Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences
Department of Food Science

Potential of Light and Temperature Exploitation for Accelerated Shelf Life Studies (ASLT) for Sauces

Emelie Elmlund

Agronommy Programme – Food Science
Independent Project in Food Science• Master Thesis • 30 hec • Advanced A2E
Publikation/Sveriges lantbruksuniversitet, Institutionen för livsmedelsvetenskap, no 386
Uppsala, 2014

Potential of Light and Temperature Exploitation for Accelerated Shelf Life Studies (ASLT) for Sauces

Emelie Elmlund

Supervisor: Roger Andersson, Professor in Plant Food Science, SLU

Assistant Supervisor: Caroline Jonsson, Product Development Technologist, Santa Maria AB

Examiner: Lena Dimberg, Professor in Plant Food Science, SLU

Credits: 30 hec
Level: Advanced A2E
Course title: Independent Project in Food Science
Course code: EX0425
Programme/education:

Place of publication: Uppsala
Year of publication: 2014
Cover picture: -
Title of series: Publikation/Sveriges lantbruksuniversitet, Institutionen för livsmedelsvetenskap
Serie no: 386
Online publication: http://stud.epsilon.slu.se

Keywords: Accelerated Shelf Life, Light and Temperature, Sauces, Descriptive Sensory Evaluation, Pigment Degradation, Arrhenius Equation, Q_{10} – modeling.

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences
Department of Food Science

Abstract

The advantage of being “First to Market” is tremendous, but keeping a high and consistent level of quality is determinant as well for the success of a food company. Low quality products cause damage to the brand and monetary loses in the long run. Quality is strongly influenced by a correct estimation of shelf life, but full length shelf life tests demands large inputs of time and money. The need for a more efficient method of estimating shelf life is therefore required, and the use of accelerated storage tests has gained in popularity in recent years. “Accelerated Shelf Life Tests” is by definition a method that allows the estimation of shelf life through short term storage tests. This is done by converting the accelerated storage results mathematically to represent normal storage conditions, often using different kinetic models. This project intends to evaluate the potential of using accelerated shelf life as a method for shelf life estimation for wet sauces. Two sauces was evaluated in this study; Pizza topping and Taco sauce with previously known shelf life of nine months and 18 months respectively.

The shelf life was estimated by exposing the samples to high temperatures and light during a time period of eight weeks in Climate Chambers (Sanyo Gallenkamp Prime Incubator, INC-000- MA1.9). The light source was a LED lamp that emitted light around 680 to 770 lux and the samples was stored at 22° C, 30° C and 40° C. The samples were then evaluated by sensory analysis and by measuring pigment degradation.

The result showed some inconsistencies with the theoretical aspects of the study. The Pizza topping was estimated to have a shelf life of eight months, and the Taco sauce was predicted to maintain quality for about 17 months. These values correspond well to the current estimated shelf life used. However, the results yielded different estimations depending on how the results were calculated. Q_{10} – modelling, a method that deduces a conversion factor that allows for direct translation of accelerated storage test results into normal storage condition yielded considerably shorter estimated shelf life values while the use of the Arrhenius equation seemed to results in more realistic values. In addition, the colour analysis resulted in different results when compared to the sensory analysis.

The recommendation is that accelerated shelf life tests have the potential to be a valuable tool when predicting product shelf life in a fast-paced innovation environment. However, due to the inconsistencies of the results it is recommended to perform further investigations before adopting accelerated shelf life tests as a standard method for shelf life estimation.

Table of Content

Introduction

According to Giménez *et al.* (2012) consumers are becoming more interested in eating fresh, healthy and high-quality food. Consumer demand for fresh and convenient food products has fuelled a development towards food companies providing new and improved products that is distributed world-wide. The shelves in supermarkets are becoming increasingly crowded with food products, and the advantage of being “first to market” has inspired many companies to adopt goals such as “Speed & Innovation” (Kotler, 2008). The tough competition on the food market demands for a high total quality throughout the shelf life of the food product, and the consumer’s perception of quality is the most relevant measurement of product quality (Heymann & Lawless, 2010). High quality results in many benefits for the company such as higher brand equity, less waste and fewer monetary losses in the supply chain (Young, 2011). Maintaining a superior quality is of great importance if a company wants to continue to grow. The sensory qualities of food is a favoured measurement for overall product quality (Heymann & Lawless, 2010) and sensory attributes is the determining factor for shelf life of foods that is not affected by microbiological spoilage.

The most accurate prediction of shelf life is achieved by full length storage tests under normal storage conditions. However, the pressure to minimize cost while ensuring high quality has paved the way for methodologies such as accelerated shelf life tests (ASLT). By definition, ASLT refers to any method evaluating long-term shelf life of food products on the basis of short-term tests. To achieve this goal, food product is exposed to environmental factors considered to be well above general storage conditions met by the product, and the result is mathematically converted into normal storage conditions. Any storage condition may be altered as long as the following deterioration process can be measured accurately and evaluated by a valid kinetic model (Hough, 2010; Taoukis & Labuza, 1996).

Most ASLT studies involve one single test condition such as temperature which is commonly evaluated by the Arrhenius equation (Mizrahi, 2011). The use of the Arrhenius model is generally accepted and has proven experimental validity (Mizrahi, 2011). Unfortunately, not all deterioration processes is equally accelerated by an increase in temperature. Manzocco *et al.* (2012) describes the problem that arise when the reaction causing the quality deterioration has a low thermal activation energy (<50 kJ/mol). Low thermal activation energy is closely related to temperature independence; hence the process will not increase in rate due to a higher temperature. Food that is especially relevant when considering this is foods containing high amounts of lipids, pigments and vitamins (Kristensen *et al.*, 2001; Ramírez *et al.* 2001). One approach is to combine light and temperature to increase the rate of deterioration. Very few studies have been conducted where the two environmental variables are combined, and Manzocco (2011) suggests that the lack of robust and validated mathematical models that describe the effect of light on food quality is one reason for this. Manzocco *et al.* (2012)

suggests the use of the simple “Power Law” equation for the purpose of describing shelf life by the use of light as an accelerating factor.

1.1 Aim and purpose

The purpose of this work was to investigate the potential use of ASLT in the product development phase of wet sauces. The development of a functional ASLT method could allow a company to more accurately predict shelf life without the utilization of full time storage tests for the wet sauce production. Sauces are complex systems with many components interacting to form the premises for shelf life. The chosen products for this study, a traditional Taco sauce and an emulsion based Pizza topping, contain high levels of pigments and lipids which indicate that the use of temperature as the only accelerating factor is insufficient for achieving the time saving results demanded to justify the use of ASLT (Manzocco *et al.* 2011). It is also the aim to choose products that represent large product lines in order to produce results that is applicable to as many sauce products as possible.

This evaluation will be done using descriptive sensory analysis alongside pigmentation measurement in both sauces.

1.2 Limitations

This study focused on only two different types of wet sauces found at Santa Maria AB. ASLT results are always specific for the products investigated and it is worth remembering that sauces are complex food systems and that the results may not be applicable to sauces in general. Also, the sauces will be evaluated for sensory attributes and no analysis of the actual chemical composition or microbiological activity will be carried out. The human sense is superior in the detection of sensory changes, but the results should always be treated with an understanding of the many biases that might occur when working with sensory analysis. The shelf life of products is also highly influenced by package, process and additives and these parameters will only be discussed in theory.

As for the experimental parameters, only two types of light settings have been chosen, light versus no-light. Other light settings might cause differences in reaction rate or give rise to other reactions in sauces that is beyond the scope of this study. The experimental temperatures has been chosen in the range of 22 °C – 40 °C in order to avoid any unwanted changes in the product such as phase transitions, while exposing the products to temperatures above normal storage. Other temperatures might prove more suitable but this first approach will serve as a sufficient guide for further research.

Theoretical Background

Process, packaging and ingredients are important factors that influence food quality and hence consumer’s acceptance. Viewed in a long-term perspective, product quality can make or break a brand. Therefore, the time and monetary means spent by companies in order to ensure top quality throughout a products shelf life is often a good investment. The aspect most important for product quality also varies between different categories of food which justifies a proper investigation of the quality attributes of each product. For wet sauces, several different aspects such as packaging, ingredients and processing steps are determinant to the level of quality perceived by the consumer.

2.1 Wet Sauces

Sauces are traditional condiments that have been a part of cooking since ancient times. Sauces are rarely used by themselves, but are instead served alongside other dishes or act as an ingredient themselves. The word *“Sauce”* is derived from the Latin word *“Salsa”* meaning *“Salted”* and the oldest recorded type of sauce is *Garum,* a fish sauce used in Ancient Greece (Corrhier, 1997). Sauces often have a liquid component, but there are examples of sauces that consist of more solids than liquid, for example traditional sauces such as *Chutney, Salsas* and *Pico de Gallo*. As a food product, sauces are complex systems with many ingredients and varying production processes which demands different types of treatments for a guaranteed shelf life.

Taco sauce has its roots in the traditional *Salsa*; a Mexican derived type of sauce prepared using a *Molcajete*, a grinding tool similar to the Western mortar and pestle. The ingredient varies, and there are several examples of salsas such as *Guacamole, Salsa Criolla,* and *Mole* (Corrhier, 1997). Pizza topping is a variant of the popular white and creamy emulsion based sauce often served alongside a *Doner Kebab* in Sweden (Santa Maria AB, 2013). It is flavoured with coriander and is aimed at being served on top of pizza or used as a dip.

2.2 Product Categorization

Taco sauce and Pizza topping constitutes two different types of sauces. There are several different ways of categorize sauces and one general approach is to divide on the basis of the main components of the sauce. Sauces can be grouped according to fat content which is shown in Figure 2.1 where a general overview of retail sauces is included. Also, a further division can be made by grouping the low fat products into high/low sodium content and the high fat products according to what type of fat it is used. The packaging material may also be used as a basis for product categorization as seen in Figure 2.2.

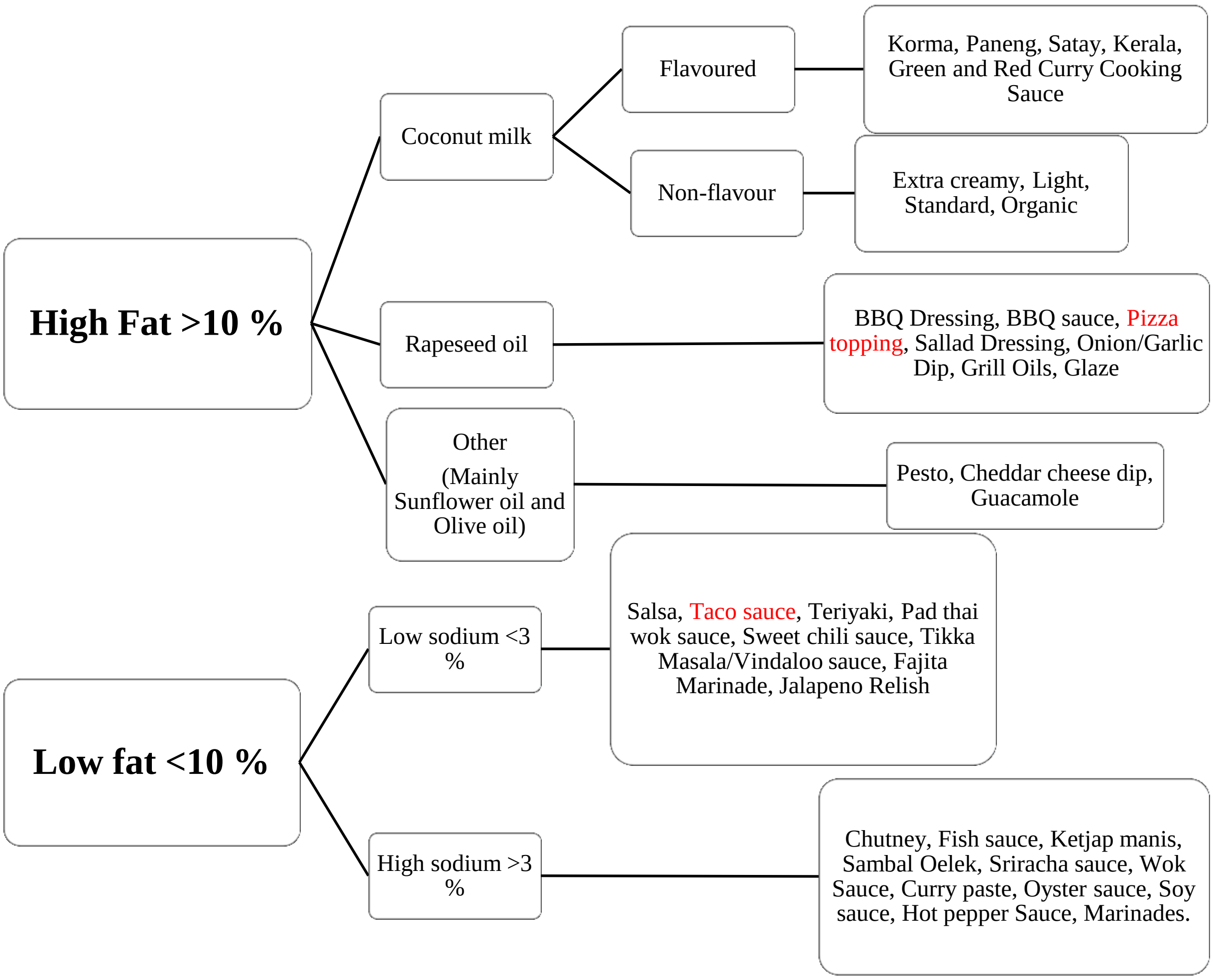

Figure 2.1. *Product categorization according to fat content (Santa Maria AB, 2013).*

Figure 2.2. *Product categorization according to type of packaging. Adopted from Santa Maria AB (2013).*

The chosen products are found in different parts of the categorization as the Taco sauce is a tomato based sauce sold in a glass jar while the Pizza topping is a rapeseed based emulsion sold in a plastic squeeze bottle. The stated shelf life for Pizza topping is nine months while the Taco sauce has an estimated shelf life of 18 months (Santa Maria AB, 2013).

2.2.1 Ingredients and their functional role - Pizza Topping

The pizza topping is a white, creamy emulsion based on rapeseed oil and water. The product is packaged in a plastic squeeze bottle containing 280 ml and all the ingredients are listed as follows:

Rapeseed oil, water, sugar, vinegar, egg yolk powder, onion powder (1.5 %), salt (1.5 %), garlic (1 %), modified corn starch, cumin, other spices, acidity regulator (citric acid), stabilizing agent (xanthan gum), preservatives (E202, E211), oregano.

Emulsions are colloidal systems of two immiscible phases, where the dispersed phase is formed in the continuous phase after vigorous mixing. The system dissolves quickly after the agitation stops, and the dispersed phase coalesce to form a layer. Emulsions also include suspended air and solids, which makes it a complex system. Common emulsions are *oil-in water* (e.g. mayonnaise) and *water- in oil* systems (e.g. butter). The emulsion can remain stable if a stabilizing agent is added. Common stabilizing agents are different types of food gums, exudates or substances obtained from non-cereal seed or microorganisms. All gums are defined by the extensive branching of the molecules that easily traps water, which forms the characteristic high-viscosity aqueous phase (Coultate, 2009). For the pizza topping, Xanthan gum is used (Santa Maria AB, personal communication). Xanthan gum is a polymer which is obtained from commercially grown bacteria (*Xanthomonas campestris*) and the molecule easily associates/dissociates which results in the thixotropic behaviour of the gum. Besides the stabilizing effect of emulsions, Xanthan gum also allows relatively large particles to be suspended evenly in the readily flowing solution (Coultate, 2009) and the seasoning in the topping is dispersed evenly in each bottle. The modified corn starch that is added can also be used as a stabilizing agent, but in the pizza topping is serves primarily as a thickener (Santa Maria AB, personal communication). The starch is treated with hydrochloride acid followed by neutralization, which results in a small proportion of the glycosidic bonds to be broken. This causes the starch to form stronger and clearer gels that adds to the organoleptic properties, such as mouth-feel of the Pizza topping (Coultate, 2009).

The citric acid as well as the spirit vinegar help control the pH of the product, and hence acts as a defence against deterioration. A low pH is inhibiting microbial growth, mainly through destabilizing important macromolecules for bacterial growth (Coultate, 2009). Pathogens rarely grow in pH <6, but several yeasts and filamentous fungi show no inhibition of growth in environments with pH reaches as low as pH ≈ 4. For the Pizza topping, which shows a pH in the range of 3.6 – 4.0, preservatives E202 (potassium sorbate) and E211 (sodium benzoate) are added (Santa Maria

AB, personal communication). Both preservatives are efficient in reducing the growth of yeast and filamentous fungi, especially in acidic food products since the low pH increase the solubility of the growth inhibitory substances.

The Pizza topping contains almost 50 % rapeseed oil, which is unsaturated oil prone to oxidation. In order to prevent the oil from becoming oxidized during the pasteurization step, an antioxidant is added which is consumed during the heat treatment. Also, the pH-stabilizing citric acid binds trace metals which without the presence of an antioxidant could have increased the rate of browning and rancidity through oxidation in the Pizza topping (Coultate, 2009).

2.2.2 Ingredients and their functional role - Taco Sauce Mild

The Taco sauce is a tomato-based chunky sauce with pieces of tomatoes, onion and jalapeño. The product is packed in a glass jar sealed with a metallic lid. The container holds 230 g. The following ingredients are included according to Santa Maria AB (2013):

Tomato puree, tomatoes (36 %), onion (19 %), chili (7.5 %), modified corn starch, vinegar, salt (1.3 %), garlic, and other spices.

The main purpose of the addition of modified corn starch is for the ingredient to act as a thickener. The modified corn starch contributes to both gelatinization and mouth-feel of the product (Coultate, 2009) and it allows the Taco sauce to remain liquid, while not dripping off the nachos too easily for example.

The Taco sauce does not contain any preservatives, but still show a long shelf life. This is due to the combination of a pasteurization step, hot filling and a low pH. The pH is controlled by the addition of vinegar and the value is measured to pH < 4.2. This provides enough protection alongside the pasteurization step to ensure microbiologically safe product (Santa Maria AB, personal communication). The Taco sauce is seasoned with chili and garlic, and the product contains as much as 7.5 % chili, which gives a sensation of heat. The other spices, as well as salt, contribute to the overall flavour of the Taco sauce.

2.2.3 Process and packaging – Pizza topping

As seen in Figure 2.4, the process for Pizza topping includes a mixing stage where the main ingredients, oil and water, are mixed together in a tank. The dry ingredients are added under agitation after the emulsion has formed, and the mixture is heated to 90 °C during five minutes in order to pasteurize the product. After pasteurization, the emulsion is quickly cooled down to 25 °C before the product is filled into plastic squeeze bottles. The bottles are sealed with aluminium foil and packed in units of six bottles (Santa Maria AB, personal communication).

It is important to bottle the product immediately after the cooling step in order to avoid re-contamination of microorganisms. Also, several other critical control points are checked in order to ensure that the product is safe, such as pH, salt content, a_w and the addition of the correct amount of preservatives.

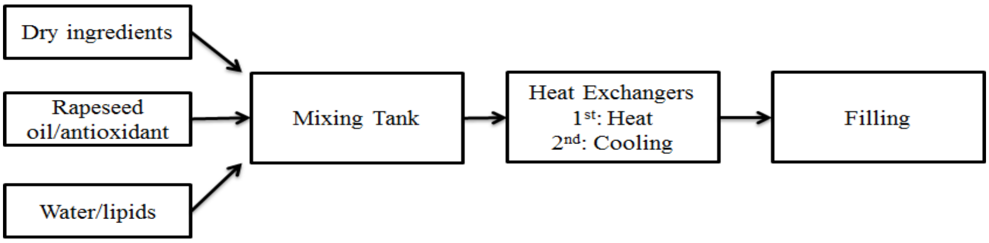

Figure 2.3. *Process specification of Pizza topping* (Santa Maria AB, personal communication).

2.2.4 Process and packaging - Taco sauce

The taco sauce is produced by several different suppliers, but the process is basically the same as depicted in Figure 2.3 (Santa Maria AB, personal communication). The ingredients are mixed in a kettle, and pasteurized before the filling step. The heat treatment is done at 95 °C and the filling stage is performed in a temperature range of 82 to 93 °C. The taco sauce is filled in glass jars sealed with metallic lids. Due to the high filling temperature, the lid tightens and seals the jar efficiently after cooling. The control parameters that are checked are pH and salt content.

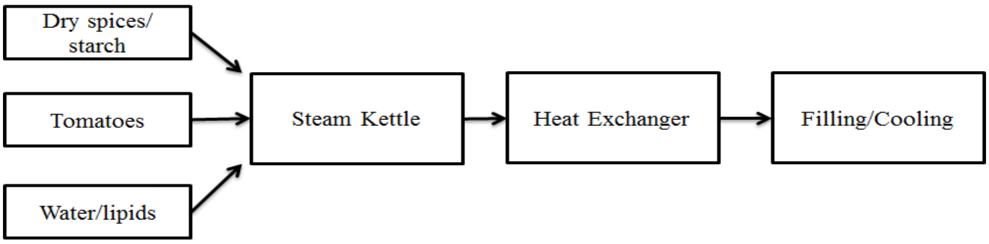

Figure 2.4. *A general process specification of Taco sauce. Adopted from Santa Maria AB (*Santa Maria AB, personal communication*).*

2.3 Quality Assurance of Food

Food quality is defined by many different factors and aspects and quality means different things to producers and consumers (Earle *et al.* 2001). However, quality should always be founded on the basis of safe food products with a consistent shelf life. All over the world, different regulatory bodies collaborate with the food sector in order to ensure that consumers are protected against hazardous or inferior food products (Adams & Moss, 2008). The food producing companies themselves have a lot to gain from high quality products which will enhance their brand equity and market share in the long run (Kotler, 2008).

In order to achieve the high quality needed, most producers today use the *Hazard Analysis Critical Control Point* (HACCP) concept (Adams & Moss, 2008).

The concept was originally developed as a part of the United States space program and adopted in 1973 by the US Food and Drug Administration before it became widely applied in the food sector. The concept has the advantage of not only detecting hazards, but also actively preventing potential hazards and then applying controls to these critical steps. Although HACCP is efficient, the system requires that good manufacturing and hygienic practices is in place before the concept is applied (Shapton & Shapton, 1991).

According to authors like Rozin & Tourila (1990) and Jaeger (2006) the consumer perception of product quality is very much dependent on the information given on the label. Inappropriate shelf life labelling can lead to serious economic implications for the producer and hurt consumer's trust in a brand (Harcar & Karaya, 2005). On the other hand, there are potential downfalls if producers have a too rigorous hold on quality. According to Nellman *et al.* (2009) as much as 25 to 50 % of all produced food is wasted along the supply chain due to quality effects that does not impose any risks to the consumer. Waste is not only an economic loss in itself, but an efficient waste management system implies high costs to an organization (Nellman *et al.* 2009). Most food producers aim at minimizing waste while guaranteeing a high total quality throughout the supply chain and a key aspect is an appropriate shelf life.

2.3.1 Deterioration of Food and the Impact on Quality

Food will deteriorate sooner or later and become inedible. The deterioration of food is primarily caused by one or more of the three following mechanisms (Kilcast & Subramaniam, 2011):

1. *Microbiological spoilage*
2. *Chemical and enzymatic activity*
3. *Moisture and/or vapour migration*

The sensory characteristics are often affected before the food poses any health risk for the consumer (Heymann & Lawless, 2010). For the consumer, the total quality of a product is often based on how well the sensory characteristics are retained during the distribution and consumption stages. Kilcast & Subramaniam (2011) lists the potential ways of controlling the deterioration process of food through the control of different aspects of the product or process:

1. *Moisture/ and or water activity*
2. *pH*
3. *Process treatments (e.g heat, irridation, pressure etc.)*
4. *Emulsifier system*
5. *Preservatives and additives*
6. *Packaging*

For pasteurized products such as Pizza topping and Taco sauce, chemical and enzymatic activity are the main reasons for deterioration. The Pizza topping also contains preservatives as well as an antioxidant which protects the product against the development of microbial growth and rancidity. For the Taco sauce, the shelf life relies on the combined effect of pasteurization and a low pH for quality. This is often referred to as the *Hurdle effect.* Leistner & Gould (2002) described the phenomenon as the collective use of several product parameters that inhibits microbiological growth. Each inhibitory aspects such as pH, process treatments or preservatives are not enough used alone to slow down microbial growth but the collective strength of several used together creates a sub-optimal medium for most microorganisms.

2.3.2 Lipid Oxidation in Food

The chemical deterioration of fats and oils in food products are often referred to as rancidity and the process causes the accumulation of unpleasant odours and flavours to occur in food. There are two types of mechanisms which lead to the development of a rancid flavour, namely oxidative rancidity or hydrolytic rancidity (Coultate, 2009; Reische *et al.*, 2008). Hydrolytic rancidity is the process of fatty acids being cleaved from the triglyceride in the presence of water (Kristott *et al.* 2000). This reaction can be either spontaneous or caused by enzymes. In the case of enzymatic cleavage the process is often referred to as lipolytic rancidity. Lipolytic rancidity occurs primarily in dairy fats and the causing agent is often the microbial flora (Coultate, 2009).

Oxidative rancidity is occurring in the fat of meat, fish and vegetables and impairs quality through smell and taste (Coultate, 2009). The rancidity is the result of autoxidation of unsaturated fatty acids and the process has been described to contain three distinct phases described (Figure 2.3.1). In the first stage, an initiator denoted as “X” (heat, irradiation, or metal catalysts) causes a hydrogen atom to be cleaved from the fatty acid molecule and an alkyl radical is formed. This alkyl radical is denoted as “$R^{\cdot}$” and is most often referred to as a *free radical.* The free radical is highly reactive and reacts with atmospheric oxygen (O_2) in the propagation step which leads to the formation of a peroxyl radical ($ROO^{\cdot}$). When the peroxyl radical reacts with unsaturated fatty acids (RH) hydroperoxide (ROOH) is formed, alongside a new alkyl radical. The two first steps leads to an accumulation of free radicals in the food until the amount are sufficient enough for the free radicals to react with each other which create stable end products. This phase is called the termination step (McClement & Decker, 2008).

1. **Initiation**

$X^{\cdot} + RH \rightarrow R^{\cdot} + XH$
Or
$RH \rightarrow R^{\cdot}\ H^{\cdot}$

2. **Propagation**

$R^{\cdot} + O_2 \rightarrow ROO^{\cdot}$
$ROO^{\cdot} + RH \rightarrow ROOH + R^{\cdot}$

3. **Termination** $R^{\cdot} + ROO^{\cdot} \rightarrow$ Stable, non-radical products

Figure 2.3.1. *The process of rancidity with (˙) corresponding to a unpaired electron, R˙ denotes the free radical, RH an unsaturated fatty acid and X˙ the process initiator. Adopted from Coultate (2009).*

When followed analytically, most lipid oxidations show a distinct lag phase where the oxygen accumulation is slow and the rancid taste and smell is not yet detectable by the human senses. This phase is followed by an exponentially increase of oxidation rate where the off-flavours increases rapidly. The length of the lag-phase is dependent on both internal factors such as oil unsaturation and external factors such as the presence of pro-oxidants, antioxidants and storage conditions in the form of light and temperature (McClement & Decker, 2008). The process of oxidative rancidity can be monitored through various analyses such as measuring the ansidine-value or *para*- ansidine value (Alander *et al.* 2002). The chemical analysis is often used as a complement to sensory analysis, since few methods surpass the human sense in accuracy.

2.3.3 Pigment Degradation in Tomatoes

One of the main ingredients in Taco sauce is tomatoes which gives the sauce an attractive colour. In tomatoes, the carotenoid lycopene is the most abundant pigment and the lycopene content in tomatoes normally varies between 3 to 5 mg/100 g raw fruit depending on maturity, variety and environmental conditions according to Hart & Scott (1995). The pigment is only synthesized in plants and by some microorganisms and functions primarily as a light absorbing molecule during photosynthesis. Lycopene is an antioxidant and one of the most efficient oxygen quenchers of the carotenoid family, and without the molecule fruits and vegetables is prone to photosensitization by light (Di Mascio *et al.* 1989; Conn *et al.* 1991).

Lycopene is also a healthy component in tomatoes, and the bioavailability of lycopene is highly dependent on the matrix of the food. Grinding or cooking softens the structure of the fruit or vegetable and disrupts lycopene – protein complexes. Lycopene is however, easily degraded in food systems if handled incorrectly. Lycopene degradation impairs the sensory quality through colour changes and some tomatoes products lose their bright, red colour if stored incorrectly (Shi & Le Maguer, 2010). Lycopene can be degraded by two primary pathways, isomerization and oxidation. Bleaching, heating and freezing cause loss of lycopene in most food products and these processes allows the natural *trans*- form of lycopene to convert into *cis* – form. The *cis*-form inhibits the functionality of lycopene and the molecule is no longer able to act as an antioxidant. Shi & Le Maguer (2010) could show that the amount of *cis* – form increases exponentially with temperature. The presence of reactive oxygen and peroxyl radicals can also cause lycopene to undergo reduction.

The amount of lycopene in food can be estimated using colour analysis. Often this analysis is based on the Hunter's L*A*B system. The system defines colour by the use of three coordinates in a colour space, where the vertical coordinate (L) designates black (L=0) to white (L=100). In a sense this represents what we humans perceive as lightness of a colour. The horizontal coordinate (a) shows green (-a) to red (+a), and the coordinate (b) runs from blue (-b) to yellow (+b) (Coultate, 2009). D'Souza *et al.* (1992) have developed regression equations which describe the relationship between chromaticity values and lycopene content. Although their model did not predict lycopene concentrations accurately enough to substitute entirely for chemical analysis, the authors draw the conclusion that the method could be useful for estimating lycopene concentration during on-line quality monitoring.

2.3.4 Packaging

Both Pizza topping and Taco sauce are protected by so called *primary packages*, which are major protective barrier which is in direct contact with the food (Robertson, 2006). The packaging is designed to slow down the deterioration by protecting the food from external environmental effects, for example the migration of water or oxygen. Glass provides good protection from external effects due to its rigid structure, and for a glass jar the weak point is the sealing of the opening. The Taco sauce is sealed with a metallic "click" lid, which is applied in a pasteurization tunnel and after cooling tightens by vacuum and hence "clicks" (Santa Maria AB, personal communication). Gas does not readily pass through glass, but the product is exposed to UV-radiation which is a factor that increase oxidation and pigment degradation.

The Pizza topping packaging is made from a type of polyolefin plastic called *polypropelene* (PP). Although plastic materials in general are a poor barrier against gases, PP plastics have a somewhat lower permeability for gases than other polyolefin plastics. PP plastics constitute a very good barrier against water vapour (Robertson, 2006).

2.4 Sensory Analysis

Sensory analysis of food items has been extensively used during the second half of the century and the field has been reviewed many times (Lawless & Heymann, 2010). According to the generally accepted definition of the field by Stone & Sidel (2004) sensory evaluation of food includes:

"A scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch taste and hearing" Heymann & Lawless (2010) p. 2

Sensory evaluation hold as its strength that it attempts to isolate the sensory attributes of food items themselves, without attaching the attributes to outer factors such as brands identity. Hence, a sensory analysis of a product can potentially provide unbiased information of the consumer's response to a product to product developers, brand managers and food scientists. In general, the field of Sensory analysis is divided into three separate parts, *Difference testing*, *Descriptive testing* and *Affective testing* (Heymann & Lawless, 2010). The first two types of tests are analytical, and aim to deduce if the food samples is different in any way. Affective testing answers the question whether the consumer like/dislike or prefers any product in comparison to other food products. It is highly dependent on the aim and purpose of the study when deciding on which technique is most suitable. For example, if a producer needs to alter the ingredients or processing for legal reasons, they might want to perform an easy discrimination test in order to establish if the product has changed in any way after the alterations. Another example might be if a company aims at launching a product into a new market, and they utilize some type of affective testing in order to establish general consumer liking of the product. For shelf life tests and similar projects where differences between samples need to be quantified, descriptive testing is most suitable (Heymann & Lawless, 2010).

Also, one of the main advantages of sensory analysis is that the method more closely mimics reality than any instrumental measurement. The consumer's response is a complex web of prior expectations and individual frames of reference, as well as the biological response of food when chewed and swallowed of which many no other instrument than the human sense is able to perceive (Heymann & Lawless, 2010).

2.4.1 Principles of Good Practice

According to Lawless & Heymann (2010) the results from a sensory analysis is only as useful as the amount of uncertainty it reduces. In many cases the analysis is done purely on a routine basis, and this incurs unnecessary costs and is time consuming. Sensory analysis also includes many potential pitfalls that could potentially produce misleading results. The same strength of using human senses for evaluation of food products can also be the potential downfall of a study. Lawless & Heymann (2010) argues that sensory judgment is always done based on an individual prior frame of reference and assembled based on previous experience. This is due to the fact that humans are prone to comparative analysis although very poor absolute measuring instruments. In order to ensure that the results is as reliable as possible, there are some general considerations of good practice for sensory analysis which include (Heymann & Lawless, 2010):

Sample

The samples need to be served at the same temperature in a carrier that does not affect the flavour or composition of the sample. The sample size should be large enough to allow for repeated tastings but still not exceed the amount consumed under normal conditions. All samples should be coded and randomized and no more than five-six samples should be served during a session. The panellists should also be provided with some type of palate cleanser and water.

Score sheets

The instructions should always be clear and discussed beforehand in order to avoid misinterpretations. The scale and values should always be matched against the aim of the study and easily understood. According to Heymann & Lawless (2010) most studies have shown that all scale have acceptable level of sensitivity if used properly. The scale can either be constructed as a discrete or continuous scale (Lundberg, 1981). A discrete scale has predetermined values and offers structure, but the structure can also be a potential hindrance if the panellists feel trapped between two values. If that is a risk, an unstructured scale is often preferred but the problem can also be solved by allowing the panellist's to leave comments. An unstructured scale impose the need for more statistical calculations in order to convert the ratings into numerical values, but the work has the potential to provide the researcher with more precise results. When working with an expert panel, it is important to remember that the scale should never measure hedonic liking, but rather collect qualitative ratings since the trained assessors perception is far from the naïve perceptions of the consumer.

Environment

It is important that the testing area is free of distractions. Noise and uncomfortable temperatures or humidity tends to disturb the focus of panellists and should therefore be avoided. The light should be at least 300-500 lx at the table surface as well as even and shadow free. For products affected by discolouration, some type of reduced light setting should be used. In the case of the Taco sauce, the intricate interactions between colour and flavour should also be taken into account. It has been shown in numerous studies that when food has a more deep and intense colouring, the food product tends to score higher values in flavour intensity (Dubose *et al.* 1980; Zellner & Kautz, 1990).

Also, it is important to look at the incentives of the panellist's themselves. The study might suffer harm if one or several panellists' loose motivation or fail to perform during the assessment. The panel should not be driven solely by compensation, but they should always be motivated in some way (Gimenez *et al.* 2012).

2.4.2 Descriptive Analysis Techniques

This methodology is regarded as a highly sophisticated method for sensory analysis, and it is often applied when the sensory evaluation serves to describe the differences between food samples or measure the specific level of difference (Lundgren, 1981). In general, a descriptive test includes a trained panel consisting of eight to twelve panellists who work with a quantitative scale for intensity of different product attributes in the food product. The scale is often adapted to suit the needs of a specific descriptive technique, but most often a discrete scale with word anchors is used. The scale allows for statistical analysis to be done, and it has been shown that the results of a descriptive sensory analysis is comprehensive and allows the result to be related to consumer preference tests (Stone & Sidel, 2004).

There are several types of descriptive analysis techniques such as Flavour Profile®, QDA®, Texture Profile® and Sensory Spectrum® (Heymann & Lawless, 2010).

Heymann & Lawless (2010) describes the general steps for conducting a descriptive sensory analysis, and the first step always includes training of the panel. Without sufficient training, the evaluation renders useless results and the work has been in vain. Depending on what types of descriptive study is performed; the panel may be trained using a consensus or ballot approach. The two types differ in the way the describing product attributes are deduced during the training phase. During consensus training the panellists are exposed to different reference products, and during silence each member proposes attributes that correctly describes the product. All members then compile a list of all attributes found, and the list is refined during the subsequent training sessions. For ballot training, the panel leader presents a list of compiled attributes that the panel then work according to. Sulmont *et al.* (1999) found that consensus training helps panellists to perform better, with the exception of meat studies which include a very narrow range of descriptive attributes.

It is important to determine the panel's reproducibility before the actual products are evaluated. This is usually done be presenting samples in triplicates and conducting at least three separate evaluation sessions (Heymann & Lawless, 2010). Statistical analysis of the results reveals if there are any inconsistencies between the panel members, and all inconsistencies should be corrected by additional training sessions. The actual evaluation phase should follow the principles of good practise, and the samples are typically served in duplicates. Most panels evaluate the samples monodically, that is all attributes for a specific sample is evaluated separately. In some cases, the samples are examined by all panel members seated together around a table and the intensity of the attributes is decided upon by consensus. This is often referred to as *consensus profiling* (ISO 13299, 2010) and the method allows for more samples to be tested at the same time by fewer trained individuals.

2.5 Shelf Life Testing

Shelf life testing is an important part of the quality maintenance in the food industry, and for food producers the concept represent the time period for which top quality can be guaranteed (Young, 2011). Most food product does however, remain fresh for several days after their shelf life date if the product is stored and distributed correctly (IFST, 1993). Some more sensitive products that are prone to bacterial spoilage are marked with an expiry date which indicates that the product should not be consumed after the set date.

Performing tests to determine the shelf life of food prone to microbiological spoilage is easily done by different microbiological essays (Heymann & Lawless, 2010). Other quality aspects are more important when dealing with shelf life estimations of products where microbiological spoilage is not the main deterioration pathway that occurs. Chemical changes, enzymatic deterioration and vapour migration is best analysed by sensory evaluation (Gacula, 1975). According to Giménez *et al.* (2012) the basic set up for a sensory shelf life test includes:

1. *Determination of the objectives of the study*
2. *Getting representative samples of the product*
3. *Determining of the relevant chemical and physical composition of the product*
4. *Selecting the storage conditions*
5. *Setting up the test design*
6. *Selecting an appropriate methodology*
7. *Setting up the criteria's for the sensory evaluation*
8. *Conducting the experiments*
9. *Analysing the results and estimate the shelf life*

In order to obtain valid results from a shelf life study there are several strategic choices to be made. The storage conditions should in general mimic the conditions met by the product during storage and distribution (Heymann & Lawless, 2010). For example, no valuable results can be collected from measuring sensory changes in ice cream if it is stored at room temperature. Also, a sensory evaluation study relies on the proper reference or control products which should remain unchanged throughout the sensory evaluation. It is also important that the small difference that naturally occurs between product batches does not interfere with the reference products. Ideally the reference samples is collected from the same batch as the test products, and stored in such a way that the reference samples remain unchanged. One approach is to freeze the reference samples or use a so-called reversed test design so that all samples including the references is tested in the same day (Giménez *et al.* 2012).

When working with sensory evaluation, a proper cut-off point also needs to be established. The cut-off point indicates that the product has reached a pre-determined point which indicates product failure. The product is no longer saleable and it has reached the point where the quality falls below what is acceptable. The cut-off point may be decided upon based on several different considerations. Heymann & Lawless (2011) states some possible approaches that may be used including a significant difference found through the use of discrimination tests or consumer rejection data. If no such data is available the labelling might serve as a basis for a cut-off point. The shelf life represent a point in time where the food producer find the overall quality to drop below acceptable standards, although this might have little correlation to actual consumer acceptance (Giménez *et al.* 2012). There are no legal constraints for the formation of off-flavours in sauces, and hence the producer is left to arbitrarily choose the value.

2.5.1 Accelerated Shelf Life Testing

Although full length shelf life studies provide the most accurate results, problems occur when products have a shorter development phase in comparison with the actual shelf life. Full length storage tests do not only demand a considerable investment in time, but they are also expensive to perform. One approach is to accelerate the shelf life by the increase of some environmental factor, and then using a kinetic model to predict the actual shelf life (Mizrahi, 2011).

Temperature is the single most used factor for accelerating deterioration in food products. The popularity is due to the fact that temperature is easily controlled, and that the results can be readily converted into describing shelf life for normal storage conditions using kinetic models such as the Arrhenius model. As pointed out by Manzocco *et al.* (2012) not all quality deterioration processes are similarly accelerated by temperature alone. The use of temperature as an accelerating factor in ASLT studies is dependent on the thermal activation energy of the chosen depletion process. A low thermal activation energy level, that is negligible temperature dependence, indicates very little change in deterioration rate in the food product with an increased temperature. Hence, the main purpose of ASLT is lost. Low thermal activation energy is also associated with light-induced deterioration of food in food products rich in lipids, pigments or vitamins (Ramírez *et al.* 2001; Kristensen *et al*, 2001). Manzocco *et al.* (2012) has shown that the combination of light and temperature induce deterioration faster and more efficiently than by temperature alone in a study performed for vegetable oils. Pizza topping is prone to oxidation, and contains as much as 50 % vegetable rapeseed oil while the Taco sauce has a high amount of the pigment lycopene. One might therefore suspect that the two products chosen for this study could show a faster deterioration if exposed to both high temperatures and light.

It is also important to note, that even if the deterioration will increase with high temperatures, using temperatures over 50 °C might cause other deterioration processes to take place which is not seen at normal storage temperatures. Food is a complex product with many components that may interact causing invalid results. One example is unwanted phase transitions, and amorphous carbohydrates may crystallize. The water activity may also increase in dry foods which causes an increase in reaction rates (Heymann & Lawless, 2010). ASLT studies have the potential to considerably shorten the shelf life testing period, but the pitfalls should not be neglected.

Taoukis & Labuza (1996) defined quality loss as either the loss of a quantifiable substance A or the formation of the unwanted quantifiable substance *B.* The reactions may be expressed by the following equations (2.1 and 2.2).

$$\frac{d[A]}{dt} = \mathrm{k}[A]^{n} \qquad \text{eq. 2.1}$$

$$\frac{d[B]}{dt} = \mathrm{k}[B]^{n'} \qquad \text{eq. 2.2}$$

k and k' denotes the reaction rate, while n and n' represent the reaction order. If A and B is integrated as a linear function the equation can be expressed as follows at t = 0,

$$F(A) = kt \qquad \text{eq. 2.3}$$

F(A) denotes the level of quality and is highly dependent on the order of the reaction. A zero order reaction is seen as a straight line when the concentration is plotted against time as described by $F(A) = A_0 - A$, while a first order reaction is found when $F(A) = lnA_0 - lnA$. Second order reactions are dependent on one second order reactant or two first order reactants, and takes the form of $F(A) = \frac{1}{A_0} - \frac{1}{A}$. When dealing with food deterioration, especially if the deterioration is caused by microbial activity or chemical processes, the most common order of reactions is either zero order or first order.

2.5.2 Light and Temperature as Accelerating Factors

Most ASLT studies is performed using temperature as the single accelerating factor, and the most common way of describing the rate of deterioration in relation to temperature is by the Arrhenius Equation (eq.2.4).

$$k = k_0 exp\left(-\frac{E_a}{RT}\right) \qquad \text{eq. 2.4}$$

In the Arrhenius equation, k is the reaction rate constant expressed in kJ/mol K, k_0 the Arrhenius equation constant, E_a denotes the activation energy in kJ/mol, T represent the absolute temperature expressed in K and R the universal gas constant of 8,3144 J/mol K (Mizrahi, 2011).

The activation energy (E_a) is given by eq. 2.5:

$$lnk = lnk_0 - \frac{E_a}{R}\left(\frac{1}{T}\right) \qquad \text{eq. 2.5}$$

E_a can also be found by plotting ln(k) versus 1/T in a graph. Although the activation energy is imaginative in a way, it serves as an indicator of how prone a food item is to deterioration and helps predict how a food product will react at different temperatures (Heymann & Lawless, 2010). According to Manzocco *et al.* (2012) the activation energy for most food systems may range from as low as 2-5 kJ/mol to as much as 300-400 kJ/mol, and a low activation energy (E_a < 50 kJ/mol) dictates a scarce temperatures dependence. If a food product has low temperature dependence, elevated temperature will not induce any significant increase in reaction rate of the deterioration. For high E_a (>50 kJ/mol), the opposite is true and the reaction rate of the deterioration marker will increase with elevated temperatures.

ASLT studies are often performed at temperatures 10 °C apart, which enables the so called Q_{10} – factor to be calculated from equation 2.6:

$$Q_{10} = \frac{k_T + 10}{k_T} = \frac{S_T}{S_T + 10} \qquad \text{eq. 2.6}$$

k_T + 10 and k_T denotes the rate constants for the corresponding shelf life estimates S_T and S_T + 10 at the temperatures T and T + 10 (Heymann & Lawless, 2010). From this relationship, an alternative way to deduce the activation energy can be found by using equation 2.7:

$$ln(Q_{10}) = \frac{10E_a}{RT^2} \qquad \text{eq. 2.7}$$

One of the advantages of using Q_{10} lies in the fact that the activation energy can be calculated using only two separate measurements. The method is also fairly straightforward (Sewald & DeVries, 2003) The Q_{10} – factor helps predict the time-temperature relationship from ASLT tests, and in order to convert the result into normal storage condition temperatures the accelerating factor, *AF*, is needed. If the E_a is known, *AF* is deduced from equation 2.8.

$$AF = exp\left[\frac{E_A}{R}\left(\frac{1}{T_x} - \frac{1}{T_{test}}\right)\right] \qquad \text{eq. 2.8}$$

Where, T_x = Actual (user) storage temperature in K, and T_{test} = Accelerated test temperature in K. Once the *AF* is known, the failure time (*FT*) can easily be found by multiplying the number of days before the cutoff point is met by the *AF* (eq. 2.9):

$$FT = FT_{test} \times AF \qquad \text{eq. 2.9}$$

In order to ensure that the confidence limits are narrow, at least five or six different temperatures are recommended for the Arrhenius equation, while the Q_{10} – modeling only requires at least two different temperatures (Taoukis & Labuza, 1996).

It has been suggested that light is an efficient accelerating factor for photosensitive foods such as the pizza topping is suspected to be (Kristensen *et al.*, 2001; Ramírez *et al.* 2001). The high amount of vegetable oil indicates that rate of rancidity formation may be increased by the utilization of light in combination with high temperatures. In a study by Manzocco *et al.* (2012) the accurate estimation of the shelf life for soybean oil could be reduced to just two days under the illumination by 5000 lx at 30 ° C in comparison to 2-3 weeks with the illumination of 600 lx at 20 °C. The study found that the data representing light intensity in comparison to oxidation rate could be described by a simple Power Law equation (eq 2.10):

$$k = k_d + E_{l1} \times L^{E_{l2}} \qquad \text{eq. 2.10}$$

Where L is the light intensity (lx), k_d denotes the reaction rate under no illumination while E_{l1} and E_{l2} represent the electromagnetic energy needed to induce the deterioration reaction in photosensitive food and the values are similar the E_a for thermal reactions (Manzocco *et al.* 2012).

In the study by Manzcco *et al.* (2012), the authors showed that when studying the values of E_a and the estimated reaction rates for the food stored without illumination, the temperature dependence of E_{l1} and E_{l2} could be described by the equation of a straight line (eq 2.11)

$$E = m \times T + q \qquad \text{eq. 2.11}$$

E represents the values of E_{l1} or E_{l2} while m and q are simply the regression parameters of the equation. In short terms, equation (2.11) illustrates the effect of temperatures on light activated deterioration if the food is stored under illumination.

In order to facilitate the use of both temperature and light in an ASLT study, the combination of both accelerating factors light and temperature was combined into one equation by Manzocco *et al.* (2012). The Arrhenius equation was substituted into the Power Law equation in order to predict the deterioration rate under different conditions (eq. 2.12).

$$k = k_{ref} \times e^{-E_A\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)} + (m_1 \times T + q_1)L^{(m_2 \times T + q_2)} \qquad \text{eq. 2.12}$$

It might be expected that light and temperature act in a synergistic manner for food products with scarce temperature dependence, which would lead to the prediction that the combination of the two factors light and temperature could lead to a dramatically decreased storage time when performing ASLT.

Material and Methods

The study was performed using temperature and light as the accelerating factors for both sauces. The results were evaluated using descriptive sensory analysis with an in-house expert panel in combination with the measurement of pigmentation. The shelf life prediction was based on the Arrhenius equation only, since no significant change between the levels of the deterioration marker for light and temperature could be seen. Hence light was omitted from the results as an accelerating factor for the sensory analysis results.

3.1 Experimental Design

The two types of sauces were collected directly from the production plant in Kungsbacka, Sweden. All samples were from the same batch, and the Taco sauce was tasted to ensure that the sauce had a mild chili heat. The fresh reference samples were also collected from the batch while samples close to the best before date was found at the reference stock held by Santa Maria. For this shelf life study, LED-lights was installed in the existing incubators at the manufacturing plant in Mölndal (Sanyo Gallenkamp Prime Incubator, INC-000- MA1.9), and the light was measured with a lux-meter by an in-house electrician. The temperatures was set to 22 °C, 30 °C and 40 °C, and the temperature was checked by the use of an external thermometer during several separate measurements. Half of the samples were covered with aluminium foil to prevent the light from interacting with the samples. During the test period, samples were collected once a week and after the sensory analysis the samples was kept refrigerated until the pigmentation was measured at Swedish University of Agricultural Sciences, BioCentrum in Uppsala. For the colour analysis, a spectrophotometer was used (Konica Minolta CM-600d).

3.2 Descriptive Sensory Evaluation

The sensory evaluation was performed by an expert in-house panel consisting of four individuals working at Santa Maria AB in Mölndal. All individuals had previous experience from working with sauces and performing sensory analysis. The panel used a discrete scale that ranged from 1 to 5 with the word anchors *none* to *very strong* describing the product attributes. The scale has previously been developed by Santa Maria AB and used by the panel during similar sensory analysis tests. In order to create a complete list of all relevant attributes the panel was presented with several samples of both sauces ranging in age from fresh to well pass the stated best before date. The panel compiled a list through consensus after tasting and smelling the samples, and the list was refined during three separate sessions. In order to establish that all panel members describe the listed attributes with the same word, some reference samples were brought to the panel (Table 3.2.1)

Table. 3.2.1. *Reference samples used for sensory training and product attributes.*

Attribute	***Scale value[a]***	***Product reference***
Pizza Topping		
Herbs	*5.0*	*Pizza Topping Spice Mix (Santa Maria AB)*
Acidity	*4.0*	*Vinegar diluted by water (1:4) (Zeta AB)*
Rancidity	*5.0*	*Line Seed Oil (Zeta AB)*
Off-flavour	*1.0*	-
Taco Sauce		
Acidity	*4.0*	*Taco Sauce Mild (Santa Maria AB)*
Tomato Sweetness	*4.0*	*Canned Crushed Tomatoes (Delizie)*
Off-flavour	*2.0*	*Canned Crushed Tomatoes (Kung Markatta)*
Crispness Onion bits	*5.0*	*Raw Yellow Onion (Sliced)*
Crispness Tomato bits	*5.0*	*Swedish Unripe tomatoes (Red Round, cut into cubes)*

[a] *All of the above values run from 1 to 5.*

The training step of the panel members was evaluated during three separate sessions for each sauce where the panellists were exposed to triplicates of the collected reference stock. The panel was told that the real storage test had begun, and that the samples they tested was actual test samples. The product attributes was rated individually for each sample, and the training results was analysed by Minitab® Statistical Software using ANOVA in order to determine panel reproducibility. A General Linear Model, or GLM, was performed where the interaction effect for each panellist was determined. The statistical investigation revealed that no member required extra training.

During the actual product tests, the tempered and randomized samples were presented in paper plates to the panellists. Through consensus profiling, the panel decided upon the correct intensity of the attributes. A red light- setting was used when the panel was working with the Taco sauce in order to avoid any unwanted colour-flavour interaction if the sauce showed discolouration. The evaluation continued until the sauces reached the pre-determined point of quality loss that corresponds to the intensity of attributes for the best before reference samples.

3.4 Measuring Pigment Degradation in Food

The colour of both sauces was estimated using a spectrophotometer (Konica Minolta CM-600d). The sauces were measured in triplicates after the product was poured into a shallow and wide aluminium container. The sauces were covered by a plastic film before the actual measurement in order to avoid damage to the instrument. Before the measurement, attention was given to remove all air bubbles underneath the plastic film to allow for a smooth test surface. The effects of light, temperature and time were studied by analysis of variance (ANOVA) by the use of GLM (Minitab® Statistical Software).

Results

The results obtained from the performed ASLT tests are presented visually on plots as well as the resulting values for E_a, *AF*, *FT* and the corresponding Q_{10} – factor. The measured values from the reference samples for sensory attributes and pigmentation analysis are presented in Table 4.1 and Table 4.2.

Table 4.1. *Sensory analysis of reference samples for Pizza topping and Taco sauce. All values range from 1 to 5 and are calculated mean values.*

Taco sauce					
Attribute	***Sweetness***	***Acidity***	***Off-flavour***	***Hardness, tomato***	***Crispness, onion***
Fresh	2	3	1	2	4
Best before	2	3	3	3	3
Pizza topping					
Attribute	***Herbs***	***Acidity***	***Rancidity***	***Off-flavour***	
Fresh	1	4	1	1	
Best before	2	3	3	3	

Table 4.2. *Reference values for Colour Analysis.*

Taco sauce			
Values	***L****	***a****	***b****
Fresh	29.17	19.22	16.36
Best before	26.16	17.65	17.85
Pizza Topping			
Values	***L****	***a****	***b****
Fresh	78.11	3.06	17.18
Best before	78.74	3.51	19.04

4.1 Sensory analysis of Pizza topping

The Pizza topping showed only small sensory changes during the assessment period of eight weeks for the temperatures 22 °C and 30 °C. For the highest temperature, 40 °C, sensory changes corresponding to the cut off-point was seen for all attributes. When the sensory analysis results were examined by the use of GLM with a confidence interval of 95 %, only the attribute "Rancidity" showed any statistically significant change. A GLM test for the parameters "Light", "Temperature" and "Date" also revealed that the light did not act as an accelerating factor for the deterioration of the sensory attributes of Pizza topping. The results from the Pizza topping exposed to light in combination with temperature were therefore excluded from the analysis of the sensory results. Instead the shelf life under normal storage conditions was deduced from eq. 2.4 by the use of the sensory data from the sauce which had been exposed to temperature alone.

Due to the fact that "Rancidity" was the only attribute that changed during storage, Figure 4.1.1 depicts only the change of rancidity over time stated in weeks. The attribute "off-flavour" also showed a significant change during the assessment period, however, it was concluded that the attribute "off-flavour" and "rancidity" were the same quality deterioration. This conclusion was based on the fact that the two attributes was coupled to each other and comments left by the panel strengthened this belief.

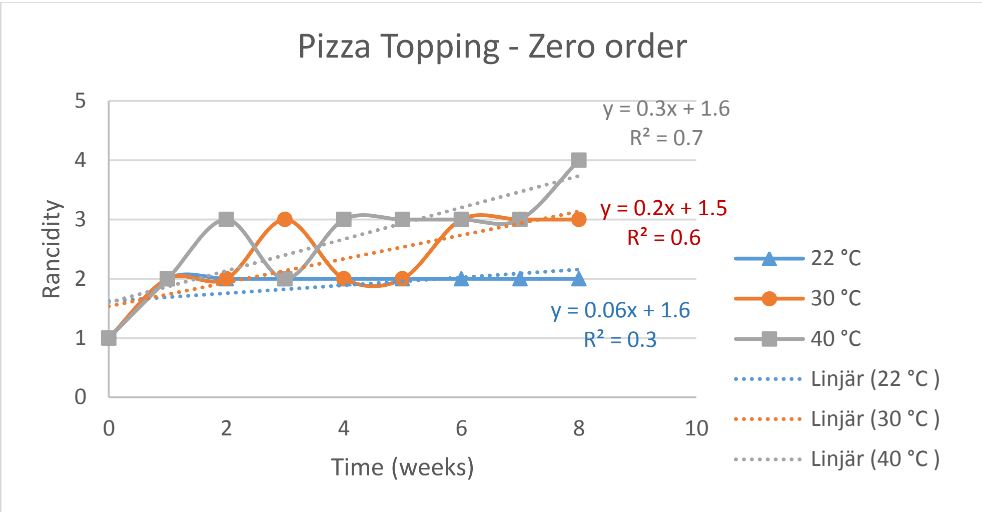

Figure 4.1.1. *Intensity of rancidity of Pizza topping plotted in a scale ranging from 1 to 5 against time (weeks). The equation of the linear trend line as well as the correlation coefficient R^2 can be seen in the graph for each temperature.*

It was assumed that the reaction followed zero order kinetics despite the fact that R^2 was found to be range between 0.3 for 22 °C to 0, 7 for 40 °C.

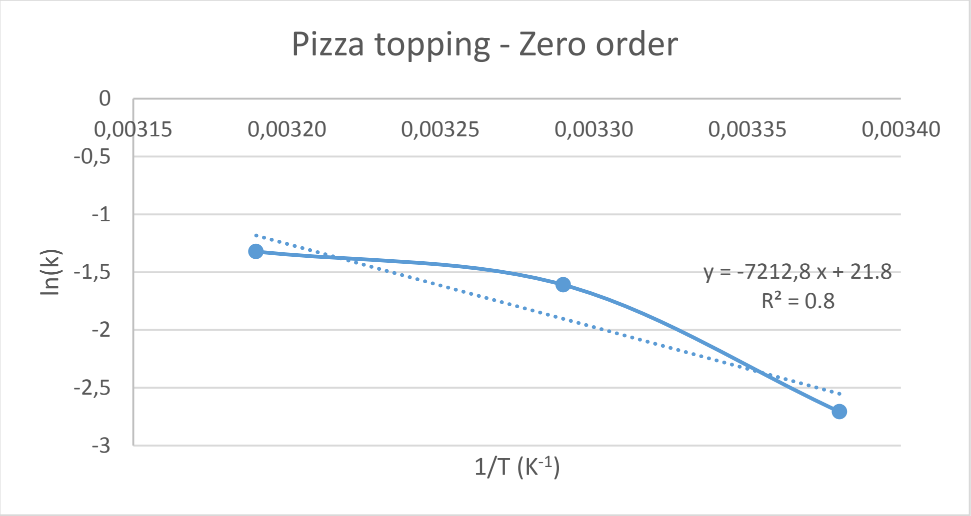

Figure 4.1.2. *Zero order Arrhenius plot for intensity of rancidity for Pizza topping with equation of the trend line shown in the graph, as well as the correlation coefficient* R^2.

The Arrhenius plot was found by plotting the natural logarithm of the reaction rate constant *k,* versus the inverse temperature in Kelvin. The plot also gives an indication through the activation energy of how prone the sauce is to develop a rancid flavour by exposing the product to elevated temperatures. The activation energy can be deduced from the slope seen in the Arrhenius as $-E_a/R$. For the Pizza topping, the E_a was found to be 59.97 kJ/mol. If the E_a is known, the so called accelerating factor AF can be found by exponentiation of the activation energy. By using the AF, which was estimated to be 4.8, the shelf life of the product could be found based on how fast the topping deteriorate at 40 °C. On average, the topping will remain unaffected by rancid flavour for 269 days, or around 9 months. This corresponds to the stated shelf life that is used today by Santa Maria AB.

The Q_{10} – factor was estimated to be 1.33. These values indicates that the time needed for reaching the cut-off point for rancidity will be 1.3 times shorter for every 10 °C rise in temperature.

4.2 Sensory analysis of Taco sauce

The Taco sauce was subjected to few changes in the sensory composition of flavours during the assessment period. The only attribute that reached the pre-determined cut-off point was "off-flavour" and the following calculations were based on that attribute only. The Taco sauce was also not affected by light when viewing the results from the sensory profiling. This was confirmed by running a GLM with a 95%- confidence interval. The deterioration of the Taco sauce was assumed to also follow a zero order reaction since the linear slope plotted for the intensity of off-flavour versus time showed the best linear fit despite the fact that the correlation coefficient R^2, ranged from 0.17 to 0.79. This plot is showed in Figure 4.2.1.

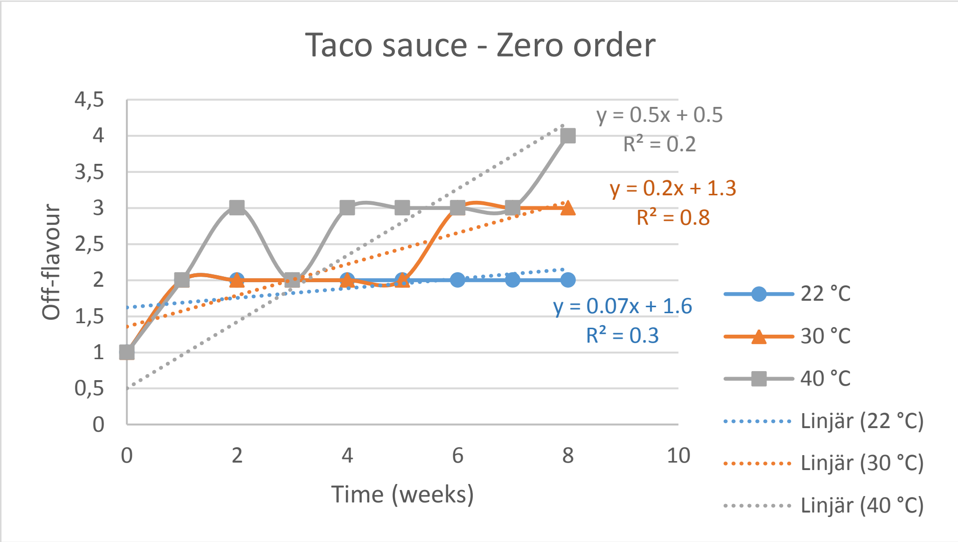

Figure 4.2.1. *Intensity of "off-flavour" for Taco sauce from 1 to 5 is plotted against time (weeks). The equation of the linear trend line as well as the correlation coefficient R^2 can be seen in the graph for each temperature.*

The Arrhenius plot was composed by plotting the natural logarithm of the reaction rate against the inverse temperature in Kelvin and the plot is shown in Figure 4.2.2. The activation energy was estimated to 84.17 kJ/mol, which indicates that the flavour stability of Taco sauce is more temperature dependent than the flavour stability of Pizza topping, which showed an E_a of 59.97 KJ/mol. For the Taco sauce, an AF factor of 9.09 was calculated which gives an average shelf life for flavour to be 509 days or 17 months. This correlates to the stated 18 months shelf life used by Santa Maria today. The corresponding Q_{10} –factor was estimated to 2.13.

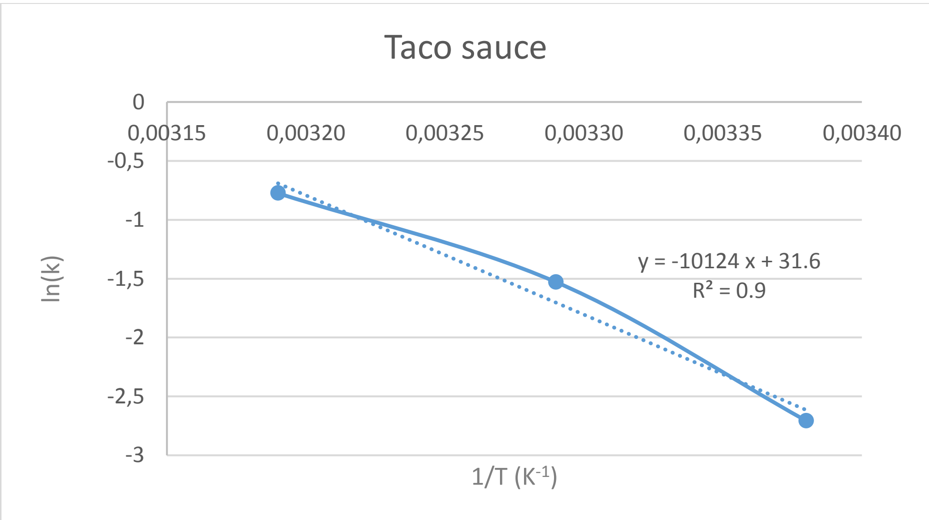

Figure 4.2.2. *Zero order Arrhenius plot for intensity of "off-flavour" for Taco sauce with equation of the trend line shown in the graph, as well as the correlation coefficient R^2.*

4.3 Colour Analysis – Pizza topping

The Pizza topping showed a clear change in colour nuance from lighter white to darker beige during the assessment period. No statistically significant change in a* - values or b* - values was detected and the colour change did not seem to be related to light. Instead, after assessing the relationship between both accelerating factors and the recorded deterioration by the use of ANOVA and a general linear model (GLM), temperature was the only factor affecting deterioration with p>0.05.

The graph showed the best linear fit for a zero order kinetic model with R^2-values ranging from 0.30 for 22 °C to 0.78 for 40 °C. However, also the second order approach seemed appropriate at first view but when plotting the corresponding curved Arrhenius model (1/ (L*) versus 1/T in Kelvin) it was clear that the reaction was better described by a zero order approach. It was assumed that since the colour analysis measure a colour nuance changing from light to dark, rather than an actual formation or degradation of a substance, the negative values of the slope for L* versus time was disregarded.

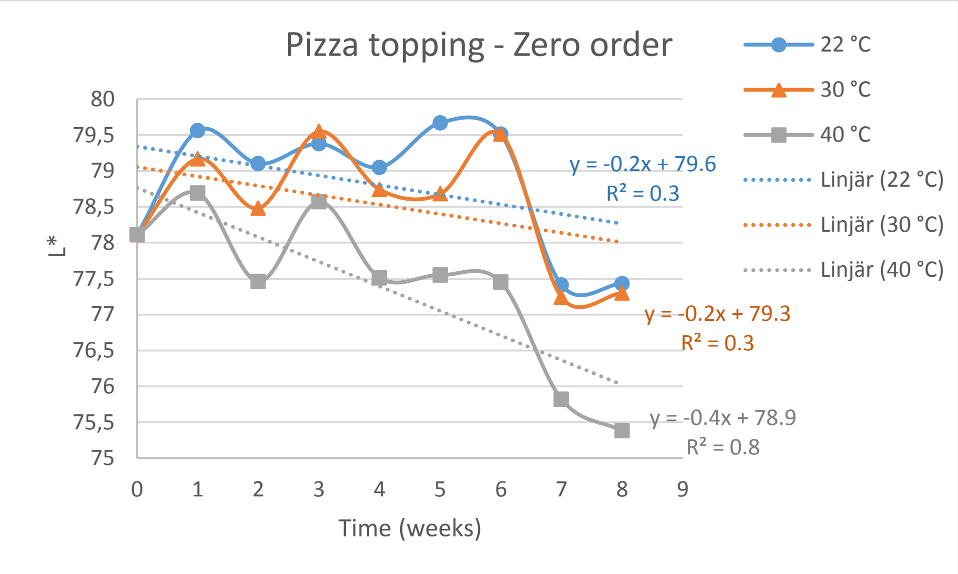

Figure 4.3.1. *L* values for Pizza topping plotted against time (weeks). The equation of the linear trend line as well as the correlation coefficient R^2 can be seen in the graph for each temperature.*

E_a was estimated to be 133.37 kJ/mol which results in an AF-factor of 29.96. This implies that the average shelf life for colour stability is 1677 days or 4.5 years. The corresponding Q_{10} –factor is 2.2.

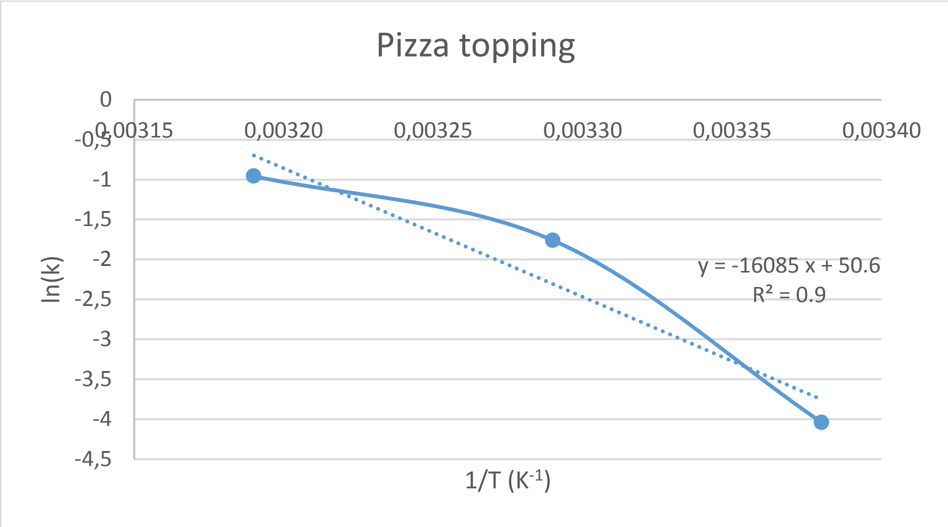

Figure 4.3.2. *Zero order Arrhenius plot for lightness for Pizza topping with equation of the trend line shown in the graph, as well as the correlation coefficient* R^2.

4.4 Colour Analysis – Taco sauce

The values obtained from the colour analysis of Taco sauce was somewhat biased by the fact that the pieces of onion and jalapeño caused shadows and an uneven surface during the measuring of the pigmentation. It could be seen however after performing an interaction plot in Minitab® Statistical Software, that the value b* followed a trend while L* and a* was found to change order of kinetics after about four weeks of the study. This suggests that several different types of chemical reactions are taking place within the food matrix, and the complexity of the processes make any prediction of quality change unreliable. The obtained data did not allow for any shelf life to be estimated using standard kinetic procedures and hence the measurements were omitted from further processing.

Discussion

This chapter discusses the results in the light of the theoretical background presented in Chapter 2. The result differs somewhat from what was expected and some potential explanatory aspects are provided.

The Pizza topping was estimated to retain flavour quality for at least nine months based on the sensory test values calculated using the Arrhenius equation. This corresponds to the current shelf life stated by the manufacturer of the sauces (Santa Maria AB). The colour analysis yields a potential shelf life of nearly 5 years. This value was based on the change in lightness of the sauce (L*) and the colour will remain stable for a considerably longer period of time in comparison to the actual flavour of the topping. This is only expected from a product based on vegetable oil, prone to oxidation which impairs the flavour rather than the colour. However, one must also remember that the reference samples for Pizza topping did only show a small change in rancid taste from 1 to 3 on a scale ranging from 1 to 5. One might suspect that an average consumer would not be able to distinguish between a stored sample and a fresh. This finding might lead to questioning the current shelf life and whether there is potential for extending the stated shelf life of the pizza topping. A longer shelf life is both desirable from a profit view, but also helps reduce the amount of products being rejected as waste. It is of course a sensitive question since a consistent quality level throughout the products shelf life helps ensure consumer satisfaction.

The consistent and rather high quality found for pizza topping differs from what might be suspected to find in a high fat product. The topping is also pasteurized during the manufacturing process and the preservatives added inhibit microbial growth. The main quality deterioration process should therefore be due to the development of rancidity. According to the literature (Manzocco *et al.* 2012; Kristensen *et al.*, 2001; Ramírez *et al.* 2001) this type of high fat product should also be sensitive to light exposure, which a GLM ($p>0.05$) for the influence of light found insignificant. The ASLT results also indicate that the products should be influenced to some extent by light since the activation energy was found to be in the range of 50 kJ/mol. Since no influence of light was seen or any significant development of rancidity, some type of inhibitory process was believed to be present in the finished product. The explanation that was most likely pointed to some type of residual antioxidant activity left in the topping from the pasteurization step. This was investigated by Santa Maria, and residual antioxidant activity was found in the heat treated rapeseed oil. The decision was made to keep the current process and the word “antioxidant” will be added to the ingredient list during the next printing.

The Taco sauce showed very little change in sensory quality for the lower temperatures 22 °C and 30 °C during the storage test. The estimated shelf life for retained flavour quality calculated from 40 °C using the Arrhenius equation was 17 months. This corresponds to the shelf life used by Santa Maria AB today. For the colour analysis, some inconsistencies in the measured values might be explained by the difficulty in making correct measurements from a sauce containing big pieces of onion and jalapeños. The pieces caused an uneven surface and shadows which may have affected the measurements. When analysing the data with statistical tools, no correlation of light to colour change was found. It was also found after performing an interception plot that the values of L* and a* seemed to change kinetic order after about four weeks while b* seemed to follow a trend. It has been suggested that this is due to the complex web of chemical reactions occurring in the food matrix. Any predictions of shelf life becomes unreliable when no significant trend for quality change can be detected, and it was concluded that colour analysis for Taco sauce is not a reliable way of estimating shelf life by kinetic models. By removing any pieces from the liquid before performing a colour analysis of similar sauces the results will most certainly display more cohesive results and colour analysis for tomato based sauces should not be ruled out based on the results from this study.

A so called Q10- factor was also calculated for both sauces based on the sensory analysis. However, when using the Q_{10} – factor all shelf life values was considerably decreased. Q_{10} – modelling offers a more simple and fast approach to the estimation of activation energy, but the use of the Arrhenius equation results in more realistic numbers and both sauces was found to retain quality longer than stated by the Q10- model. This is to be expected since working with Q_{10} – modelling only requires two separate measuring points while the general recommendation for Arrhenius equation is at least three and some sensitivity is naturally lost when using Q_{10}-modeling. The advantage of Q_{10} – modelling is however, that a Q_{10} – factor may be deduced which allows for quick and easy estimations of shelf life for other similar products.

ASLT has been proven to be a valuable tool for estimating shelf life in a time-saving manner in previously done studies, but it has also been pointed out that working with kinetic models in order to extrapolate a prognosis is difficult and requires accurate data. The advantages of ASLT can possibly become a burden if the data is misinterpreted or handled incorrectly. The need for precise measurements has also been seen in this study. The study showed that there is very small changes between a fresh and a stored product, and one might suspect that the scale used during the sensory analysis were too rough to detect those changes correctly. This was even noted by the expert panel during some assessments as they felt reluctant to increase the rating of the attributes by one whole step, even though they detected a difference.

Also, for this study a consensus profiling method was used. This allows for more samples to be tested at each assessment by a smaller panel and the method is in general time-saving. The ability to test more samples at one occasion was important for this particular study, since the Arrhenius equation calls for at least three separate test temperatures for both sauces and accelerating factors. The recruitment was also done in-house which limits the number of panel members and consensus profiling generally requires fewer panel members (ISO 13299, 2010). However, working with consensus profiling includes some drawbacks since no monitoring of panel performance can be done during the assessment period which is generally recommended (Heymann & Lawless, 2010). As it has been pointed out, ASLT based on sensory analysis only measures the overall quality level, and it is worth remembering that the results could potentially be different if only one substance reacts in a different way in the intricate web of chemical processes that determine food quality. Sensory analysis is therefore a preferred tool and it makes no sense to disregard the collective strength of the human senses and rely only on quantitative values measuring a small fraction of what is considered to be quality by the consumer.

Conclusion and further work

ASLT could be used as a valuable tool to indicate shelf life for sauces or raw materials but further tests needs to be done before any conclusive results can be obtained for these particular tested products. Further test could yield more reliable Q_{10} – values.

The results in this study should be used with care due to some biases, but the study does suggest that the shelf life used today is estimated correctly. The study also raises some questions regarding the potential for extending the current shelf life of the two products. A decision to extend the shelf life could potentially increase the profit and minimize waste, but it is the consumer's perception of consistent top quality that should act as a determinant for such a decision. Potentially reduced product cost could be the result if this is investigated further with a more sensitive ASLT.

If proceeding with ASLT, it is important to consider using another scale if the quality measurements are done by sensory analysis. A more sensitive scale would allow the detection of the small decrease in quality found between stored and fresh products. Also, despite the fact that the sauces showed no significant influence from the effect of light the activation energy for the Pizza topping suggests that without the protecting effect of an antioxidant, the product will deteriorate faster by light exposure. It would therefore be of interest to investigate the deterioration for similar products where the antioxidant is not presence. In the light of the results for the Pizza topping, some type of fatty acid composition analysis should also be done for the rapeseed oil since the proneness for the development of rancid flavour is dependent on the actual composition of the oil. The light setting used for this study was as stated fairly low in intensity and an increase in lux-strength could possibly have a larger impact on the product.

References

Adams, M.R., & Moss, M.O. (2008) Food Microbiology. 3rd Edition. RSC Publishing, Cambridge.

Alander, J., Andersson, A., Bagge, C, Helmbring, G., Hjorth, M, Hägre, J., Komen, G., Kristoffersson, C., Modig, M., Nilsson, J., Norberg, S., Pedersen, M., Wennermark, B., & Wennermark, M. (2002). Handbook – Vegetable Oils and Fats. *Karlshamns Oils & Fats Academy*, Karlshamn.

Earle, M., Earle, R., & Andersson, A. (2001) Food Product Development. Boca Raton, FL: CRC Press

Conn, P. F., Schalch, W., and Truscott, T. G. (1991). The singlet oxygen and carotenoid interaction. *Journal of Photochemistry and Photobiology*, 11**,** 41–47.

Corriher, S. (1997). Cookwise, the hows and whys of successful cooking. 1st Ed. New York: William Morrow & Company, Inc.

Coultate, T. (2009). Food – The chemistry of its components. 5th Edition, RSC Publishing

Dethmer, A.E. (1979). Utilizing sensory evaluation to determine product shelf life. *Food Technology*, 33, 40-43

Di Mascio, P., Murphy, M. C., & Sies, H. (1991). Antioxidant defense systems, the role of carotenoid, tocopherol and thiols. *American Journal of Clinical Nutrition*. 53, 194-200.

D'Souza, M. C., Singha, S., & Ingle, M. (1992). Lycopene concentration of tomato fruit can be estimated from chromaticity values. *Horticultural Science*, 27, 465–466.

Dubose, C.N., Cardello, V.A., & Maller, O. (1980). Effects of colourants and flavourants on identification, perceived flavour intensity and hedonic quality of fruit-flavoured beverages and cake. *Journal of Food Science,* 45, 1393-1399, 1415.

Gacula, M.C. (1975). The design of experiments for shelf life failures. *Journal of Food Science,* 40, 399-403.

Giménez, A., Ares, F., & Ares, G. (2012). Sensory shelf-life estimation: A review of current methodological approaches. *Food Research International,* 49, 311-325.

Harcar, T., & Karakaya, F. (2005). A cross-cultural exploration of attitudes towards product expiration dates. *Psychology & Marketing*, 22, 353-371.

Hart, D. J. and Scott, K. J. (1995). Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chemistry,* 54, 101–111.

Heymann, H. Lawless, H (2010) Sensory Evaluation of Food. Principles and Practices. 2nd Edition, Food Science Text Series, Springer Link

Hough, G. (2010). Sensory Shelf Life Estimation of Food Products. Boca Raton: CRC Press, Taylor & Francis Group.

Kilcast, D. & Subramaniam, P. (2011). Introduction. In: Kilcast, D., & Subramaniam, P. (ed.) *The Stability and Shelf Life of Food*. Woodhead Publishing Limited.

Kotler, P., Armstrong, G., Wong. V., & Saunders, J. (2008) Principles of Marketing. 5th Edition. *FT Prentice Hill,* London.

Kristensen, D., Hansen, E., Arndal, A., & Tinderup, R.A. (2001). Influence of light and temperature on the colour and oxidative stability of processed cheese. *International Dairy Journal,* 11, 837-843

Kristott, J. (2011). Fats and Oils. In: Kilcast, D., & Subramaniam, P., (ed.) *The Stability and Shelf Life of Food*. Woodhead Publishing Limited.

IFST (1993). Shelf life of foods: Guideline for its determination and prediction. *Institute of Food Science and Technology,* London.

ISO 13299 (2010). Sensory analysis- Methodology – General guidelines for establishing a sensory profile. *SIS Swedish Standard Institute.* Stockholm: SIS Förlag AB.

Jaeger, S.R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference,* 17, 132-144.

Leistner, L., & Gould, G.W. (2002). Hurdle Technologies. *Kluwer Academic/Plenum Publishers*, 194-195.

Lundgren, B. (1981), Handbook for Sensory Analysis, Swedish Institute of Food Science, Report no 470, Lund.

Manzocco, L., Panozzo, A. & Calligaris, S. (2012). Accelerated shelf life testing (ASLT) of oils by light and temperature exploitation. *Journal of American Oil Chemists' Society,* 89, 577-583.

McClement, D.J., & Decker, E.A., (2008). Lipids. In: Damodaran, S., Parkin, K.L., & Fennema, O.R., (eds.) *Fennema's Food Chemistry,* 4th Edition, Boca Raton: CRC Press, Taylor & Francis Group, 155-216.

Mizrahi, S., (2011). Accelerated shelf life testing of foods. In: Kilcast, D., & Subramaniam, P. (ed.) *The Stability and Shelf Life of Food*. Woodhead Publishing Limited.

Nellman C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., & Prins, A.G. (2009). The environmental food crisis – The Environment's role in adverting future food crises. Norway: United Nations Environment Programme (UNEP)

Ragnarsson, J.O. & Labuza, T.P. (1977). Accelerated shelf- life testing for oxidative rancidity in foods—A review. *Food Chemistry,* 2, 291-308.

Ramírez, G., Hough, G., & Contarini, A., (2001). Influence of temperature and light exposure on sensory shelf life of a commercial sunflower oil. *Journal of Food Quality,* 24, 195-204.

Reische, D.W., Lillard, D.A., & Eitenmiller, R.R. (2008). Anioxidants. In: Akoh, C.C., & Min, D.B., (eds.) *Food Lipids: Chemistry, Nutrition and Biotechnology,* 3rd Edition. Boca Raton: CRC Press

Robertson, G.L. (2006). *Food Packaging, principles and practices.* 2nd Edition. Boca Raton: CRC Press, Taylor & Francis Group

Rozin, P., & Tourila, H. (1993). Simultaneous and temporal contextual influences on food acceptance. *Food Quality and Preference,* 4, 11-20

Shapton, D.A., & Shapton, N.F. (1991). Principles and Practices for the Safe Processing of Food. Butterworth – Heinemann, Oxford

Shi, J., Le Maguer, M., Kakuda, Y., and Liptay, A. (1999). Lycopene degradation and isomerization in tomato dehydration. *Food Science and Nutrition,* 40, 1–42.

Stone, H., & Sidel, J., Sensory Evaluation Practices, In: Heymann, H. & Lawless, H, (2010). Sensory Evaluation of Food. Principles and Practices. 2nd Edition, Food Science Text Series, Springer Link, page 2.

Sulmont, C., Lesschaeve, I., Sauvageot, F., & Issanchou, S. (1999). Comparative training procedures to learn odor descriptors: Effects on profiling performance. *Journal of Sensory Studies,* 14, 467-490

Taoukis, P., & Labuza, T.P., (1996). Summary: Integrative Concepts: Application of Kinetics to Shel-life Modeling. In: Fennema, O.R., (ed.) *Food Chemistry,* 3rd Edition, 1013-1042

Young, N.W.G. (2011) The influence of ingredients on product stability and shelf life. In: Kilcast, D., & Subramaniam, P., (ed.) *The Stability and Shelf Life of Food*. Woodhead Publishing Limited.

Zellner, D.A & Kautz, M.A., (1990). Colour affects perceived odor intensity. *Journal of Experimental Psychology: Human Perception and Performance.* 16, 391-397.

Internet

Gourmetsleuth (2013), *The History of Salsa,* [electronic] Available: http://www.gourmetsleuth.com/Articles/Ethnic-Unique-Foods-Ingredients-645/history-of-salsa.aspx (2013-11-14)

SLV, Swedish Food Administration (2013), *Food Regulation,* [electronic] Available: http://www.slv.se/sv/grupp1/Lagstiftning/ (2013-12-19)

Santa Maria AB (2013), *Our Products,* [electronic] Available: http://www.santamariaworld.com/produkter/ (2013-10-11)

Sewald, M., & DeVries, J. (2003). Food Product Shelf Life. Medallion Laboratories, Minnesota, United States, [Electronic][Brochure]. Available (2013-10-25) http://www.medlabs.com/TechnicalPublications.aspx

Statistical Software

Minitab® Statistical Software, Version 16 (2013).

Acknowledgements

This report is a Master’s Thesis project comprising of 30 hec for the double Degree Master in Food Science and Food Agronomist at the Swedish University of Agricultural Sciences. The project was conducted at Santa Maria AB in Mölndal.

During my time at Santa Maria I met with many highly skilled and wonderful personalities, and I would like to give a special thanks to my supervisors Caroline Jonsson and Gunilla Kjellmer at the R&D department at Santa Maria AB. They have given me countless good advice and helped my work forward many times and without them, the road to a finished thesis would have been considerably longer.

Also I would like to thank my supervisor Roger Andersson at SLU for guiding me through the process of setting up an experiment and analysing the results. More than once, his eye for details has helped me sort out problem.

A warm “Thank you” is also directed to my panel consisting of Anette Zetterqvist, Thorbjörn Lilliebielke, Caroline Jonsson and Gunilla Kjellmer who all spent so many hours tasting sauces and reference samples. I am also grateful for all the advice Anette Zetterqvist has given me on how to conduct a sensory testing experiment, and the employees of the R&D department of Santa Maria AB for the support and warm welcome.

Last but not least, I would like to send my gratitude to my friends and family for their never-ending encouragement and support.

Appendix

Appendix 1. Popular Scientific Abstract

There is a lot to gain from making sure that all food products have a high quality and remain fresh as long as the shelf life states on the package. The competition between food companies are often very fierce, and just one batch of defect products might cause the company to lose market share. It is also very important for food companies to launch new products quickly, before any competitor enters the market with a similar idea.

New and improved products is the way to go if a food company wants to continue to grow, but the creation of a new product is not done without considerable investment of time and money. Many companies also struggles with the fact that these new and improved products often have a long shelf life which outlast the actual development phase of the new food product. The actual estimation of the shelf life is therefore often based on previous experience or knowledge on how similar products behave. Another approach, accelerated shelf life tests, has been proposed to be a way around the problem and through which you can test the actual product itself. In short, this new way of estimating shelf life means that the food is exposed to some type of harsh environment which causes the food to become bad more quickly than during normal storage. Then mathematical equations allows the company to calculate how long time the same process would have taken if the food product were stored normally.

This project intends to evaluate the potential use of accelerated shelf life tests for sauces, and this project looks specifically at Taco sauce and Pizza topping. Taco sauce is a tomato based sauce sold in a glass jar while the Pizza topping is a rapeseed based emulsion sold in a plastic squeeze bottle. The sauces were kept in high temperatures and under intense light for eight weeks. The quality of the sauces was then evaluated every week by tasting and measuring colour.

The results from the evaluations was compiled and looked at by statistical methods and it could be seen that none of the sauces was sensitive to light, but high temperatures made them loose in quality fast. It could also be seen that colour was a poor way of determining product quality. According to the results, the Taco sauce would keep its flavour for 17 months and the Pizza topping would keep for eight months when the kinetic equations were applied. This is roughly the shelf life used today for such products.

The conclusion is that accelerated shelf life tests could be used for estimating shelf life for sauces, but some sources of error in the study suggests that further research is needed before the method is put into practise.

Appendix 2. Scale used for attribute evaluation.

1	None	When you taste the food, you cannot find the attribute at all.
2	Weak	You need to taste and look for the attribute in order for you to detect it. The attribute is present, but the intensity is *weak.*
3	Evident	You can feel the attribute when you taste the product. The intensity of the attribute is *evident.*
4	Strong	You can taste the attribute at once and the intensity is *strong*.
5	Very Strong	The sensation of the attribute is immediate and the sensation *very strong*.

Appendix 3. Raw data from the sensory evaluation

Intensity of attributes

Pizza topping

December 20th, 2013

Sample no.	Herbs	Acidity	Rancidity	Off-flavour
502	1	4	2	1
931	1	4	3	1
728	1	4	2	1
445	2	4	1	1
328	1	4	1	1
678	1	4	1	1

January 7th, 2014

Sample	Herbs	Acidity	Rancidity	Off-

no.				flavour
502	2	3	2	1
931	2	3	2	1
728	1	3	3	1
445	2	3	2	1
328	2	3	2	1
678	2	3	2	1

January 13th, 2014

Sample no.	Herbs	Acidity	Rancidity	Off-flavour
502	2	3	2	1
931	2	3	3	1
728	2	3	2	1
445	2	3	2	1
328	2	3	2	1
678	2	3	2	1

January, 21st, 2014

Sample no.	Herbs	Acidity	Rancidity	Off-flavour
502	2	3	2	1
931	2	3	2	1
728	2	3	3	1
445	2	4	2	1
328	2	4	2	1
678	2	3	2	1

January 27th, 2014

Sample no.	Herbs	Acidity	Rancidity	Off-flavour
502	2	3	2	1
931	2	3	2	1
728	2	3	3	3
445	2	3	3	1
328	2	3	2	1

678	2	3	3	3

February 3rd, 2014

Sample no.	**Herbs**	**Acidity**	**Rancidity**	**Off-flavour**
502	2	3	2	1
931	2	3	3	1
728	2	3	3	2
445	2	3	3	1
328	2	3	2	1
678	2	3	3	2

Ferbuary 10th, 2014

Sample no.	**Herbs**	**Acidity**	**Rancidity**	**Off-flavour**
502	2	3	2	1
931	2	3	3	2
728	2	3	3	1
445	2	3	2	1
328	2	3	2	1
678	2	3	3	1

February 18th, 2014

Sample no.	**Herbs**	**Acidity**	**Rancidity**	**Off-flavour**
502	2	3	2	1
931	2	3	2	1
728	2	3	4	2
445	2	3	3	1
328	2	3	3	1
678	2	3	4	3

Intensity of attributes

Taco sauce

December 20th, 2013

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	4
572	2	3	2	2	3
431	2	3	2	2	4
863	2	3	3	2	3
102	2	3	2	2	3
372	2	3	3	2	2

January 7th, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	3	2	2	3
431	2	3	3	2	3
863	2	3	2	2	3
102	2	3	2	2	3
372	2	3	3	2	3

January 13th, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	3	2	2	3
431	2	3	2	2	3
863	2	3	2	2	3
102	2	3	2	2	3
372	2	3	3	2	3

January, 21st, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3

572	2	3	2	2	3
431	2	3	3	2	3
863	2	3	3	2	3
102	2	3	3	2	3
372	2	3	3	2	3

January 27th, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	2	2	2	3
431	2	2	3	2	3
863	2	3	2	2	3
102	2	3	2	2	3
372	2	3	3	2	2

February 3rd, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	3	3	2	3
431	2	3	3	2	3
863	2	3	2	2	3
102	2	3	3	2	3
372	2	3	3	2	3

February 10th, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	3	3	2	3
431	2	3	3	2	3
863	2	3	2	2	3
102	2	3	2	2	3
372	2	3	3	2	3

February 18th, 2014

Sample no.	Sweetness	Acidity	Off-flavour	Hardness tomato	Crispness Onion
845	2	3	2	2	3
572	2	3	3	2	3
431	2	3	3	2	3
863	2	3	2	2	3
102	2	3	2	2	3
372	2	3	4	2	3

Appendix 4. Raw data from the Colour Analysis

Colour Analysis
Pizza topping

December 20th, 2013				*January 7th, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
502	79.56	3.15	17.83	**502**	79.01	3.16	17.48
931	79.17	3.13	17.49	**931**	78.48	3.27	17.63
728	78.69	3.19	17.62	**728**	77.46	3.43	17.94
445	78.92	3.05	17.58	**445**	80.16	3.1	17.97
328	78.1	3.07	17.24	**328**	79.13	3.19	18.03
678	79.08	3.14	17.62	**678**	78.54	3.31	18.97
January 13th, 2014				*January, 21st, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
502	79.38	3.33	17.61	**502**	79.05	3.37	17.76
931	79.55	3.35	18.28	**931**	78.74	3.37	18.08
728	78.57	3.57	18.7	**728**	77.51	3.66	18.87
445	79.5	3.09	17.52	**445**	79.61	3.31	18.12
328	78.47	3.33	18.05	**328**	79.61	3.16	18.02
678	77.88	3.43	18.81	**678**	78.55	3.48	19.2
January 27th, 2014				*February 3rd, 2014*			

Sample no.	L*	a*	b*	Sample no.	L*	a*	b*
502	79.67	3.3	17.79	**502**	79.51	3.45	17.61
931	78.68	3.51	18.35	**931**	79.51	3.38	17.61
728	77.55	3.66	19.11	**728**	77.45	3.7	18.84
445	79.59	3.22	17.73	**445**	77.58	3.06	18.11
328	78.94	3.19	17.95	**328**	79.05	3.33	18.08
678	77.68	3.7	19.53	**678**	77.78	3.95	19.68
February 10th, 2014				*February 18th, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
502	77.41	3	17.8	**502**	78.43	3.05	18.14
931	77.24	3.26	18.6	**931**	77.5	2.99	17.79
728	75.82	3.47	19.76	**728**	76.38	3.43	19.77
445	77.66	2.84	18.28	**445**	77.26	3.1	18.3
328	77.69	3.19	19.17	**328**	77.62	3.29	18.85
678	75.47	3.34	19.63	**678**	75.71	3.44	19.63

Colour Analysis
Taco sauce

December 20th, 2013				*January 7th, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
845	26.95	19.29	18.96	**845**	28.8	16.89	16.8
572	28.79	16.97	17.8	**572**	29.22	18.36	18.4
431	27.67	19.47	20.61	**431**	26.85	19.42	20.38
863	26.84	19.29	20.39	**863**	28.74	18.93	18.93
102	27.16	19.48	18.33	**102**	28.86	19.05	19.37
372	25.4	20.61	21	**372**	29.09	17.76	19.32
January 13th, 2014				*January, 21st, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***

845	27.91	18.56	22.9	**845**	30.06	17.89	16.38
572	28.27	17.72	17.38	**572**	29.02	19	17.83
431	28.71	17.73	16.87	**431**	27.75	19.07	17.18
863	28.18	18.43	18.85	**863**	29.52	18.27	17.91
102	27.23	19.68	18.4	**102**	29.21	18.09	17.26
372	26.06	19.56	19.06	**372**	26	19.94	18.47
January 27th, 2014				*February 3rd, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
845	29.96	17.64	16.45	**845**	29.39	17.83	17.88
572	27.46	19.26	19.31	**572**	26.21	20.02	20.01
431	27.72	18.39	18.64	**431**	25.43	20.02	20.1
863	29.56	17.93	16.52	**863**	29.38	17.48	16.91
102	27.4	19.52	15.56	**102**	28.72	17.99	17.62
372	27.14	19.27	18.4	**372**	27.48	18.08	18.16
Ferbuary 10th, 2014				*February 18th, 2014*			
Sample no.	**L***	**a***	**b***	**Sample no.**	**L***	**a***	**b***
845	27.55	19.3	17.92	**845**	29.04	17.89	15.93
572	26.65	18.96	18.07	**572**	26.32	20.15	18.03
431	25.42	19.1	17.37	**431**	24.66	19.46	18.54
863	26.31	19.16	17.73	**863**	25.92	21.03	19.06
102	26.89	18.01	16.74	**102**	27.11	20.11	18.89
372	25.98	17.67	16.57	**372**	27.51	19.79	18.06

Appendix 5. Calculations for Sensory Analysis - Pizza topping

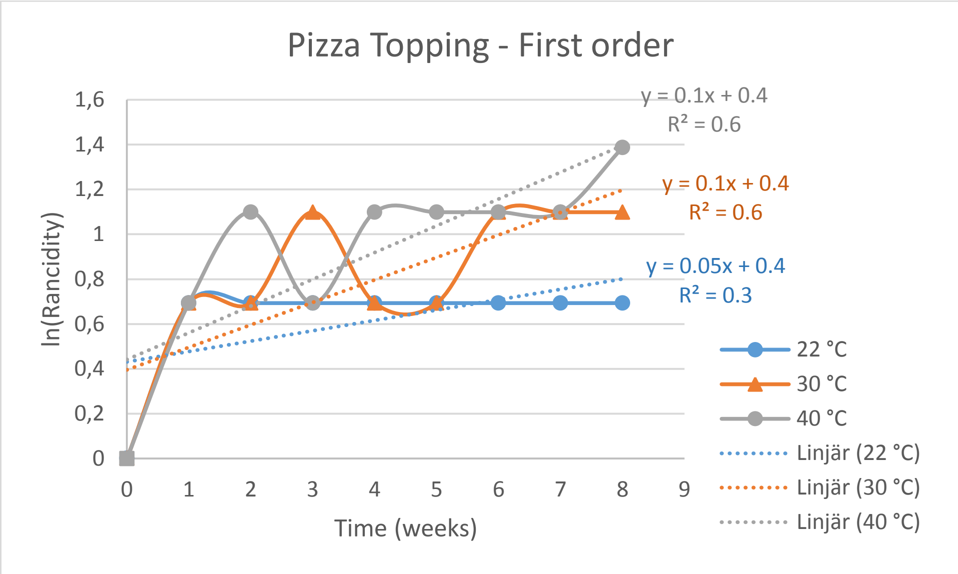

Figure 1. *First order reaction plot for ln (rancidity) against time (weeks). The equation of the trend line is given in the graph, as well as R^2.*

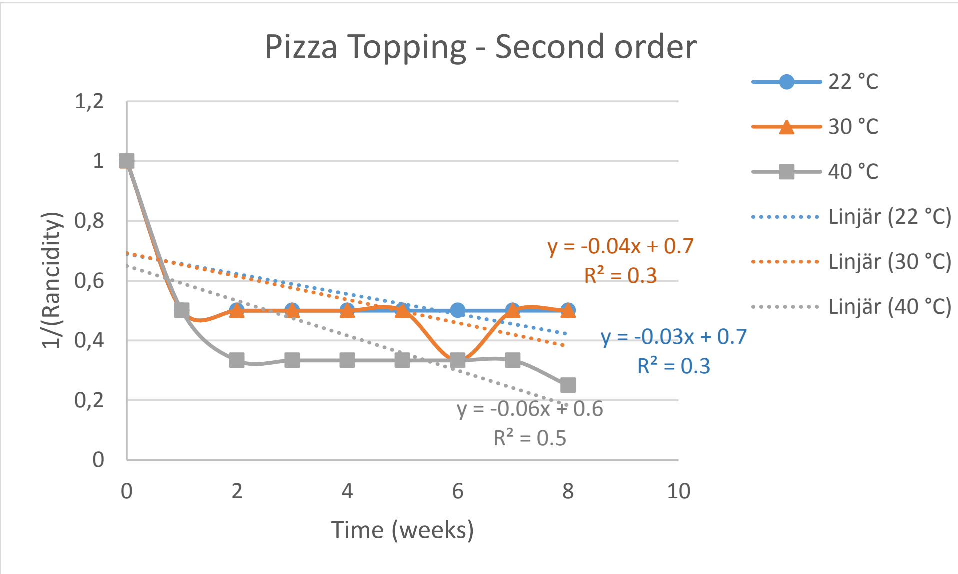

Figure 2. *Second order plot of 1/Rancidity versus time in weeks. The linear trend line is displayed, as well as the equation with R^2.*

E_a(activation energy in kJ/mol) calculated from Arrhenius equation zero order reaction:

k = Reaction rate constant

R = Ideal gas constant (8.3144 J/K/mol)

T = Temperature in Kelvin

$$k = \frac{-E_a}{R} = -k \times R$$

$$E_a = 7212.8 \times 8.3144 = 59970.1043\, J/mol$$

$$59970.1043 \approx 59.97\; kJ/mol$$

***Ea*(activation energy in kJ/mol) calculated from Q_{10}:**

k_{t+10} + k_t = Reaction rate constants at temperatures T + T_{+10}

$$Q_{10} = \frac{k_T + 10}{k_T}$$

$$\frac{k(40\,°C)}{k(30\,°C)} = \frac{0{,}2627}{0.2} = 1.3135 \;\approx 1.31$$

$$\ln(Q_{10}) = \frac{10E_a}{RT^2} = E_a = \frac{\ln(Q_{10}) \times RT^2}{10}$$

$$E_a = \frac{\ln(1{,}31) \times (8.3144 \times 303.15 \times 313.15)}{10} = 20703.28\; J/mol$$

$$\approx 20.70\; kJ/mol$$

***AF* (Accelerating factor) calculated from E_a = 59.97 kJ/mol**

$$AF = exp\left[\frac{E_A}{R}\left(\frac{1}{T_x} - \frac{1}{T_{test}}\right)\right]$$

$$AF = exp\left[\frac{7212.8}{8.3144}\left(\frac{1}{293.15} - \frac{1}{313.15}\right)\right]$$

$$AF = \exp(7212.8 \times 0.0002181) = \exp(1.57)$$

$$AF = 4.8$$

***FT* (Failure time) calculated from E_a = 84.17 kJ/mol**

$$FT = FT_{test} \times AF$$

$$FT = 56\; days\; X\; 4.8$$

$$FT \approx 269\; days \;\approx 9\; months$$

Appendix 6. Calculations for Sensory Analysis - Taco sauce

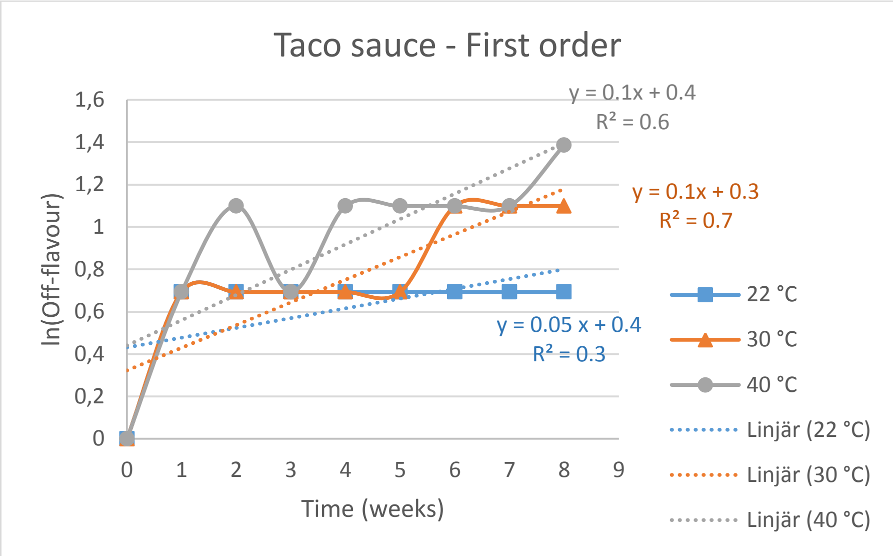

Figure 3. *A first order plot of the natural logarithm of the attribute "off-flavour" plotted against time in weeks. Equations of the linear trend line are displayed alongside the correlation coefficient R^2.*

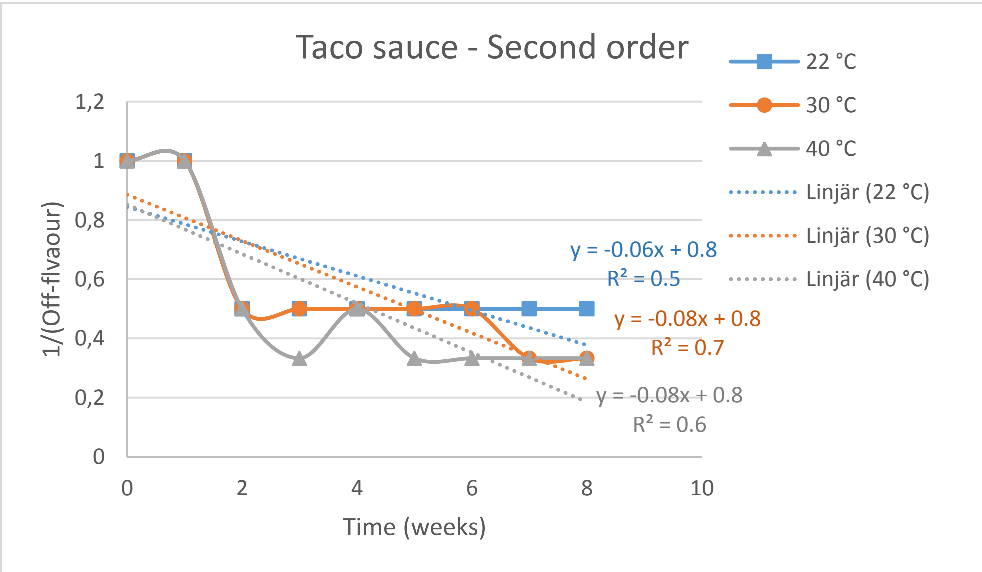

Figure 4. *Second order plot for Taco sauce. The graph displays 1/ (off-flavour) against time in weeks as well as the corresponding equations and correlations coefficients R^2.*

E_a(activation energy in kJ/mol) calculated from Arrhenius equation zero order reaction:

k = Reaction rate constant

R = Ideal gas constant (8.3144 J/K/mol)

T = Temperature in Kelvin

$$k = \frac{-E_a}{R} = -k \times R$$

$$E_a = 10124 \times 8.3144 = 84174.9856\, J/mol$$

$$84174.9856 \approx 84.17\, kJ/mol$$

E_a(activation energy in kJ/mol) calculated from Q_{10}:

k_{t+10} + k_t = *Reaction rate constants at temperatures T + T_{+10}*

$$Q_{10} = \frac{k_T + 10}{k_T}$$

$$\frac{k(40\,°C)}{k(30\,°C)} = \frac{0.4608}{0.2167} = 2.1264 \approx 2.13$$

$$\ln(Q_{10}) = \frac{10E_a}{RT^2} = E_a = \frac{\ln(Q_{10}) \times RT^2}{10}$$

$$E_a = \frac{\ln(2.1264) \times (8.3144 \times 303.15 \times 313.15)}{10} = 59457.89\ J/mol$$

$$\approx 590.45 kJ/mol$$

AF (Accelerating factor) calculated from E_a = 84.17 kJ/mol

$$AF = exp\left[\frac{E_A}{R}\left(\frac{1}{T_x} - \frac{1}{T_{test}}\right)\right]$$

$$AF = exp\left[\frac{84174.9856}{8.3144}\left(\frac{1}{293.15} - \frac{1}{313.15}\right)\right]$$

$$AF = \exp 10124(0.0002181) = \exp(2.20)$$

$$AF = 9.09$$

FT (Failure time) calculated from E_a = 84.17 kJ/mol

$$FT = FT_{test} \times AF$$

$$FT = 56\ days\ X\ 9.09FT \approx 509\ days\ \approx 17\ mont$$

Appendix 7. Calculations for Colour Analysis – Pizza topping

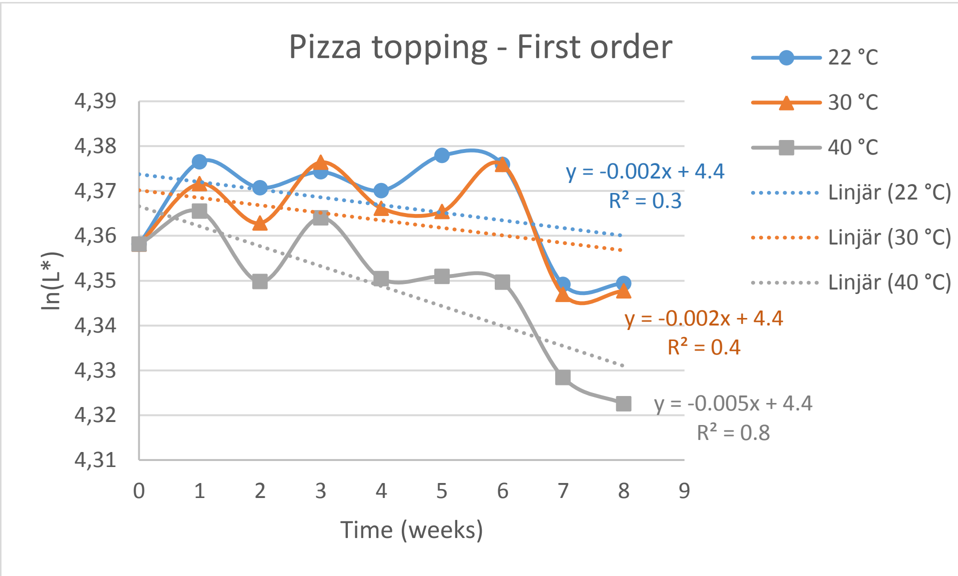

Figure 6.1. *Graph displaying the natural logarithm of L* versus time in weeks. All linear equations and R^2 – values are shown.*

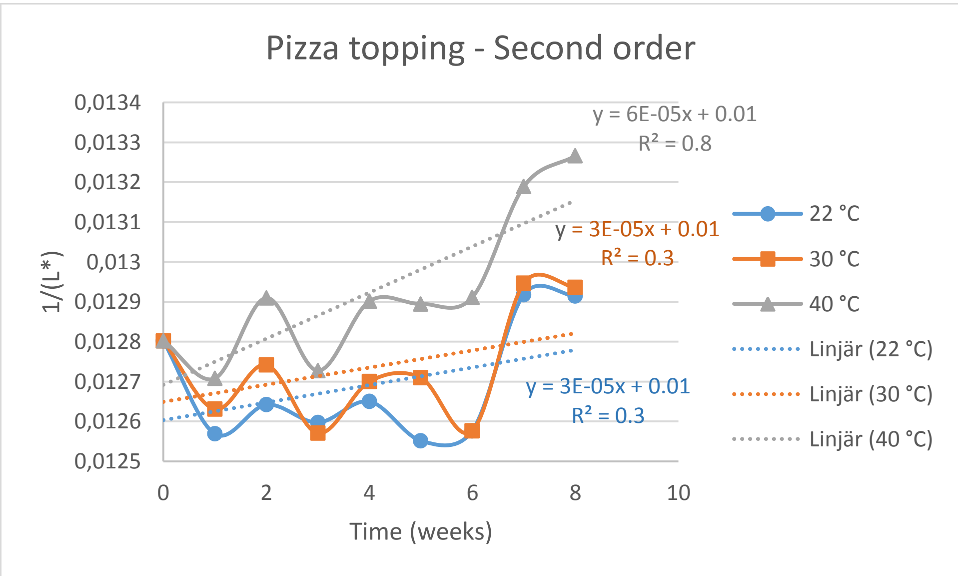

Figure. 6.2. *Graph plotting a Second order reaction for 1/(L*) against time in weeks. Displayed in the graph are also all linear equations and R^2.*

E_a(activation energy in kJ/mol) calculated from Arrhenius equation zero order reaction:

k = Reaction rate constant

R = Ideal gas constant (8.3144 J/K/mol)

T = Temperature in Kelvin

$$k = \frac{-E_a}{R} = -k \times R$$

$$E_a = 16085 \times 8.3144 = 133737.124\, J/mol$$

$$133737.124\, J/mol \approx 133.37\ kJ/mol$$

Calculation of the Q_{10} – factor:

$k_{t+10} + k_t$ *= Reaction rate constants at temperatures T +* T_{+10}

$$Q_{10} = \frac{k_T + 10}{k_T}$$

$$\frac{k(40\ °C)}{k(30\ °C)} = \frac{0.3842}{0.172} = 2.233 \approx 2.2$$

AF **(Accelerating factor) calculated from E_a = 133.37 kJ/mol**

$$AF = exp\left[\frac{E_A}{R}\left(\frac{1}{T_x} - \frac{1}{T_{test}}\right)\right]$$

$$AF = exp\left[\frac{133737.12}{8.3144}\left(\frac{1}{293.15} - \frac{1}{313.15}\right)\right]$$

$$AF = \exp(3.4)$$

$$AF = 29.96$$

FT **(Failure time) calculated from E_a = 133.37 kJ/mol**

$$FT = FT_{test} \times AF$$

$$FT = 56\ days\ X\ 29.96$$

$$FT \approx 1677\ days\ \approx 54\ months \approx 4.5\ years$$