Acrylamide in Ready-to-Eat Potato Products

25 February 2019

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Abstract

The formation of the suspected carcinogenic compound acrylamide has become a noticed problem in the heat processing of several types of carbohydrate rich food items. The European Union is currently working to mitigate these levels, where one strategy is to implement a new regulation with benchmark levels for acrylamide in different products. The regulation also includes recommendations on how to reduce the levels of acrylamide for different types of food products. This new regulation forces food producers within Europe to work actively in order to reduce acrylamide levels if such are currently exceeded.

French fries and other potato based products are food products in which high levels of acrylamide can form during heat treatment. These levels are problematic and therefore these products are included in the regulation. This study aimed at evaluating how different combinations of temperature and time of the cooking preparation affects the formation of acrylamide in three different potato products. A requirement in this study was also that the products would still meet the sensorial qualities set by the producer, after changing these settings. Three different potato products from the producer Orkla Foods were included in the study; Pommes Frites, Pommes Criss Cut, and Klassiska Rösti.

In the method, four different temperature settings including the current temperature recommendation and temperatures 5 °C, 15 °C, and 25 °C below the current instructions were tested. The different temperatures were also tested in combinations with different cooking times, in order to find combinations at each temperature that resulted in good sensorial qualities of the food items. The analytical method included quality control by carefully monitoring the temperature in the oven and in the food items, as well as a sensorial evaluation. The analytical method also included two different methods for colour analysis. The samples with combinations of temperature and time that gave good sensorial properties were sent in for analysis of acrylamide to a certified analysis laboratory.

The results from the colour analysis were problematic to evaluate because of problems with the method. For a majority of the samples analysed the benchmark level was not exceeded, but it was exceeded slightly for the samples of the product Pommes Criss Cut. The findings of this study suggest that, from the few samples analysed for acrylamide in this study, the cooking temperature that resulted in the lowest acrylamide content for all three products was 220 °C.

Acknowledgements

I would like to thank my main supervisor Assoc. Prof. Ingegerd Sjöholm and my second supervisor Prof. Kerstin Skog for agreeing to be my supervisors in this project. Their vast knowledge in food technology, and previous experience with several studies on acrylamide in food has been very helpful.

I am grateful to my examiner Assoc. Prof. Andreas Håkansson for giving me great suggestions for improvements in my report.

I am very grateful to several people at the company Orkla Foods for giving me the opportunity to do my thesis on this very interesting topic, and providing me with the food products for my experiments. These include Richard Clerselius, who gave me the opportunity to do this project as my thesis, Liza Björnström, who answered all my questions during the project and also arranged for me to get a guided tour of the production plant. I would also like to thank Cecilia Enelund for her help during the project, and Nada Zovic for her expertise regarding quality control and acrylamide levels in potato products. I have greatly appreciated that Gert Olofsson from Orkla Foods has taken the time to deliver the food products to my university.

Finally, I want to offer my special thanks to PhD student Erika Norén for her guidance in writing in an academic language.

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1. Introduction

In the year of 2002 the Swedish National Food Administration and the University of Stockholm announced that their researchers had discovered a substance called acrylamide in food items (Matthaeus and Haase, 2014). Acrylamide is normally utilized in the plastic industry, where it is manufactured in the form of a polymer called polyacrylamide. Polyacrylamide is used in wastewater treatment and paper production. Acrylamide can also be found in high concentrations in filtered cigarette smoke (Singh and Kaur, 2016). Prior to this discovery, there was no existing report of acrylamide within food items. The public announcement was published in an alarming way and widely reported as dangerous by the media. The amounts discovered in food were through the media perceived as more toxic than the scientific evidence suggested. It was indicated that by eating these food items it would be a guarantee to get cancer instantly, and not, as the research suggested, that there is an increased risk to develop cancer after a long-term exposure to high concentrations (Lofstedt, 2003).

After this initial discovery of acrylamide in food in 2002, a lot of research has been performed concerning this problem. The research has led to understanding of possible reaction pathways for the formation of acrylamide, and in what food items this happens (Matthaeus and Haase, 2014). Acrylamide can be formed in certain types of food as a result of the Maillard reaction when the food is heated in temperatures above 100 °C. The Maillard reaction is a non-enzymatic browning reaction in food that can give desired flavours but also can result in acrylamide formation. Acrylamide is only formed when the food is fried, deep-fried, oven baked or roasted but not when food is boiled. Examples of food that can contain high levels of acrylamide are carbohydrate rich food such as potato chips, french fries, coffee, bread, crackers and biscuits. The main precursors to acrylamide are the amino acid asparagine and any form of reducing sugar (Matthaeus and Haase, 2014;, Livsmedelsverket, 2018).

Potato based products such as potato chips and french fries are a group of products that usually contains a very high concentration of acrylamide. Strategies on how to mitigate these levels within the whole chain of the production have been developed since 2002 based on research on acrylamide in food. There are strategies for all steps in the production chain, from agricultural production and all the way to processing and cooking (Matthaeus and Haase, 2014). Official recommendations for reducing acrylamide levels have been developed throughout the years. In April 2018, the European Union by EFSA (European Food Safety Authority) has started implementing benchmark levels for acrylamide in different food categories, where the manufacturers need to take actions if the levels are exceeded. Food producers in Europe therefore need to implement the new recommendations of how to handle the food product, which might impact the current processes and the cooking instructions on the consumer packaging (European Comission, 2017).

1.1 Aim

The aim of this project was to evaluate how the two parameters, time and temperature, affects the formation of acrylamide in commercially precooked frozen potato products in the final cooking step in a domestic oven. Within this aim, the cooked products also needed to fulfil certain sensory qualities after cooking, that were set by the producer. The current temperature instructions of 225 °C for the products in the study should be reduced to 220 °C or lower, but still fulfil the sensory demands, and result in an acrylamide level under the benchmark level. The products that were evaluated in the study were two different types of french fry products ('Felix Pommes Frites' and 'Felix Criss Cut Pommes'), and one product similar to hash browns ('Felix Klassiska Rösti') from the brand Felix from the producer Orkla Foods. Due to food safety demands, the temperature had to be monitored in the oven, on the surface of and in the centre of the food products during cooking to ensure that no bacteria remained in the product. Within the scope of the study was also to try to investigate correlations between acrylamide content and colour and water content of the products, in order to try to evaluate how the formation of acrylamide is affected by, or correlate to these factors.

1.2 Limitations

This project will only evaluate the cooking instructions for preparation in oven and not cooking by deep frying or pan frying. To evaluate the acrylamide levels after deep frying or frying in a frying pan is also of interest, but did not fit within the scope of this project. It was not possible to analyse all samples from the preparation trials for acrylamide content due to limited financial resources. Additional temperature settings and cooking times could be evaluated but was limited in order for the amount of experiments to fit within the scope of this project. Further testing needs to be performed to evaluate the different cooking methods for optimisation to ensure that the acrylamide content is mitigated for all different cooking methods.

2. The Farm-to-Fork Journey for a Potato, from Seed to a French Fry

2.1 Origin of Potato

The potato, *Solanum tuberosum L.*, originates from the Andean region in western South America. The potato has been cultivated in this area for around 8000 years. It was not until during the 16^{th} century that the crop was brought overseas to several places in Europe, and after this it has been exported to many other parts of the world (Kumar Chakrabarti et al., 2017). Today the potato is cultivated on a total area of 20 million hectares around the world. It is considered the fourth most important staple crop worldwide with only rice, wheat and maize considered as more important (Singh and Kaur, 2016).

The cultivation of the potato in the Andes in South America, where there are several different agro-ecosystems, has shown that the potato has been able to adapt to differences in the environmental conditions (Singh and Kaur, 2016). This has resulted in a highly diverse biological material for the many different varieties of potato. Today there are several thousand varieties of potato in South America, including both cultivars and landraces (Kumar Chakrabarti et al., 2017). This diversity is something valuable to preserve, and in South America several measures have been taken to conserve the biological diversity of the potato. There are several centers with collections of different potato varieties and gene banks, including both old landraces and more modern cultivars (Singh and Kaur, 2016). The largest gene bank for potatoes is the CIP (The International Potato Center) with 4787 different potatoes (Kumar Chakrabarti et al., 2017). The different potato genes could be used to develop potato varieties that are adapted and optimized to grow better in various conditions, more resistant to different pests, increase the nutritional value and to have desirable properties that makes the potatoes well suited to be processed in different ways (Singh and Kaur, 2016).

2.1.1 Potato Composition

A potato consists of approximately 80 % water and 20 % dry matter. Most of the dry matter consists of starch, approximately 70 % depending on the variety. The sugar content is between 1 to 7 g/kg depending on the variety, the cultivation and how mature the tuber is. Young tubers have a higher level of reducing sugars. These levels will decrease as the tuber reaches a more mature state towards being harvested. The conditions and durance of the storage after harvest will affect the sugar content of the potatoes. The potato also contains protein, calcium, potassium, phosphorous, iron, vitamin C and antioxidants. In the North American diet, potatoes are the third main source of antioxidants (Singh and Kaur, 2016).

2.1.2 Growth and Harvest

To grow potatoes, either seeds or pieces of potato or whole tubers that can sprout can be used. It is more common to use tubers or pieces of these than to use botanical seeds. Propagation using seeds usually demands extra time for the initial growth of the seeds. What time of the year of the plantation takes place depends on the local climate, but in the temperate areas in the northern hemisphere the planting occurs between April and early June. In some climates, year-around production is possible and therefore also year-around planting (Navarre and Pavek, 2014).

A propagating tuber piece can either be planted directly into the soil, or first be pre-sprouted and then planted. Pre-sprouting demands special equipment but can be beneficial in geographical places with a colder climate and therefore shorter growing season, for example northern Europe. The pre-sprouted tubers will result in an earlier harvest (Navarre and Pavek, 2014).

When the seeds or the tuber pieces have been planted, the sprouts will grow upwards and reach the earth surface. Above ground the exposure of light will cause the stems to start developing leaves. The crop will continue to grow branch stems, flowers, roots and stolons. When the conditions are right for the tubers to start developing, a signal is sent from the leaves to the tip of the stolon. This will induce the tuber growth by ceasing the elongating growth of the stolon and cause the stolon tip to start swelling by radial cell expansion, which will form a sphere at the end of the stolon. The tuber reaches a diameter of approximately 0.8 cm and at this point the cell division becomes oriented in random directions. The tuber will continue to grow, and it is mature when it reaches a maximum level of dry matter, and a minimum level of reducing sugars. The tubers should be harvested at this point. A high level of dry matter is favourable if the potatoes are to be processed into e.g. french fries. This is because a higher level of dry matter also means a lower level of water, which will demand less energy for heating. The lower water content will also result in a lower oil uptake during frying (Navarre and Pavek, 2014).

The geographical location of where the potatoes are grown will have an effect in what the mineral profile of the potatoes will be depending on which minerals and what levels are present in the soil where the potatoes grow. It has been discovered that the mineral profile also affects the levels of reducing sugars in the potatoes. Potassium and calcium has shown a negative correlation to reducing sugars and zinc and copper has shown a positive correlation to a higher level of reducing sugars. Differences in if, how, and when fertilizers are used on the potato field can also affect the nutrient content of the potatoes. If nitrogen is added to the field during the latter part of the growing season, the maturation of the tubers will be delayed. This will also lead to a higher level of reducing sugars in the tubers. After summers that are especially warm, it has been observed that the potatoes contain less reducing sugars (Singh and Kaur, 2016).

During the growth phase and the harvest, all of the tubers stay dormant, meaning they will not start sprouting. The tubers can also stay dormant after harvest depending on surrounding conditions. Low temperatures will prolong the dormancy (Navarre and Pavek, 2014). If a potato has started sprouting it should no longer be used for consumption or processing (Singh and Kaur, 2016).

2.1.3 Storage

In order to have a supply of potatoes throughout the whole year and not only after harvest, the potatoes need to be stored accordingly. The storage conditions are extra important in locations with just one crop season per year. The conditions of the post-harvest storage of potatoes are of importance since the potatoes will continue to respire after harvest. To prohibit the tubers from start sprouting the surrounding temperature is kept low with the help of refrigeration or air-cooling. An additional method is to use sprout suppressants. Potatoes of good quality can be stored between

2 to 12 months, depending on the conditions and use of sprout suppressants (Singh and Kaur, 2016).

If the tubers have a high concentration of reducing sugars at harvest (higher than 0.15% of the total weight of the potato) there will be a faster increase of reducing sugars in the tuber during storage. Therefore it is favourable if the tubers are harvested at the right degree of maturity. Potatoes that naturally have a lower concentration of reducing sugars should be used if the potatoes are to be processed into a product where this content is critical. A natural process that increases the concentration of reducing sugars during storage is LTS, Low Temperature Sweetening. LTS is the process where the starch in the potato is metabolized into fructose and glucose at a higher rate in temperatures below 8-10 °C, compared to temperatures above this. The low temperature sweetening happens as a part of the respiration of the potatoes, where the starch is hydrolysed into reducing sugars. The LTS process is presumed to be a defence mechanism in the potatoes as protection against frost. Therefore this process is much faster when the temperature is below 8 °C, closer to temperatures of frost. This hydrolysis process will lead to a loss in dry matter as more starch is turned into reducing sugars. There is a dilemma in what storage temperature to use, because the best storage temperature to keep the potatoes sprout-free is between 4 and 7 °C and to keep them from LTS is above this temperature interval. The LTS is a process that can be partially reversible, if the potatoes are to be reconditioned in at a higher temperature for a few weeks before processing or consumption (for example at 15 °C for 3 weeks with a reduction in reducing sugars as a result from studies). However, long-term LTS is not reversible. The higher reconditioning temperature will also cause the potatoes to age faster (Blenkinsop et al., 2002;, Singh and Kaur, 2016).

The surrounding conditions, in the form of the air composition during storage, will influence the starch and reducing sugar content. The reducing sugars can increase if the air around the potatoes has a carbon dioxide concentration of 3 – 4 %. Efficient ventilation is therefore important, so that the carbon dioxide produced through the tubers' respiration is removed. This type of sweetening of the potatoes can be reversible if the conditions are changed (Singh and Kaur, 2016).

The same storing conditions have different impacts for different potato genotypes. Therefore, it is important that the potato variety is chosen accordingly to what the potato is going to be used for. A potato that is to be processed into french fries should have the correct basic properties before being processed, meaning a low concentration of reducing sugars, in order to prevent a high level of acrylamide in the final product. Current research is working towards developing potato cultivars that are resistant to low temperature sweetening (Singh and Kaur, 2016).

2.2 Processing

Potatoes can be processed in different ways depending on what the final product will be. The different properties and qualities of various potato types are also important factors to consider based on the planned end-product. Prior to processing a batch of potatoes, a quality control needs to be performed. If the potatoes are to be processed into french fries the reducing sugar content is critical and needs to be measured. The size and shape of the potatoes also make them more or less suitable to be processed into various products. Small sized potatoes generally have a higher concentration of reducing sugars. The length of the potatoes also matters when producing cut potato products. Potatoes that have a long oval shape, and a low content of reducing sugars, are the best option when producing french fries. The reason that a low reducing sugar content is important for french fry production and other fried potato products is the formation of acrylamide during the processing. It is also favourable if the potatoes have a high dry matter content for this specific potato product. The two potato products that are produced in the largest quantities are french fries and potato chips. Frozen french fries is the most commonly produced processed potato product in the world (Singh and Kaur, 2016).

2.2.1 The Maillard Reaction and Acrylamide Formation

Acrylamide in food is mainly formed as one possible product during the Maillard reaction (Gökmen, 2016). The Maillard reaction is a process that takes place in many different types of food during heating at a temperature above 100 °C. The reaction takes place between amino acids and sugars. The reaction causes a non-enzymatic browning of the food that also develops desired flavours in the food, i.e. baked or fried flavours in french fries, or aromas connected to toast or newly baked cookies. Low water concentrations, which give a higher concentration of the precursors, and a neutral or alkaline pH will favour the Maillard reaction. The Maillard reaction can result in the creation of different products where a few examples are HMF and cyclic compounds as maltol and sotolon. Most outcomes and effects of the Maillard reaction are desirable, but it can also result in unwanted compounds where several are potential, or actual, carcinogens (Coultate, 2009).

The Maillard reaction is required in order to contribute to the favourable organoleptic properties of fried and baked food, but preferably without having created acrylamide as a final product. The amino acid asparagine is the precursor to the main formation of acrylamide in food. When the food is heated, a condensation reaction takes place with asparagine and reducing sugars or a carbonyl source (Taeymans et al., 2004). The precursors to acrylamide are naturally present within the food. This is the reason why acrylamide is only formed in elevated concentrations during heating of certain foods such as different plant materials including grains, potatoes, coffee beans etc. Conditions that affect the formation of acrylamide when asparagine and a helping precursor are present have been studied and include temperature, pH and moisture content (Gökmen, 2016).

The mechanism for the acrylamide formation through the Maillard reaction (Figure 1) works as follows: asparagine and a reducing sugar form a N-glycolsyl derivative of the amino acid. This N-glycosyl molecule will lose a water molecule to form a Schiff base. After this point it can take different routes that will result in acrylamide as the final product. In a system with a lot of water the next step is a rearrangement to an Amadori compound, which can thereafter undergo a hydrolysis or enolization reaction that will change the Amadori compound into a deoxysone. The deoxysone can thereafter undergo several reactions that will in the end result in compounds that give the desired flavour and colour of fried food.

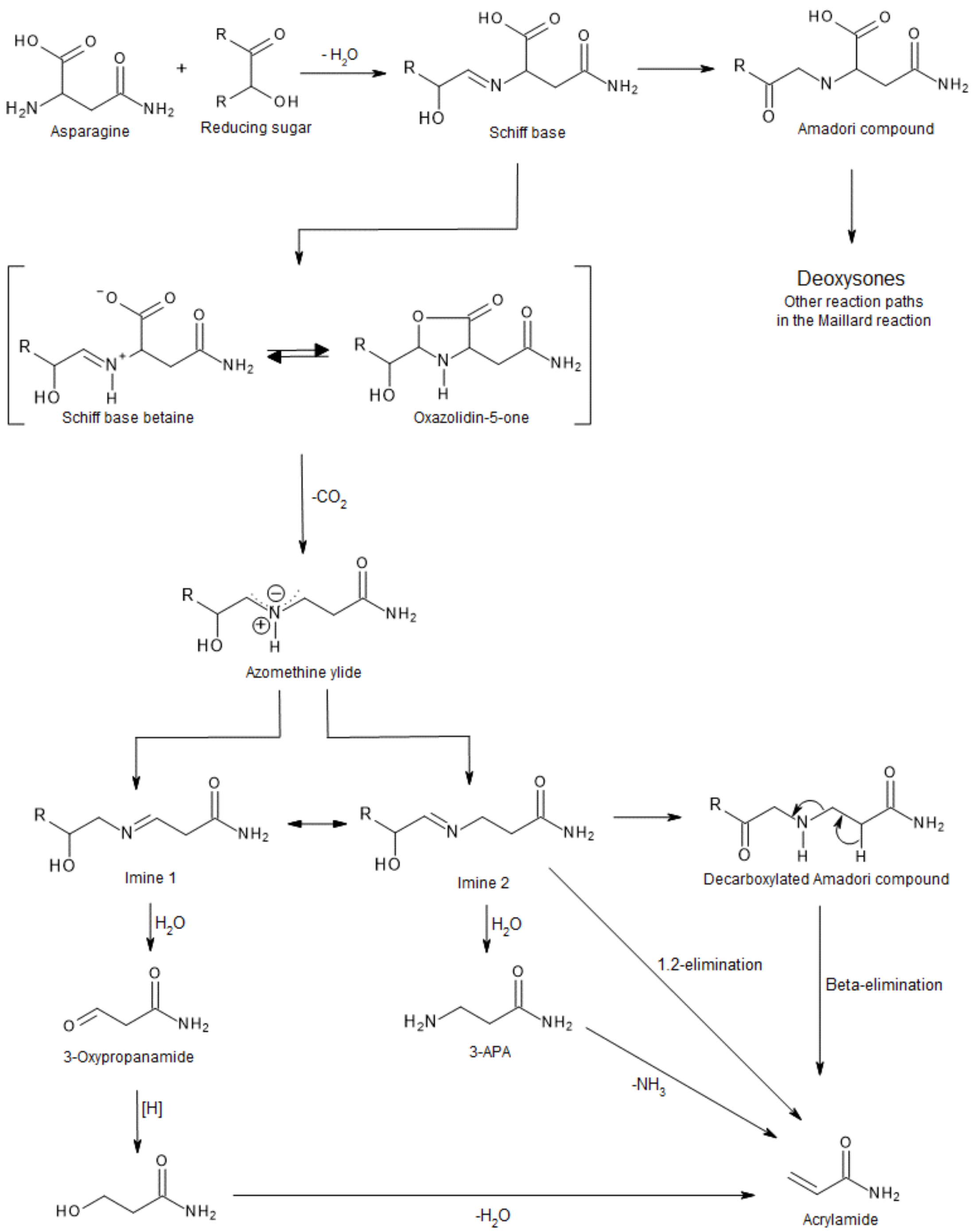

Figure 1. *Reaction routes in the Maillard reaction that can result in acrylamide. Based on mechanism schemes by Singh and Kaur (2016) and Taeymans et. al. (2004).*

In a dry system, the main reaction will instead be the N-glycosyl, created from the asparagine, and a reducing sugar giving the Schiff base, and after rearrangement and decarboxylation creating Azomethine ylide. After this, the Azomethine ylide can undergo rearrangement into either Imine 1 or Imine 2. The Imine 2 can undergo a 1,2-elimination, which will directly result in acrylamide. Another alternative is the Imine 2 rearranging into a decarboxylated amadori compound and this can via β-elimination, where the carbon-nitrogen bond is cleaved, result in acrylamide. The Imine 2 can also result in acrylamide through two steps, first a hydrolysis step that will create 3-aminopropionamide, or 3-APA, that after losing an ammonia molecule (NH_3) will result in acrylamide. If the decarboxylated Schiff base instead take the form of Imine 1, the route to acrylamide involves more steps and therefore probably contributes less to the total acrylamide production, compared to the other routes. The Imine 1 will through hydrolysis first create 3-Oxopropanamide, also called the Strecker aldehyde. Thereafter a reduction of the Strecker aldehyde to the corresponding alcohol and a second hydrolysis will finally result in acrylamide. What pathway of the Maillard reaction that is favoured, resulting in more or less production of acrylamide, depend on the surrounding conditions and properties of the foodstuff and process. The Maillard reaction will only in a few cases result in the creation of acrylamide, compared to all the Maillard reactions that take place within the food during heating. This is due to the many different routes this reaction can take, which can result in many other products than acrylamide (Taeymans et al., 2004, Gökmen, 2016).

The decarboxylated Schiff base will create acrylamide under both dry and wet conditions, but it has been concluded that a lot more acrylamide is created in a dry system than in an aqueous system. It has also been shown that asparagine without the presence of reducing sugars can create acrylamide after decarboxylation and deamination caused by thermal treatment, but the amount of acrylamide created from asparagine is much higher if a reducing sugar is present (Singh and Kaur, 2016, Gökmen, 2016). An additional pathway to create acrylamide is from acrylic acid (Taeymans et al., 2004).

Studies have shown that the reducing sugars, fructose and glucose will help to form roughly the same amount of acrylamide from asparagine under the same conditions. However, it has also been shown that in general, slightly more acrylamide is formed with fructose than with glucose. This could be due to different factors, one of them being the lower melting point for fructose compared to glucose. The lower melting point makes the fructose more inclined to react with other precursors within the Maillard reaction. Another explanation could be that fructose will form a fructose Schiff base during the Maillard reaction, which is more stable compared to the glucose Schiff base. Therefore, the fructose could allow a higher reaction rate of the following reactions, due to the molecular properties, than the corresponding version with glucose. Even though the reducing sugar fructose gives a somewhat higher content of acrylamide when reacting with asparagine, both fructose and glucose contribute a lot to the formation of acrylamide in different foodstuff. If asparagine and sucrose are the present components as reactants, there will be a much lower formation of acrylamide compared to the reducing sugars (Gökmen, 2016).

2.2.2 Cutting of the Potato into French Fries

The size and shape of the french fries matter to the acrylamide formation, since it is mainly formed in the surface layer. A larger surface-to-volume ratio will therefore result in a higher total content of acrylamide in the fries. Thinner and/or smaller cut french fries will result in a higher acrylamide content after thermal treatment in the form of frying or baking (Singh and Kaur, 2016).

2.2.3 Blanching

An initial step of blanching the cut raw potato fries or other cut potato products can be beneficial to produce a product that will have a lower final acrylamide concentration. In a french fry production process there can be up to three blanching steps, depending on the production line. The blanching will cause some of the acrylamide precursors to leach out from the fries into the blanching water. Less precursors means less opportunity for acrylamide to be produced during later process steps. The time and temperature of the blanching process can be tailored so that as much reducing sugars as possible is leached out from the raw potato fries. Dependent on how much reducing sugars the potatoes contain before starting processing, a shorter or longer blanching process can be performed. Potatoes that have been stored for a longer time contains higher amounts of reducing sugars, as mentioned previously, and therefore a more intensive blanching process can be performed when using potatoes that has been stored for a long time. The blanching process can not be too aggressive though, since an intense blanching step will change the texture too much. Blanching will also inactivate enzymes in the potato and the surface of the fries will get a layer of gelatinized starch. This layer will limit the oil absorption during the later frying step, and also improve the texture (Singh and Kaur, 2016). In one study it was determined that a blanching process step with a water temperature of 70 °C for 10-15 minutes resulted in a reduction of 65% of acrylamide in the final french fry product (Mestdagh et al., 2008). The effect of the blanching process will also depend on the concentration of the extracted soluble components in the process water, since a higher concentration of reducing sugars in the water will give a less effective extraction of reducing sugars from the raw potato fries. Exchanging the water frequently would give a resource intensive and costly process (Singh and Kaur, 2016).

2.2.4 Heating

In one study where the acrylamide content in thin potato chips (not french fries) was examined, cooking at the temperature 170 °C resulted in a lot more acrylamide when cooking the chips in the oven compared to frying at the same temperature. When cooking at the temperatures 180 °C and 190 °C it was vice versa, the fried potato chips contained more acrylamide than the ones that had been oven-baked. The absolute highest concentration in this study was for the potato chips that had been fried at 190 °C. In this study the results concluded that the highest level of acrylamide from the baked potato chips was if they had been baked at 170 °C. Generally, the acrylamide formation increases greatly if there is less water in the product which causes the acrylamide formation to increase a lot during the last part of the cooking of the potato products. The potato chips cooked at 170 °C were cooked during a longer time, and could therefore lose more water during cooking (Palazoğlu et al., 2010).

2.2.5 Heat Transfer in Cooking

When heating food items the heat exchange can happen through conduction, convection and radiation. Conduction is the heat transfer on the molecular level and it is transferred though the movements of the molecules. Convection happens when a liquid or gas comes in contact with a solid item, for cooking this is a food item, and the heat will transfer if there is a the temperature difference between the gas or liquid, and the solid food item. Radiation takes place through emissions of electromagnetic waves from one surface, and absorption in the surface of the food item being heated. The properties of the food item being heated and the heating medium will affect how the heat transfer occurs. The heating medium in a household oven is the heated air in the oven where the molecules are far apart, which makes the conduction less effective. Heat can also be transferred by conduction from the surface the food item is placed on, in an oven this could be a baking tray that is warm. The convection contributes to the heat transfer in an oven, and radiation contributes from radiation from the oven walls to the food item (Singh and Heldman, 2014).

2.3 Toxicity of Acrylamide

Acrylamide is by the International Agency for Research on Cancer classified into the category group 2A, which states that it is a probable carcinogen to humans. This classification is mainly based on animal studies (rodents). The research has concluded that acrylamide is carcinogenic and neurotoxic in both female and male rodents. It can cause tumours primarily in the mammary glands, lung, skin, thyroid gland in rats and/or mice, and it is a reproductive toxicant and developmental toxicant in both mice and rats (Gökmen, 2016).

In the body, acrylamide is partly metabolized to form glycidamide. This happens through a reaction that is catalysed by cytochrome P450 2E1. How much of the acrylamide that is metabolised into glycidamide varies between individuals depending on the presence of cytochrome P450 2E1 in the body (World Health Organization, 2011). Both acrylamide and glycidamide are water-soluble and have a biological half-life of 4-5 hours in the body and are then excreted as mercapturic acids. The metabolite glycidamide is considered to be the main cause of the genotoxic effects. Acrylamide and the metabolites have a chromosome exchanging effect, and due to this no "safe levels" can be determined since it may cause an effect from minimal exposure (Livsmedelsverket, 2018;, Gökmen, 2016).

2.4 Dietary Exposure of Acrylamide in Humans

According to a survey by the Swedish National Food Administration in 2010-2011, it was estimated that from the general diet of an adult the daily intake of acrylamide from food was 30-40 μg. The main sources for this are from three groups of foods. Potato products contribute to around a third of the total daily intake, grain products in the form of bread, cracker bread, cookies, etc. also contribute to about a third of the total intake. The third main source is from coffee, which contributes to 10-20 % of the total daily intake (Livsmedelsverket, 2018). In a WHO report from 2011, evaluations from data from eight different countries around the world gave an estimated daily dietary exposure of acrylamide of 1 μg/kg of body weight as a representative of the general population. For children this exposure can be considerably higher per bodyweight (World Health Organization, 2011).

2.5 Analysis of Acrylamide

The most common methods for analysing acrylamide are liquid chromatography-mass spectrometry (LC-MS) and gas chromatography-mass spectrometry (GC-MS). LC-MS has an advantage in that it is simpler to perform since the food sample with acrylamide does not have to be derivatised (usually by bromination), which a sample going through a GC-MS needs to be. The difficulty with analysing acrylamide is that the different foods consist of a very complex matrix of many different substances (Taeymans et al., 2004).

Additional methods that are faster and more easily accessible have been developed. These methods are not officially recommended as LC-MS and GC-MS are, but can still be very useful. There are methods that use colour indication as measurement of acrylamide. The Maillard reaction causes the food to change in colour as previously explained, as well as creating acrylamide. Studies have shown a correlation between the intensity of the browning through the Maillard reaction and the levels of acrylamide in the food. The level of acrylamide can be compared to the colour L*a*b* system, where L* is the lightness, a* is the green to red scale and b* is the blue to yellow scale. Research has reported that the a* component can be correlated to the level of acrylamide in coffee, wheat flour and potato chips during thermal treatment. This can be utilized to evaluate the level of acrylamide in a fast simple way, by measuring the colour of the food. Computer vision through image analysis is most accurate in doing this. This method can be used for real time analysis or screening for acrylamide, which the different chromatography methods can not be used for (Hu et al., 2015).

There are several additional methods to analyse acrylamide and these include different enzyme-linked immunosorbent assay methods (ELISA), electrochemical biosensing, fluorescence biosensing and supramolecular recognition based methods (Hu et al., 2015).

2.6 Mitigation Strategies

In order to reduce the acrylamide content in food different approaches can be implemented. For potatoes, the presence of the precursors asparagine and reducing sugars directly affect the formation. One strategy is therefore to reduce the availability of the precursors. Another approach is to manipulate or limit the Maillard reaction so that less acrylamide can be produced. Choosing certain potato cultivars, harvesting the potatoes at the right time and having efficient storage conditions can reduce the availability of the precursors. Interference with the Maillard reaction, so that less acrylamide is created, has been tried by using certain additives in the processing. One method is to lower the pH, but in trials the pH has to be lowered a lot in order to give a lower acrylamide content. This has also affected the sensorial properties of the fries, which makes it a non-applicable method. Among additives calcium lactate, citric acid, and asparaginase have been investigated in trials. Asparaginase is an enzyme that can inhibit asparagine, and prohibit the formation of acrylamide. This has not shown to be effective in reducing acrylamide in the production of french fries, but could be more effective in potato dough products (Medeiros Vinci et al., 2012).

Several strategies have been taken into action in order to reduce the amount of acrylamide within different foods. These mitigation strategies cover everything from cultivation, harvest, storage and process adjustments. In 2006 the “Acrylamide toolbox” was introduced by the European Food & Drink Industries where different actions that will reduce the acrylamide content of the food are explained. This is directed at the industry so that they are encouraged to implement these strategies. It includes 33 different tools that are confirmed to reduce the acrylamide content for different food categories, as well as additional proposed methods. This toolbox has helped manufacturers to reduce the acrylamide content in the food they produce (Gökmen, 2016).

Another mitigation strategy is to inform customers about the correlation between acrylamide and a darker colour for food as toast, frozen french fries and other food products that are further heated at home (Singh and Kaur, 2016).

2.6.1 EU Regulation

In 2017 the European Union voted to start implementing regulations that food production companies need to follow in order to take action to lower the concentration of acrylamide in certain products where the acrylamide levels are high. These rules were created to continuously lower the acrylamide content in the food. The food producers actively need to work with their production in order to produce food with an acrylamide content below the benchmark level for the category of that food product. The different categories include french fries, coffee and bread among others (Livsmedelsverket, 2017). These rules were implemented in April in 2018 and include guidelines that will help the producers to lower the acrylamide levels for different products. For french fries and other cut potato products the benchmark level is 500 µg/kg product. For potato dough based products, which is the category for the Rösti, the benchmark level is 750 µg/kg product (European Comission, 2017).

3. Materials and Methods

3.1 Experimental Plan

The overall aim of this master thesis was to investigate how to combine cooking times and cooking temperatures lower than the current temperature instructions and still fulfil the required sensorial properties listed for each product by the producer. The three investigated commercial products were Pommes Frites, Pommes Criss Cut and Klassiska Rösti. The current cooking instructions for these products are a temperature of 225 °C for all three products, and a cooking time of 25-30 minutes for the two french fry products and 10-15 minutes for the Rösti. The products from the batches used in this study were produced from the potato type Fontane.

The idea was to first prepare the products according to the current instructions for temperature and time to get a reference as to what the sensorial properties should be. After this, the food products were to be cooked at lower temperature settings than the original but they were to be cooked so that they attain equivalent sensorial properties. Different time settings were to be tried for each temperature, to evaluate what cooking time gives the best result at each temperature setting. The temperatures used for the experiments were 225 °C as the original instructions, 220 °C, 210 °C and 200 °C.

The original temperature 225 °C was tested at three different cooking time settings that span the whole time instruction range for cooking, 25-30 min. For the lower temperatures, at least three different cooking times were tried. The three different cooking times that gave an edible result were repeated once more to confirm that the result attained the same sensorial properties with the same settings.

The experimental plan, with what combinations of temperature and time was investigated for the three different products, is presented in Table 1 for Pommes Frites, Table 2 for Pommes Criss Cut, and Table 3 for Klassiska Rösti.

Table 1. *Pommes Frites experimental plan.*

Time (min) / Temperature (°C)	225	220	210	200
25	1 sample	2 samples		
27.5	1 sample			
30	1 sample	2 samples	1 sample	
33			2 samples	1 sample
36			2 samples	2 samples
38			2 samples	
39				2 samples
42				2 samples
49				1 sample

Table 2. *Pommes Criss Cut experimental plan.*

Time (min) / Temperature (°C)	225	220	210	200
25	1 sample	2 samples		
27.5	1 sample			
30	1 sample	2 samples	1 sample	
33			2 samples	1 sample
35			2 samples	2 samples
37			2 samples	2 samples
39				2 samples

Table 3. *Klassiska Rösti experimental plan.*

Time (min) / Temperature (°C)	225	220	210	200
10	1 sample			
12.5	1 sample	2 samples		
15	1 sample	2 samples	2 samples	
17			2 samples	1 sample
19			2 samples	2 samples
21				2 samples
23				2 samples

All three different products are shown in Figure 2.

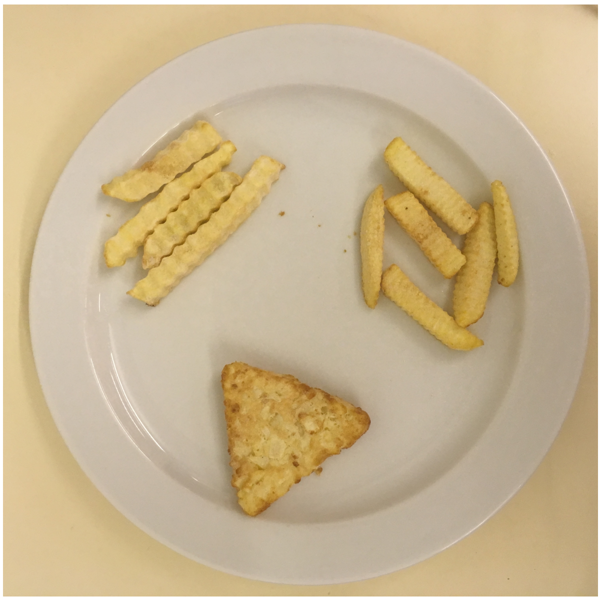

Figure 2. *The three investigated products. Top left is Pommes Frites, top right is Pommes Criss Cut and bottom is Klassiska Rösti. The products are not oven cooked in the picture.*

3.1.1 Pre Trials

The temperatures that were to be used in the experiment were decided on before starting the experiments, but not the cooking times (except for the reference tests at 225 °C). This was due to that the food products should be cooked so that they reach the requested sensorial properties. The cooking times used in the tests were decided on during the experiments dependent on the previous results. The experiments were performed starting at the highest temperature, and then reducing to the next temperature. When starting experiments on a new temperature, the first time setting used was one that had good or adequate sensorial properties from the previous, higher, temperature. This was applied for all new temperatures for all three products. How the other cooking times were decided depended upon how well cooked the product was in the first trial for the new temperature. If the product appeared uncooked compared to the sensorial properties it should have, the time was increased more. If the product just seemed mildly undercooked, the next time setting was increased less.

The experiments were issued as follows; the first product tested was the Pommes Frites, followed by Pommes Criss Cut and finally the Klassiska Rösti. Both types of french fries, Pommes Frites and Pommes Criss Cut had the same setup for the experiments. This could lead to the experiment routine being performed more well-rehearsed and better during the Criss Cut tests, due to more experience of the setup. In order to minimise the eventual problems during the first few experiments, a few experiments were performed to test the equipment before starting the actual experiments where the data was used for the results. The same was performed for the Klassiska Rösti, a few trial experiments were performed to get a good routine with the partly different equipment and routine during these experiments.

3.2 Equipment

The following equipment was used in the experiments:

- Domestic oven Electrolux Elektro Helius SI6505S
- PicoLog model TC-08
- Thermocouples type K
- Convection oven Termaks
- Black plywood photo box (62x76x98 cm) with digital camera Nikon D3300
- Colorimeter Konika Minolta CR-400 Chroma Meter
- Agtron E30-FP

3.3 Temperature Logging and Calibration

A PicoLog model TC-08 Thermocouple Data Logger with eight outlets was used, connected to a computer with the software PicoLog Recorder. Eight thermocouples type K were connected to the PicoLog data logger. These eight thermocouples were calibrated at two temperature points. The first temperature point was at 0 °C, where a mixture of ice and deionised water was used. The ice and water mixture was prepared in a bowl, and the mixture was stirred for two minutes before the measurements started. One at a time, the thermocouples were placed into the water and ice mixture during two minutes and the thermocouple was moved around in the mixture during the duration of the recording. In between the measurements the ice water mixture was stirred. The temperature was logged every 5 seconds throughout the tests. An average temperature from this two-minute measurement was calculated and later used for the calibration. For the second temperature point, deionised water was heated in a pot on a stove and brought to a boil. Each thermocouple was individually placed into the boiling water and the temperature was recorded during two minutes. The average temperature during these two minutes was calculated and used for the calibration of each individual thermocouple. The calibration was done in the software PicoLog Recorder with the function “scaling”, where the thermocouples that had recorded temperatures differing from 0 °C in the ice water mixture, and 100 °C for the boiling water, was scaled from the temperature that had been recorded for these temperature points, to the accurate temperatures of 0 °C and 100 °C. The calibration was performed prior to starting the experiments, and not regularly.

3.4 Oven Trials

Trials in which the temperature in the oven (Electrolux Electro Helius SI6505S) was logged with the calibrated thermocouples and software PicoLog Recorder were performed. This was done in order to determine how long it took for the temperature in the oven to stabilise, how much it varied in amplitude, and how uniform it was throughout the oven. Since the oven tray is placed at the middle shelf of the oven when the products are cooked, this test examined how the temperature in level with this shelf of the oven could be estimated by two thermocouples placed at a lower and a higher level. The first thermocouple was placed in the centre of the oven in level with the middle shelf. The second thermocouple was placed close to the oven door on the left side in level with the top shelf. The third thermocouple was placed on the left side close to the oven door in level with the bottom shelf. It was also examined how the temperature control knob corresponded to the actual measured temperature in the middle level of the oven. By logging the temperature in trials at 200 °C and 220 °C it was decided how the temperature control knob should be turned to correspond to a certain temperature. Markings were made with different coloured pens on the temperature control knob when finding the more accurate settings for the temperatures of 200 °C and 220 °C.

3.5 Oven Setup and Routine for the Experiments

The oven was set to the temperature of the experiment and the PicoLog Recorder was started with two thermocouples placed in the oven. One was placed on the left side close to the oven door in level with the top shelf in the oven, and the second thermocouple was placed on the left side and close to the oven door, in level with the bottom shelf. To stabilise the temperature before the experiment the oven was left running for 45-60 minutes after turning it on before starting the experiments.

The average temperature from two or three stabilised oscillating periods from the logged temperature was calculated for both thermocouples placed in the oven. An average temperature between the two thermocouples was calculated. If this was the correct temperature for the current experiment, the experiment could continue. If the temperature was differing more than 0.5 °C from the set temperature, the temperature control knob was adjusted and the average temperature was calculated again after it had stabilised at the new setting. This was repeated if the temperature did not give an average temperature that differed less than 0.5 °C to the temperature of the experiment. If the temperature was within the 0.5 °C limit, the experiment could start and one packaging of the food product for the experiment was collected from the freezer. The packaging with the food was weighted on a scale and the contents of the packaging were placed onto a room-temperature oven tray (no baking sheet was used). The empty packaging was weighted and subtracted from the total weight. The experiment continued as descried in section 3.6 for the products Pommes Frites and Pommes Criss Cut, or as described in 3.7 for Klassiska Rösti.

3.6 French Fry Trials

The fries were spread evenly on the tray. The tray with fries on was thereafter placed on the middle shelf of the oven and a timer set to 10 minutes was started. After 10 minutes of cooking the tray was quickly removed from the oven, and the oven door was closed. The fries were flipped around using a spatula. Two thermocouples were placed into the centre of two different large long fries. The thermocouples were inserted approximately 2-3 cm into the fries from the centre of the ends of the french fries. Into two different fries, two thermocouples were inserted to measure the surface temperature. These were inserted close to the surface and the tip of the thermocouple was placed so that it was visible through the skin of the french fry. The oven tray was placed back into the oven and the fries were cooked for the remaining test time. The oven tray with fries was removed from the oven and the thermocouples were removed from the fries. The fries were removed from the tray and placed into a large bowl that was weighted on the scale. The cooked fries were spread onto a baking sheet on a table after being weighted. The bowl was weighted so that the mass of the cooked fries could be calculated. From the logged temperature it was confirmed in each trial that the centre kept a temperature of 70 °C or more during at least two minutes, and that the surface temperature was at least 75 °C during 30 seconds, to guarantee a safe food product without harmful bacteria. A picture of a baking tray with Pommes Frites on with a PicoLog to the right is shown in Figure 3. The picture shows one thermocouple connected to a french fry on the tray.

Figure 3. *Picture of a baking tray with Pommes Frites and the PicoLog with thermocouples connected to it to the right.*

3.7 Rösti Trials

The Rösti were distributed evenly on the tray in one layer. The tray with the Rösti on was placed on the middle shelf of the oven and the timer set to the full cooking time for the test was started. After the Rösti had been cooked for the full time of the test, the oven tray was removed from the oven and the Rösti were removed from the tray with the help of a spatula and placed onto a baking sheet. A cooking thermometer was placed into the centre of a Rösti from the middle of one of the sides of the triangular shape of the Rösti. It was monitored that the centre held a temperature of at least 70

°C during two minutes. An IR thermometer was used to measure the surface temperature, and confirm that it was at least 75 °C during 30 seconds. The baking sheet with the Rösti was placed onto a room temperature tray, which was thereafter placed onto the scale so that the mass could be decided. The tray and the baking paper were weighted again without the Rösti, so that the weight of the Rösti after cooking could be calculated.

3.8 Sample Preparation

For all three tested products, after each cooked batch around 300 g of the cooked potato product was weighted and placed back into the original packaging, which was sealed and marked with product code, product name, batch number and if it was cooked or uncooked. The sample was placed into a freezer (-20 °C) until some of the samples were sent in for analysis.

The remaining cooked product was put into a small plastic bag and labelled with the cooking time and temperature. When a few experiments had been performed these samples were used for photo documentation for the colour analysis.

3.9 Sensory Requirements and Analysis

The sensory evaluation was based on quality demands that were stated for each product by the producer Orkla Foods. The sensory analysis considered the surface texture, the texture in the centre of the product, taste, colour and specific properties for the different products. The sensory analysis properties are described for each product. The sensory properties were only evaluated by one person in these experiments.

3.9.1 Pommes Frites

The flavour should be the typical taste of deep fried potato, without flavours of rancid fat, sweetness, acidity or other off-flavours. The colour should be evenly golden brown. The product should not be brown, patchy or discoloured. The consistency at the surface layer should be crispy, somewhat chewy and without blisters. The centre should have a boiled, floury consistency and stick to the surface without air bubbles. The product should not be soggy or mushy.

3.9.2 Pommes Criss Cut

The flavour should be the typical taste of deep-fried potato, without flavours of rancid fat, sweetness, acidity or other off-flavours. The colour should be evenly distributed and light golden. The product should not be brown, patchy or discoloured. The consistency at the surface layer should be crispy, somewhat chewy and without air blisters. The centre should have a boiled, floury consistency and stick to the surface without air bubbles. The product should not be soggy or mushy.

3.9.3 Klassiska Rösti

The flavour should be pure potato flavour, seasoned with onion and spices, without flavours of rancid fat, sweetness, acidity or other off-flavours. The colour should be golden brown. The product should not be burnt, patchy or discoloured. The surface layer should have a crispy roasting surface. The centre should have texture from the potato pieces. It should be firm and not dry, soggy or sticky. The individual Rösti pieces should hold together and not stick to each other.

3.10 Colour Analysis

Two different methods for colour analysis were used. The main colour analysis for these experiments was with the use of a colorimeter. The french fries were photo documented in order to perform a colour analysis. The setup for taking the pictures consisted of a box with plywood walls that had been painted black on all walls on the inside. Four luminous lamps had been rigged onto all four sides of the ceiling in the box. A camera was rigged from a pole in the ceiling so that the lens of the camera was directed at the floor of the box. The samples were placed below the camera in order to take photos. The frame to the door of the box had rubber linings, so that no other light could penetrate the construction of the black box. The camera had a USB cord connected to a computer, in which the software digiCamControl was used to shoot the photos. The inlet into the box for the USB cord had been wadded so that no light could seep through. The cooked potato product was placed in a black circular container. The container was filled with a product from one of the trials. The product was distributed so that it would be avoided to see the bottom of the container. The container was placed into the photo box, the door to the box was closed and a picture was taken from the computer.

When the pictures had been taken they were printed together with the trial specifics (product, time, temperature and number) onto paper so that the colour could be measured using a colorimeter. The result was given according to the CIELAB where the scale L*a*b* is used. For this scale L* gives the lightness (black to white), a* gives the green to red spectrum and b* gives the blue to yellow spectrum. For the three L* parameter the scale goes from 0 to 100, and for the other two parameters the scale goes from -100 to 100. For each photo 15 measurements were taken. For the french fry products three measurements of five different fries were taken. For the Rösti five measurements of three different Rösti were taken. Between each photo a measurement was made on the white edge of the paper in order to more easily separate the measurements. Notes were taken to connect the experiment to the numbers of the measurements in the colorimeter. The data from the colorimeter was imported into a computer and moved to Microsoft Excel. Average values for L*, a* and b* were calculated for each experiment.

3.10.1 Colour Analysis with Agtron Equipment

At the quality control at the production site the colour analysis is performed with a different method for these products. The equipment used is an Agtron analysis instrumentation, which gives the result as an Agtron score that is graded 0-100. A lower value corresponds to a darker colour of the product. This instrumentation is developed to measure the colour of french fries and other potato products. The calibration standard for the Agtron is a black plate and a yellow plate. The Agtron analysis instrumentation is first calibrated using the calibration plate. Thereafter measurements can be made on samples where the food product is put into a black circular container that is specifically used for the equipment. The container is put into the Agtron Instrumentation and a reading will give a value.

Measurements on the Agtron Instrumentation was performed for three real food samples, along with measurements on the printed photos for the samples that were going to be sent in for acrylamide analysis.

3.11 Determination of Moisture Content

The moisture content was determined by drying samples of each product in a convection oven/drying cabinet. For each product three samples with a weight ranging from 3-5 g were distributed into small circular metal containers. The containers were weighted, first empty and then with the sample. These were placed into the convection oven, which had been heated to 103 °C, during 24 hours. After this, the samples were removed from the oven and placed into a desiccator for 30 minutes. The containers with dried samples were weighted, and the moisture level for wet base was calculated.

3.12 Acrylamide Analysis

Four samples for each product were sent for analysis in a laboratory. The first sample was uncooked from the packaging, the second was cooked according to instructions with fulfilled sensory qualities. The third sample was cooked at 220 °C with a good result in sensory qualities and the final sample was cooked at 200 °C and had good sensory qualities. The analysis laboratory that was consulted was Eurofins. The method for analysis used was LC-MS/MS. The detection limit (LOD) for their acrylamide analysis was 10 μg/kg and the measurement uncertainty for the method was 12 % (Eurofins, 2018).

4. Results and Discussion

4.1 Quality Control

4.1.1 Monitoring of Temperature in Oven

From the temperature logging in the oven it could be estimated that the oven needed to be put on for 45-60 minutes to reach a stabilised temperature. Figure 4 shows the temperature logging after switching on the oven at 200 °C. The temperature first climbed to a quite much higher temperature than the one set. After around 45 minutes the temperature oscillations had stabilised.

From the set up with three thermocouples it could be confirmed that the temperature in the centre of the oven could be estimated as an approximate mean value of the temperature at the top and the bottom shelf in the oven. The temperature accuracy in this experimental setup was ±1 °C. Figure 4 shows that the temperature at the high point is always a bit higher than in the centre, and at the low point it is a bit lower than in the centre. The accuracy was controlled in several attempts at 220 °C and 200 °C.

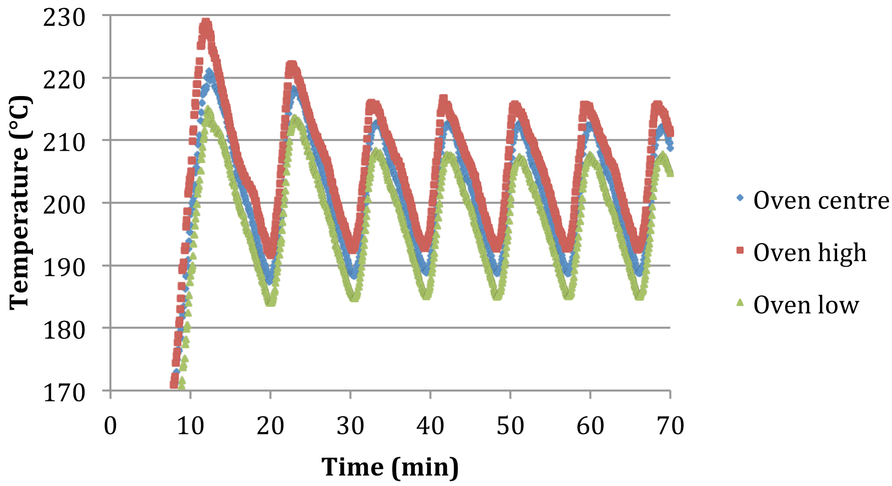

Figure 4. *Temperature logging when switching on the oven. The thermocouples are placed at a high and low point in the oven, and in the centre of the oven.*

When comparing the setting of the temperature control knob of the oven to the actual average temperature in the centre of the oven, the measured temperature in the oven was higher than the temperature setting on the control knob. The markings made on the temperature control knob for the more accurate settings for 220 °C and 200 °C can be viewed in Figure 5. The accuracy between the temperature control knob and the actual temperature in an oven could of course differ a lot between different ovens.

Figure 5. *Temperature control knob on oven, with lines drawn for more accurate temperature settings. The red line is for 220 °C and the green line is for 200 °C.*

4.1.2 Temperature Monitoring for French Fry Products

An example of the temperature logging throughout the experiments for the product Pommes Frites is shown in Figure 6. The blue and red curves that oscillate around 220 °C are the thermocouples that measured the temperature in the oven, at a high point and at a low point as explained in the method chapter. At the time 45 minutes there is a sudden temperature drop, this is when the baking tray with fries is put into the oven. At the time around 55 minutes the tray is removed from the oven and thermocouples are inserted into the fries. It was for all experiments easy to confirm that the minimal temperature demands to ensure a safe food product, with 75 °C on the surface and 70 °C in the centre of the food products, were met. The centre and surface temperatures always reached 100 °C for Pommes Frites and Pommes Criss Cut.

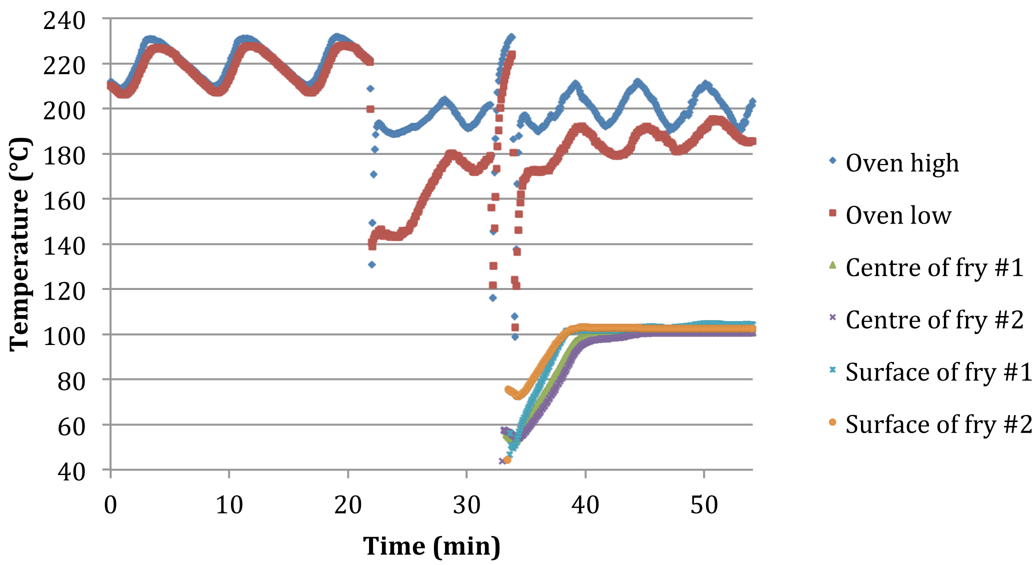

Figure 6. *Temperature logging in oven and in the centre and on the surface of fries during an experiment for Pommes Frites at 220 °C with the cooking time 30 minutes.*

Another example of the results from the logged temperature during cooking is shown in Figure 7. The chart is very similar to the one in Figure 6, except that the cooking temperature was 200 °C, the cooking time 37 minutes and the product was Pommes

Criss Cut. In Appendix A, additional temperature logging graphs for other experiments can be found.

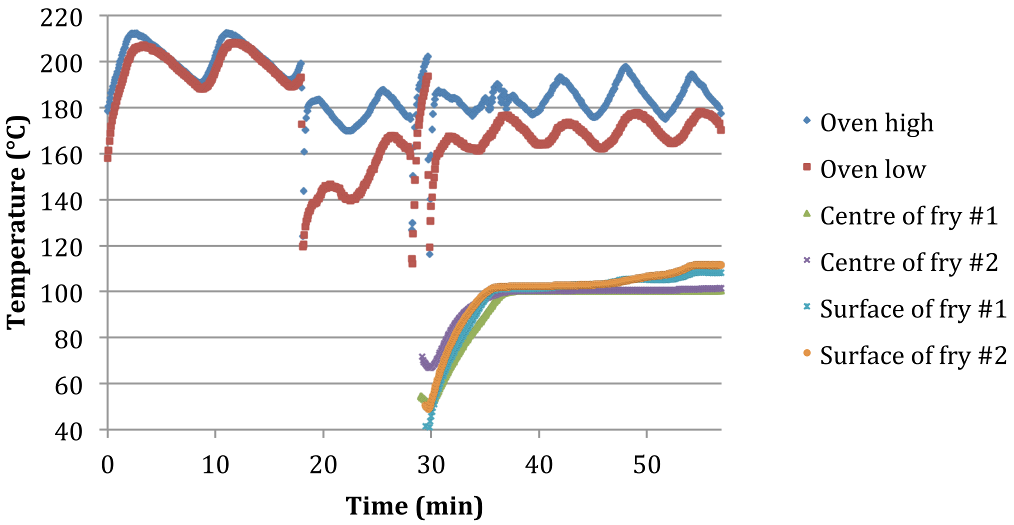

Figure 7. *Temperature logging during the cooking of Pommes Criss Cut at 200 °C with a cooking time of 37 minutes.*

From the logged temperature it could be discovered that the oven temperature oscillates approximately 10 °C above, and 10 °C below the set temperature, in the oven used for these experiments.

The surface temperatures from measurements performed on Pommes Frites are compared for the different cooking temperatures in Figure 8. The surface temperature generally rises quicker in the higher cooking temperatures. For the temperatures 200 °C and 210 °C this is vice versa. This could be due to how warm the oven was (in the oscillating temperature) at the time the fries were put back into the oven after the thermocouples were inserted. For all tested temperatures the surface temperature reached 100 °C long before the cooking time was finished.

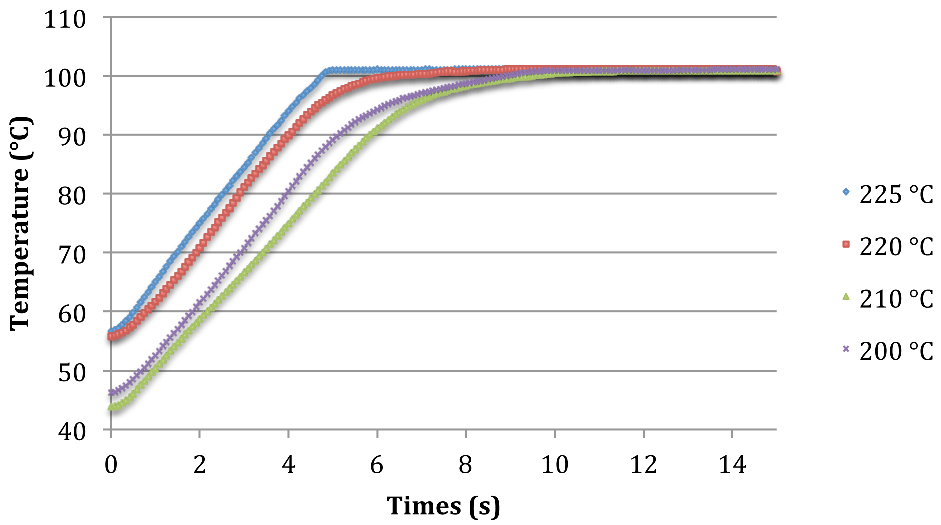

Figure 8. *Surface temperatures for Pommes Frites that are cooked at different temperatures.*

4.1.3 Temperature Monitoring for Rösti

The quality control temperatures for the centre and the surface of the Rösti were achieved in all experiments. The results from these measurements are viewed in Table 4.

Table 4. *Quality control temperature measurements of Rösti.*

Cooking temperature (°C)	Cooking time (min)	Centre temperature at the end of 2 min measurement	Surface temperature during 30 seconds (°C)
225	10	71	76-79
225	12.5	82	80-88
225	15	89	85-90
220	12.5 #1	80	88-90
220	12.5 #2	82	84-90
220	15 #1	83	86-90
220	15 #2	82	84-90
210	15 #1	80	84-89
210	15 #2	80	84-86
210	17 #1	81	87-90
210	17 #2	81	80-87
210	19 #1	83	88-93
210	19 #2	83	84-87
200	17	84	89-94
200	19 #1	83	84-90
200	19 #2	81	79-85
200	21 #1	84	83-87
200	21 #2	83	86-92
200	23 #1	81	80-86
200	23 #2	81	81-90

4.1.4 Quality Evaluation of Experimental Plan

A shortcoming of the experimental model is that the tests were not performed in a randomised order. To minimize the effect of human error the experimental plan should have had a randomised experiment order, where different temperatures and different products are tested during the same day. However, during the experiments it took a considerable amount of time for the oven to reach a stabilised temperature, and to find the exact correct temperature for the experiment. Therefore, several experiments using the same temperature were performed in series during the same day. If the experiments should have been carried out in a randomised order it would have resulted in fewer experiments performed in total. Furthermore, the experiments for the three different products were not spread out and randomised over the whole experiment period due to several reasons. Firstly, when the initial experiments were performed only one of the products was available for testing. Secondly, prior to starting the experiments it had not been decided if two or three products should be tested, if there would be shortage of time during this project. And thus, all tests for the second product was carried out before starting the experiments with the third product.

4.1.5 Sensorial Evaluation

The results for the sensorial analysis are presented in Table 5-8 for Pommes Frites, in Table 9-12 for Pommes Criss Cut, and in Table 13-16 for Klassiska Rösti. In these tables the weight reduction, dry matter contend and water content are presented. The sensorial properties in the form of colour, surface consistency and centre consistency are evaluated. These are based on the stated requirements for the different products from the producer, Orkla Foods. Generally all tested combinations of temperature and cooking time resulted in adequate or good sensorial qualities for the food products. The shorter cooking times at the lower temperatures gave the poorest results, with the products not being cooked enough and therefore a bit soft. Also the sample of Pommes Frites cooked at 200 °C during 49 minutes gave a non-satisfactory result with it being overcooked and dry. In the Tables 5-16 the cooking time that gave the best result for each temperature is highlighted in grey.

Table 5. *Sensorial properties for Pommes Frites cooked at 225 °C.*

Temperature	225 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
25	27.3	54.1	45.9	Golden brown A few pieces a bit burnt.	Almost all pieces have a crispy texture. A few bubbles on some pieces.	Boiled potato, the filling sticks to the surface layer.
27.5	30.6	56.6	43.4	Golden brown Few small pieces a bit burnt.	Crispy texture.	Boiled potato, the filling sticks to the surface layer.
30	34.5	60.0	40.0	Golden brown. Thin pieces are burnt.	Crispy texture, for all pieces.	Boiled potato, the filling sticks to the surface layer.

Table 6. *Sensorial properties for Pommes Frites cooked at 220 °C.*

Temperature	220 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
25	25.4	52.7	47.3	Golden brown/golden. No burnt pieces.	Some pieces have a crispy texture, some have a softer texture.	Boiled potato, the filling sticks to the surface layer.
30	30.2	56.3	43.7	Golden brown. Almost no burnt pieces.	Most pieces have a crispy texture, some are a bit softer.	Boiled potato, the filling sticks to the surface layer.

Table 7. *Sensorial properties for Pommes Frites cooked at 210 °C.*

Temperature	**210 °C**					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
30	27.0	53.8	46.2	Golden. No burnt pieces.	Not crispy.	Soft boiled potato, filling sticks to the sides.
33	28.7	55.1	44.9	Golden to golden brown, no burnt pieces.	Many pieces have a crispy texture, but not all.	Soft boiled potato, filling sticks to the sides.
36	33.3	58.9	41.1	Golden brown Almost no burnt pieces.	A majority of the pieces have a crispy texture.	Soft boiled potato, filling sticks to the sides.
38	36.6	62.0	38.0	Golden brown. Almost no burnt pieces.	Crispy texture. A few bubbles on the skin.	Soft boiled potato, filling sticks to the sides for most fries, some have bubbles.

Table 8. *Sensorial properties for Pommes Frites cooked at 200 °C.*

Temperature	200 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
33	25.5	52.8	47.2	Golden.	Some pieces have a crispy texture, but many have a soft texture.	Soft boiled potato, filling sticks to the sides.
36	30.0	56.1	43.9	Golden to golden brown.	Many pieces have a crispy texture, but some have a soft texture.	Soft boiled potato, filling sticks to the sides.
39	32.6	58.3	41.7	Golden to golden brown.	Many pieces have a crispy texture. A few have a soft texture.	Soft boiled potato, filling sticks to the sides.
42	35.3	60.7	39.3	Golden brown.	Crispy texture. Some pieces are crispy and dry throughout.	Soft boiled potato, filling sticks to the sides for many, for some the filling does not stick to the sides.
49	41.2	66.8	33.2	Golden brown to brown. Small pieces burnt.	Crispy texture. Dry.	Soft boiled potato for some. Others are dry and the filling does not stick to the sides in these.

Table 9. *Sensorial properties for Pommes Criss Cut cooked at 225 °C.*

Temperature	225 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
25	25.6	47.3	52.7	Golden. Partly golden brown.	Almost all pieces have a crispy texture. A few pieces have a softer texture.	Boiled potato, the filling sticks to the surface layer.
27.5	29.5	49.9	50.1	Golden, partly golden grown. Small pieces a bit burnt.	Crispy texture for almost all pieces, a small number have a softer texture.	Boiled potato, the filling sticks to the surface layer.
30	31.5	51.4	48.1	Golden brown, partly golden. Thin pieces are burnt.	Crispy texture, for all pieces.	Boiled potato, the filling sticks to the surface layer. Small pieces a bit dry.

Table 10. *Sensorial properties for Pommes Criss Cut cooked at 220 °C.*

Temperature	220 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
25	24.6	46.7	53.3	Golden and golden brown.	Most pieces have a crispy texture, some have a softer texture.	Soft boiled potato, the filling sticks to the surface layer.
30	30.8	50.9	49.1	Golden brown, partly golden. Small pieces are brown (a bit burnt).	Crispy texture.	Soft boiled potato, the filling sticks to the surface layer.

Table 11. *Sensorial properties for Pommes Criss Cut cooked at 210 °C.*

Temperature	210 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
30	26.6	48.0	52.0	Golden. A little bit golden brown.	Many pieces have a crispy texture, but several have a soft texture.	Soft boiled potato, filling sticks to the sides.
33	30.7	50.8	49.2	Mainly golden. For many pieces one side is golden brown.	A majority have a crispy texture, a few have a soft texture.	Soft boiled potato, filling sticks to the sides.
35	33.1	52.6	47.4	Golden and golden brown. Small pieces are brown.	Crispy texture, a few have a semi-crispy texture.	Soft boiled potato, filling sticks to the sides.
37	36.0	55.0	45.0	Golden brown. Small pieces completely brown.	Crispy texture for all pieces.	Soft boiled potato, filling sticks to the sides. Small pieces are dry throughout.

Table 12. *Sensorial properties for Pommes Criss Cut cooked at 200 °C.*

Temperature	**200 °C**					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
33	25.9	47.5	52.5	Golden. Some fries have one golden brown side	Some pieces have a crispy texture, but many have a soft texture.	Soft boiled potato, filling sticks to the sides.
35	29.9	50.2	49.8	Golden. Some fries have one golden brown side	Many pieces have a crispy texture, but some have a soft texture.	Soft boiled potato, filling sticks to the sides.
37	31.2	51.2	48.8	Golden. Many fries have one golden brown side	Crispy texture. A few pieces have a softer texture.	Soft boiled potato, filling sticks to the sides.
39	33.7	53.1	46.9	Golden and golden brown.	Crispy texture. A bit dry	Soft boiled potato, filling sticks to the sides for most fries, some are dry.

Table 13. *Sensorial properties for Klassiska Rösti cooked at 225 °C.*

Temperature	225 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
10	4.2	41.8	48.2	Edges are golden. Centre is yellow.	Crispy texture.	Quite firm, a little bit soft. Potato pieces gives texture.
12.5	8.8	43.9	56.1	Golden brown edges, the centre is golden.	Crispy texture.	Firm, the potato pieces gives texture.
15	13.8	46.4	53.6	Golden brown, edges are darker than centre.	Crispy texture.	Firm, the potato pieces gives texture.

Table 14. *Sensorial properties for Klassiska Rösti cooked at 220 °C.*

Temperature	220 °C					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
12.5	7.4	43.2	56.8	Golden brown edges, yellow centre.	Crispy texture	Firm consistency, potato pieces gives texture
15	11.7	45.3	54.7	Golden brown.	Crispy texture.	Firm consistency, potato pieces gives texture.

Table 15. *Sensorial properties for Klassiska Rösti cooked at 210 °C.*

Temperature	**210 °C**					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
15	9.9	44.4	55.6	Golden brown edges, yellow centre.	Dry texture, but not crispy.	Firm, a bit softer. Potato pieces gives texture.
17	12.9	45.9	54.1	Golden brown, centres a bit yellow.	Mostly crispy texture.	Firm, potato pieces gives texture.
19	15.6	47.4	52.6	Golden brown.	Crispy texture.	Firm, potato pieces gives texture.

Table 16. *Sensorial properties for Klassiska Rösti cooked at 200 °C.*

Temperature	**200 °C**					
Time (min)	**Weight reduction (%)**	**Dry matter (%)**	**Water content (%)**	**Colour**	**Surface consistency**	**Centre consistency**
17	10.2	44.5	55.4	Golden brown, centres more yellow.	Semi-crispy texture.	Firm, potato pieces give texture.
19	13.0	46.0	54.0	Golden brown, centres more yellow.	Semi-crispy texture. Not too dry and not too soft.	Firm, potato pieces give texture.
21	15.5	47.3	52.7	Golden brown.	Crispy texture.	Firm, potato pieces give texture. Not dry.
23	18.3	49.0	51.0	Golden brown.	Very crispy texture.	Firm, potato pieces give texture. A little bit dry.

4.2 Acrylamide Content

The results from the acrylamide analysis performed by Eurofins and the corresponding cooking temperatures are displayed in Table 17 and Figure 9. The measurement uncertainty for the analysis was ±12 %, and can be viewed as numbers in the table and as the error bars in the chart.

Table 17. *Results from the acrylamide analysis for the samples cooked at different combinations of temperature and time. The measured value for acrylamide is presented with the measurement error for each sample.*

Product	Temperature (°C)	Time (min)	Acrylamide (µg/kg)
Pommes Frites	Uncooked	Uncooked	160 ± 19
Pommes Frites	200	39	420 ± 50
Pommes Frites	220	30	390 ± 47
Pommes Frites	225	30	540 ± 65
Pommes Criss Cut	Uncooked	Uncooked	240 ± 29
Pommes Criss Cut	200	37	580 ± 70
Pommes Criss Cut	220	30	520 ± 62
Pommes Criss Cut	225	30	670 ± 80
Klassiska Rösti	Uncooked	Uncooked	280 ± 34
Klassiska Rösti	200	21	370 ± 44
Klassiska Rösti	220	12.5	250 ± 30
Klassiska Rösti	225	12.5	280 ± 34

For both french fry products, Pommes Frites and Pommes Criss Cut, the acrylamide content for the two samples cooked at 200 °C and 220 °C have an overlap in the measurement error range. There are too few analysed samples in this study in order to evaluate the statistical significance for these values. It can, however, be pointed out that no guaranteed difference can be stated between the samples that have an overlap in the measurement error bars. There is no overlap in the acrylamide content for the Pommes Criss Cut cooked at 220 °C and 225 °C. For the Pommes Frites there is no overlap in the acrylamide content between the sample cooked at 225 °C and the two other cooked samples. Therefore it is suggested from these samples that the acrylamide content for Pommes Frites cooked at 225 °C is higher than at the other two cooking temperatures. From the analysis it is also suggested that the acrylamide content in Pommes Criss Cut cooked at 225 °C is higher than when cooked at 220 °C. Since only one sample at each temperature is analysed for acrylamide, no general differences can be proved.

For the Rösti the results are unexpected since the sample cooked at 220 °C has a lower acrylamide content than the uncooked sample. Since all products are from the same batch there should not be a large difference in the acrylamide content in the products in the different packaging before cooking. This indicates that the product should contain more acrylamide after being cooked in an oven. The sample with the highest content of acrylamide in the Rösti was the one cooked at 200 °C. This is probably due to the much longer cooking time, compared to when it was cooked at a higher temperature. This indicates that for this product a longer cooking time can result in a higher content of acrylamide, more so than cooking at a higher temperature (during a shorter time). The solution to achieve cooking instructions that result in lower levels of acrylamide is a balance between using a lower temperature and not having a cooking time that is too long. Comparing the weight reduction (loss of water) during cooking from the Rösti samples that were sent in for analysis, in Tables 10, 11 and 13, the Rösti cooked at 200 °C had the largest weight reduction at 15.5 % compared to the quite similar 7.4 % and 8.8 % for the samples cooked at 220 °C and 225 °C. This suggests that for this product, the lower content of water towards the end of the cooking time had caused more formation of acrylamide, compared to the higher temperatures but shorter cooking times where there was a smaller loss of water.

It is of interest to see that the acrylamide levels for all products cooked at 225 °C are higher compared to when cooked at 220 °C for the same time duration, even if there are overlaps which does not clearly prove that there is a difference in acrylamide content for the Rösti cooked at these temperatures. However, this difference can not be said to be the general acrylamide content for the products cooked at these temperatures, since only one sample from each temperature was analysed.

Furthermore, from these experiments all three cooked samples of Pommes Criss Cut exceeded the benchmark level at 500 µg/kg, as well as the sample of Pommes Frites cooked at 225 °C. The Pommes Frites cooked at 225 °C and the Pommes Criss Cut cooked at 220 °C may not actually exceed the limit if the error range is considered, but the other two cooked Pommes Criss Cut samples does definitely exceed the benchmark level. The rest of the analysed samples do not exceed the benchmark level.

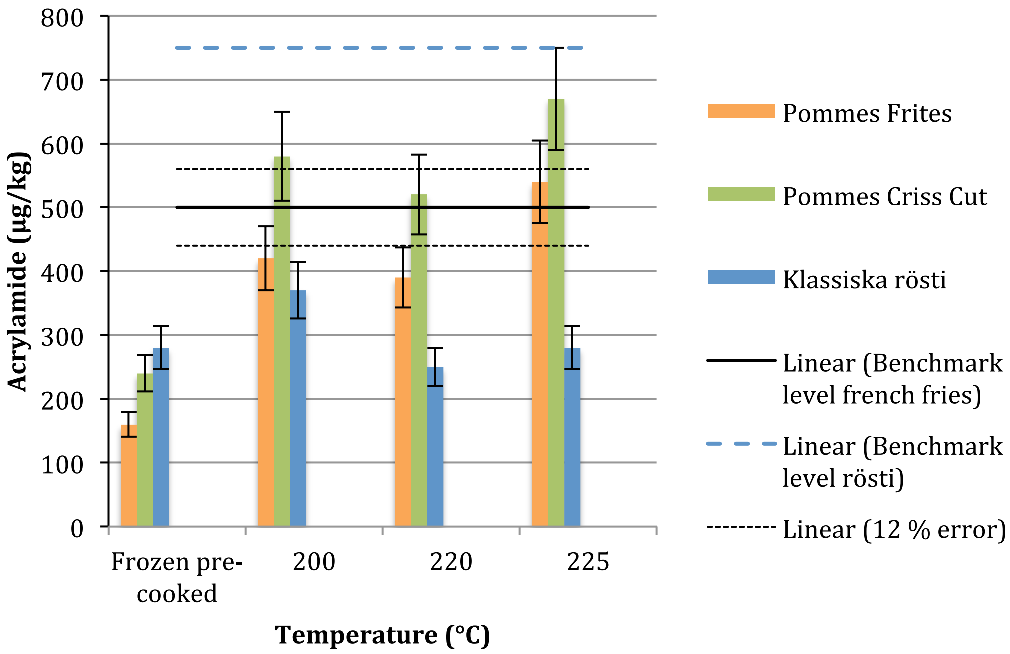

Figure 9. *Acrylamide content results from analysis, compared by cooking temperature for the three products. The benchmark level for acrylamide is 500 µg/kg for the french fries and 750 µg/kg for the Rösti.*

With the measurement error from the analysis of the acrylamide being 12 %, this error range for the benchmark level for the french fries is also visible in Figure 9. For these results this error range does not make any differences in if the results are too high. It does however show that there is a challenge to judge if a value is below the benchmark level, since the limit at 500 µg/kg could be between 440-560 µg/kg, due to the error range of the analysis method. This makes it a bit complicated to evaluate the results that are close to the benchmark level.

4.2.1 Comparison with Other Available Data on Acrylamide

It is interesting to compare the results for acrylamide content from this study with the ones from other studies. In Table 18 the acrylamide content from the analysed samples in this study are presented along with the dry matter for the different samples.

Table 18. *Acrylamide content and the dry matter content for the analysed samples in this study.*

Product	**Temperature (°C)**	**Time (min)**	**Acrylamide (μg/kg)**	**Dry Matter (%)**
Pommes Frites	Uncooked	Uncooked	160 ± 19	39.3
Pommes Frites	200	39	420 ± 50	58.3
Pommes Frites	220	30	390 ± 47	55.9
Pommes Frites	225	30	540 ± 65	60.0
Pommes Criss Cut	Uncooked	Uncooked	240 ± 29	35.2
Pommes Criss Cut	200	37	580 ± 70	51.6
Pommes Criss Cut	220	30	520 ± 62	50.3
Pommes Criss Cut	225	30	670 ± 80	51.4
Klassiska Rösti	Uncooked	Uncooked	280 ± 34	40.0
Klassiska Rösti	200	21	370 ± 44	47.6
Klassiska Rösti	220	12.5	250 ± 30	43.4
Klassiska Rösti	225	12.5	280 ± 34	43.9

Comparing these values with the ones from other investigations show that the results are within the same range. Investigations on acrylamide in different types of food were performed by the National Food Agency of Sweden in 2011 and 2012. French fries at different fast food places were analysed and the results gave acrylamide contents ranging from 22-821 μg/kg. The average for this was 349 μg/kg of acrylamide. The full results on french fries from this study can be viewed in the Appendix C (Karl-Erik Hellenäs et al., 2013). The average acrylamide value from the investigation by the National Food Agency of Sweden is lower than all the french fry results from this study, but they are all lower than the highest analysed value from the National Food Agency investigation.

A study from Lund University from 2008 investigated the acrylamide content in another potato product, home prepared potato wedges that were made from five different potato varieties. The acrylamide content in the potato wedges in this study ranged from 120-260 μg/kg. The results from this study are shown in Table 19. The acrylamide contents in these potato wedges are much lower than in the french fries in the present study. There are several reasons to why this is the case. If the dry matter contents are compared, the result for the cooked product in the present study ranges from 43.4 to 60.0 %. In the potato wedge study the dry matter ranges from 29 to 35 % (Skog et al., 2008). The higher dry matter content in the present study would result in higher amounts of acrylamide due to the lower water content of the products. Further, the french fries are most probably slimmer and smaller than the potato wedges and therefore have a higher surface to volume ratio. There is a larger surface per piece that can develop a golden brown colour and more acrylamide can be formed through the routes of the Maillard reaction that are favoured with a lower moisture content.

Examples of benchmark levels for acrylamide from the EU regulation for other food products are for wheat based soft bread 50 µg/kg, for biscuits, wafers and cripsbread 350 µg/kg, for roast coffee 400 µg/kg and, for potato chips 750 µg/kg. Potato based products have the highest benchmark levels compared to the other product groups, with the exception of gingerbread (800 µg/kg) (European Comission, 2017).

Table 19. *Results from a study on home-prepared potato wedges performed at Lund University in 2008. BS = blanching with salt. B = blanching without salt. (Skog et al., 2008)*

Potato variety	Cooking method	Time (min)	Acrylamide (µg/kg)	Dry matter (%)
Ditta	Roasting	20+15	260 ± 8	33
	BS/Roasting	10+15	140 ± 3	30
	B/Roasting	10+15	90 ± 4	30
Asterix	Roasting	20+15	200 ± 8	35
	BS/Roasting	10+15	80 ± 8	32
	B/Roasting	10+15	100 ± 1	33
Superb	Roasting	20+15	180 ± 15	34
	BS/Roasting	10+15	80 ± 2	29
	B/Roasting	10+15	110 ± 4	30
Fontane	Roasting	20+15	130 ± 3	32
	BS/Roasting	10+15	50 ± 2	31
	B/Roasting	10+15	70 ± 4	32
Bintje	Roasting	20+15	120 ± 15	33
	BS/Roasting	10+15	110 ± 7	29
	B/Roasting	10+15	60 ± 3	31

4.3 Moisture Content

The results from the moisture content measurements are shown in Table 20.
The water contents for the different products are quite similar. Something that is a bit surprising is that the product Pommes Criss Cut has the highest moisture content, since this is the product that also has the highest levels of acrylamide. A higher moisture content should favour other routes of the Maillard reaction that does not create acrylamide.

Table 20. *The moisture content for the uncooked products. Based on averages of three samples of each.*

Product	Water content wet base (%)
Pommes Frites	60.7 ± 4.1
Pommes Criss Cut	64.8 ± 0.52
Klassiska Rösti	60.0 ± 1.9

4.4 Colour Analysis

Figure 10 shows an example of the pictures taken in the photo box.

Figure 10. *Picture of Pommes Frites cooked at 225 °C for 25 minutes.*

4.4.1 Colour Analysis with Colorimeter

Tables with the values from the colour analysis result for each sample can be viewed in the Appendix B.1. The colour analysis method using the colorimeter did not give satisfactory results. The comparison between the different cooking times and the value for L*, for the different cooking temperatures is viewable in Figure 11 for Pommes Frites. The same but for the a* values is visible in Figure 12. For the other products these charts can be found in the Appendix B.2.

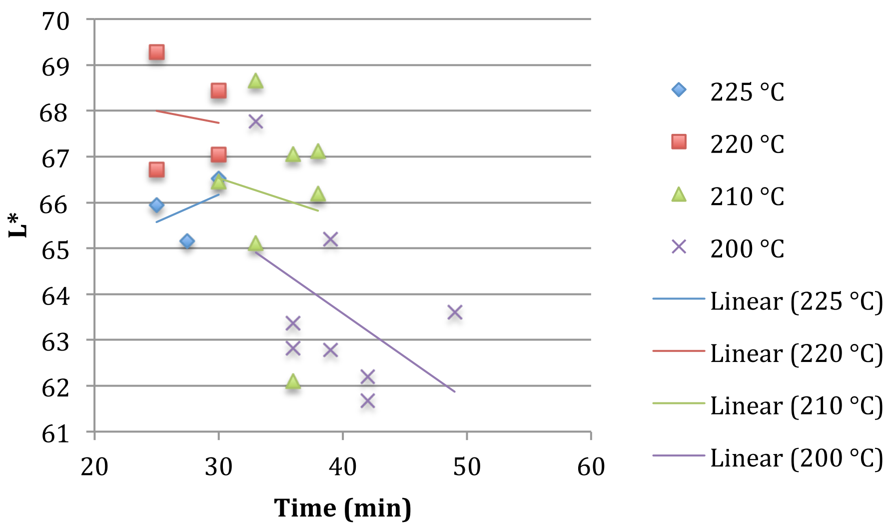

Figure 11. *The L* values for the different cooking times at each temperature for Pommes Frites.*

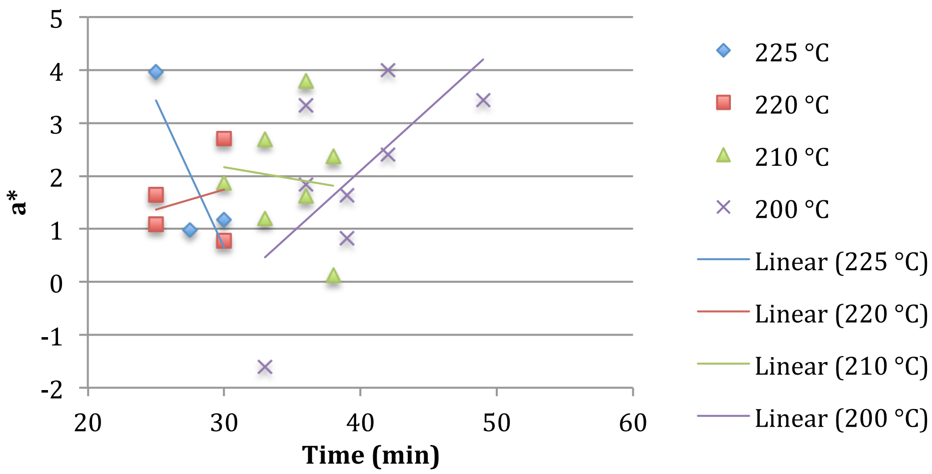

Figure 12. *The a* values for the different cooking times at each temperature for Pommes Frites.*

As stated previously, a longer cooking time at the same temperature should achieve a darker colour and give a higher content of acrylamide, and hence it should give a lower value for L*. The linear approximations for the different series should decrease with increasing cooking time for the same temperature since a longer cooking time should result in a darker product. The results do not show this correlation for all the different temperatures, this can be viewed in Figure 6 for Pommes Frites and in the Appendix B.2 for the other products. Because of this the acrylamide content based on the change in colour is hard to evaluate. The values for L* are not extremely different for the different samples either. To achieve a better trend on how the colour changes with a longer cooking time, and connect this to the acrylamide formation, an investigation on cooking times that spans from a very short to a long cooking time would probably be better to evaluate. This is however not interesting for this project since the product should have certain sensorial properties, which makes the interesting cooking time span small.

For the a* values the results are hard to evaluate as well. According to studies performed on potato chips, the a* value typically increase with a higher acrylamide content (Pedreschi et al., 2005, Serpen and Gokmen, 2009). From the results in this study, it is hard to evaluate if this seems to be the case with a longer cooking time with the change in colour.

Difficulties with this colour analysis method are many. One problem is that the result will depend a lot on exactly where on the picture the measurements were taken. As mentioned in the methods chapter, 15 measurements were taken for every picture and then the average for each L*, a*, and b* value was used for each sample. Even so, the chosen points for the measurements will affect the result and could give an unrepresentative result for the whole sample. A flaw in the method is that the measurement points are chosen from looking at the pictures with the human eye. The colour reproduction that the printer gives could also affect the colour measurement, if the colours on the printed picture are not accurate compared to the picture taken. A way to improve this method would be to use computer vision to analyse the colour for the whole picture. This would most probably give more representative values for the colour analysis. That only a portion of the cooked product was analysed does also affect the accuracy, the fries or Rösti that can be viewed in the pictures may not be completely representative for the experiment.

4.4.2 Colour Analysis with Agtron

The results for the samples that were analysed with the Agtron analyser are presented in Table 21. The results do not differ a lot between the different experiments. They are all in between 27.6 and 31.0. All values are too low compared to Orkla Foods quality control values (Pommes Frites Agtron 43-57, Pommes Criss Cut Agtron 38-48, and Klassiska Rösti Agtron 33-47). The measurements with the Agtron meter were mainly performed on the printed pictures, but three measurements were performed on food samples in order to control that the pictures seemed to give an accurate reading. Rösti was used for these samples. This comparison is displayed in Table 22. The readings from the pictures gave lower values than the ones from the cooked samples. For the two cooked samples there is definitely a difference, but it is not enormous. For the uncooked sample the difference is very large. This indicates that the rest of the Agtron readings performed on the pictures gave values that are lower than they should be. This could be due to the colour replication in the printed pictures and maybe also the difference in the surface of a paper and an actual Rösti.

Table 21. *Colour analysis for the three products cooked at three different temperatures. Results from both the analysis with the Agtron and the colorimeter.*

Product	Temperature (°C)	Time (min)	Agtron	L*	a*	b*
Pommes Frites	225	30	29.0	66.28	4.24	17.87
Pommes Frites	220	30	29.6	64.87	2.88	19.59
Pommes Frites	200	37	30.6	60.89	5.02	11.70
Pommes Criss Cut	225	30	30.7	66.53	1.18	15.92
Pommes Criss Cut	220	30	29.2	68.44	2.71	19.83
Pommes Criss Cut	200	39	30.5	65.19	0.82	18.09
Klassiska Rösti	225	12.5	28.5	63.65	-0.87	9.53
Klassiska Rösti	220	12.5	27.6	63.38	1.84	12.59
Klassiska Rösti	200	21	31.0	66.30	1.75	12.44

Table 22. *Comparison between Agtron measurements on cooked and uncooked Klassiska Rösti and pictures of the same samples of Rösti.*

Temperature (°C)	Time (min)	Agtron food sample	Agtron picture
225	15	33.8	28.2
220	17	34.2	30.5
Uncooked	Uncooked	56.9	30.2

4.4.3 Comparison between the Colour Analysis Methods

Unfortunately no good correlation between the Agtron measurements and colorimeter measurements could be found from the analysed samples. Since the values from the colorimeter measurements are not satisfactory this is probably the reason that no correlation can be found. There is also not a large difference between the colour in the different samples and this could make it hard to find any correlation.

4.5 Water Reduction – Cooking Time – Acrylamide

The eventual correlation between the weight reduction (in the form of water reduction), cooking time and acrylamide content was investigated. This comparison is shown in Figure 13 for Pommes Frites, Figure 14 for Pommes Criss Cut and Figure 15 for Klassiska Rösti. In all the temperature series the weight reduction increases with an increased cooking time in a linear manner. The values for R^2 (coefficient of determination) are displayed in the three figures and the value is always close to one, which indicates that the linear approximation is accurate. When looking at the acrylamide levels, no correlation can be found. In order to better evaluate if there is some correlation between these, more samples would have to be analysed, but this was not possible in this study. The weight reduction in the form of water reduction can not solely explain a correlation between less water content and a higher level of acrylamide.

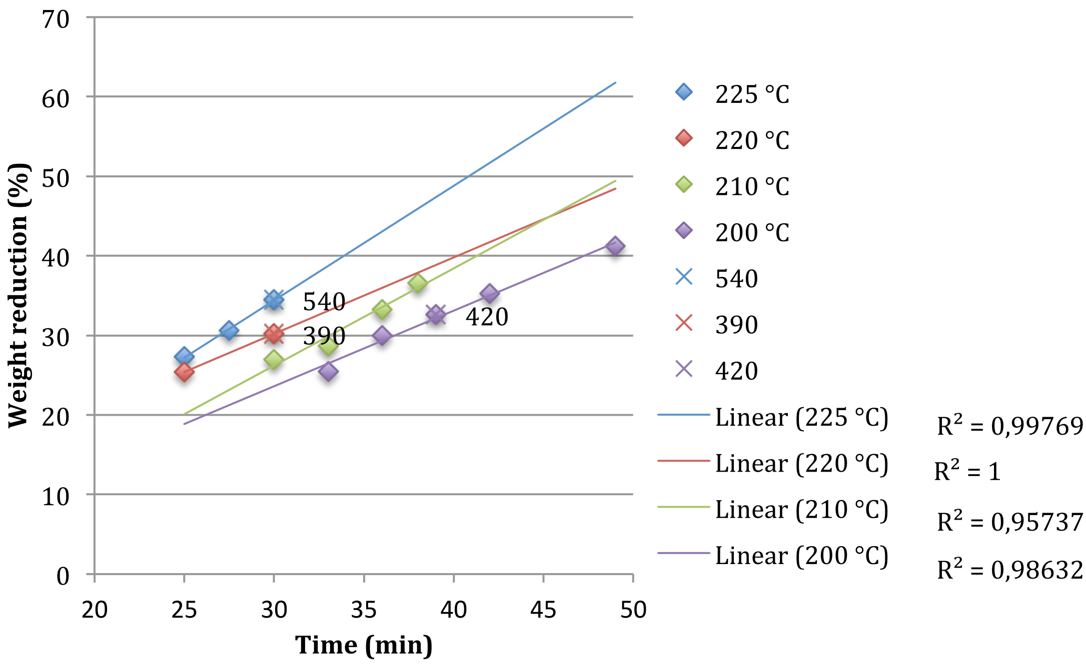

Figure 13. *Weight reduction for the different temperature series for Pommes Frites. The results for the analysed samples for acrylamide are displayed in the chart.*

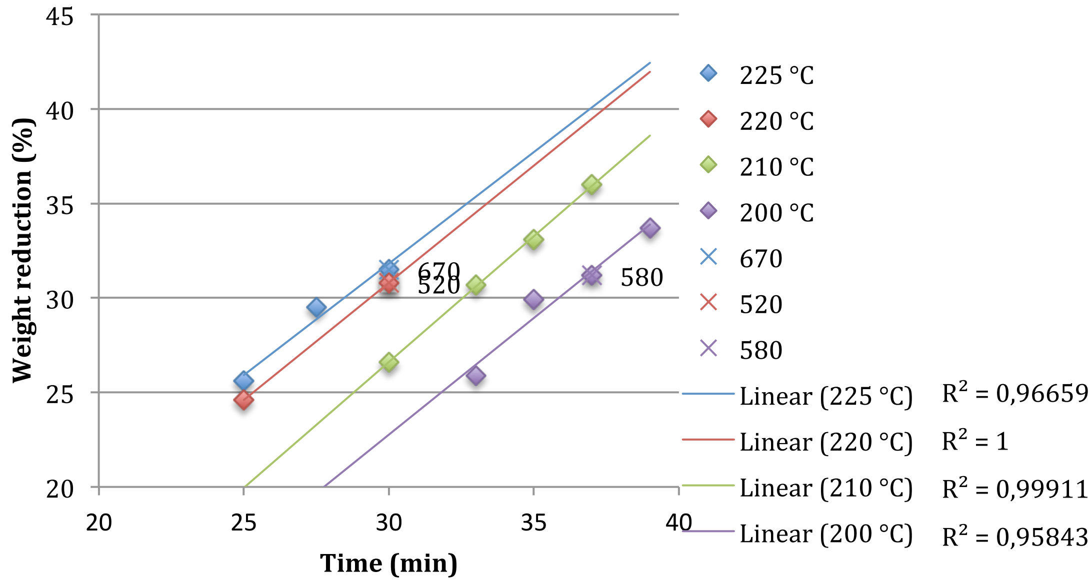

Figure 14. *Weight reduction for the different temperature series for Pommes Criss Cut. The results for the analysed samples for acrylamide are displayed in the chart.*

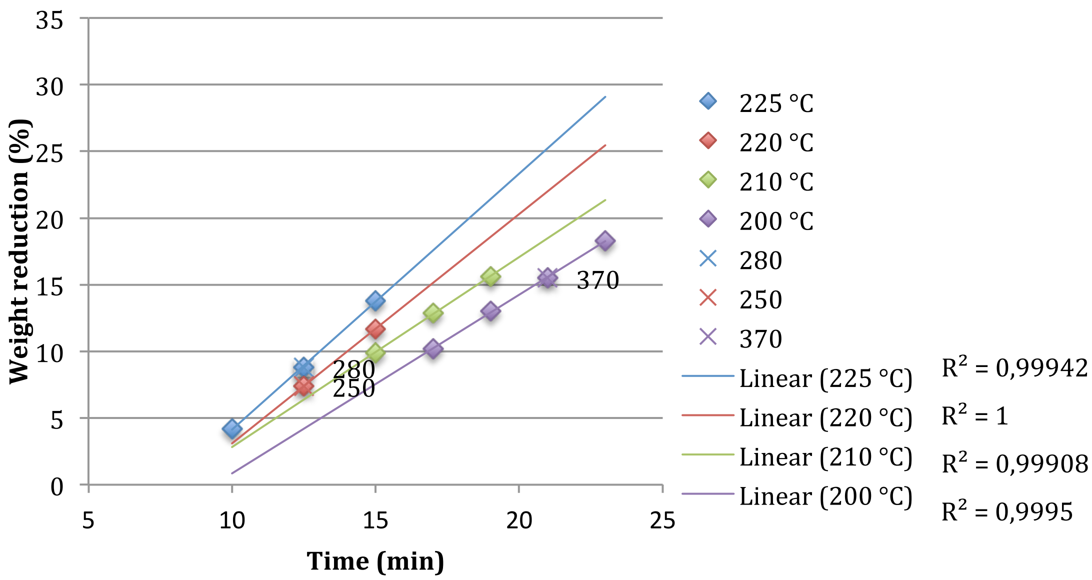

Figure 15. *Weight reduction for the different temperature series for Klassiska Rösti. The results for the analysed samples for acrylamide are displayed in the chart.*

4.6 Acrylamide Model Evaluation

If trying to create a model for how an examined parameter changes when two decided parameters are changed, one method is central composite design. First the factorial design in the model is constructed, creating the outer limits for the model. Measurements to get the extreme combinations for the two parameters are made. The changed parameters in this case would be the cooking time and the cooking temperature, and the examined parameter is the acrylamide content in the product. For this study it would be to combine a low setting for both parameters, combine a low temperature and a long time, combine a high temperature and a short time, and finally combine a high temperature and a long cooking time. With this the outer ranges for the model can be established. Further, several measurements can be performed in the centre of the model, meaning a temperature and time in between the extreme points. Several measurements can be performed around this point to get a good result. Finally measurements are made in the axial points which are points with one of the set parameters is high or low, and the other one in the middle of the high and low values used in the factorial design (Brereton, 2003). Since this experiment has other criteria to fulfil, in the form of sensorial qualities, not all combinations of temperature and time are interesting to look at. A low temperature and short time or a high temperature and a long time are combinations that will not give satisfactory sensorial results. Instead a thin band, in which the sensorial properties are adequate, in the matrix of combinations of cooking time and temperature were tested. From the analysis in this project a model for how the acrylamide changes with time and temperature is not applicable to create, since only measurements more to the centre of the possible time/temperature matrix were examined.

4.7 Customers Preparing the Products at Home

There are differences in how the products were prepared in this study compared to how someone would prepare them at home. In this study the oven temperature was thoroughly monitored to be even and accurate. If preparing the products at home the product would probably be put into the oven sooner (when it is indicated that the oven has reached the set temperature), before the temperature oscillations in the oven would stabilise. The temperature control knob could also be inaccurate compared to the actual temperature in the oven. If the oven would run on a higher temperature compared to the setting, this would most probably result in more acrylamide for the same cooking time. In this study it was not examined if there is a difference in the acrylamide content if the product is cooked before the temperature has stabilised. This could be something interesting to investigate. Because of the inaccuracy of the temperature in household ovens, it could not be guaranteed that the products would reach the same levels of acrylamide as in this study. If the oven runs on a higher temperature than what is indicated by the temperature control knob, the product could be overcooked and dry, and more acrylamide would form if the cooking time was the same as used in the oven in this study. The producer also states in the instructions on the packaging of the products that differences in different ovens should be considered and therefore the appropriate cooking temperature and time can vary.

5. Conclusion

The aim of the study was to investigate combinations of cooking temperatures and cooking durations that meet the quality demands for temperature and sensory qualities without resulting in too high levels of acrylamide in comparison with the benchmark level. The temperature demands were always reached, and the sensorial demands were met for at least one test for each temperature. The most interesting finding was that, from the samples sent in for analysis, the temperature resulting in the lowest acrylamide content for all products was 220 °C, with levels distinctly lower than the levels for the samples cooked at 225 °C. For all three products the analysed value was lower at 220 °C than at 225 °C. The results for the analysed samples in this study suggest that, only a temperature reduction of 5 °C in this temperature range, with the same cooking time, resulted in a distinct reduction. These results support the recommendation from EU that states that the cooking temperature for these products should not exceed 220 °C. The difference in the sensorial qualities when cooking for the same time durance at either 225 °C or 220 °C are barely noticeable. The time recommendation could therefore be kept, or slightly increased, according to the results from this study. Although, these results are based on only one sample per temperature and product, and the results can not be interpreted as general levels of acrylamide for the products. Further, the trials were performed using one specific oven, which means that the results could differ when using other ovens. Since household ovens may not give the actual temperature that is indicated on the temperature control switch, the same trial in another oven could result in different levels of acrylamide with these cooking recommendations.

For trials at the lowest investigated temperature of 200 °C, longer cooking time was needed in order to keep the desired organoleptic properties of the food products, which resulted in higher levels of acrylamide. This cooking temperature is therefore deemed to be too low for these products. The samples cooked at 210 °C in this study were not analysed for acrylamide, but it could be interesting to see if this would give a higher content of acrylamide compared to 220 °C due to the longer cooking time, or if the lower temperature resulted in less acrylamide formation. An extra acrylamide analysis value at 210 °C could perhaps have indicated if a correlation between cooking time and acrylamide content can be found for these products.

The results showed that the acrylamide content was slightly high in general for the product Pommes Criss Cut. The results for Rösti are questionable since the acrylamide content was not markedly increased after cooking compared to the uncooked sample in this study. It can however be stated that all Rösti samples were far from approaching the benchmark level at 750 µg/kg. The acrylamide content in the Pommes Frites was lower than the benchmark level, except for the sample cooked at 225 °C, which was slightly above the benchmark level.

From the results from the samples analysed in this study it can be suggested that the best combination of temperature and cooking time would be to keep the current time instructions but change the temperature instructions from 225 °C to 220 °C to reach an acrylamide content below the benchmark level. This applies to all three products evaluated in this study.

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Appendix

A. Temperature Data during Cooking

A.1 Pommes Frites

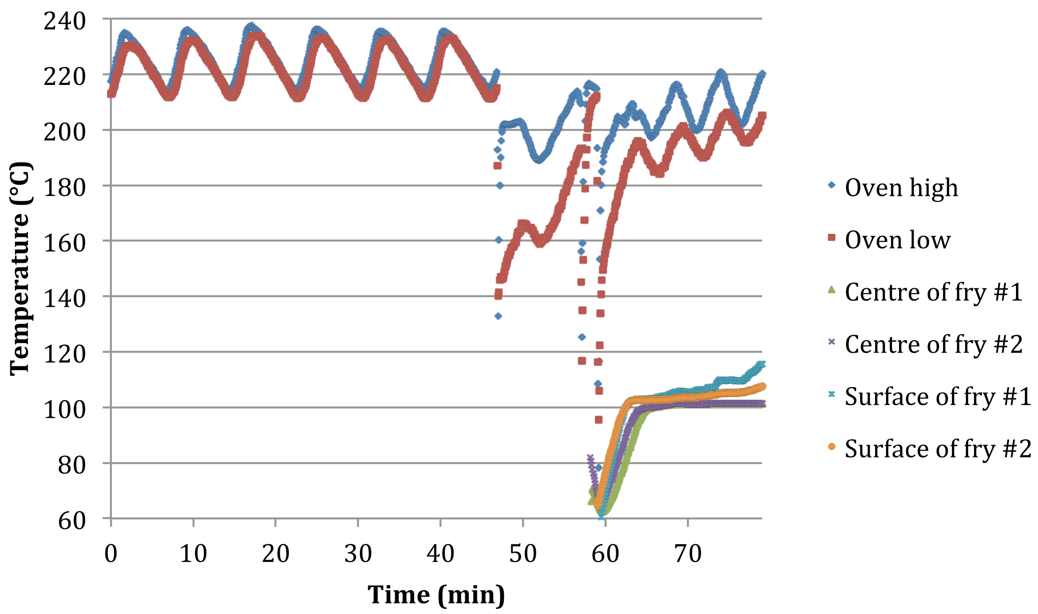

Figure A.1. *Pommes Frites cooked at 225 °C during 30 minutes.*

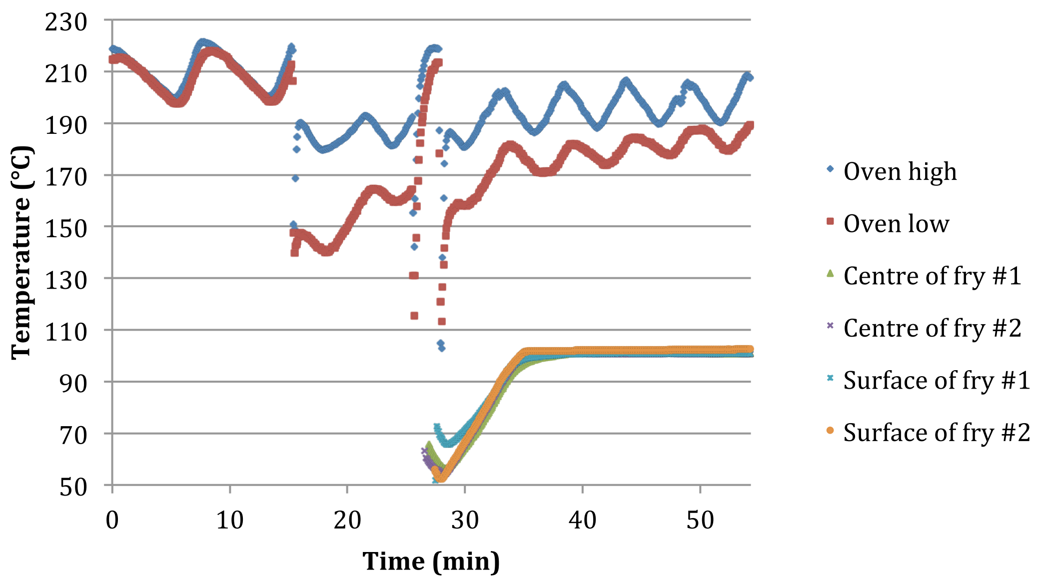

Figure A.2. *Pommes Frites cooked at 210 °C during 36 minutes.*

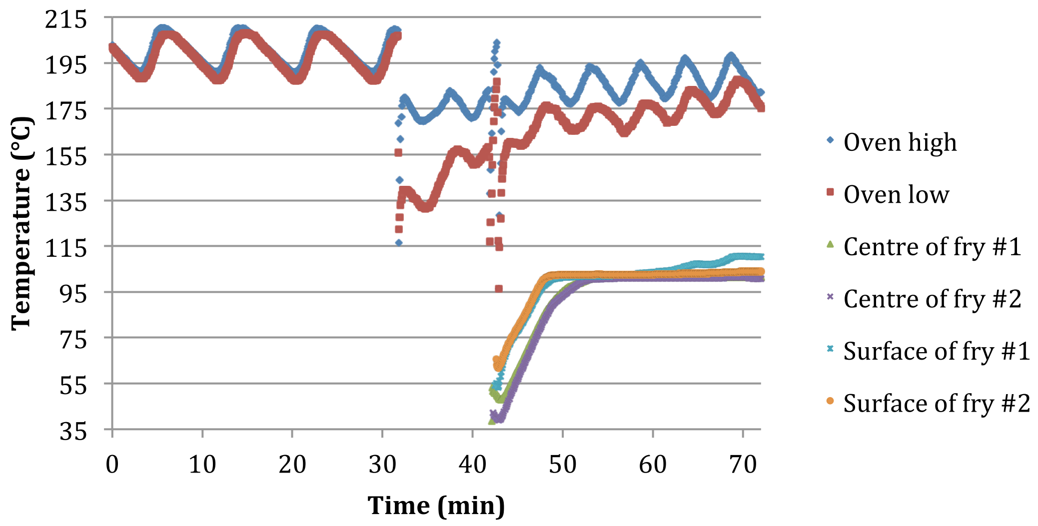

Figure A.3. *Pommes Frites cooked at 200 °C during 39 minutes.*

A.2 Pommes Criss Cut

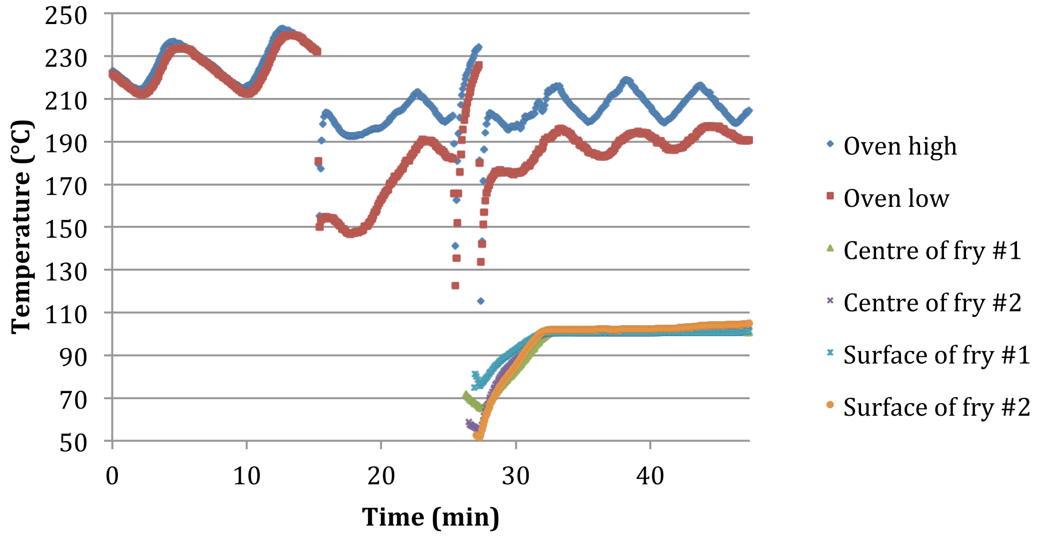

Figure A.4. *Pommes Criss Cut cooked at 225 °C during 30 minutes.*

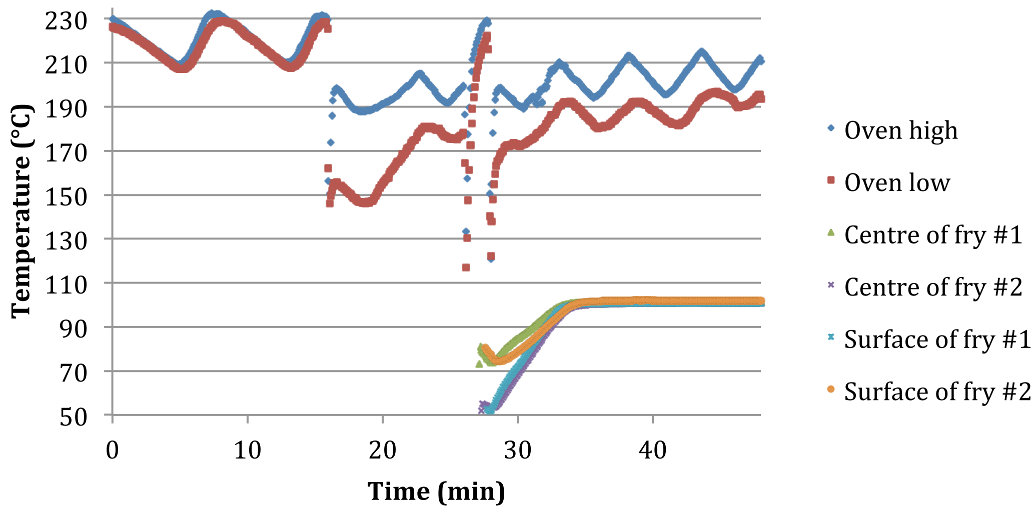

Figure A.5. *Pommes Criss Cut cooked at 220 °C during 30 minutes.*

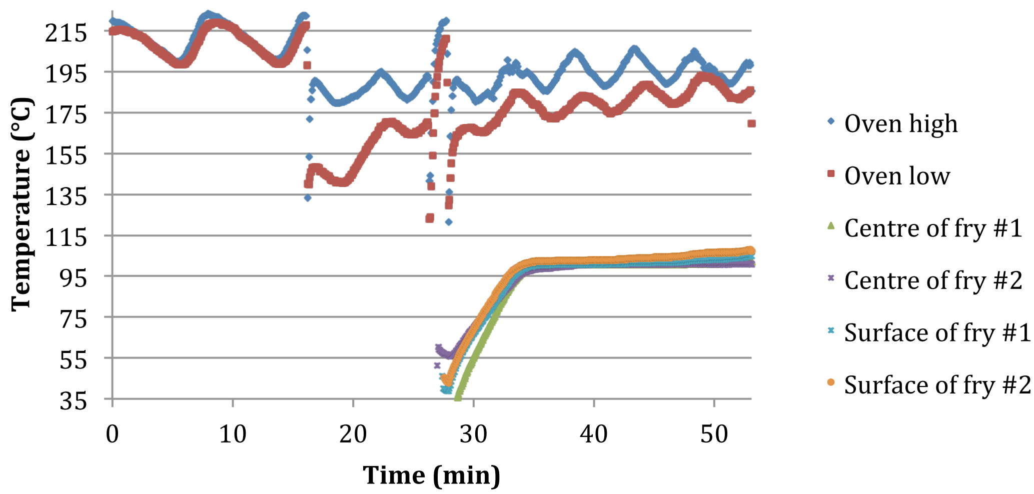

Figure A.6. *Pommes Criss Cut cooked at 210 °C during 35 minutes.*

B. Colour Analysis

B.1 Colour Analysis with Colorimeter

Table B.1. *Colour Analysis with colorimeter for Pommes Frites.*

Temperature (°C)	Time (min)	L*	a*	b*
225	25	65.93	3.96	20.74
225	27.5	65.15	0.98	19.35
225	30	66.53	1.18	15.92
220	25	66.73	1.09	16.62
220	25	69.27	1.64	19.47
220	30	67.04	0.78	17.71
220	30	68.44	2.71	19.83
210	30	66.46	1.88	15.89
210	33	68.67	2.69	21.84
210	33	65.11	1.20	16.90
210	36	67.06	3.80	18.84
210	36	62.09	1.62	18.24
210	38	66.19	0.12	15.86
210	38	67.12	2.37	20.15
200	33	67.77	-1.60	16.43
200	36	63.36	1.84	17.88
200	36	62.82	3.34	20.04
200	39	62.79	1.63	16.33
200	39	65.19	0.82	18.09
200	42	61.67	4.00	17.14
200	42	62.19	2.40	15.80
200	49	63.60	3.43	12.02
Uncooked	Uncooked	67.60	2.74	13.55

Table B.2. *Colour analysis with colorimeter for Pommes Criss Cut.*

Temperature (°C)	Time (min)	L*	a*	b*
225	25	64.87	1.64	19.64
225	27.5	66.63	-0.34	15.89
225	30	66.28	4.24	17.87
220	25	61.96	5.78	22.07
220	25	67.66	0.89	19.14
220	30	64.87	2.88	19.59
220	30	67.97	2.28	15.50
210	30	67.12	0.15	13.35
210	33	68.65	0.46	17.45
210	33	66.42	2.04	16.95
210	35	66.33	3.11	16.16
210	35	69.12	0.19	17.36
210	37	68.71	1.07	14.86
210	37	63.68	3.29	16.28
200	33	63.82	2.70	14.36
200	35	64.46	1.96	9.80
200	35	65.94	3.26	18.27
200	37	66.91	1.88	14.82
200	37	60.89	5.02	11.70
200	39	65.95	4.33	15.02
200	39	62.14	5.88	15.50
Uncooked	Uncooked	67.06	3.59	18.51

Table B.3. Colour analysis with colorimeter for Klassiska Rösti.

Temperature (°C)	Time (min)	L*	a*	b*
225	10	63.41	0.91	9.26
225	12.5	63.65	-0.87	9.53
225	15	64.87	-0.28	10.32
220	12.5	63.03	1.44	10.95
220	12.5	63.38	1.84	12.59
220	15	61.63	1.57	11.05
220	15	63.01	1.86	12.31
210	15	63.36	2.54	14.31
210	15	65.49	1.36	11.57
210	17	61.54	4.04	15.41
210	17	64.21	1.88	13.57
210	19	61.98	1.92	8.71
210	19	60.23	4.01	14.08
200	17	62.88	5.67	13.72
200	19	64.13	4.00	14.42
200	19	63.62	5.97	16.21
200	21	66.30	1.75	12.44
200	21	62.32	5.00	15.99
200	23	61.53	5.22	15.08
200	23	62.63	6.21	15.71
Uncooked	Uncooked	65.93	3.51	14.82

B.2 Colour Analysis Correlation Between Cooking Time and L* or a*

Charts for the product Pommes Frites can be viewed in the report.

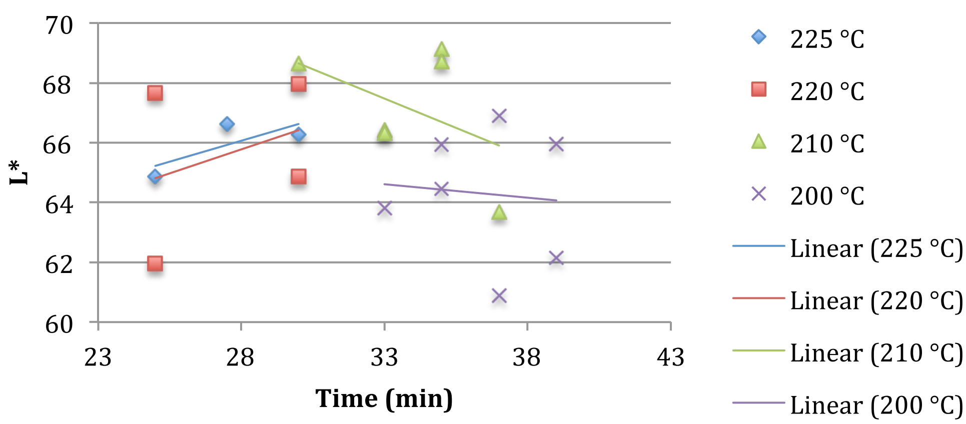

Figure B.1. *L* values from the colour analysis with the colorimenter for Pommes Criss Cut.*

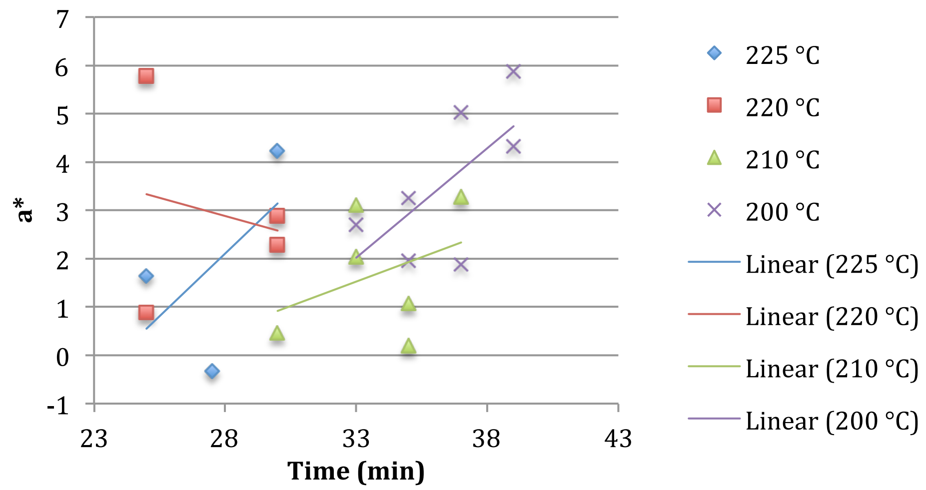

Figure B.2. *a* values from the colour analysis with the colorimenter for Pommes Criss Cut.*

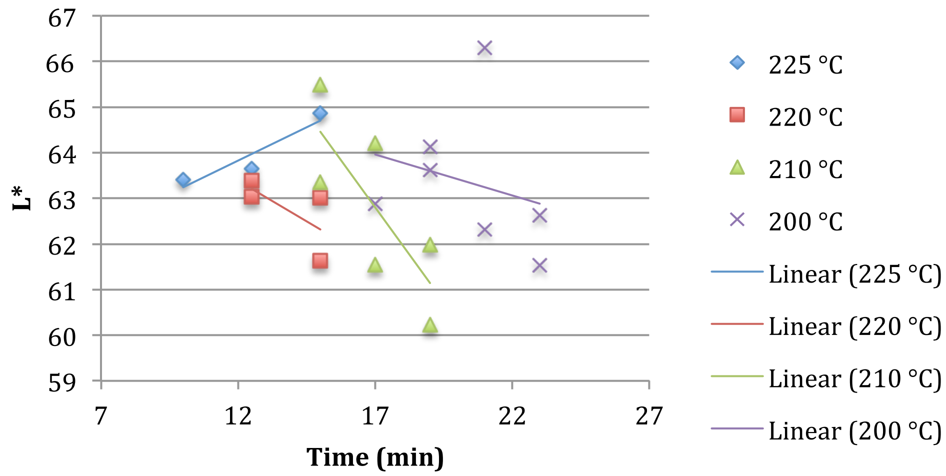

Figure B.3. *L* values from the colour analysis with the colorimenter for Klassiska Rösti.*

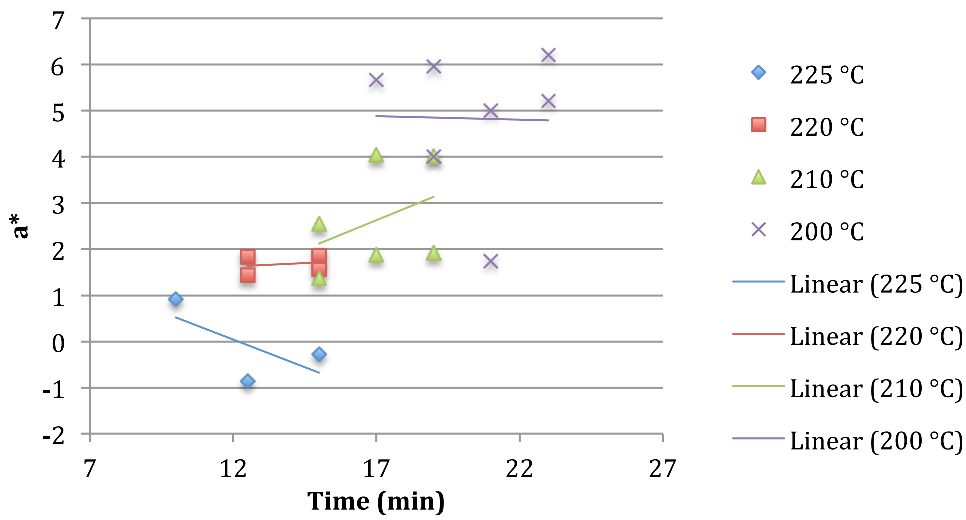

Figure B.4. *a* values from the colour analysis with the colorimenter for Klassiska Rösti.*

C. Acrylamide Comparison Data

Table C.1. *Acrylamide Content in french fries from investigations performed by the National Food Agency of Sweden.*

Producer/Brand	**Acrylamide (µg/kg)**	
	Year 2011	**Year 2012**
Burger King, Uppsala City	248	
Burger King, Uppsala City		312
Flogstagrillen, Uppsala	292	
Frasses Rasta, Nyköpingsbro		274
Kebab House, Uppsala Stora Torget	160	
Max, Nyköping Gumsbacken		246
Max, Sundsvall		632
Max, Uppsala City		444
Max, Uppsala Kvarnängsgatan	336	
Max, Uppsala Kvarnängsgatan	295	
McDonalds, Uppsala Forumgallerian		447
McDonalds, Nyköping västerport		821
McDonalds, SJ Sundsvall		560
McDonalds, Uppsala Forumgallerian	570	
McDonalds, Uppsala Forumgallerian	602	
Sibylla Inn, Sundsvall		133
Sibylla Ofvandals, Uppsala		214
Svartbäcksgrillen, Uppsala	28	
Svartbäcksgrillen, Uppsala	22	