life and also in the industry. Our storage room is in a bigger storage room, they must install some sensors to sense, for example, ammonia or some people use co2 sensors, because we have to monitor the air. Also, for the cars, you know, people have the sensor to sense the combustion gas to make sure that the quality of the combustion gas is fulfilled, the quality the requirement from the Society for everything, right. So, I think sensors, released sensors, actually, are very important in the modern world. Yeah. Because it's everything. Yeah. So our work is a bit about the technology of food and sensors, and we are specifically looking at meat, and we know that they extract some gasses when it goes bad.

Do you think that a graphene sensor would be possible to implement on food products?

- I think in the future definitely, I'm pretty sure about that. But currently, you know file objectives like a meat food, vegetable things, it is very complicated if we only talk about the gas. Nowadays there are still several very basic and also physics questions we are still trying to figure out, we are still kind of struggling you know. We normally start from very simple gasses like Co, h2, these very simple molecules, then we try to move to organic molecules. Of course, we're always starting from very simple organic molecules, like acetone, isopropanol, this type because they are easy, right, what everything is, when this background is so well fixed, I think we definitely will move to very other advanced and also complicated systems like food systems. Yeah. So, I'm pretty sure that in the future we will move to this.

So, we'll continue, are you developing these graphene sensors yourself?

- I've got a group, something between 5 to 10 people. We are a group. So yeah, because it's very difficult for one just one person to really develop the whole system is quite complicated. For the sensor research field, there are several different types of sensing mechanisms. For hours, many are working on for example, working on mechanical sensing is like for example, we use a very, very small tip, first of all try to functionalize the reference surface we use the Smarty to detect and to see what type it is and also work on other mechanisms called Chemiresistor and resistance like we tried to put a laterals with your readings through a current we try to see the change of the current. So then we can get responsibility and selectivity. I mean, there are different types of mechanism and also some for one specific sensing mechanism; actually they might only fit one specific to gas. So, this is something we have to identify and that is a lot of work. So, several people are working on this.

Are these graphene sensors expensive to produce, or how much do they cost?

- No, not the materials. If we only talk about the materials cost, it looks quite expensive. For example, for a one centimeter square it costs something like more than 3000 Swedish crowns, but I think that for one centimeter square sample we can fabricate into millions of sensors if you divide for example by milling is nothing actually. That is also because of the surface area because to get a good sensitivity, we need some real surface but for 2d material, they have a huge surface, so I can tell you the smallest gas sensor is only 20 nanometre. I guess it might be the smallest in the whole world. We have a paper in nanoscale, think published like one half years ago. The functional gap is only 20 nanometres. You see, if your sensor is only 20 nanometre, you can place something like at least 500 sensors there but you only need one sensor to sense the NO_2 gas. So actually, the price is nothing

Are they digital or how do you do the readings for the sensor?

- Yeah, okay for the reading actually we're talking about naturally there's also depend on the mechanism. For example, let's go back to this auto sensor. We have two sensors in the middle, we have two contact pads, and we try to drive through our current, the current is constant. When the gas sensor is exposed to some air like NO2 atmosphere, the current will increase. So we can directly read from any kind of, normally we use a source meter to read. So, you can directly read from there. And also from the response, you can also calculate, what's the concentration of the N02 gas. If we see there is 100% increase in the conductivity it normally for example means the concentration is something like a one PPM if you get a 200% response, that actually the sensitivity of the concentration is two ppm, roughly, this is very simple. That's why for this, we call it the chemiresistor type gas sensor. We can easily fabricate the sensor in the circuit in the computer chip. So, which means that probably in the future, if we solved all of the technical problems, probably we can directly implant this one in the small area of the iPhone chip. So probably you can directly sense if the combustion gas is too much or something. Yeah. And anyway, this is promising and future work.

Really sounds promising. These are reusable?

- Yes, that actually is also one of the benefits from this 2D tool, because it is very, very robust to the material. Probably you can easily check from Wikipedia, what's graphene. I think that graphene has near the hardening as a diamond is very hard. Mechanically, it's very difficult to replicate and also it is quite inert, which means that when once the sensor is made, you probably need to heat the sample to 3000 degrees. Otherwise, you cannot really damage it. So, there is a premise that it's very, very productive, I have to say. But of course, nowadays, we have to say that we still have a lot of technical problems. I mean, for example, electrodes, you need some metal electrodes. Normally we use gold to drive through the current and everything right. But of course, the connection is not good, because graphene is a semimetal. And gold is a pure metal and there is huge contact resistance. And I mean, there are so many technical problems. And also, when the sensor goes several times, probably you'll see a dramatic decrease in the performance. But that is not from a graphene, that is probably from this gold contact, because gold is soft. It can be damaged. Yeah. So, I have to say there are still a lot of things to do for these technical questions. But for the material itself, it is indeed very promising. That's why you know, we are a network called a flagship, probably you have heard about that European flagship. At this lecture. There are only two projects, one is about graphene. One is about the human brain, I guess. But the human brain is a small project. Yeah, the other title is for that we you can check the graphing flagship actually university and Chalmers are or you know, flagship, we are also in the flagship and also, we have a there's a specific aspect that we that is about graphene for sensing, kind of after we are mainly in that topic. So that's why we also got found.

So we're actually starting to near the end of our questions. Next question.
We had a question about if they are recyclable or biodegradable?

- For the bio part, I'm not sure because probably, currently, probably is not. Yeah, it's not because, you know, we have never tested that. But I don't think there will be bio compatibility because, you know, I know, Carbon Nanotube and also graphite flicks. They are kind of toxic. They're toxic because they are very chemically inert once they are inside the human body, there is no way to react. So, they will stay there forever. So, that is kind of a toxic So, currently, I don't think they are biocompatible

Quite dangerous to use for food products then would you say?

- Yeah, so, we usually have to, we have to monitor everything on the chip and also we have to seal the chip, only expose a small area for the sensing volume things. Yeah, but for graphene compared with graphite flakes or nano carbon nanotubes. I think there is one advantage for graphene is because, you know, for carbon and fuel, so you can, you know, for toxic materials. Yeah, it is definitely also toxic. But you also need wheat, you also need an amount. That is the good thing for graphene, graphene is very small, and just a monolayer. So even if we talked about some, some amounts to killing people, then it is not realistic for graphing because graphene is too small, and also too little. But also graphing is very toxic. But we don't know.

I think that was all of our questions. It was really nice talking to you. Really interesting work, you do, and I hope to see more of this in the future.

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