# Towards An Approach To Assess Critical Quality Points (CQPs) In Food Production Systems

A Case Study On French Fries Production

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# Towards An Approach To Assess Critical Quality Points (CQPs) In Food Production Systems

## A Case Study On French Fries Production

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# Dedication

I dedicate this humble effort to the people of Pakistan for their resilience against all kind of internal and external terrorism. Bravo my nation.

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# Chapter 1

## General Introduction

## 1.1 Quality management systems for food quality

Quality is of prime importance in the agribusiness and food industry. Food companies operate in a very competitive and dynamic market, which put high requirements on quality management. Quality management refers to all activities that organisations use to direct, control, and coordinate quality, including formulating a quality policy, setting quality objectives, quality planning, control, assurance, and improvement (ISO, 2005). Due to various severe safety problems in the food supply chain in the last decade, the focus was on implementing quality assurance (QA) standards and guidelines, like HACCP, prerequisite programmes, British Retail Consortium, into company specific food safety management systems (Van der Spiegel, et al, 2003; Van der Meulen and Van der Velde, 2004; Luning, et al, 2008, 2009). However, due to the increased interest in health issues (like obesity, functional foods), extended shelf life, excellent sensory quality, and convenience, attention is shifting towards control and assurance of quality attributes (Ravetz, 2002; Smith et al, 2004;Grunert, 2005; Van Boekel, 2005; Manning, et al, 2006). Control refers to all activities aimed at keeping product properties, processes but also people handling within acceptable tolerances, whereas assurance activities aim at providing confidence and evidences that the control system is effective by setting system requirements, evaluating its performance and organising necessary changes (Luning and Marcelis, 2009a). The shift in focus from safety to quality necessitates the development of quality management systems that specifically aim at control and assurance of quality attributes in an efficient and effective way. Most QA guidelines and standards focus mainly on food safety, whereas others are not specific for food (like ISO9001). To illustrate, HACCP is a worldwide acknowledged and applied process control system to assure product safety (Ropkins and Beck, 2000). It is based on identifying, evaluating, and monitoring those steps in food manufacturing where hazards may occur that are critical to product safety (NACMCF, 1998). The determination of critical control points is supported by a systematic risk assessment procedure, in order to scientifically underpin if a hazard forms a risk and thus needs to be controlled (SSC, 2000). This procedure is, however, not directly applicable for assessment of critical control points for quality attributes (Luning, van der Speigel, and marcelis, 2007). For food safety hazards, the negative impact hazards can have on human health determines criticality, but how to assess scientifically what is critical for quality attributes? Quality attributes are defined as the physicochemical product properties, that are noticeable by sensory observation or via communication, and that contribute to quality perception and experience of consumers (Van Trijp and Steenkamp, 2005). Quality attributes are complex and multidimensional. Complexity is due to the variety in physicochemical properties that can be affected by different food processes (like chemical and biochemical reactions), as well as by the applied technological conditions (like time-temperature settings). Multidimensionality refers to the fact that quality can be decomposed into various attributes like flavour, shelf life, convenience, health, which can be further decomposed into sub attributes; for example, flavour in aroma and taste. Development of control systems for quality attributes of a particular food product, in comparison to control systems for chemical, microbial, and physical hazards requires another approach.

## 1.2 Basic principles of quality control

"*The core mechanism of quality control is to maintain desired quality by measuring product properties and processes, comparing actual measurement outcomes with the standard, and taking necessary corrective actions to ensure that final quality will meet or exceed customer/ consumer needs or legal requirements*" (Luning and Marcelis, 2007). Quality control comprises four basic activities; a) measuring process and/or product parameters, b) testing to compare measured values against a standard and tolerances, c) regulating in order to set extent and direction of corrective action, and d) taking actual corrective actions to handle 'out of control' situation. To design control systems one should have insight in the sources of variation since every process is subject to variation. The total variation in a process is an outcome of variations due to controllable and uncontrollable input factors. A process is called 'in control' when all variation is predictable by knowing the controllable input factors (due to natural or inherited sources including people, material, machine, tools, and methods). It is called 'out of control' when unpredictable variation occurs due to uncontrollable input factors including, for example, defects in the raw material, operator errors, improperly adjusted machines (Montgomery, 2008; Luning & Marcelis, 2009a) (Figure 1.1).

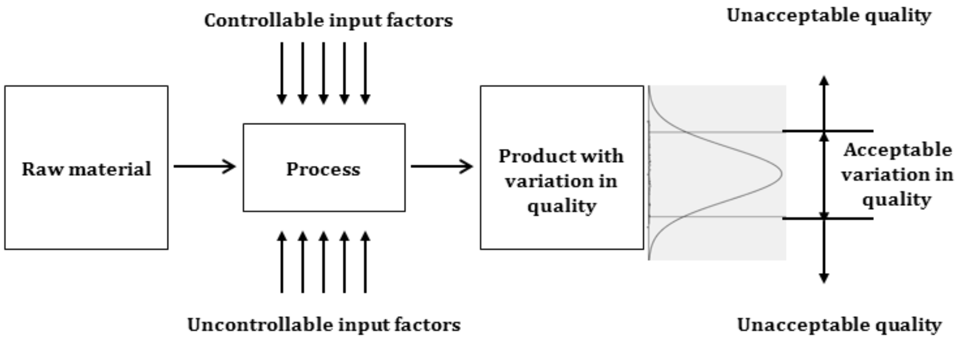


***Figure 1.1*** *Schematic overview of how variation in quality is influenced by controllable and uncontrollable input factors (after Luning & Marcelis, 2009).*

If one manages to reduce variation in quality attributes, then the quality of a product will increase resulting in greater planning efficiencies, fewer line stoppages, reducing quality loss due to scrap and rework, and ultimately satisfied customers with repeated sales (Montgomery, 2008). Food quality and variability have an inverse relationship, so a profound understanding of major causes of variation affecting (unacceptable) variation in final quality attributes could support in designing effective control systems.

## 1.3 Which sources of variation should be considered?

What types of sources of variation need to be analysed to obtain a comprehensive understanding of the possible factors that need to be controlled in a food production system; to achieve constant quality over time? Obviously, one should gain insights in the product and process factors that could affect the quality attributes. However, the International Standardisation Organisation (ISO, 2005) acknowledged the importance of the role of people in realising and assuring quality, and proposed that efforts should be put in gaining insight in the effects of human transactions in quality systems. More specifically, Luning and Marcelis (2006, 2009b) discussed that food quality is an outcome of the behaviour of food systems as well as the decision-making behaviour of people that produce the food products; it requires an interdisciplinary approach. The techno-managerial research approach comprises "an integrative use of technological and managerial theories, in order to explain and predict food quality from food and human behaviour".

In a food quality relationship model it is proposed that:

FQ=f(FB, HB), and

FB=f(FD, TC), and HB=f(HD, AC)

*FQ= food quality, FB= food behaviour, HB= human behaviour, FD=food dynamics, TC=technological conditions, HD=human dynamics, AC=administrative conditions (Luning and Marcelis, 2006)*

In line with this research approach, one should thus not only analyse sources of variation due to characteristics of a food production system, but one should also analyse possible sources of variation due to decision-making behaviour of people controlling the food production system.

### 1.3.1 Technological sources of variation

On the one hand, the FQ relationship model shows the dependency of food quality on food behaviour. More specifically, behaviour of food systems is dependent on the dynamics of the food systems (e.g. due to biological variability, dynamic chemical processes) and the applied technological conditions (like process conditions, equipment and buildings) (Luning and Marcelis, 2006). Food products are perishable and liable to natural variability. Interactions between food components and the dynamic chemical, physical, microbial, physiological, and or physical food processes change the food properties over time (Van Boekel, 2008; Luning and Marcelis, 2009a). Therefore, the analysis of technological sources of variation should concern the assessment of which product components, food processes, and or technological (process) conditions might affect variation in the quality attributes of a final product for consumption.

### 1.3.2 Managerial sources of variation

On the other hand, the FQ relationship model shows the dependency of food quality on human behaviour. People can affect food quality by their decisions. For example, they take decisions on accepting or rejecting a batch of supplied materials, they decide to correct or keep a process parameter, they can decide to purchase certain processing equipment, they can decide to follow or deny a work procedure, etc. Such decisions can affect the quality of a product. In a *food quality decisions model* different types of decisions have been distinguished that can affect food quality in line with the earlier mentioned *food quality relationship model* (FQ=f ((FD,TC), (HD, AC)) (Luning and Marcelis, 2007). Decisions on food dynamics (FD) determine the extent of variability in product properties by setting specifications. Decisions on human dynamics (HD), i.e., variability of individual decision-making determine the degree of variability in people's decisions, by specifying their actions. For example, by providing specific information or by giving detailed instructions, it is attempted that people will take similar decisions and this will result in less variation in decision outcomes. Decisions on technological conditions (TC) specify process parameters, equipment, and buildings. Decisions on administrative conditions (AC) specify people's competencies, organisational arrangements (like procedures), and information systems, therewith restricting the room of decision-making. In summary, decisions on the dynamics (of food and human systems) aim at reducing variation by selecting preferred alternatives, whereas decisions on (technological and administrative) conditions create circumstances that prevent undesirable properties and or people actions (Luning and Marcelis, 2007).

When focusing on the quality control function, typical control decisions concern decisions on

1) out-of-tolerance of product properties and taking corrective actions (FD),

2) deviations from process or equipment parameters and taking corrective actions (TC),

3) out of tolerance of people actions and correcting their actual behaviour (HD), and

4) deviations from requirements on personnel, and procedures and taking corrective actions (AC) (Luning and Marcelis, 2007, 2009a).

The analysis of managerial sources of variation should therefore focus on decisions on product and process parameters that can affect variation in quality attributes. Moreover, one should analyse if decisions on human dynamics (i.e. how, for example, managers correct daily behaviour of food handlers) and or decisions on administrative conditions (e.g. providing instructions or not) affect decision-making behaviour of food handlers at the crucial product and process parameters.

Since final product quality is not realised in just one step in the food supply chain, but many factors along the chain can have an impact (Knura, Gymnich, Rembialkowska, and Petersen, 2006; Luning and Marcelis, 2009a), one should analyse technological causes of variation and the crucial control decisions from a chain perspective.

## 1.4 Demarcation of the thesis

In order to get insight in how to develop an approach for the design of effective control systems for quality attributes, the production chain of French fries was selected as a case study. The thesis focused on colour and texture as they are considered major quality attributes of French fries (Agblor and Scanlon, 2000; Scanlon, 2003; Van Loon, 2005). These attributes are formed due to various chemical and physical processes, and product composition and applied process conditions can affect these processes; so it involves complex quality attributes. The typical physicochemical properties of the potatoes, the basis of the French fries, can be affected at various steps in the French fries production chain, which requires an analysis from a chain perspective. Moreover, the final preparation step of French fries is commonly done by food handlers, so we expect an interference of their control decisions on the final quality attributes. Based on the above characteristics we expect that the French fries production will serve as an appropriate case to gain insight in assessing sources of variation and establishing a way to design control systems for quality attributes.

## 1.5 Aim and outline of the thesis

The major aim of the thesis was to get a quantitative insight in technological and managerial factors that affect variation in the major quality attributes of French fries, in order to develop a systematic approach for the assessment of critical quality points (CQP) as a basis for effective quality control systems.

### Research questions

The following research questions were formulated to achieve the aim of the thesis:

1. Which product and process factors, along the whole production chain, can affect variation in final quality attributes of French fries?

2. How much can these factors contribute to the variation in quality attributes at the final preparation step, frying and at the preceding step, blanching?

3. What is the contribution of variation in food handler's decisions on frying conditions to variation in quality attributes of French fries? Can administrative conditions reduce variation in this decision-making and affect variation in the quality attributes?

4. How to use the above insights to propose a systematic approach to assess critical quality points (CQPs)?

**Thesis outline**

The production chain of French fries was analysed to get an insight in the contribution of different sources of variation to the final variation in the major quality attributes of French fries along the whole production chain (Chapter 2). For this purpose, a comprehensive literature search on potato and French fries production was conducted. The literature study was focused on those studies that provided insight in the quantitative contribution of product and process factors to variation in final quality attributes of French fries. Since such studies were restricted, experiments were executed to gain accurate insight in the impact of process conditions at final frying on the variation in texture and aroma of French fries (Chapter 3). To gain further insight in the contribution of sources of variation earlier in the chain, the impact of blanching conditions (during processing of par fried frozen fries) on the variation in texture and colour of fried French fries was studied (Chapter 4). In the last study, the quantitative contribution of food handler's decisions during frying on the variation in texture and colour was analysed, as well as the impact of instructions (Chapter 5). In chapter 6, an approach towards the assessment of critical control points is proposed as basis for effective control systems for quality attributes.

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# Chapter 2

## Unraveling the causes of variation in the major quality attributes of French fries: A quality control perspective

## Abstract

One of the fundamental objectives of quality control is reducing variation in the final quality attributes, which makes it essential to understanding causes of variation in these quality attributes. This study aims at getting an insight in causes of variation in the major quality attributes of French fries based on a comprehensive literature analysis. The analysis focused on those locations/ points in chain where product and process factors have an effect on variation in final product properties, referred to as critical control points (CCPs) for quality attributes. Current literature does not allow to quantitatively establish variation in the final quality attributes, however, selection of suitable cultivar, time-temperature regimes during bulk storage, blanching and final frying conditions were found to be potential factors influencing variation in the final quality output. Moreover, a Monte-Carlo simulation demonstrated that, for instance, slight variation in frying time and temperature induced considerable variation in colour index. Lack of control over these critical control points may thus lead to unacceptable variation in quality attributes of the final product from a consumer perspective.

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## 2.1 Introduction

Quality is of utmost importance for the food industry to survive in the competitive market. Nowadays, safety and quality control have become an essential part of daily food production (Efstratiadis, Karirti, and Arvanitoyannis, 2000, Luning and Marcelis, 2009). Much attention has been paid to the development of effective food quality management systems (like HACCP, BRC, ISO 22000, SQF and IFS), to ensure food safety and regain consumer trust (Ropkins and Beck, 2000; Luning, Bango, Kussaga, Rovira, and Marcelis, 2008; Luning, Marcelis, Rovira, Van der Spiegel, Uyttendaele, Jacxsens, 2009). Hazard Analysis and Critical Control Points (HACCP) principles indeed guide in developing a lean and cost effective on-going food safety management system that enables the systematic identification, evaluation and control of those steps in food manufacturing that are critical to food safety (Jacxsens, Devlieghere, and Uyttendeale, 2009; Luning & Marcelis , 2009). Various authors suggested that the HACCP concept could be also applicable for quality attributes (Peters, 1998; Bertolini, Rizzi and Bevilacqua, 2007). However, they did not present a concrete methodology on how to assign critical control points (CCPs) for quality attributes, and it is questionable whether the HACCP principles are just applicable to other quality attributes. Food safety is a rather straightforward concept with evident limits based on scientific risk assessment (commonly established in legislative norms), which enables a systematic assignment of CCPs (Jacxsens et al, 2009; Luning and Marcelis, 2009). In contrast, quality is a more complex and a multidimensional concept (Luning and Marcelis, 2009). Quality attributes are the result of complex physicochemical properties of the food matrix, which can be affected by dynamic processes (like chemical and enzymatic reactions) in the food itself as well as by the technological conditions that are applied (like time-temperature regimes). Moreover, also the behaviour of decision-making people has an impact (Luning and Marcelis, 2006). Multidimensionality refers to the fact that quality can be decomposed into various attributes like flavour, shelf life, health, convenience, which can be further decomposed in sub-attributes, like for flavour, i.e. aroma and taste, and for taste into, e.g., sweet, sour, bitter, salty. Moreover, setting of standards and tolerances to control quality attributes, is usually driven by customer and consumer demands and less by legislative requirements or scientifically based assessment studies, like for safety hazards. The above mentioned aspects of food quality may complicate a straightforward analysis of CCPs for quality attributes, similar as the assignment of CCPs for safety (chemical, microbiological, physical hazards). However, as a general requirement on food quality, quality attributes should be constant over time while complying with consumer desires (Deming, 1982).

The diversity of factors that can affect final product composition and thereby various perceivable quality attributes and the requirements to realise constant product composition over time put demands on the control of the influencing product/ process/ people factors. If one manages to reduce variation in quality attributes, then the quality of a product will increase. Although every process is subject to variation as it is a natural phenomenon, yet a process must be capable of operating with little variability around the product's quality characteristics eventually meeting customer requirements. To get a grip on this, an understanding of product and process factors that can lead to variation in final quality attributes is needed. A process is called in control when all variation is predictable by knowing the controllable input factors. It is called out of control when unpredictable variation occurs due to uncontrollable input factors (Luning & Marcelis, 2007, 2009).

The objective of the present study was to get insight in the product and process factors that affect variation in final product properties, and to discuss how to progress towards the control of quality attributes as the basis for an effective and lean quality system.

We have selected the production of French fries as case study because of their distinct quality attributes, which are affected by dynamic processes in the food matrix as well as by the technological conditions that are applied along the whole production chain. In the coming sections the main quality attributes of French fries have been identified together with the major product and process factors involved in the formation of these attributes. Subsequently, from literature on product and process factors affecting quality and safety attributes of French fries, major sources of variation have been identified. It will also be discussed whether or not these can be the basis for establishing critical points with respect to quality attributes along the French fries production chain.

## 2.2 Product and process factors affecting main quality attributes of French fries

The main desirable quality attributes of French fries include a light yellow to golden brown colour, fried aroma notes free from rancidity, bitterness and off odours, a crispy crust with homogeneous mealy interior that does not separate from the crust, and a firm yet delicate shape that is not lump (Gould, 1999; Agblor and Scanlon, 2000; Scanlon, 2003; Van Loon, 2005). Each of these attributes can be affected by one or more product factors (like compositional characteristics of the potatoes, chemical reactions) and process factors (such as the technological parameters in cultivation, harvesting, storage, and processing). To illustrate the above mentioned complexity of food behaviour, a quality wheel has been compiled for French fries production chain (Figure 2.1) showing the main quality attributes, the main product factors including major mechanisms and intrinsic product properties, and the major process factors that influence the formation of the quality attributes.

The formation of the major quality attributes of French fries are affected by similar product (like reducing sugars, amino acids and Maillard reaction), as well as process factors (time and temperature) as shown in the quality wheel (Figure 2.1). More in detail, the development of the light yellow to golden brown colour is mainly due to the Maillard reaction (Marquez and Anon, 1986; Nourian and Ramaswamy, 2003b; Olsson, Svensson, & Roslund, 2004). The concentrations of glucose and fructose are the major product parameters (Ezkeil, Singh and Kumar, 2003; Olsson et al., 2004), while the time-temperature regime is the key technological factor (Krokida, Oreopoulou, Maroulis and Marinos-Kouris, 2001; Nourian and Ramaswamy, 2003b; Ezkeil et al., 2003; Pedreschi, Leon, Domingo, Moyano, Pedreschi, Kaak and Granby, 2007a). Although in this study we are focussing on quality attributes, we cannot ignore those health hazard compounds formed during the same process involved in the formation of certain quality attributes. The carcinogenic compound acrylamide is formed concomitantly with colour as it is formed as an intermediate in the Maillard reaction (Mottram, Wedzicha and Dodson, 2002; Stadler, Blank, Warga, Robert, Hau, Guy, Robert and Riediker, 2002). Like for colour, the major precursors of acrylamide are glucose, fructose along with asparagine (Amrein et al., 2003; Yaylayan, Wnorowski, & Locas, 2003; Olsson et al., 2004; De Wilde et al., 2006; Brunton, et al., 2007; Viklund, Olsson,

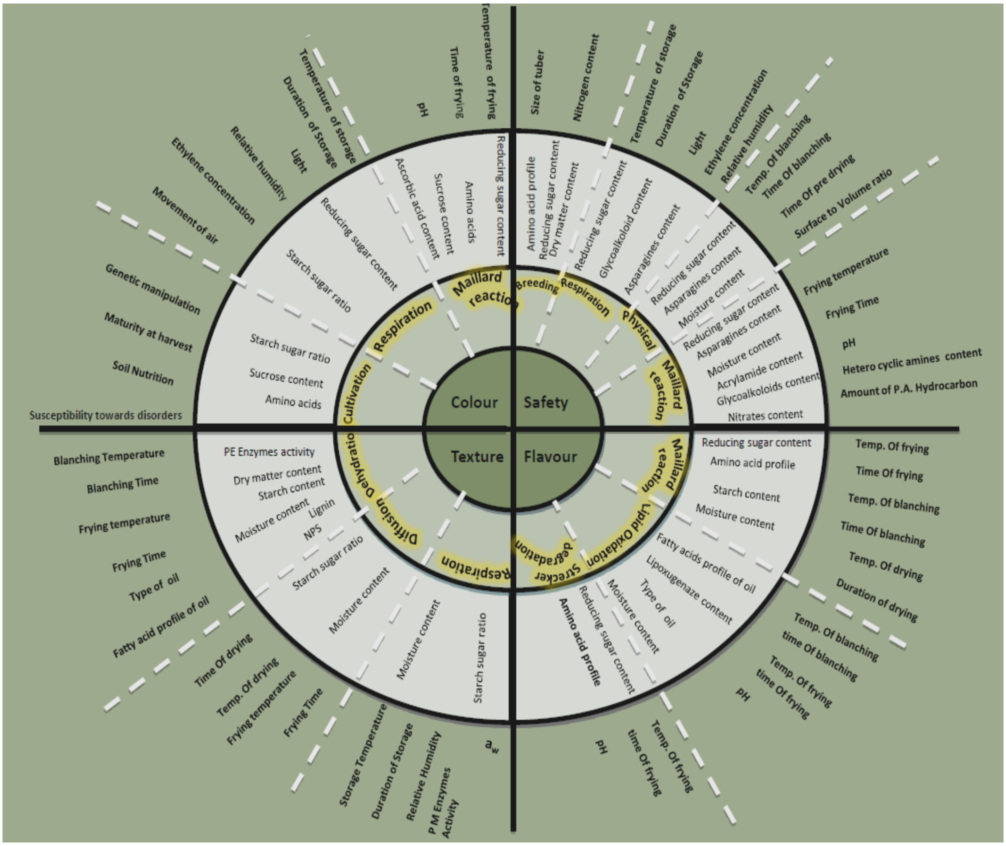


*Figure 2.1:* *Quality Wheel Model decomposing complexity and multidimensionality of major quality attributes (inner most circle) into underlying processes (second circle inside out), major product properties (third circle inside out) and technological conditions (outer most circle) affecting these processes and properties and ultimately influencing final quality attributes of French fries.*

Sjohlom and Skog, 2008), while also time and temperature are the key technological parameters involved (Grobe et al., 2003; Pedreschi et al., 2007a; Fiselier, Bazzocco, Gama-Baumgartner, & Grob, 2006; Romani, Bacchiocca, Rocculi, & Dalla Rosa, 2008). In addition, the rate of water loss due to evaporation, and the change in pH are crucial for the formation and degradation of acrylamide (Rydberg, Eriksson, Tareke, Karlsson, Ehrenberg and Tornqvist, 2003; Gertz, Klostermann & Kochhar, 2003; Taeymans et al., 2004).

The typical texture of French fries is the result of two stage phenomena where French fries get softened due to the gelatinization of starch followed by hardening due to the crust formation in the second phase (Anderson, Gekas, Lindi, Oliveira, and Oste, 1994; Pedreschi, Aguilera and Pyle, 2001; Nourian and Ramaswamy, 2003a; Moyano and Pedreschi, 2006). Texture of French fries develops during frying by the evaporation of water and penetration of oil primarily into the external layer (Lisinska and Golubowska, 2005). The components of potatoes affecting final texture include starch (Nourian and Ramaswamy, 2003a), non-starch polysaccharides (NSP), pectin substances like pectin and proto-pectin (Tanjer-Czopek, 2003), cellulose, hemi-cellulose and lignin (Golubowska, 2005). The time-temperature regime influences final texture through heat transfer (affecting thermal degradation and enzyme activities) and mass transfer (by gelatinization and pasting of the surface starch and water evaporation) (Anderson, et al., 1994; Pedreschi, et al., 2001; Moyano and Pedreschi, 2006).

The aroma of French fries is an outcome of the formation of a wide range of volatile odour compounds during the Maillard reaction and Strecker degradation in the potatoes, and lipid oxidation of the frying oil (Maga, 1994; Brewer, Vega and Perkins, 1999). Among the 122 identified volatile odour compounds, 85% originated from sugar degradation and/or Maillard reaction, with typical compounds like 2-methylpropanal, 2-methylbutanal, 3-methylbutanal (may cause a rancid off-flavour), and 26 pyrazines (fried potato notes). About 15% of the volatiles were lipid-derived, of which ethanol, 2-propanol, hexanal, and nonanal (deep-fried notes) are the most dominant ones (Wagner and Grosch, 1997; Brewer et al, 1999). Very few studies are available on the role of technological conditions on the development of aroma compounds of French fries.

## 2.3 Analysis of sources of variation in the French fries production chain

After having established the potential process and product factors, in this section we analyse the possible contribution of these factor along the production chain (Figure 2.2) to variation in the quality attributes of French fries for consumption (Table 2.1).

### 2.3.1 Production of potatoes for French fries processing

#### *A Sources of variation in selection of potato cultivar*

Inadequate selection of a cultivar suitable for French fries production can have a considerable impact on the variation and actual level of colour, as one of the major quality attributes of French fries. Studies have shown large variation in reducing sugars (glucose and fructose) among different potato cultivars (Haase and Weber, 2003; Amrein et al., 2003; Williams, 2005; Wicklund, Ostlie, Lothe, Knutsen, Brathen, and Kita, 2006; Brunton et al., 2007). For example, Haase and Weber (2003) found two fold differences in the concentrations of reducing sugars for the varieties Agria, Panda, Sempra and Saturna, ranging from 0.49 g/kg (FW) for variety Sempra up to 0.95 g/kg (FW) for variety Panda. Also Brunton and co-authors (2007) reported large differences (80 fold) in reducing sugar levels (fructose + glucose) over the course of the study (11 months) with values ranging from 0.002–0.123; 0.003–0.088; and 0.003–0.079 g/kg (FW) for the varieties Rooster, Record, and Oilean, respectively (Table 2.1). The consequences of these differences in the reducing sugars for the extent of colour development during frying of French fries have been reported in various studies (Ezekiel et al., 2003; Olsson et al., 2004; Brunton et al., 2007; Viklund et al., 2007). Olsson and co-authors (2004) found that 11-60% of the variation in colour of the processed potatoes was due to the genetic variation in reducing sugar concentrations of the potatoes used. Moreover, it has been demonstrated that the differences in initial concentration of reducing sugars also affected the extent of acrylamide formation in the processed potatoes (e.g. Grob et al., 2003; Beclaski et al., 2004; Williams, 2005; De Wilde et al., 2005 & 2006; Matsuura-Endo et al., 2006; Viklund et al., 2007, 2008). For example, Amrein and co-authors (2003) have used 17 potato cultivars for analyzing variation in the glucose and fructose concentration and their potential to form

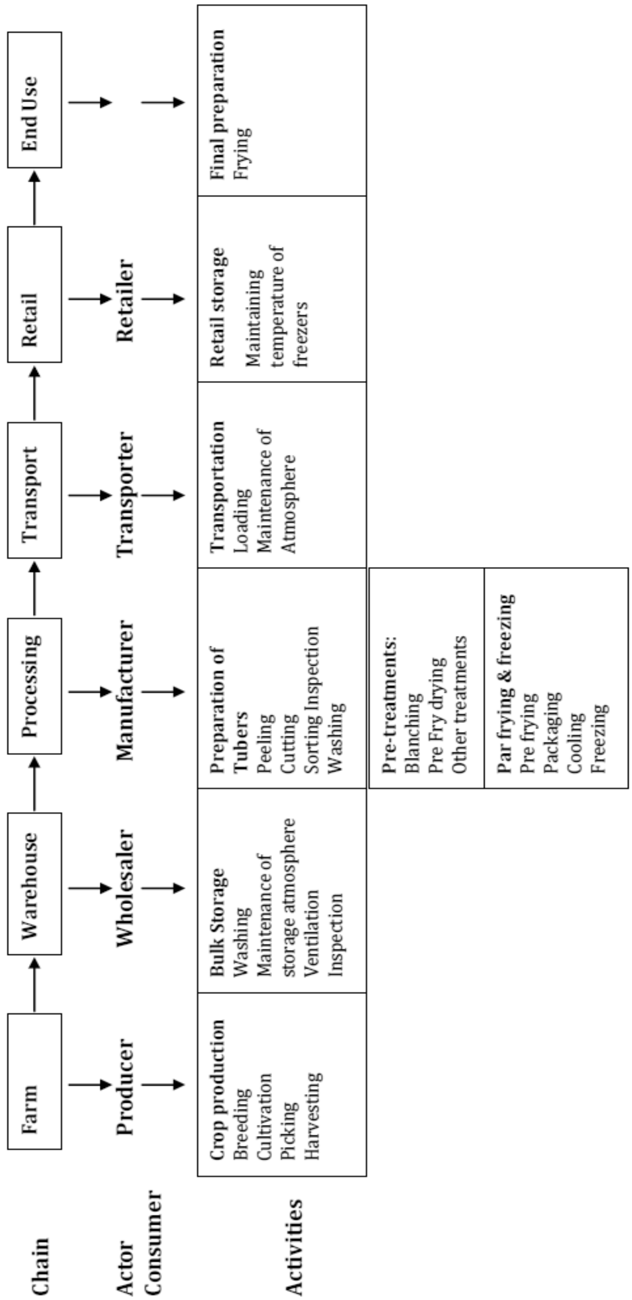



***Figure 2.2*** *Characterization of Potato Supply Chain for the production of French fries (Modified from Mosley, 2006 and Cummins et al, 2008).*

acrylamide. Glucose concentration varied from 0.10-2.55 g/kg (FW) for the varieties Marlene and Naturella, respectively. Fructose concentration varied in a similar fashion but with lower magnitude than glucose, ranging from 0.03-1.50 g/kg (FW) for the varieties Markies and Naturella, respectively. Free asparagine was also found in abundance in all varieties ranging from 2.01-4.25 g/kg for the varieties Naturella and Lady Claire, respectively.

### *B Sources of variation in bulk storage activities*

Insufficient control of temperature during bulk storage of potato tubers can have serious consequences for the concentration of reducing sugar, which ultimately affects the final colour as well as acrylamide content of the French fries. The bulk storage of potato tubers depends on storage potential of the particular cultivar and the intended end use (Mosley, 2006). The concentration of reducing sugars can change largely depending on the time-temperature regime and the type of potato cultivar. Several studies have demonstrated that lowering temperature during storage resulted in the accumulation of reducing sugars (e.g. Blenkinsop, Copp, Yada, and Marangoni, 2002; Ezkeil et al., 2003; DeWilde et al., 2006; Matsuura-Endo et al., 2006; Viklund et al., 2007). More specifically, Matsuura-Endo and co-authors (2006) found a two-fold difference in the accumulation of reducing sugars among the cultivars after 10 weeks of storage at 2°C with an average change of 4 g/kg FW (Fresh Weight) for the cultivar Inca-no-mezame, and 8 g/kg FW for the cultivar Snowden. Other studies confirmed the effect of low temperature storage (3-9 °C) on the increase in darkening of the French fries (Nourian, Ramaswamy and Khushalappa, 2003; Blenkinsop et al., 2002; Matsuura-Endo et al., 2006). Olsson and co-authors (2004) investigated the effect of low temperature storage (for the period of six months) on colour, and found a 0.7 fold change in colour (from 7; lightest to 4.7; darkest) at 3 °C as compared to 10°C where it actually reduced to 0.2 fold (from 7.3 to 6.6). Marquez and Anon (1986) found a 3 fold increase in glucose and fructose concentration (from 2 to 6 g/kg FW), when stored at 3 °C for six months. They also observed a corresponding 4 fold increase in the colour development (from -0.4 to 0.8) in terms of a / b chromaticity ratio. Besides, lowering of the storage temperature also increased the amount of acrylamide formed (e.g. Biedermann, Noti, Biedermann-Brem, Mozzetti and Grob, 2002; Grobe *et al.,* 2003; Chuda et al., 2003; Matthäus, Hasse and Vosmann, 2004; Cummins, Butler, Brunton and Gormley, 2008; De Wilde et al, 2006; Viklund et al, 2008).

DeWilde and co-authors (2006) studied sixteen potato cultivars and found significant differences (17 fold) in the reducing sugar content (from 0.4 to 6.8 g/kg on DM) with a corresponding effect on the acrylamide formation that was 10 fold (104-1021 μg/kg) for the variety Lady Claire and Tebina, respectively. Chuda and co-authors (2003) found almost a 13 fold increase in acrylamide concentration (from 2600-34000 μg/kg of the product) when potatoes were stored at 2 °C as compared to those stored at 20 °C (Table 2.1). Likewise, Matsura–Endo and co-authors (2006) found an increase (15 fold) in the acrylamide formation from 2000 to 30,000 μg/kg of product when potatoes of Inca-no-mezame cultivar were stored at 10 and 2 °C for 4 weeks, respectively. Therefore, low temperature storage (especially below 8˚C) for longer period of time (exceeding 10 weeks) can result in considerable variation in reducing sugars at the end of storage. A higher accumulation of sugars will require more rigorous pre-treatments, like blanching to reduce concentrations of reducing sugars to acceptable levels for final French fries preparation.

### 2.3.2 Sources of variation in processing activities

Typical activities involved in industrial processing of potato tubers are washing, trimming, cutting, grading, and subsequent treatments like, blanching, pre-fry drying and other pre-treatments like immersion in water, soaking in various solutions, and or lactic acid fermentation (Bunger, Moyano and Rioseco, 2003; Pedreschi, Moyano, Kaack, & Granby, 2004; Park et al., 2005; Baardseth et al., 2006). However, lack of control during blanching may lead to variation in the blanching time and temperature, ultimately resulting in a major change in one or more of the final quality attributes like colour, texture and safety (acrylamide formation) of French fries.

Blanching mainly aims at extraction of reducing sugars and asparagine to prevent excessive browning and to restrict acrylamide formation (Anderson et al, 1994; Grobe et al., 2003; Pedreschi, et al., 2004; Abu-Gannum and Crowley, 2006; Liu and Scanlon, 2007; Pedreschi et. al., 2007a) (Table 2.1). Agblor and Scanlon (2000) found that blanching at 70 °C for 10 minutes (low temperature long time, LTLT treatment) increased lightness (L-value) about 10 % (50.7) as compared to control (55.2). Moreover, about 5 % increases in the lightness (53.2) was observed under blanching at 97 °C for 2 minutes (high temperature short time, HTST treatment). They also found that

LTLT blanching increased the peak force (a measure of texture) by 6% (2.61N) as compared to the control (2.76 N), whereas, in case of HTST blanching, peak force actually decreased by 13% (2.31N). In another study Pedreschi and co-authors (2007a) used high temperature blanching (HTST; 85 °C for 3.5 min) followed by air drying till 60 % moisture (wet Basis) and finally frying at 120, 140, 160 and 180 °C till a final moisture content of 1.8 % (wet basis). They found that colour was less dark (expressed as $\Delta$ E; lower values, less dark) for the blanched strips ranging from 19.34 to 45.3 (1.5 fold) as compared to the un-blanched strips ranging from 36.65 to 55.27 (1.5 fold). Various studies have investigated the effect of different blanching conditions on the acrylamide formation during final frying (Pedreschi, Kaack, & Granby, 2006; Pedreschi, Moyano, Kaack, Granby, & Troncoso, 2007 b; Mestdagh et. al., 2008a). For example, Pedreschi and co-authors (2007b) showed that HTST blanching (85 °C for 3.5 minutes) extracted about 76 % of glucose and 68% of asparagine resulting in a 45-70 fold reduction in acrylamide formation after frying. Moreover, longer blanching times, such as 80 minutes at 50°C and 45 minutes at 70°C resulted in lower acrylamide formation (342 and 538 µg/kg respectively) as compared to the blanching treatments with higher temperature and shorter time like 90 °C for 3 and 10 minutes (as average for all the temperature tested) (Pedreschi et. al., 2006). In contrast to the above findings, blanching temperature was found to have a greater influence on acrylamide formation than that of time, whereas time has a pronounced impact at lower blanching temperatures as compared to higher blanching temperature (Mestdagh et. al., 2008a). Mestdagh and co-authors (2008a) observed a (maximum) 1.8 fold (81%) reduction in the acrylamide formation upon blanching at 86 °C for 20 minutes as compared to un-blanched French fries with an acrylamide formation of 2115 µg/kg of French fries.

### 2.3.3 Sources of variation in final frying activities

Final frying usually takes place in foodservice establishment settings (restaurants, catering, etc.) or at home. Although initial concentrations of reducing sugars can be affected by the incoming material, control (check on specification) of these initial concentrations is usually a given fact. However, variation in the time-temperature settings during frying activity may lead to a large variation in the final quality attributes like texture and colour of the French fries. The variation due to the time–temperature settings may also be influenced by differences in thickness and portion size (product to oil ratio) of the frozen fries used for the final frying by the end users. In this section we have focused on studies demonstrating variation in various factors (process and product conditions) critically influencing the final quality attributes of the French fries (Table 2.1).

Various studies revealed a linear increase in darkness (colour development) of French fries as function of both frying temperature and time (Marquez & Anon, 1986; Agblor & Scanlon, 2000; Krokida et al., 2001; Nourian & Ramaswamy, 2003b; Pedreschi et al., 2007a; Romani et al., 2008; Mestdagh et al., 2008b). Nourian and Ramaswamy (2003b) found 1.8 fold increase in total colour change (ΔE) (high values of ΔE implies more darkening of the fries; from 250 to 450) when potato fries were fried for 25 minutes at 160 °C and 190 °C, respectively. However, these fries were not subjected to par frying and freezing prior to final frying. Similarly, Pedreschi and co-authors (2007a) observed almost 2.4 fold increase in total colour change (ΔE) (from 19 to 45) when par fried frozen fries were subjected to frying at 120 to 180 °C till final moisture of 1.8 %. Effect of frying time on the colour of French fries was also investigated by Romani and co-authors (2008). They showed 0.63 fold (36 %) decrease in the lightness (L-values) (from 76 to 48) and 4 fold increase in the redness (a-values) (from -7 to 14) of the French fries when frying time was increased from 3 to 9 minutes at a traditional frying temperature of 180 °C. This decreasing lightness and increase in redness with time demonstrated progressive darkening of the French fries. Some studies have shown an association between colour development and acrylamide formation and found a linear correlation between the two as a function of both frying time and temperature (Mestdagh et al., 2008b). But in contrast to the linear response of colour development, an exponential response in acrylamide formation was observed at higher frying temperature (> 190 °C) for longer time (> 5 minutes). For example, Gokmen, Palazoglu, & Senyuva (2006) observed an increase in acrylamide formation from 100 to 800 μg/kg when frying time was increased from 3 to 9 minutes at 170 °C. However, formation of acrylamide increased exponentially from 400 to 1400 μg/kg when the same frying intervals (3-9 minutes) were applied at higher temperature (190 °C). Similarly, Romani and co-authors (2008) also reported 12 fold increase in acrylamide formation from 68 to 830 μg/kg when French fries were subjected to frying at 180 °C and frying time was increased from 5 to 9 minutes, respectively. Time - temperature settings also affect the rate of starch gelatinization followed by the crust formation, which determines the final texture of French fries. Nourian and Ramaswamy (2003a) in their study performed on the raw potato fries, showed 0.2 fold (81 %) decrease in hardness (from 11 to 2 N/mm) of French fries in the first 5 minutes of frying in a temperature range from 160 to 190$^{o}$C. Afterwards, the hardness increased 2 fold (from 2 to 4 N/mm), 8.5 fold (from 2 to 17 N/mm) and 7.5 fold (from 2-15 N/mm) when subjected to 25 minutes of frying at 160$^{o}$C, 180$^{o}$C and 190$^{o}$C, respectively. Romani and co-authors (2008) also found 0.2 fold (80 %) reduction (from 25 N to 5 N) in $F_{max}$ (maximum shear force necessary to cut the French fry) during the first 5 minutes, and observed a subsequent 5 fold increase to 20N during 5-9 minutes of frying when par fried frozen fries were subjected to frying at 180 $^{o}$C.

In addition, studies have also demonstrated that some other factors like thickness of French fries (Krokida et al., 2001; Tajner-Czopek , Figiel, & Carbonell-Barrachina, 2008), product to oil ratio (portion size) (Fiselier et al., 2006; Romani, Bacchiocca, Rocculi, & Dalla Rosa, 2009) and type of fryers (Romani et al., 2009) affected the frying time and temperature, thereby ultimately affecting the final quality attributes. Krokida and co-authors (2001) reported that during first 5 minutes of frying at 170 $^{o}$C, a significant increase in the lightness (L-values), from 74 to 78, was observed when thickness of French fries ranged from 5 to 15 mm, respectively. Also difference in portion size affected the acrylamide formation. Fiselier and co-authors (2006) reported that an increase from 100 to 200 g at an initial temperature of 175 $^{o}$C, dropped the oil temperature from 158 $^{o}$C to 136 $^{o}$C, which resulted in a decrease of acrylamide formation from 45 to 25 µg/kg. However, this study did not give any quantitative data about other quality attributes. Romani and co-authors (2009) have found an increase of 1.5 fold in $F_{max}$ (a measure of hardness) of French fries with product to oil ratio of 1/8 (19.30 N) as compared to 1/4 (12.7N) when potato fries were subjected to frying at 180 $^{o}$C after 10 minutes in a domestic type of fryer. Moreover, $F_{max}$ for the French fries prepared in domestic type of fryer with product to oil ratio of 1/4 (12.7 N) was found 1.6 fold higher as compared to the French fries with similar ratio but prepared in catering type fryer (8.1N) under the similar frying conditions. The same study revealed 1.3 fold difference in the formation of acrylamide (380-500) in French fries with product to oil ratio of 1/4 and 1/8, respectively, after 10 minutes of frying at 180 $^{o}$C in a domestic type fryer.

**Table 2.1 Inventory of quality points where variation (differences) in product properties / process factors reveal an effect on variation (differences) in quality attributes**

| Product /process factors | Actual product properties and process conditions | Observed changes in Quality attributes | References |
|---|---|---|---|
| **Production of potatoes for French fries processing** | | ***Selection of cultivar*** | |
| *Glucose /Fructose Concentration* | Glucose conc. varied among 17 potato varieties from 0.097-2.55 g/kg (FW) (27 fold) for the varieties Marlene and Naturella respectively. Fructose conc. varied in similar fashion but with lower magnitude than glucose, ranging from 0.03-1.50 g/kg (FW)for (47 folds) the varieties Markies and Naturella, respectively. | **Safety:** Variety Nicola found to have maximum potential for acrylamide formation (2020 μg/ kg) whereas, variety Panda exhibited lowest mean potential (80 μg/ kg). The difference between the two extreme was found 28 folds. | Amrein et. al., 2003 |
| | Average glucose build up during storage, 8 clones of potato at 3 °C for 3 years, was 300 g/kg of total sugars ranging from 5.5 g/kg for clone B to 13.9 g/kg in clone D (average for all years). | **Colour:** frying of potato slices from 8 cultivars after 3 years storage at 3 °C resulted in variation in fry colour from 3.6 for clone E (darkest ) to 6.2 for Hulda (lightest).<br>Reducing sugar accounted for 52-64 % yearly, 18-62% monthly and 11-60 % genetic variation in fry colour. | Olsson et. al., 2004 |
| | Wide range differences in reducing sugar content were observed over a period of 11 months ranging from 0.0015-0.123, 0.003-0.088, and 0.0028-0.079 g/kg (FW) for varieties Rooster, Record, and Olean respectively. | **Safety:** A wide variation (up to 80 fold) in reducing sugar level was observed in the 11 months course of study resulted in high level of acrylamide (up to 2970 μg/kg). | Brunton et. al., 2007 |
| **Production of potatoes for French fries processing** | | ***Bulk Storage*** | |
| *Glucose /Fructose concentration* | Higher reducing sugar content was observed when 5 potato cultivars were stored at 4 °C than at 8 °C for 24 weeks. Maximum glucose build up was observed in case of Bintje variety that was 14.7 g/kg at 4 °C as compared to 9.0 g/kg at 8 °C. Similarly, fructose build up was 9.0 and 4.5 g/kg at 4 and 8°C, respectively. | **Safety:** Acrylamde formation increased when potatoes were stored at 4 °C (15000 μg/ kg) as compared to 8 °C (8000 μg/ kg).<br>Although No correlation (R= 0.1) between Asparagine content and acrylamde formation was established, however, strong correlation of asparagines content with acrylamide formation was found when ratio between fructose and asparagine is less than 1. | Viklund et. al., 2008 |
| *Time-temperature Regime during storage* | Reducing sugar content of potato tubers markedly increased when stored below 8°C. However, minor effect on amino acids was observed. | **Safety:** reducing sugar correlated well with acrylamide formation when fructose / aspergine ratio was less than 2(<2). When it is greater than 2 by low temperature storage than aspergine rather than reducing sugars was found to be the limiting factor. | Matsuura-Endo et. al., 2006 |
| | 50-fold difference (0.05-2.5 mg/g ) in glucose content per | **Safety:** More than 10 times increase in acrylamide level was found when | Chuda et. al., |

| | | | |
|---|---|---|---|
| | gram of raw tuber was observed when potatoes were stored at 2°C and 20°C, respectively. | potatoes were stored at 2 °C as compared to 20 °C. | 2003 |
| **Processing** *(Pre Treatment)* | | ***Blanching*** | |
| *Time-temperature Regime during blanching* | Potato strips subjected to blanching at 85 °C for 3.5 min. (HTST[1]), blanched /unblanched fries were subjected to frying at 120, 140, 160 and 180 °C till a final moisture content of 1.8 % ( wet basis). | **Colour**: colour in unblanched strips (expressed as Δ E; lower values, less dark) ranged from 36.65 to 55.27 (1.5 fold), whereas blanched strips colour ranged from 19.34 to 45.3 (1.5 fold). However colour was less dark for blanched strips.<br><br>**Safety**: the concentration of acrylamide ranged from ca .03 to 1.6(μg/kg) in the unblanched strips after frying at 120 and 180 °C respectively, whereas, in case of blanched strips it ranged from ca 0.01-0.80 (μg/kg) respectively. Blanching reduced acrylamide in potato chips to 68%, 75% and 49% at 120, 150 and 180 °C. | Pedreschi et. al., 2007a |
| | Potato strips subjected to blanching at 70 °C for 10 min. (LTLT[2]) as well as at 97 °C for 2 min.( HTST) , later on subjected to frying at 166 °C for 2.5 min. | **Colour:** LTLT blanching increased Lightness (L value) by 9% (55.2) as compared to Control (50.7) and also higher as compared to HTST conditions (53.2).<br><br>**Texture:** LTLT blanching also increased peak force (texture) by 6 % (2.61N- 2.76 N) as compared to control , whereas, in case of HTST blanching peak force decreased by 13 % (2.61N-2.31N). | Agblor and Scanlon, 2000 |
| | Potato strips blanched at temperatures ranging from 62.8-90.6 °C and duration from 2-20 min. | **Texture:** A negative correlation of texture ($F_{max}$) and blanching time and temperaturewas found which was r =-0.63 for blanching temperature < 74.5 °C compared to r =-0.82 for all temperature tested while it was r =-0.05 for the blanching time used for temperature < 74.5 °C as compared to all times tested (r =-0.34). | Liu and Scanlon, 2007 |
| **Processing** *(Pre Treatment)* | | ***Pre drying*** | |

| | | | |
|---|---|---|---|
| *Time-temperature settings during pre-Fry drying* | Potato strips were pre dried at air drying till 60 % moisture (wet basis) with blanching at 85 °C for 3.5 min. These strips were fried at 120, 140, 160 and 180 °C till a final moisture of 1.8 % (wet basis). | **Colour:** colour in pre dried strips ( expressed as Δ E; lower values, less dark) ranged from 26.52 to 41.23 (1.5 fold), however colour was less dark as compared to controlbut more dark as compared to blanched strips.<br><br>**Safety:** the concentration of acrylamide ranged from ca 0.2 to 0.85 (mg/kg) in the pre dried strips after frying at 120 and 180 °C respectively, whereas, in case of un blanched strips it ranged from 0.03-1.60(μg/kg) respectively. Only at 180 °C, pre dried conditions showed lower level of acrylamide (44%) as compared to unblanched strips. | Pedreschi et. al., 2007a |
| | Pre fry drying of potato strips at 70°C for 10 min.(LTLT) and 90°C for 20 minutes followed by frying at 166 °C for 2.5 min. | **Colour:** LTLT conditions decreased lightness (L values) by 3 % (49.0) as compared to standard (50.7), however, lightness was not affected by HTST conditions.<br><br>**Texture:** Peak force was reduced by 6 % under LTLT conditions (2.47) as compared to standard (2.61), whereas, under HTST conditions peak force further reduced by 11%<br>(2.51). | Agblor and Scanlon, 2000 |
| **Final preparation** | | ***Final Frying*** | |
| *Time-temperature settings* | Potato fries subjected for different frying times varied from 0-35 min. at 160,170 and 180 °C and 0-25 min. at 190 °C. | **Colour:** A significant increase in ΔE (total colour change) was observed after 25 min. of frying at 190 °C (450) which was 1.6 fold higher as compared to 160°C (250). | Nourian and Ramaswamy, 2003a |
| | Potato strips of different thickness (5*5, 10*10, and 15*15 mm) were subjected to frying at 150, 170, and190 °C for 1, 3, 5, 7,10,13,15, and 20 min. | **Colour:** During the early stage of frying lightness (L values) decreased with increase in frying temperature at the same frying time. During first 5 min., maximum increase in lightness was observed at 150 °C (64-76), whereas, minimum increase was observed at 190 °C (66-72). | Krokida et. al., 2001 |
| | Frozen potato strips were subjected to frying at 166 °C for 3.5 min. (LTLT), 182 °C for 1.5 min (HTST) and at166 °C for 2.5 min.(standard). | **Colour:** HTST frying increased lightness by 5% (53.1) as compared to standard settings (50.7),whereas, no significant change in lightness was observed in case of LTLT frying conditions (50.4)<br><br>**Texture:** HTST frying decreased peak force by 6 % (2.51 N) as compared to standard Settings(2.66 N),whereas, no significant change in peak force was observed in case of LTLT frying conditions (2.72N) | Agblor and Scanlon ,2000 |

| | | | |
|---|---|---|---|
| | Frozen fries were subjected to frying at 180 °C for 3-9 min. | **Colour:** Fry colour in terms of lightness (L values) decreased from 76 to 48 (0.66-fold) while redness (a values) increased from -6.59 to 13.57(6 fold).<br><br>**Texture:** Hardness ($F_{max}$) reduced by 0.2-fold during first 5 min. Afterwards 5 fold increased was observed during 5-9 min.<br><br>**Safety:** A significant increase (12 fold) in acrylamide formation (68-830 µg/kg) was observed when frying time increased from 5-9 minutes respectively. | Romani et. al., 2008 |
| *Thickness* | Potato fries subjected for different frying times varied from 0-35 min. at 160,170 and 180 °C and 0-25 min. at 190 °C. | **Texture:** Almost 0.2-fold (80 %) decrease in the hardness (11-2 N/mm) of French Fries was observed after first 5 min. After wards, hardness increased by 2 fold (2-4N), 5 fold (2-10N), 8.5 fold (2-17N), and 7.5 fold (2-15N) after frying at 160, 170, 180, and 190 °C respectively for 25 min. | Nourian and Ramaswamy,2003b |
| *Portion size* | Potato strips of different thickness (5*5, 10*10, and 15*15 mm) were subjected to frying at 150, 170, and190 °C for 1, 3, 5, 7, 10, 13, 15, and 20 minutes. | **Colour:** Lightness of French fries, for the same frying time and temperature, decreased with decrease in sample thickness. | Krokida et al. , 2001 |
| | Various amounts (30-250 g) of Frozen fries in were subjected to set of initial oil temperatures ranging from 160-190 °C. | **Safety:** With an addition of 100 and 200 g of potato fries at an initial temperature of 175 °C the temperature dropped to 158 °C and 136 °C respectively, resulted in 0.55-fold decrease in acrylamide formation from 45 µg/kg to 25 µg/kg. | Fiselier et. al., 2006 |
| | Frozen fries were subjected to frying in a fryer of domestic as well as catering type at 180 °C for different frying times. Product to oil ratio used were 1/4 and 1/8. | **Texture:** After 10 minutes of frying in domestic type of fryer, one fold difference in hardness (F max) was observed (12.76 N-19.30 N) for the product to oil ratio 1:4 and 1:8, respectively.<br><br>**Safety:** 0.6 fold differences in acrylamide formation (380-500 µg/kg) was observed after 10 minutes of frying when 1:4 and 1:8 product to oil ratio, respectively was used in domestic type of fryers. | Romani et. al., 2009 |

[1] HTST; High temperature short time[2]
[2]LTLT; Low temperature long time

## 2.4 Towards assessment of critical control points (CCPs)

The key studies providing insight in major sources of variation at different chain locations/ points that can be considered as control points are summarised in Table 2.1. However, based on current available literature, it is not yet possible to firmly assign control points, critical towards final quality, in the production chain of French fries because, as mentioned, a systematic approach appears to be lacking to establish *variation* in the final quality attributes. Most of the studies have published effects of major product and process parameters on the formation of colour, texture and acrylamide. It is not yet possible to discuss what unacceptable means for certain quality attributes, as companies have their distinct product specifications. However, control points where minor deviation in the product and /or process conditions result in large variation in the desirable quality attributes (texture and colour in our case) can be indicated as potential critical control points (pCCP) for quality attributes. Based on the quantitative data available in the current literature, selection of suitable potato cultivar, t-T settings during bulk storage, blanching and frying can be indicated as pCCPs along the production chain of French fries. These pCCPs can be assigned as real CCPs if variation in the desirable quality attributes outstrips the tolerable limits specified by a company for these attributes and later on monitoring systems can be established at these points. Where exactly in the chain these monitoring systems need to be established depends on the chain perspective and the possibilities/power of actors to draw requirements on control activities.

Based on the literature findings, a Monte Carlo simulation study was performed to show the potential effects of variation in time-temperature frying conditions on the quality attribute colour. To show this, an empirical equation was chosen from literature that expresses the simultaneous effect of frying time t (in min) and temperature T (in $^{o}$C) on colour (expressed as ΔE values computed from Hunter L, a and b values, Sahin, 2000):

$$\Delta E = 346.16 - 10.57\times t - 5.46\times T - 0.02\times t^2 + 0.08\times t\times T + 0.02\times T^2 \qquad (1)$$

Though this equation is empirical and may not be universally valid, it serves our purpose to illustrate the effect of small variations in technological conditions on quality attributes. The Monte Carlo simulation was done by superimposing a normal distribution variation in time and temperature settings of frying, using 1 * $10^7$ samplings in MathCad (Gardenier, Giu, and Demas, 2011); such a simulation gives a good impression of the effect of variation in independent settings (time and temperature in this case) on the response (a colour index in this case), see for instance, van Boekel, (2008). Various combinations were attempted and it was observed that the distribution of ΔE values is in fact slightly non-normal such that the distribution becomes skewed to the right, especially as a function of variation in temperature. Figure 2.3 gives an impression. The target value for the ΔE value for 4 minutes frying at 180 $^{o}$C was 26.36 (arbitrary units) but it can be seen that huge variation appears if the settings are not well controlled (Figure 2.3, histogram with red shade, with ΔE values ranging from -9 to 75).

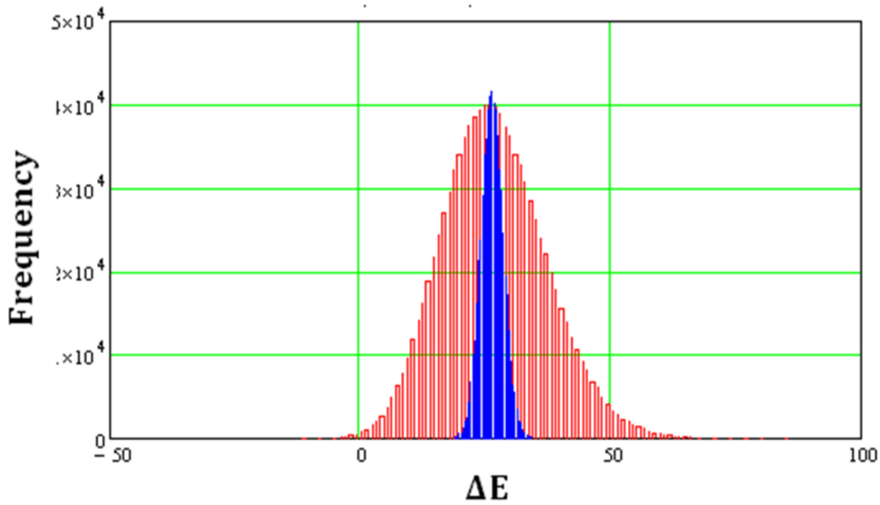
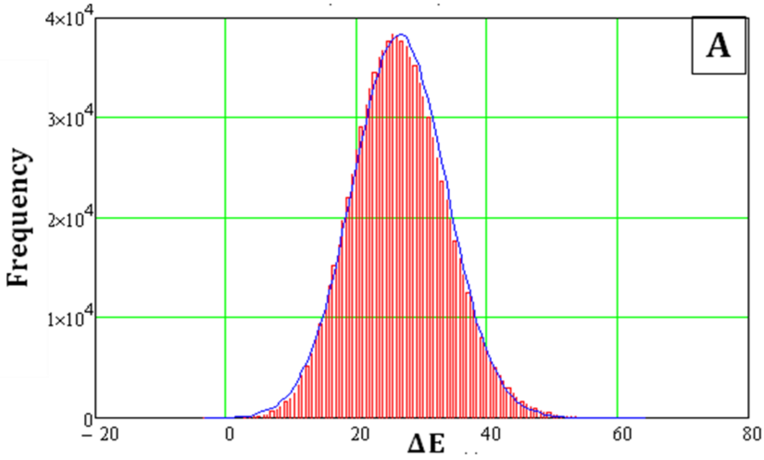



***Figure 2.3*** *Results of Monte Carlo simulations (displayed in histograms) to predict variation in the colour index **ΔE** using equation (1) as a function of variations in frying time t=4 min and temperature T=180 $^{o}$C. The predicted value for t = 4 min and T =180 $^{o}$C is **ΔE** = 26.36. A (histogram in red shade): t = 4 ± 1 min and T = 180 ± 5 $^{o}$C. B (histogram in blue shade): t = 4 ± 0.2 min and T = 180 ± 1 $^{o}$C.*

Even though the variation diminishes if the variation in settings is diminished

(Figure2.3: histogram with blue shade, ΔE values ranging from 19 - 34), the resulting distribution remains skewed even when the difference in the variation in the frying temperature was smaller i.e. 180 ± 3 and 180 ± 1 $^{o}$C, (Figure 2.4).



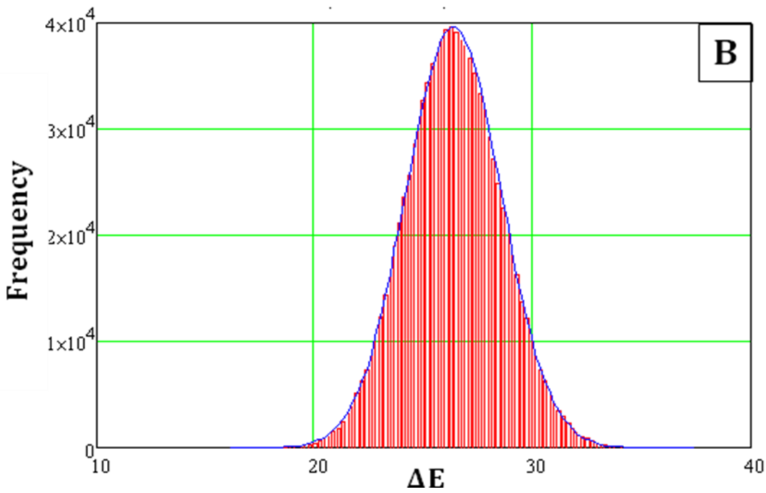




***Figure 2.4*** *Results of Monte Carlo simulations (displayed in histograms) to predict variation in the colour index $\Delta E$ using equation (1) as a function of variations in frying time t=4 min and temperature T=180 $^{o}C$. The predicted value for t = 4 min and T =180 $^{o}C$ is $\Delta E$ = 26.36. A: t = 4 ± 1 min and T = 180 ± 3 $^{o}C$. B: t = 4 ± 0.2 min and T = 180 ± 1 $^{o}C$. The curves represent the normal distribution generated using the mean and the standard deviation calculated from the Monte Carlo simulations.*

On the condition that a relationship such as equation (1) is valid, variation in quality is, therefore, actually predictable and controllable, in this case by making sure that the time-temperature settings are strictly controlled, and this illustrates the significance of establishing control points. However, this is, of course, just a theoretical exercise and actual variation needs to be established experimentally.

## 2.5 Conclusion

It is very clear from the literature what the most important controllable input factors are, namely selection of suitable cultivar, time-temperature regimes during bulk storage of potatoes, blanching and final frying. We characterize these as potential CCPs. It is also very clear that the extent of variation in quality attributes has not been studied systematically; in fact, it is unknown what the extent of variation actually is and how far uncontrollable input factors play a role in the final variation. Our Monte Carlo simulation has revealed possible effects in theory. In order to come to real CCPs for quality attributes it is necessary to study the extent of variation in more detail. Our analysis has pinpointed the controllable input factors and we will report in due course on the extent of variation in quality attributes by manipulating these factors in controlled experimental designs. In addition to these technological (process and product) factors, managerial factors (like people behaviour) as potential sources of variation (Luning & Marcelis, 2006; Sanny, Luning, Marcelis, Jinap, & Van Boekel, 2010) might also be taken in to consideration while making any strategy for the assessment of above mentioned CCPs.

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# Chapter 3

## Effect of varying frying conditions on variation in colour and texture of French fries: a quality control perspective

## Abstract

There is an increasing interest in establishing effective and efficient control measures in the food industry to assure that quality requirements other than safety are met. This requires insight in sources of variation contributing to large (unacceptable) variation in desired quality attributes. The study investigated the variation in quality attributes of French fries as a function of various fixed time-temperature (t-T) settings simulating Food service establishment frying conditions. The study revealed that increased temperature and time (from 170 to 190 $^{o}$C, and from 4 to 6 min) resulted not only in higher mean peak force values (0.98± 0.54 to 1.51±0.71 for log transformed values) and colour index (2.3 ± 0.59 to 3.43 ± 0.83 on a scale from 1-7), but also in larger variation in peak force (29 %) and colour index data (41 %). We conclude that inadequate control of these t-T settings during final frying can result in large variation in desired quality attributes of French fries and should be considered as control points critical for the final quality attributes of French fries.



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## 3.1 Introduction

Attributes like aroma, taste, texture, colour, health, convenience, and shelf life are important cues for quality perception of food products by consumers and they can contribute to repeated purchases (Grunert, Bredahl and Brunso, 2004; Van den Heuvel *et al,* 2007; Luning and Marcelis, 2009). In recent years, much effort has been spent on the development and implementation of food safety management systems due to various food crises and increased legislative requirements (Ropkins and Beck, 2000; Luning, Bango, Kussaga, Rovira, and Marcelis, 2008; Jacxsens, Devlieghere, & Uyttendaele, 2009). However, there is an increasing interest in establishing effective and efficient control measures to assure that quality requirements, other than safety, are met in order to survive in the competitive food market (Grunert, 2005; Manning, Baines, and Chadd, 2006, Verkerk, Linnemann, and Van Boekel, 2007; Luning and Marcelis, 2009). Luning and Marcelis (2009) stated that in order to comply with the conflicting requirements, i.e., assurance on the one hand and flexibility on the other hand, one should focus on those points in the process that have a decisive influence on final quality. Recently, the issue of controlling quality attributes was elaborated by analysing causes of variation in the major quality attributes along the production chain of French fries (chapter 2). During this analysis various control points (CPs) along the chain were established. However, control points where variation in product properties and or processes results in unacceptable and or irreversible deviations in required quality attributes were considered critical, and referred to as critical control points (CCPs) (Chapter 2). To assess above mentioned CCPs, product properties need to be analysed on how they contribute to required quality attributes. Process factors should be analysed on sources of variation and interaction to establish which CPs are critical; extreme variation may result in not meeting the requirements (i.e., being unacceptable). Process analysis is needed to know whether or not unacceptable product properties can be repaired downstream in the chain (i.e., the irreversibility). Chapter 2 indicated in the analysis of CCPs in French fries production that at final frying, the *process factors* temperature and time, and the *product factors* initial concentrations of reducing sugars, and thickness of fries are potential sources of variation that may contribute to unacceptable variation in colour and texture of fried French fries. The objective of this study was to get a quantitative insight in the effect of variation in frying time-temperature settings on the variation in colour and texture of thick and thin French fries under domestic frying conditions.

## 3.2 Material and Methods

### 3.2.1 Raw Material

Experiments were performed with two commercial types of frozen pre-fried potato fries (thick frozen fries; 9.5 ± 0.80 * 9.0 ± 0.90 mm and thin frozen fries; 7.5 ± 0.67 * 8.0 ± 0.54 mm) purchased at three different moments (manufacturing dates differed) from a major retailer in the Netherlands. The commercial bags purchased at the three different moments were mingled to obtain a homogeneous batch (three batches for thick and three for thin frozen fries) as starting point for the different frying experiments. The vegetable oil ("Diamant frituurvet") was also procured from a major retailer in the Netherlands.

### 3.2.2 Frying procedure

From every batch of thin and of thick French fries (FF), portions of 200 ± 3 g of frozen pre-fried fries were subjected to frying at initial oil temperature of 170.2 ± 0.20, 180.5 ± 0.15, or 190.4 ± 0.23 $^{o}$C for 4, 5, or 6 minutes as usually indicated on the commercial packages of French fries for domestic use. In total 9 different time-temperature (t-T) combinations (treatments) were applied in triplicate (n=3). Consequently, in total 81 portions (3 batches times 9 treatments times 3 replications) were fried randomly for thin and thick FF, respectively. For frying, a portion was transferred into the removable basket of a domestic type fryer, Princess classic Family Castel (3L) Type 182626/182627, which was shaken (away from the fryer) to remove ice crystals attached with the fries. The frozen fries were placed evenly in the basket and the basket was slowly placed in the pre-heated oil bath of the fryer at required oil temperature by placing a thermocouple, Peak Tech 3150, in the fryer.

To get insight in the actual temperature profile during frying, the oil temperature was monitored every 30 seconds for all the t-T settings. Just few seconds before the completion of frying, the basket was held so that the fries should come out of the fryer without any delay. The basket was placed above the fryer for 20 seconds to drain the excess of oil, taking care that the base of the basket was not in contact with the oil in the fryer. Immediately after frying, the French fries were weighed and analysed for colour and texture (within 6 ± 1 min.). The whole experiment was conducted by the same person and with the same fryer. The oil was filtered and replenished (to 3 litre) after every 3 times of frying and was completely replaced, along with thorough cleaning of the fryer, after every 27 times of frying.

### 3.2.3 Analyses

#### *A Peak force*

Peak force was used as a measure (index) of texture quality of French fries according to Agblor and Scanlon (2000). A texture analyzer (TA), model TA XT2i- HR (Stable Micro Systems, Surrey, UK), was used as described by different authors for instrumental analysis of texture with some modifications in the TA settings (Van Loon et al., 2007; Romani, Bacchiocca, Rocculi, & Dalla Rosa, 2008). A sample size of 25 French fries was used. Each French fry was fractured longitudinally with a wedge-shaped probe (30$^{\circ}$ cutting angle, 15 mm width), using a cell load of 5 kg and probe distance at 12 mm at a speed of 10 mm/s.

#### *B Colour index*

Colour index of French fries was evaluated by colour cards (USDA, Munsell Corp. USA) using a scale from 1 (lightest) to 7 (darkest). Sample size used for colour evaluation was 25 French fries ($n = 25$). All the colour analyses were conducted by the same person under similar light conditions.

#### *C Data handling and analysis*

Peak force and colour index were measured for each French fry in a random sample of 25 French fries from each fried portion. With these individual observations histograms per t-T setting were made to show the effect of different t-T settings on the peak force and colour index data for both thick and thin FF. Peak force data were not normally distributed and hence were log transformed prior to apply any parametric statistical method. Moreover, variation in the datasets for ln (peak force) and colour index per t-T setting was measured as calculated variation (Cal Var) by taking the standard deviation of (maximum) 25 French fries ($n \leq 25$) of each fried portion.

Therefore, for each type (thick and thin FF), 81 observations (3 batches times 9 treatments times 3 replications) were obtained for mean values and standard deviation (Cal Var) of ln (peak force) as well as colour index datasets. Data (above mentioned 81 observations) were statistically analysed by using SPSS software version 17. Analysis of variance (ANOVA) was carried out for the mean values as well as Cal Var (variation) in the peak force and colour index of both thick and thin FF. Furthermore, Tukey's test was used for comparing the effect of different t-T settings with $p< 0.05$ (Ott and Longnecker, 2010).

## 3.3 Results

### 3.3.1 Oil temperature profile during frying

Figure 3.1 shows the actual temperature profiles up to 360 seconds of monitoring at 170, 180, and 190$^{o}$C. An initial drop in oil temperature occurred in the first minute of frying, which was more predominant in case of the thin FF (12.5%) as compared to the thick FF (8.2%). The subsequent increase in oil temperature was higher and took longer (12 % increase after 240 seconds) in case of the thin FF as compared to the thick FF (4.7 % increase after 200 seconds). The temperature set at the initial values (170, 180, and 190 $^{o}$C) was not reached before the end of frying for any of the frying conditions for both the thick and thin FF.

### 3.3.2 Effect of frying conditions on peak force values

Initial data analysis indicated that the frequency distribution of the total set of raw peak force data (i.e. all t-T settings) of the thin FF was larger (3.71 ± 2.25) as compared to the thick FF (3.22 ± 1.71). Initial data analysis also revealed that data sets were not normally distributed (data not shown), therefore, data were log transformed for further statistical interpretation as described in section 2.3.

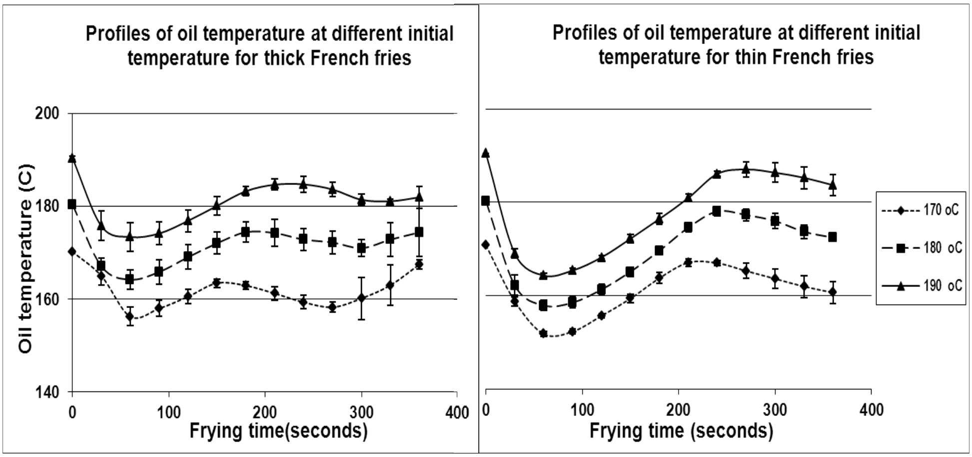


***Figure 3.1*** *Profiles of oil temperature during frying of French fries from thick (9.5*9.0) and thin frozen fries (7.5* 8.0) at 170, 180 and 190 °C for 4, 5 and 6 minutes. Each data point expresses mean of oil temperature after certain period of frying (till 240 seconds of frying N = 27, from 240 to 300 seconds N = 18, while from 300 to 360 seconds N = 9).*

Figures 3.2A and 3.2B show the histograms of the log-transformed peak force data for the thin and thick FF subjected to the different t-T frying settings. For the thin FF, the mean ln (Peak force) values were significantly increased ($p<0.05$) with all the frying times tested (4, 5, and 6 minutes) at all the frying temperatures (170, 180, and 190 °C). The mean ln (Peak force) values for the thin FF were also significantly increased ($p<0.05$) with frying temperature tested but only after 5 and 6 minutes of frying. After 4 minutes of frying no significant increase was observed with frying temperature. The thick FF showed similar results although the mean ln (Peak force) values were lower as compared to thin FF (Figure 3.2B).

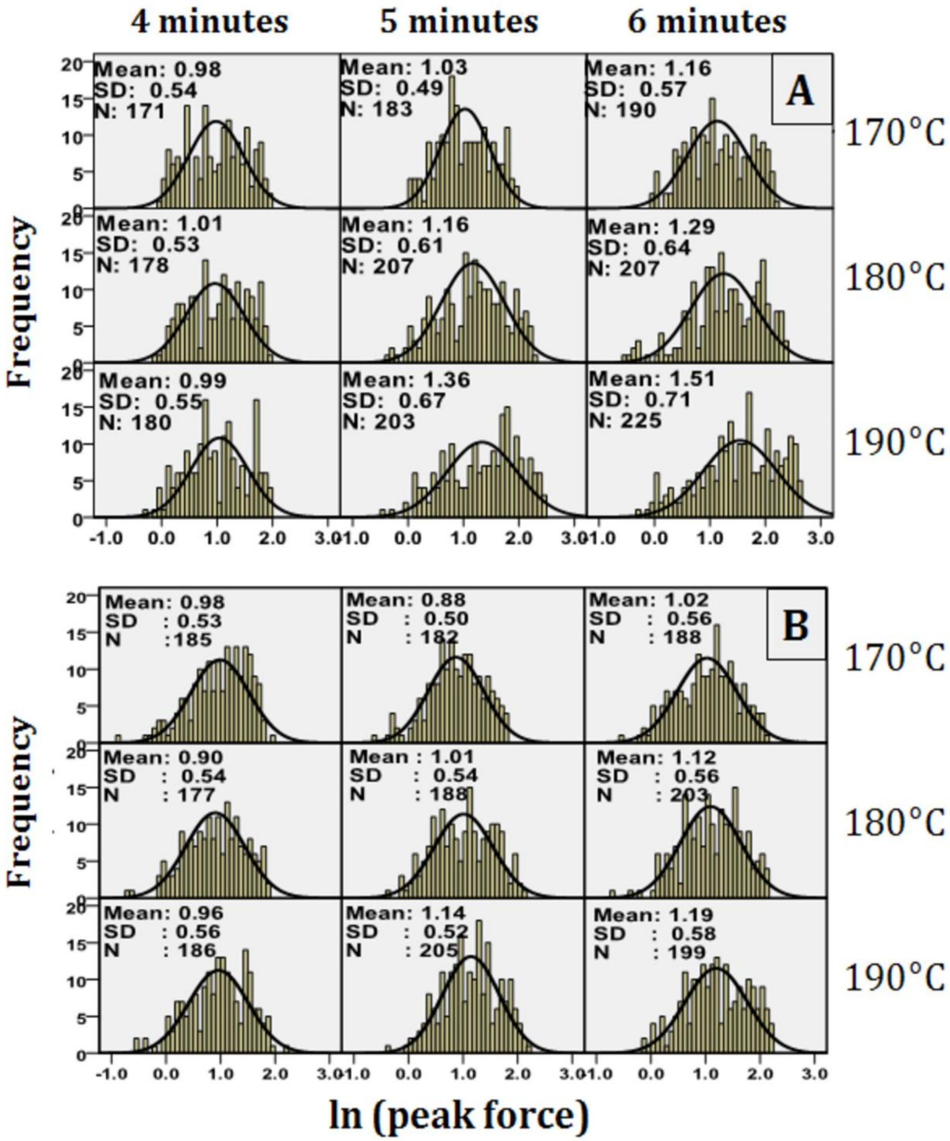


***Figure 3.2:*** *Histograms illustrating peak force (log transformed values) for A: thin FF and B: thick FF subjected to different frying time (ranging from 4 to 6 minutes) and temperature (ranging from 170 to 190 $^{o}$C) settings. Mean = average of the ln (peak force); SD = standard deviation; N = number of observations from 9 replicates of a certain* t-T *setting (treatment) where each replicate carries a maximum 25 French fries (N ≤ 225).*

Table 3.1 shows that for the thin FF, the mean variation (expressed as Cal Var, see section 2.3) in peak force data was significantly increased ($p<0.05$) with all the frying temperatures tested (170, 180, and 190°C) after 5 and 6 minutes of frying. The mean variation in peak force data was also significantly increased ($p<0.05$) with all the frying times, for all the frying temperatures (170,180 and 190 °C). However, in case of the thick FF, mean variation in the peak force data was not significantly different for any of the t-T frying settings. The mean variation in peak force data, at the different t-T frying settings, was overall larger in the thin FF than the thick FF, except for frying time of 4 minutes.

***Table 3.1*** *Illustrates the effect of variation in frying time (from 4 to 6 minutes) at a certain frying temperature (ranging from 170 to 190 °C) on variation in Cal Var in the peak force data (after log transformation) for thick and thin FF (rows) and vice the versa (columns). The values given in the table represent mean of the Cal Var taken from 9 replications of each set of the* t-T *setting (N = 9).*

| **Thin FF** | | | |
|---|---|---|---|
| **Temperature** | | **Time** | |
| | **4 Minutes** | **5 Minutes** | **6 Minutes** |
| **170 °C** | 0.55 ± 0.02 bc | 0.50 ± 0.01 a | 0.58 ± 0.01 d |
| **180 °C** | 0.54 ± 0.02 b | 0.62 ± 0.01 e | 0.65 ± 0.01 f |
| **190 °C** | 0.56 ± 0.01 c | 0.67 ± 0.01 g | 0.71 ± 0.02 h |
| **Thick FF** | | | |
| **170 °C** | 0.59 ± 0.09 a | 0.53 ± 0.12 a | 0.56 ± 0.06 a |
| **180 °C** | 0.56 ± 0.06 a | 0.55 ± 0.08 a | 0.54 ± 0.07 a |
| **190 °C** | 0.56 ± 0.11 a | 0.52 ± 0.09 a | 0.55 ± 0.11 a |

*Mean values followed by different letters for thick and thin FF were considered significantly different from each other ($p<0.05$); N = 9.*

### 3.3.3 Effect of frying conditions on colour index values

Figure 3.3 shows the histograms of the colour data for the thick and thin FF subjected to the different t-T frying settings. For the thin FF (Figure 3.3A), the mean values of the colour index significantly ($p<0.05$) increased with frying time (from 4 to 6 minutes), for all the frying temperatures (170, 180 and 190 °C) tested.

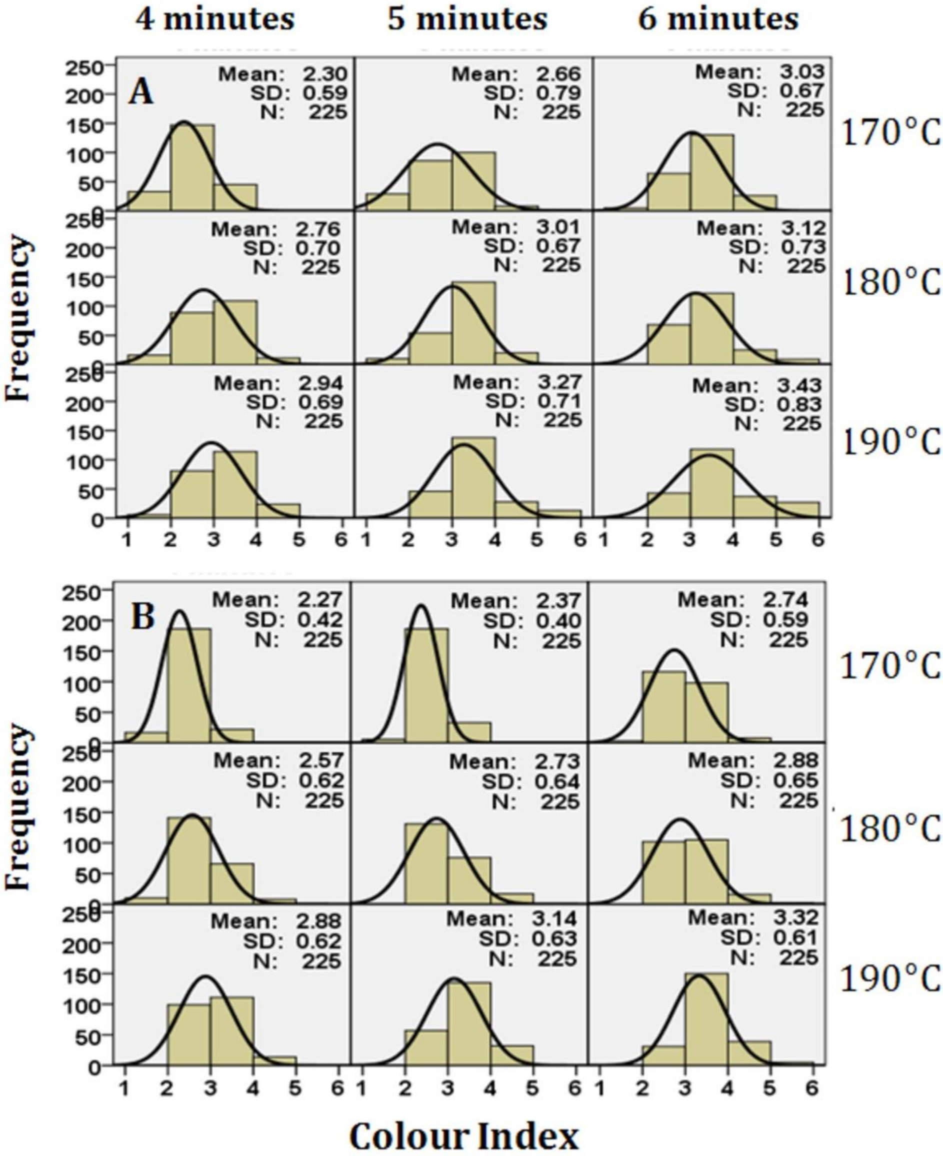


***Figure 3.3*** *Histograms illustrating raw data of colour index for A: thin FF and B: thick FF subjected to different frying time (ranging from 4 to 6 minutes) and temperature (ranging from 170 to 190 °C) settings. Mean = average of the colour index of French fries; SD = standard deviation; N = number of observations from 9 replicates of a certain* t-T *setting where each replicate comprises 25 French fries (N =225).*

A significant increase ($p<0.05$) in the mean values for colour index was also observed with increasing frying temperatures (from 170 to 190 °C) for all the frying times (4, 5, and 6 minutes) tested. Similar results were found for the thick FF (Figure 3.3B), however, the values were lower as compared to the thin FF. Table 3.2 shows that for the thin FF, a significant increase ($p<0.05$) in the mean variation in colour index data was observed when frying temperature was increased from 170 °C to 190°C after all the frying times tested.

***Table 3.2*** *Illustrates the effect of variation in frying time (from 4 to 6 minutes) at a certain frying temperature (from 170 to 190 °C) on variation in Cal Var in the colour index data ( in rows) and vice the versa (in columns) of thick FF and thin FF. The values given in the table represent mean of the Cal Var taken from 9 replications of each set of the* t-T *setting (N = 9).*

| **Thin FF** | | | |
|---|---|---|---|
| **Temperature** | | **Time** | |
| | **4 Minutes** | **5 Minutes** | **6 Minutes** |
| **170 °C** | 0.58 ± 0.09 a | 0.77 ± 0.10 d | 0.63 ± 0.09 b |
| **180 °C** | 0.70 ± 0.10 bc | 0.67 ± 0.05 bc | 0.72 ± 0.05 c |
| **190 °C** | 0.70 ± 0.07 bc | 0.70 ± 0.07 bc | 0.82 ± 0.14 e |
| **Thick FF** | | | |
| **170 °C** | 0.42 ± 0.07 a | 0.40 ± 0.06 a | 0.58 ± 0.08 b |
| **180 °C** | 0.58 ± 0.15 b | 0.63 ± 0.11 b | 0.63 ± 0.10 b |
| **190 °C** | 0.61 ± 0.07 b | 0.64 ± 0.05 b | 0.62 ± 0.15 b |

*Mean values followed by different letters for thick and thin FF were considered significantly different from each other ($p<0.05$); N = 9.*

The mean variation in colour index data was also significantly increased ($p<0.05$) when frying duration was increased from 4 to 6 minutes at all the frying temperatures tested. In case of thick FF, significant increase ($p<0.05$) in the mean variation in colour index data was observed when frying temperature was increased from 170 °C to 190 °C only after 4 and 5 minutes of frying. This mean variation was also increased significantly when frying duration was increased from 4 to 5 minutes, but only at 170 °C (Table 3.2).

## 3.4 Discussion

To our knowledge, this is the first study that explicitly analyses the effect of different fixed t-T treatments on variation in quality attributes of French fries rather than on mean values, as is commonly done. The present study revealed significant variation in the datasets of peak force (hardness) and colour index (darkness) of French fries with all the frying times (4 to 6 minutes) and temperatures (170 to 190 $^{o}$C). This variation in the datasets was more obvious in case of thin FF as compared to thick FF.

The first thing to note is that despite the exact time and same oil temperature for each individual French fry, there is a considerable variation in quality attributes. Studies have shown unequal and heterogeneous distribution of the precursors like starch, NPS and reducing sugars in the strips (Kazunori, Kenichi, Mochihumi, & Hiroshi, 2001) that can affect the attainment of final peak force and colour index of an individual fry (Signini, Dejmek, and Oste, 1999; Agblor and scanlon, 2000). Signini et al. (1999) found a large variation in the texture (from 1 to 3.5 N) for the chip made from bud end to the stem end, respectively. This initial heterogeneous distribution of precursors in the potato strips can also affect the rate of heat transfer (drying) during frying of these potato strips (Alvis, Velez, Rada-Mendoza, Villamiel , & Villada, 2009). Consequently, this variable rate of heat transfer might have an effect on the extent of variation in the datasets of peak force and colour index especially after the initiation of crust formation.

Another important aspect noted during the study was significant increase in peak force and colour index (mean values) of the French fries with increasing frying time (4 to 6 minutes) and temperatures (170 to 190 $^{o}$C). This increase in hardness and darkness of French fries was again more obvious in case of thin FF as compared to thick FF (Figure 3.2 and 3.3, respectively). These observations (only with respect to mean values) are in accordance with previous studies (Alvarez, Morillo, & Canet, 2000; Sahin, 2000; Pedreschi, Aguilera, & Pyle, 2001; Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001a; Nouirian and Ramaswamy, 2003a and b; Pedreschi, Leon, Mery, Moyano, Pedreschi, Kaak, & Granby, 2007a; Romani et al., 2008; Tajner-Czopek, Figiel, & Carbonell-Barrachina, 2008). The above mentioned increase in the hardness and darkness of French fries can be attributed to the dehydration of the external cells of potato followed by crust formation (Nourian and Ramaswamy, 2003a). Again initiation of crust formation is a crucial step as it accelerates the hardness and darkness of French fries with a faster rate (Nouirian and Ramaswamy, 2003a and b; Pedreschi et al., 2001; Romani et al., 2008).

Third important aspect noted during this study was that not only mean values, but also the variation around these mean values increase with the t-T settings. For the above said variation in the peak force and colour datasets, at a particular t-T setting, initiation of crust formation is critical. We assume that crust formation starts at the end of first stage of frying, ($t > 80$ seconds) as reflected in Figure 3.1, afterwards both peak force and colour index will increase with a faster rate. Therefore, we have found larger variation in ln peak force datasets for thin FF at 170 °C after 6 minutes of frying (0.58 ± 0.01) comparing to 4 minutes of frying (0.55 ± 0.02) with ln peak force values ranging from (min-max) -0.03 to 2.19 and -0.02 to 1.94, respectively (Figure 3.2A). Similarly, variation in the colour index datasets of thin FF increased significantly from 0.58 ± 0.09 to 0.63 ± 0.09 with frying time (from 4 to 6 minutes, respectively) at 170 °C with colour index values ranging from (min-max) 1.25 to 3.25 and 1.25 to 4.25 respectively (Figure 3.3A). This progressive increase in hardness and darkness can be attributed to crust hardening, which usually accelerates at higher frying temperatures (Pedreschi et al., 2001). Thus, the extent of variation in the datasets further increased (0.71 ± 0.02 and 0.82 ± 0.17, respectively) with actual values ranging from (min-max) -0.29 to 2.62 and 2.25 to 5.00, respectively, when thin FF were subjected to 190 °C as compared to 170 °C for the same 6 minutes of frying (Figures 3.2A and 3.3A).

The aforementioned effect of t-T settings on the hardness and darkness was more obvious in the case of thin FF as compared to thick FF. This might be attributed to the fact that the rate of moisture loss (drying) increased with frying temperature and this increment got intense with thinner samples (Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001b; Tajner-Czopek et al., 2008). These faster drying rates in thin FF might also be due to their higher surface to volume ratio (SVR) as compared to thick FF. Due to faster heat and mass transfer in the thin FF (with higher SVR) the formation of crust will be accomplished in less time. Consequently, resulting in harder texture and darker colour at higher temperatures with longer period of time (Taubert et al., 2004; Hindra and Baik, 2006; Moyano, Troncoso, and Pedreschi, 2008).

The measured actual oil temperature profiles show a considerable deviation from the initial settings, and it is quite remarkable that the intended temperature settings were not reached at the end of frying. The actual temperature profiles will be highly dependent on the capacity of the equipment and the portion sizes applied. We used a normal domestic type frying equipment, and it may be expected that the measured temperature profiles are realistic in actual practice. In any case, it shows that measurements in practical situations are needed to connect with the measurements made under laboratory conditions. For instance, when predictions are made on acrylamide formation using predictive models, measured temperature profiles should be used rather than assuming that temperatures are constant.

The present study revealed significantly large variation in the texture and colour profiles of French fries due to different t-T frying settings. Whether or not these settings be considered as a critical control point (CCP) depends on the acceptability of variation in these attributes. Nevertheless, these t-T frying settings can be considered as potential critical control point (pCCP) as small variation (that was actually well within the range mentioned on the label of the package, i.e., 4 to 6 minutes) in frying time resulted in significantly large variation in the colour and texture of the French fries, especially at higher frying temperatures (> 180 $^{o}$C). Companies, based on their established tolerances for product specifications, can decide whether or not to consider this pCCP as a real CCP. Variation due to uncontrollable input factors usually be taken as a given fact (Montgomery, 2008; Luning and Marcelis, 2009). Heterogeneous distribution of precursors is an example of such uncontrollable input factors and it is extremely difficult, if not impossible, to influence this heterogeneous distribution during any of the unit operations in French fries production (Baumann and Escher, 1995). What can be done, however, is to set narrow tolerances on the controlled input factors, in this case, t-T frying settings, and this would make it indeed a CCP.

## 3.5 Conclusion

The current study revealed significant variation in the texture and colour datasets for French fries with frying time, especially at higher frying temperatures (≥ 180 $^{o}$C). Thin French fries were found to be more susceptible to the above mentioned variation as compared to the thick FF, especially under domestic frying settings where lack of control over frying time due to variable food handler behaviour and frying temperature due to the frying equipment is nearly inevitable.

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# Chapter 4

## Quantitative assessment of the effect of blanching settings on variation in texture and colour of French fries

## Abstract

The time and temperature settings at frying of French fries are major control points to avoid unacceptable variation in the quality attributes. However, the actual variation in final quality attributes of food products is due to the cumulative effects of the different sources of variation along the supply chain. For the establishment of control points, one should thus not only focus on the end stage of the food production, but also consider previous steps in the chain that could affect actual variation in the product.

The current study was conducted to investigate whether different time-temperature blanching settings can additionally contribute to *variation* in the texture and colour data of French fries after final frying. The study showed that, for both thin and thick potato strips, different blanching settings did not result in significant difference in the *variation* in the data for dry matter and reducing sugar content. Moreover, no considerable variation in the datasets of peak force and colour index of French fries was observed except for the blanching setting at 80°C and 60°C for 10 minutes, respectively. The mean peak force values were significantly lower with increasing blanching temperature, whereas the mean colour index of French fries was significantly lower with increasing blanching time and temperature; results were more pronounced for the thin FF. Time and temperature settings are not critical for *variation* in quality attributes, but they are critical for the *level* of quality attributes.

## 4.1 Introduction

Effective control of product quality is increasingly important for food companies to survive in the competitive market (Grunert, 2005; Manning, Baines, and Chadd, 2006, Verkerk, Linnemann, and Van Boekel, 2007; Luning and Marcelis, 2009). However, much less efforts have been put in approaches to establish monitoring systems for quality attributes as compared to safety. The HACCP principles are widely acknowledged as an approach to assess critical control points for safety (chemical, microbial and physical hazards) (Jacxsens, Devlieghere, and Uyttendeale, 2009; Luning & Marcelis, 2009), but they are not straightforward applicable to quality attributes (like texture, taste, shelf life). For example, in contrast to food safety, quality is a more complex and a multidimensional concept (Luning and Marcelis, 2009) and for quality attributes there are commonly no legal norms and tolerances that can support in identifying critical locations for control. As a major requirement on food quality, quality attributes should be constant over time while complying with consumer demands (Deming, 1982). Therefore, to design an effective and efficient control system for quality attributes one should have insight in the sources of variation since every process is subject to variation.

The production chain of French fries was taken as a case to analyse various sources of variation in the major quality attributes of French fries, because these attributes can be affected by the dynamic processes in the food matrix as well as by the technological conditions that are applied along the whole production chain. In a previous study (chapter 2), it was concluded that selection of suitable cultivar with appropriate reducing sugars, time-temperature settings during bulk storage, blanching and final frying are potential locations for control. In another study (Chapter 3), it was confirmed that time-temperature (t-T) frying settings (end stage of FF production) are indeed major control points to avoid unacceptable variation in the quality attributes of FF. Results showed that increase in t and T frying settings resulted in a significant increase in the variation in the datasets of both texture (29 %) and colour (41 %) of French fries. However, the total variation in quality attributes of food products is due to the cumulative effects of the different sources of variation along the food production chain. For the establishment of control points, one should thus not only focus on the end stage of the food production, but also consider previous steps in the chain that could affect actual variation in the end-product. Therefore, to gain further insight in the contribution of sources of variation in the quality attributes of FF, the impact of blanching conditions on the variation in texture and colour of fried French fries was studied.

Blanching is indispensable for the development of good quality in terms of texture and color of French fries. Reducing sugars and dry matter content are responsible for the formation of colour, in the Maillard reaction (Marquiz and Anon, 1986), and texture development, respectively (Van Loon, 2005). It is through blanching that sugars leach out, starch gelatinizes, and cell separation is achieved (Pedreschi, 2009). Different blanching settings may lead to differences in leaching, diffusion and other biochemical reactions, which may result in variation in the initial distribution of precursors in the potato strips. Studies indeed have found considerable differences in the distribution of initial precursors in the potato strips even taken from the same tuber (Baumann & Escher, 1995; Kazunori, et al., 2001; Rommens, Shakya, Heap, and Fessenden, 2010). For example, Baumann & Escher (1995) found larger variation in dry matters in the outer (cortex and pith) as compared to the center of the potato tuber. Other studies found that potato fries with different dry matter content (Marquiz and Anon, 1986; Tajner-Czopek, Figiel, and Carbonell-Barrachina, 2008; Signini, Dejmek, and Oste, 1999; Van Loon, 2005) and different reducing sugars concentrations (Marquez and Anon, 1986; Olsson et al., 2004; Aguilera et al., 1999) significantly affected texture and colour values. Possibly, different blanching settings will not only lead to differences in the mean value but also in the variation in texture and colour of French fries.

The objective of the present study was to investigate whether different t-T blanching settings can contribute additionally to variation in quality attributes (texture and colour) of French fries after final frying.

## 4.2 Material and Methods

### 4.2.1 Raw Material

Potatoes (of variety Nicola) and vegetable oil ("Diamant frituurvet") were procured from a major retailer in the Netherlands.

### 4.2.2 Preparation of potato strips

The washed and peeled potatoes were cut into strips of two different sizes (thick potato strips: 10 mm * 10.5 mm * 60 mm and thin potato strips: 8 mm * 8.5 mm * 60mm) by using a manual cutter (Brabantia, the Netherlands). These potato strips were soaked in water for 20 minutes to get rid of excess starch from the outer tissues.

### 4.2.3 Blanching and preparation of par fried frozen fries

Potato strips were subjected to blanching in water (potato/water ratio 0.1 [w/v]) at 60, 70 and 80°C for 10, 20 and 30 minutes (9 treatments) in 4 replications. Control potato strips were not subjected to blanching (4 replications). Therefore, in total 80 portions (10 treatments * 4 replications * 2 thicknesses) were made for thin and thick FF. Both blanched and control potato strips were pre-dried at 70°C for 10 minutes in an oven (Model E104, Heraeus, Germany). Dried strips were subjected to pre frying at 175°C for 1.5 minutes. Paper towels were used gently to get rid of excess oil of the strips. Par fried potato fries were placed in the freezer (-20°C) on a metal tray for 30 minutes. The frozen fries were packed in pre-labeled packages and were stored in the freezer at -20°C for at least 48 hours.

### 4.2.4 Frying procedure

Each portion of par fried frozen fries (200 ± 5 g) was randomly subjected to frying at initial oil temperature of 180.5 ± 0.15 $^{o}$C, for 240 ± 3 seconds. For frying, a portion was transferred into the removable basket of a domestic type fryer, Princess classic Family Castel (3L) Type 182626/182627, which was shaken (away from the fryer) to remove ice crystals attached with the fries. The frozen fries were placed evenly in the basket and the basket was slowly placed in the pre-heated oil bath of the fryer at required oil temperature, which was checked by placing a thermocouple, Peak Tech 3150, in the fryer.

Just few seconds before the completion of frying, the basket was held so that the fries should come out of the fryer without any delay. The basket was placed above the fryer for 20 seconds to drain the excess of oil, taking care that the base of the basket was not in contact with the oil in the fryer. Immediately after frying, the French fries were weighed and analysed for colour and texture (within 6 ± 1 min.). The whole experiment was conducted by the same person and with the same fryer. The oil was filtered and replenished (to 3 litre) after every 3 times of frying and was completely replaced, along with thorough cleaning of the fryer, after every 27 times of frying.

### 4.2.5 Analyses

***A Analysis of potato fries***

Potato strips were examined for the reducing sugar and dry matter content after blanching treatments (and the control without blanching treatment).

***Dry matter content***

Potato dry matter was obtained by putting strips into an oven at 105°C till constant final dry weight (Moyano & Pedreschi, 2006).

***Reducing sugar content***

Reducing sugar content of the three batches of both thick and thin frozen fries was analysed (in triplicate) according to Matsuura-Endo and co-authors (2004). A sample of 10 g of finally cut frozen fries was homogenized (Ultra turrex; T 25 basic; IKA-WERKE) in 80 % (v/v) ethanol and the sugars in the homogenate were extracted at 80 $^{o}$C for 1 hour. After centrifugation (Heraeus multifuge X * 3R), the supernatant was dried in a vacuum evaporator at 40 $^{o}$C, dissolved in distilled water and passed through a membrane filter (0.2µm Omnipore, Millipore Tokyo). The concentration of sugars in the filtrate was determined by HPLC (Stationary phase: Prevail carbohydrates and Mobile phase: (Eluent A: 75% Acetonitril and Eluent B: 25 % Millipore water). Quantification of sugars in the samples was performed by standardization with external standards of fructose and glucose.

***B Analysis of French fries***

***Peak force***

Peak force was used as a measure (index) of texture quality of French fries (Agblor and Scanlon, 2000). A texture analyzer (TA), model TA XT2i- HR (Stable Micro Systems, Surrey, UK), was used as described by different authors for instrumental analysis of texture with some modifications in the TA settings (Van Loon et al., 2007; Romani, Bacchiocca, Rocculi, & Dalla Rosa, 2008). A sample size of 25 French fries was used to determine the peak force of the total sample. Each French fry was fractured longitudinally with a wedge-shaped probe (30$^{\circ}$ cutting angle, 15 mm width), using a cell load of 5 kg and probe distance at 12 mm at a speed of 10 mm/s.

***Colour index***

Colour index of French fries was evaluated by colour cards (USDA, Munsell Corp. USA) using a scale from 1 (lightest) to 7 (darkest). Sample size used for colour evaluation was 25 French fries (n = 25). All the colour analyses were conducted by the same person under similar light conditions.

### 4.2.6 Data handling and analysis

Peak force and colour index were measured for each French fry in a random sample of 25 French fries from each fried portion. These data of peak force and colour index were used to make histograms for each t-T setting, for both thin and thick potato strips. Peak force data were log transformed, as they were not normally distributed, prior to applying any parametric statistical method. The variation in the datasets for ln (peak force) and colour index per t-T setting was measured as calculated variation (Cal Var) by taking the standard deviation of 25 French fries (maximum) of each fried portion ( $n \leq 25$).

For each type of FF (both thick and thin), 40 observations (10 treatments times 4 replications) were obtained to calculate mean values and standard deviation (Cal Var) of ln (peak force) and of colour index. Data were analysed by using SPSS software version 17. Analysis of variance (ANOVA) was carried out for the mean values of dry matter and reducing sugar content for both thick and thin potato strips. ANOVA was also carried out for the mean values and the Cal Var (variation) data of peak force and colour index of the thick and thin FF. Tukey's test was used to compare the effect of the different t-T settings on mean values and Cal Var of texture and colour data with $p \leq 0.05$ as described by Ott and Longnecker (2010).

## 4.3 Results and Discussion

### 4.3.1 Effect of blanching conditions on reducing sugar concentration and colour

Table 4.1 shows that the means of reducing sugar concentrations of thin potato strips were significantly ($p<0.05$) lower after blanching at 80 °C as compared to blanching at 60 °C for both 20 (0.42 and 0.08 mg / g respectively) and 30 minutes (0.37 and 0.06 mg / g respectively) for the thin French fries. In the case of thick FF, mean reducing sugar concentrations were significantly ($p<0.05$) lower after blanching for 30 minutes as compared to 10 minutes (0.17±0.08 and 0.45±0.07, respectively) at 80 °C. However, no considerable differences in the standard deviation were observed among the blanching conditions, for the thin neither for the thick FF

***Table 4.1*** *The effect of different time and temperature settings on means and standard deviation of reducing sugar concentrations of thin and thick potato strips (N=4). The reducing sugar concentration for control was 0.65 ± 0.18 and 0.60± 0.01 mg/g for thin and thick potato strips, respectively.*

| **Thin potato strips** | | | |
|---|---|---|---|
| **Temperature** | **Time** | | |
| | **10 Minutes** | **20 Minutes** | **30 Minutes** |
| **60°C** | 0.26±0.19 ab | 0.42±0.09 b | 0.37±0.04 b |
| **70°C** | 0.21±0.09 ab | 0.21±0.08 ab | 0.20±0.07 ab |
| **80°C** | 0.25±0.02 ab | 0.08±0.01 a | 0.06±0.03 a |
| **Thick potato strips** | | | |
| **60°C** | 0.47±0.06 b | 0.29±0.04 ab | 0.30±0.04 ab |
| **70°C** | 0.29±0.01 ab | 0.23±0.08 a | 0.23±0.12 a |
| **80°C** | 0.45±0.07 b | 0.23±0.09 a | 0.17±0.08 a |

*The values followed by different letters are significantly different with p ≤0 .05.*

Mestdagh et al., (2008) suggested that blanching time is only important with lower blanching temperatures, but that might be true for longer duration (i.e. 45 and 60 minutes) as observed by Aguilera et al. (1999). This could be a reason that, in the present study, no significant difference in reducing sugar content was observed at lower blanching temperature (60 and 70 °C) with blanching time (maximum of 30 minutes). Moreover, Mestdagh et al. (2008) found a significant reduction (67 %) in reducing sugar content with high temperature (80 °C after 30 minutes) as compared to the control (without blanching) condition. In the present study, similar results were found for the thick potato strips (using thickness comparable to one used by Mestdagh et al., 2008) where almost 70 % reduction in reducing sugar was observed after 30 minutes of blanching at 80 °C as compared to the control. In the thin potato strips the reduction was even larger (90 %).

Figure 4.1A shows that the mean values of the colour index were significantly lower ($p<0.05$) when blanching temperature increased from 60 to 80 $^{o}$C for all the blanching times tested. Moreover, the mean values for colour index were significantly ($p<0.05$) lower at 30 minutes as compared to 10 minutes blanching, for all the blanching temperatures tested. Similar results were found for the thick FF (Figure 4.1B). However, the mean variation (Cal Var) in the colour index datasets was not significantly different ($p\leq0.05$) except for the blanching settings at 60 $^{o}$C for 10 minutes (table 4.2).

Figure 4.1A shows that the mean values of the colour index were significantly lower ($p<0.05$) when blanching temperature increased from 60 to 80 $^{o}$C for all the blanching times tested. Moreover, the mean values for colour index were significantly ($p<0.05$) lower at 30 minutes as compared to 10 minutes blanching, for all the blanching temperatures tested. Similar results were found for the thick FF (Figure 4.1B). However, the mean variation (Cal Var) in the colour index datasets was not significantly different ($p\leq0.05$) except for the blanching settings at 60 $^{o}$C for 10 minutes (table 4.2).

The results of the means data are in line with previous studies showing a significant decrease in darkness (in this case colour index) with blanching time and temperature (Aguilera et al., 1999; Agblor and Scanlon, 2000; Pedreschi et al., 2006).

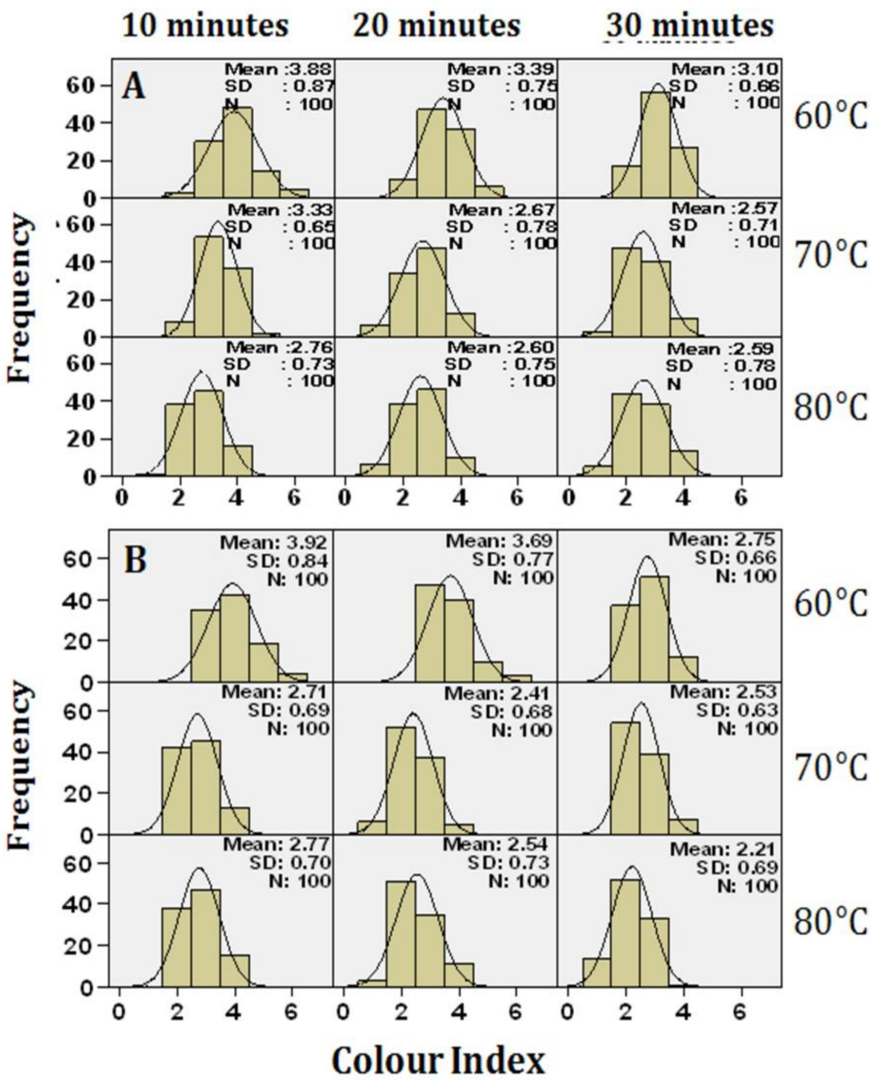


***Figure 4.1*** *Histograms illustrating raw data of colour index for A: thin FF and B: thick FF subjected to different blanching time (10, 20 and 30 minutes) and temperature (60, 70 and 80 °C) settings. Mean = average of the colour index; SD = standard deviation; N = number of observations from 4 replicates of a certain t-T setting where each replicate carries a maximum 25 French fries (N ≤ 100).*

Agblor and Scanlon, (2000) discussed that long-time blanching conditions increase the extent of leaching of precursors like reducing sugars, which will affect final colour of the French fries. Aguilera-Carbo et al. (1999) indeed found that blanching at lower temperature for longer duration significantly affected reducing sugars concentration of the strips.

***Table 4.2*** *The effect of blanching time (10, 20 and 30 minutes) and temperature (60, 70 and 80 °C) settings on variation (mean Cal Var* ± SD) *in the colour index data (after log transformation) for thin and thick FF. The values given in the table represent mean of the Cal Var taken from 4 replications of each set of the t-T setting.*

| **Thin French fries** | | | |
|---|---|---|---|
| **Temperature** | **Time** | | |
| | **10 Minutes** | **20 Minutes** | **30 Minutes** |
| **60°C** | 0.86±0.19 b | 0.76±0.02 ab | 0.67±0.03 ab |
| **70°C** | 0.64±0.01 a | 0.79±0.05 ab | 0.72±0.06 ab |
| **80°C** | 0.72±0.01 ab | 0.76±0.01 ab | 0.78±0.02 ab |
| **Thick French fries** | | | |
| **60°C** | 0.84±0.08 b | 0.78±0.09 ab | 0.67±0.04 a |
| **70°C** | 0.70±0.02 ab | 0.69±0.06 ab | 0.65±0.05 a |
| **80°C** | 0.70±0.03 ab | 0.74±0.03 ab | 0.69±0.04 ab |

*The values followed by different letters are significantly different with p ≤ 0.05.*

### 4.3.2 Effect of blanching conditions on dry matter content and texture

Table 4.3 shows the means of dry matter contents of thin and thick potato strips for the different blanching conditions. The means of dry matter contents did not significantly ($p<0.05$) differ for any of the blanching conditions. Likewise, no considerable differences in the variation (in terms of standard deviation) in the datasets of dry matter contents for both thin and thick potato strips were found. Canet et al. (2005)

also found that different blanching temperatures (60, 70, and 80 °C for 60 minutes) did not result in a significant difference in dry matter content of potato strips.

***Table 4.3*** *The effect of different blanching settings on the dry matter content (mean* ±SD) *of thin and thick potato strips (N = 4).The dry matter content for control was 23.13 ± 3.23 % and 24.06 ± 1.69 % for thin and thick potato strips, respectively.*

| **Thin French fries** | | | |
|---|---|---|---|
| **Temperature** | **Time** | | |
| | **10 Minutes** | **20 Minutes** | **30 Minutes** |
| **60°C** | 21.94±1.72 a | 22.97±2.11 a | 21.89±2.82 a |
| **70°C** | 19.11±1.22 a | 18.14±1.73 a | 20.55±2.35 a |
| **80°C** | 19.68±1.02 a | 21.14±0.98 a | 20.12±2.02 a |
| **Thick French fries** | | | |
| **60°C** | 20.83±1.22 a | 23.46±2.81 a | 21.74±1.14 a |
| **70°C** | 22.66±0.80 a | 22.46±1.15 a | 20.07±0.88 a |
| **80°C** | 19.92±3.22 a | 20.16±1.70 a | 20.91±2.13 a |

*The values followed by different letters are significantly different with $p \leq .05$.*

Table 4.4 shows that only for the blanching setting at 80 °C for 10 minutes the variation in the peak force datasets (expressed as cal var) of the thin FF was significantly larger as compared to the blanching settings at 60 °C. Although previous studies have shown that differences in dry matter content of potato strips resulted in significant differences in texture of French fries (Marquiz and Anon,1986; Tajner-Czopek et al., 2008; Van Loon, 2005). Table 4.3 shows, however, that the variation in dry matter content was not significantly different for any of the blanching conditions whereas in the texture data the variation was larger when blanching at 80°C for 10 minutes as compared to 60°C for 10 minutes.

Figures 4.2a and 4.2b show the histograms of the log-transformed peak force data for both the thin and thick FF, subjected to the different blanching t-T settings. The mean ln (Peak force) values were significantly larger ($p<0.05$) at 60 °C as compared to 10 minutes at 80 °C for the thin FF. These values were also significantly larger ($p<0.05$) after 30

***Table 4.4*** *The effect of blanching time (10, 20 and 30 minutes) and temperature (60, 70 and 80 °C) settings on variation (mean Cal Var* ± SD) *in the peak force data (after log transformation) for thin and thick FF. The values given in the table represent mean of the Cal Var taken from 4 replications of each set of the t-T setting (N = 4).*

| **Thin French fries** | | | |
|---|---|---|---|
| **Temperature** | **Time** | | |
| | **10 Minutes** | **20 Minutes** | **30 Minutes** |
| **60°C** | 0.54±0.12 a | 0.58±0.09 ab | 0.58±0.09 ab |
| **70°C** | 0.59±0.08 ab | 0.57±0.06 ab | 0.55±0.09 a |
| **80°C** | 0.76±0.12 b | 0.60±0.05 ab | 0.53±0.03 a |
| **Thick French fries** | | | |
| **60°C** | 0.36±0.07 a | 0.50±0.06 a | 0.44±0.09 a |
| **70°C** | 0.54±0.07 a | 0.49±0.13 a | 0.52±0.04 a |
| **80°C** | 0.40±0.09 a | 0.56±0.11 a | 0.48±0.10 a |

*The values followed by different letters are significantly different with p ≤ .05.*

minutes as compared to 10 minutes of blanching, but only at the blanching temperature of 80 °C. However, the mean ln (Peak force) values for the thick FF were not found significantly different ($p<0.05$) for any of the t-T blanching settings. These findings are in line with previous studies (Aguilera-Carbo, et al., 1999; Agblor and Scanlon, 2000; Canet et al., 2005; Liu and Scanlon, 2007; Lisinska et al., 2007). Agblor and Scanlon (2000) found larger mean peak force values for the French fries subjected to low temperature (LTLT) as compared to high temperature (HTST) blanching and also control conditions. Peak force tends to decrease (softening) with increasing blanching temperature, while at higher blanching temperatures it tends also to increase with blanching times. Softening of the texture is a result of the swelling pressure of starch gelatinization, coupled with hydrothermal degradation of pectin (Andersson, Gekas, Lind,

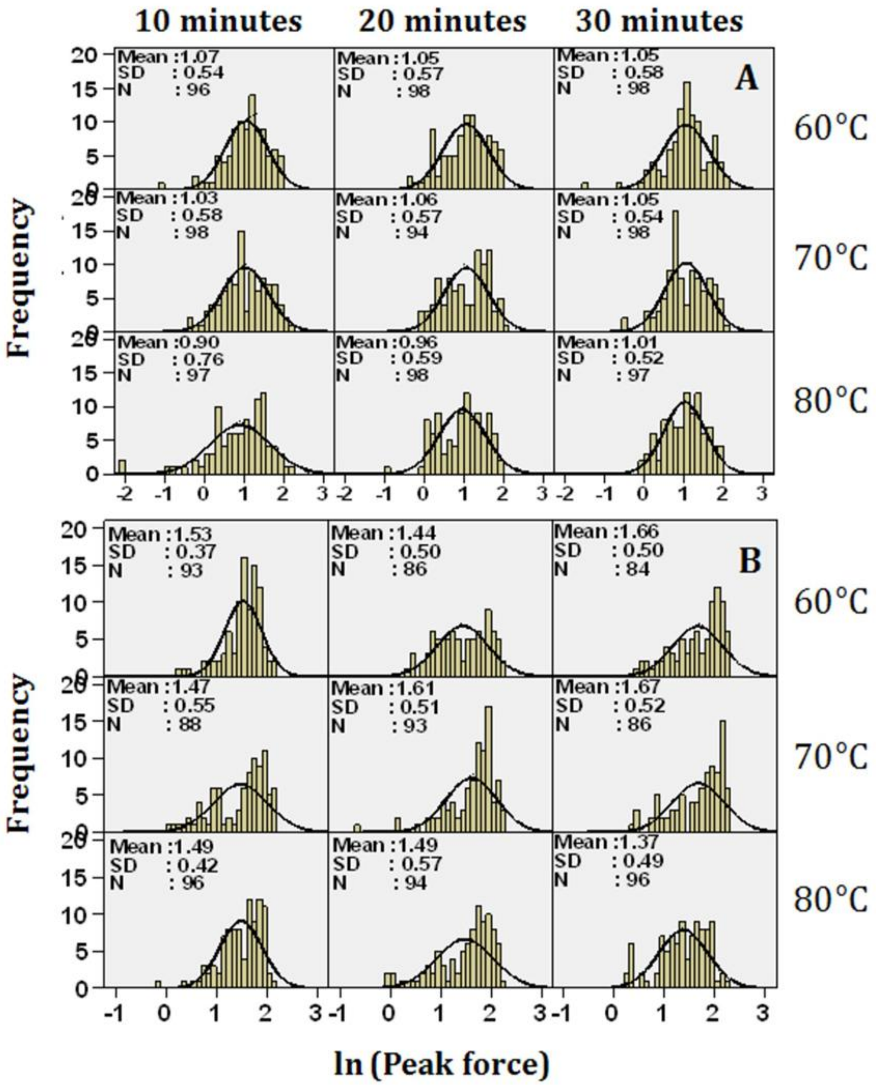


***Figure 4.2*** *Histograms illustrating peak force (log transformed values) for A: thin FF and B: thick FF subjected to different blanching time (10, 20 and 30 minutes) and temperature (60, 70 and 80 °C) settings. Mean = average of the ln (peak force); SD = standard deviation; N = number of observations from 4 replicates of a certain t-T setting where each replicate carries a maximum 25 French fries (N ≤ 100).*

Oliveira, Öste, 1994). During LTLT blanching, the swelling pressure exerted by starch gelatinization is simply insufficient to breakdown the above mentioned linkages, strengthened by the activity of PME (Agblor and Scanlon, 2000; Liu and Scanlon, 2007). Thickness of the potato strip also plays an important role in this context as starch gelatinization takes more time in thicker strips as compared to thin strips. On the whole, we do not see considerable differences in variation due to blanching conditions. We noticed two exceptions, one in texture, after 10 minutes at 80 $^{o}$C and the other in colour, after 10 minutes at 60 $^{o}$C. However, these exceptions, though statistically significant, were marginally significant but definitely not a big variation. Thus we conclude, keeping all the data in view, that blanching conditions do not cause significant differences in variation.

Therefore, blanching settings used in the current study did not resulted in any considerable variation in the colour index and peak force data of French fries. However, these blanching settings played an important role in the attainment of final (mean values) peak force and colour index of French fries.

## 4.4 Conclusion

The ultimate goal of quality control is to keep final quality attributes at the correct level (mean value) with little variation (narrow tolerances). The outcome of the present study shows that t-T blanching settings affected considerably the actual level (mean values) of texture and colour of French fries but did not contribute to variation in profiles of texture and colour after final frying of French fries. Thus, t-T blanching settings are control points for the required level of a quality attribute but need not to be considered as critical control point because variation in quality attributes at the final frying is not affected substantially.

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# Chapter 5

## Impact of frying practices on variation in texture and colour of French fries.

## Abstract

Quality control aims at reducing variation in quality attributes in the final food products, and instructions aim at reducing variation by directing food handlers' decision-making behaviour in control tasks. This study investigated the effect of providing frying instructions to food-handlers (making decisions on frying time and portion size) on the variation in texture and colour data of French fries. Implementation of frying instructions, combined with strict monitoring on compliance to the instructions, reduced variation in the observed frying time and portion size (from 0.45 to 0.003 seconds and 0.32 to 0.003, respectively; for the log transformed data). This reduction in variation resulted in the reduction in variation of texture data by 17% and colour data by 23% of thin French fries.

The study concluded that variation in control decisions of food handlers leads to large variation in texture and colour of French fries, but providing frying instructions in combination with strict monitoring on compliance to instructions can reduce this variation.

## 5.1 Introduction

Quality control is of prime importance for agri food business. Although the establishment of science-based control systems for safety hazards is now common practice (Luning, Bango, Kussaga, Rovira, and Marcelis, 2008; Jacxsens, Devlieghere, & Uyttendaele, 2009), less is known about how to assess control points for other quality attributes (like texture, colour) in a systematic science-based way (Luning and Marcelis, 2009). Principally, quality control aims at reducing variation in quality attributes in the final food products (Deming, 1982). Since the overall variance in final quality attributes is due to the sum of variances in the various factors influencing these attributes (Kasper, 2007), it is necessary to get an understanding of those product and process-related causes that lead to large variation in the final quality attributes (Chapter 2).

The production chain of French fries was used as case study to get an insight in the possible causes of variation in the major quality attributes of French fries. A comprehensive literature analysis showed that the selection of suitable cultivars, time-temperature (t-T) setting during bulk storage, blanching, and final frying respectively are factors potentially influencing variation in the final quality attributes of French fries. A Monte-Carlo simulation indicated that slight variation in frying time and temperature induced considerable variation in colour index (Chapter 2). This effect was confirmed in a study about the quantitative impact of different t-T frying settings on variation in texture and colour profiles of French fries. The study showed large variation in the texture and colour datasets at 190 $^{o}$C for 6 minutes (0.71±0.02 and 0.82±0.17, respectively) as compared to 170 $^{o}$C for 4 minutes (0.55±0.02 and 0.58±0.09, respectively). Thus at higher t-T frying settings, minor deviations in frying time and/or temperature might lead to large variation in the final quality attributes. Therefore, t-T frying settings were considered as potential critical control point (pCCP). Inadequate control at these pCCP's may thus lead to large (undesirable) variation in quality attributes of the final product.

However, food handlers' decisions in daily control are rather variable, which can influence food quality (Luning and Marcelis, 2007, Sanny, et al, 2010, 2011a). The variation in food handlers' decisions during frying may be a crucial additional source of variation. Providing instructions aims at guiding decision-making behaviour of food handlers in a certain direction and to reduce variation in the decisions taken by them (Luning and Marcelis, 2006, 2007). Less variation in food handlers' decisions in daily control might lead to less variation in final quality attributes. However, instructions may not always be effective due to the difficulty experienced by people involved to understand technical terms (Luning and Marcelis, 2009), efficacy of instructions (Park and Jung, 2003; Latham and Ernst, 2006)), and lack of motivation (Azanza and Zamura-Luna, 2005). Moreover, inadequate equipment (frying facility) is also mentioned as one of the barriers to effectiveness of instructions (Clayton et al., 2002; Sanny et al., 2010; Seaman and Eves, 2008)

To our knowledge the quantitative effect of variable decision-making on the variation in food quality attributes has been scarcely studied. The objective of this study was, therefore, to get quantitative insight in the effect of instructions to food handlers, on the variation in decisions on frying time and portion size and its subsequent effect on the variation in  texture and colour of thin and thick French fries. To be able to observe the effect of instructions per se, the actual compliance to the provided frying instructions was monitored strictly.

## 5.2 Material and methods

### 5.2.1 Raw Material

Experiments were performed with two commercial types of frozen pre-fried potato fries (thick French fries (thick FF); 9.5 ± 0.80 * 9.0 ± 0.90 mm and thin French fries (thin FF); 7.5 ± 0.67 * 8.0 ± 0.54 mm) purchased from a major retailer in the Netherlands.

### 5.2.2 Sample

The experiment was conducted with a diverse group of 40 participants (mostly University students and employees) from 15 different countries, 40% (16) of which were females. The mean age of participants was 27 ± 3 years (ranging from 23 to 35 years). The age of participants has also been found to be an influencing factor on people behaviour (Buccheri et al., 2010), however, this factor is assumed not to contribute to the variation in the present study due to little variation in the age of participants. Almost all the participants were having the same education level, from different fields of interest, e.g. food sciences, plant sciences, social sciences and animal sciences.

### 5.2.3 Development and implementation of frying instructions

Every participant was asked four times to perform frying in two sessions. In the first session, participants were asked to fry, the first two portions (using thin and thick frozen fries, respectively), without the specific instructions, and they were free to select portion size and frying time according to their judgment. However, they were provided with the general frying instructions with some precautions to take care during the frying. These instructions included shaking of the basket containing frozen fries to remove ice crystals prior to place it in the oil for frying. Potato fries should be placed evenly in the basket and the basket should be slowly placed in the pre-heated oil bath of the fryer at the required oil temperature (180 $^{o}$C). A thermocouple, Peak Tech 3150, was placed in the fryer to monitor that frozen fries were immersed in fryer at 180 $^{o}$C every time. In the rest of the study, the terms '*uninstructed or before instructions*' were used to refer to this first session.

In the second session (for the third and fourth frying), detailed oral and written instructions were provided to the participants. The specific frying instructions included: the portion size must be 300 g and must be weighed before frying; frying duration must be 3.5 minutes for thin and 4.0 min for thick FF; the amount of oil must be at the 3 litter as marked in the Fryer. The participants were provided with a weighing balance and a stopwatch so that they could determine portion size and frying time precisely, according to the instructions. In addition, the researcher monitored strictly the participants to check that they were correctly y complying with the prescribed instructions. In the rest of the study, the terms '*instructed or after instructions*' were used to refer to the second session. After the completion of frying, the basket should be placed on the fryer for 20 seconds to drain the excess of oil, taking care that the base of the basket was not in contact with the oil in the fryer. This was monitored by the researcher during both the sessions.

Immediately after frying, French fries the researchers weighed and analysed for colour and texture analysis (within 6±1 minutes). After frying of every four portions, the oil was filtered and volume was made up to the 3 litre mark. After frying every 20 portions, the oil was replaced completely and the fryer was thoroughly washed and cleaned.

### 5.2.4 Analysis

***Peak force analysis***

Peak force was used as measure (index) of texture quality of French fries (Agblor and Scanlon, 2000). A texture analyzer (TA), model TA XT2i- HR (Stable Micro Systems, Surrey, UK), was used as described by different authors for instrumental analysis of texture of French fries with some modifications in the TA settings (Van Loon et al., 2007; Romani, Bacchiocca, Rocculi, & Dalla Rosa, 2008). Each French fry was fractured longitudinally with a wedge-shaped probe (15 mm width), using a cell load of 5 kg and probe distance at 12 mm at a speed of 10 mm/s. Twenty five potato sticks were analyzed for peak force (N) per frying by using the software Texture Exponent 32 (Stable Micro Systems, Surrey, UK).

***Colour analysis***

Colour index of French fries was evaluated by using USDA colour cards (Munsell Corp. USA) using scale 1 (lightest) to 7 (darkest). A sample size of 25 French fries was used for colour evaluation for each portion. The colour analysis was performed by the same person using similar light conditions.

### 5.2.5 Questionnaire design

In order to get insight in the characteristics of the respondents that may affect their decision-making behaviour we developed a questionnaire (appendix 1).

The cognitive-behaviour barrier model to HACCP guideline adherence, for individuals comprising HACCP team, was taken as input for the selection of knowledge and attitude (Azanza and Zamura-Luna, 2005) as major characteristics of food handlers to be analysed. The model subdivides knowledge (body of acquired facts) into awareness, familiarity and comprehension, and attitude (defined as mental reaction to knowledge) into agreement and commitment subcategories. The questionnaire was developed by using these categories.

The questionnaire included four sections 1: Socio-demographic characteristics of the participants (gender, age, nationality, education level, professional category); 2:

characteristics related to safety consciousness (self-reported behaviour related to health and hygiene, food handling, food safety concerns; 3: knowledge (frying practices, French fries, quality attributes of French fries); 4: attitude (self-reported behaviour with respect to instructions given on the label, response to those instructions, effectiveness of the instructions). For section 2 and 3 respondents were asked questions with only one right answer that will give them 10 scores and a wrong answer will give 0 score. However, in the section 4, questions concerning respondents frying attitude, for every question there were three statements carrying 0, 5, and 10 scores, respectively. Based on the response to this questionnaire, for each of the characteristics, (section 2-4) participants were scored between 0 and 40.

### 5.2.6 Data handling and analysis

Peak force and colour index were measured for each French fry in a random sample of 25 French fries from each fried portion of every participant. With these individual observations for thick and thin FF, histograms were made showing variation in peak force and colour index data. Histograms were also made to show portion size and frying time selected by the participants before and after the provision of the detailed instructions. The data for portion size, frying time and peak force were not normally distributed; therefore, data were log transformed for further statistical analysis. The average peak force and colour index was determined by measuring mean values from 25 FF of each portion. Standard deviation measured from 25 FF of each fried portion was used as calculated variation (Cal Var) in ln (peak force) and colour index data of both thick and thin FF. Therefore, for each type (thick and thin FF), 40 observations (n = 40) were obtained for mean values as well as Cal Var (variation) in ln (peak force) and colour index data before and after instruction.

To get insight in the effect of different respondent characteristics on the variations in the data sets, a secondary data analysis was done. For each of the respondent's characteristics, peak force datasets were divided into two groups 1) respondents scoring between 0 and 20 and 2) respondents scoring between 21 and 40 for the respective characteristics. Each group carried observations for mean values as well as Cal Var (variation) in ln (peak force) before and after instructions.

One way Analysis of variance (ANOVA) and Tukey's test ($p \leq 0.05$) were carried out by using SPSS software version 17, to investigate the significance and comparison among the different groups (Ott and Longnecker, 2010).

## 5.3 Results

### 5.3.1 Effect of instructions on actual frying practices

Figure 5.1 A and B show the variation in the actual portion size (weight) and the actual frying time (raw data), as decided by the participants, for the thin FF before and after providing the specific frying instructions. The datasets for portion size, and frying time were not normally distributed and therefore were log transformed for further statistical interpretations (as described in section 5.2.6) of the variation in the datasets.

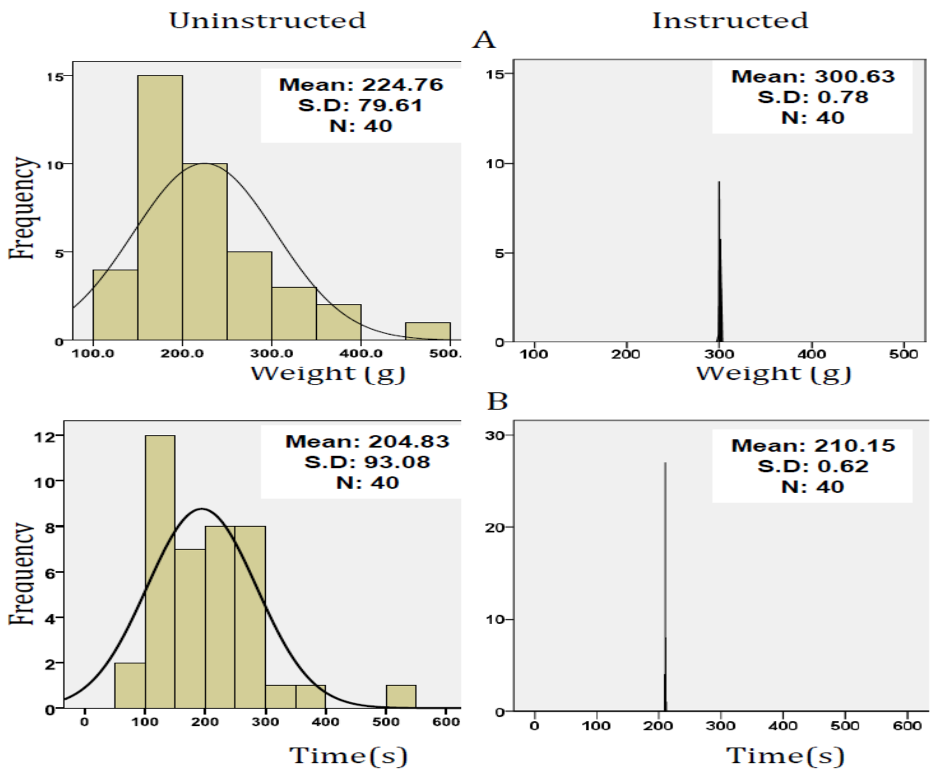


***Figure 5.1:*** *Variation (before and after instruction) in the raw data of portion size (A) and frying time (B) used for frying of thin frozen fries. The relevant statistical parameters are indicated in the figure.*

Table 5.1 shows that for the thin FF the variation (expressed as standard deviation) in portion size and frying time was significantly ($p<0.05$) lower after instructions (0.32 compared to 0.003 g, and 0.45 compared to 0.003 seconds, respectively). Similar results were found for the thick FF (Table 5.1). Table 5.1 also indicates that, for the thin FF, the average portion size and frying time were significantly higher ($p<0.05$) after as compared to before instructions (5.71 ± 0.003 compared to 5.36 ± 0.32 and 5.35 ± 0.003 compared to 5.23 ± 0.45 for the log transformed data, respectively). Similar results for thick FF were found in case of average portion size, however, average frying time was significantly lower ($p<0.05$) after implementation of instructions (5.48 ± 0.002 compared to 5.57 ± 0.36; for the log transformed data).

***Table 5.1*** *The effect of frying instructions on the portion size, frying time, texture and colour (mean values) (N = 40) of the thick and thin French fries. The values in a row followed by different letters were considered significantly different (p ≤0.05).*

| | **Uninstructed** | | **Instructed** | |
|---|---|---|---|---|
| | **Thin fries** | **Thick fries** | **Thin fries** | **Thick fries** |
| **Portion size*** | 5.36 ± 0.32 a | 5.56± 0.32 b | 5.71± 0.003 c | 5.71 ± 0.003 c |
| **Frying time*** | 5.23 ± 0.45 a | 5.57± 0.36 d | 5.35 ± 0.003 b | 5.48 ± 0.002 c |
| **Texture*** | 1.57 ± 0.25 a | 1.53 ± 0.12 a | 1.62 ± 0.21 a | 1.59 ± 0.11 a |
| **Colour** | 2.13 ± 0.48 b | 2.18± 0.47 b | 1.97 ± 0.56 ab | 1.78 ± 0.30 a |

** log transformed values*

### 5.3.2 Effect of frying instructions on variation in texture and colour

The variation in the datasets (raw data) of peak force and colour index of thin FF, before and after providing the specific frying instructions, is shown in Figure 5.2 A and B. Similar differences in the profiles of the datasets were observed in the case of thick FF (data not shown). The datasets for peak force were not normally distributed and therefore were log transformed for further statistical interpretations (as described in section 5.2.7) of the variation in the datasets.

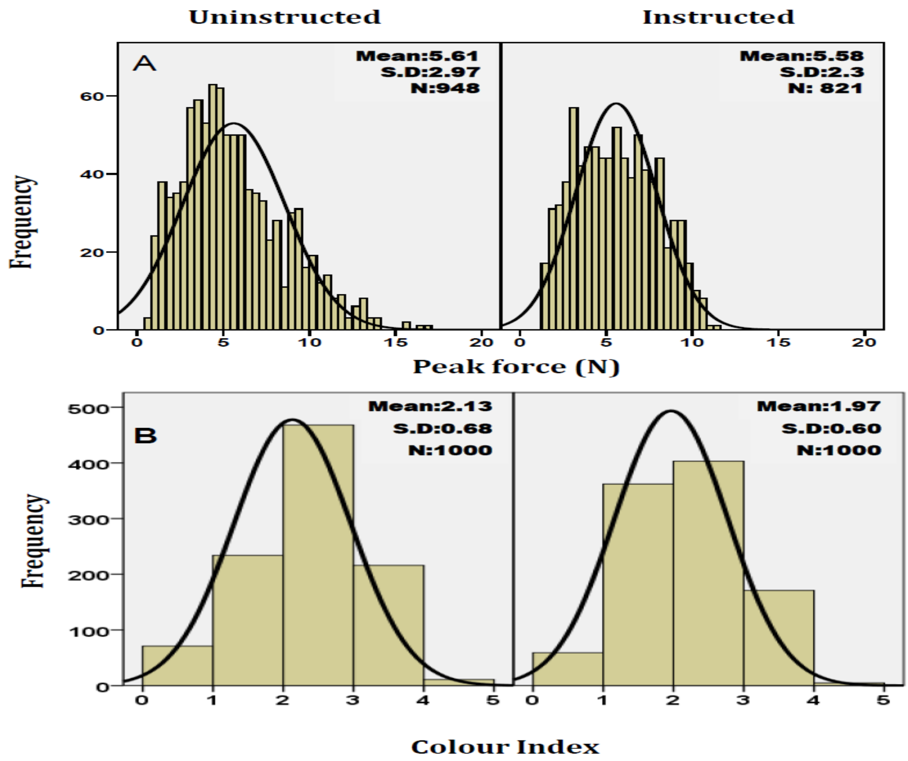


***Figure 5.2:*** *Variation (before and after instructions) in the datasets of A: peak force and B: colour index of thin French fries. The relevant statistical parameters are indicated in the figure.*

Table 5.2 shows the extent of variation (Cal Var) in the datasets of peak force and colour index of the thin and thick FF before and after the instructions. After the instructions, the variation in peak force data for thin and thick FF was significantly ($p<0.05$) lower (0.44 ± 0.08 compared to 0.53 ± 0.16, and 0.35 ± 0.09 compared to 0.42 ± 0.09 for the log transformed data, respectively,). Similar results were found for the variation in colour index data of thin and thick FF (Table 5.2). For the average peak force values no significant difference ($p<0.05$) were found before and after frying instructions for both the thin and thick FF (Table 5.1). The average colour index of the thick FF was significantly lower ($p<0.05$) after instructions (from 2.18 ± 0.47 to 1.78 ± 0.30).

***Table 5.2*** *The effect of frying instructions on variation (Cal Var) in the datasets of the texture and colour of the thick and thin French fries (N = 40). The values in a row with different letters were considered significantly different at p ≤0.05.*

| | **Texture*** | | **Colour** | |
|---|---|---|---|---|
| | **Thin fries** | **Thick fries** | **Thin fries** | **Thick fries** |
| **Uninstructed** | 0.53 ± 0.16 c | 0.42 ± 0.09 b | 0.69 ± 0.13 b | 0.67 ± 0.14 b |
| **Instructed** | 0.44 ± 0.08 b | 0.35 ± 0.09 a | 0.53 ± 0.07 a | 0.54 ± 0.07 a |

** based on log transformed values*

However, no significant difference ($p<0.05$) was observed in the average colour index of thin FF (Table 5.1).

### 5.3.3 Effect of instructions, in relation to difference in respondent's characteristics

The responses in the questionnaire showed that 19 participants (47 %) scored between 21 and 40 for their knowledge regarding French fries and frying process, while 30 participants (75 %) scored between 21 and 40 for their safety consciousness and 26 participants (65 %) scored between 21 and 40 for frying attitude.

Histograms in Figure 5.3 and 5.4 show the variation in the raw data of peak force for the thin FF, before and after instruction, when comparing participants with different scores for food safety consciousness and frying attitude.

Table 5.3 shows that before instruction, the variation in peak force data (for the log transformed data) was significantly larger ($p<0.05$) for the participants scoring between 0-20 as compared to those scoring between 21-40 for safety consciousness (0.64 ± 0.2 as compared to 0.47 ± 0.1; for the log transformed peak force data) for the thin FF.

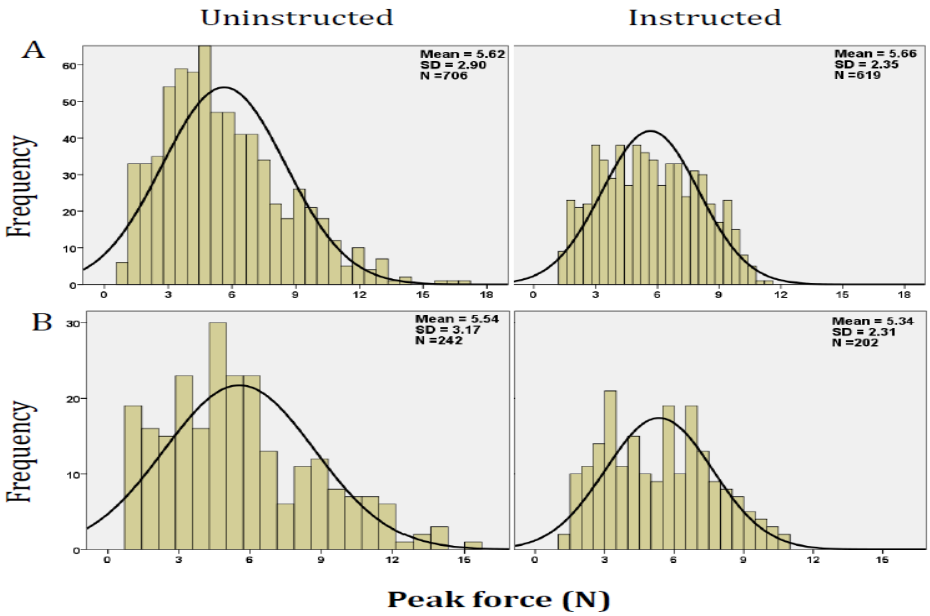


***Figure 5.3:*** *Histograms showing extent of variation in the raw data of peak force for thin FF, after frying instructions provided to the participants with A) scores between 21-40 and B) scores between 0-20 for their food safety consciousness. The relevant statistical parameters are indicated in the figure.*

*Table 5.3 Differences in variation in the peak force datasets of thin and thick French fries, before and after instructions, for respondents scoring between 0- 20 versus those scoring between 20-40 for their respective characteristics. The data was log transformed and values with different letters in the same row under the columns of each characteristic were considered significantly different at p ≤ 0.05.*

| | **Safety Consciousness** | | **Knowledge** | | **Attitude** | |
|---|---|---|---|---|---|---|
| | **21 - 40** | **0 - 20** | **21 - 40** | **0 - 20** | **21 - 40** | **0 - 20** |
| Thin uninstructed | 0.47 ± 0.1 a | 0.64 ± 0.2 b | 0.54 ± 0.2 a | 0.52 ± 0.2 a | 0.45 ± 0.1 a | 0.65 ± 0.2 b |
| Thin Instructed | 0.42 ± 0.1 a | 0.46 ± 0.1 a | 0.45 ± 0.1 a | 0.43 ± 0.1 a | 0.41 ± 0.1 a | 0.46 ± 0.1 a |
| Thick uninstructed | 0.38 ± 0.1 a | 0.48 ± 0.1 b | 0.41 ± 0.1 a | 0.42 ± 0.1 a | 0.38 ± 0.1 a | 0.47 ± 0.1 b |
| Thick instructed | 0.34 ± 0.1 a | 0.39 ± 0.1 a | 0.36 ± 0.1 a | 0.34 ± 0.1 a | 0.33 ± 0.1 a | 0.39 ± 0.1 a |

Similar results were found for frying attitude of the participants (Table 5.3). However, after instructions the variation was not anymore significantly different (p=0.74 and p=0.61, respectively). Similar results were observed for thick FF, however, extent of variation, before and after instruction, for all the characteristics were lower as compared to thin FF (Table 5.3).

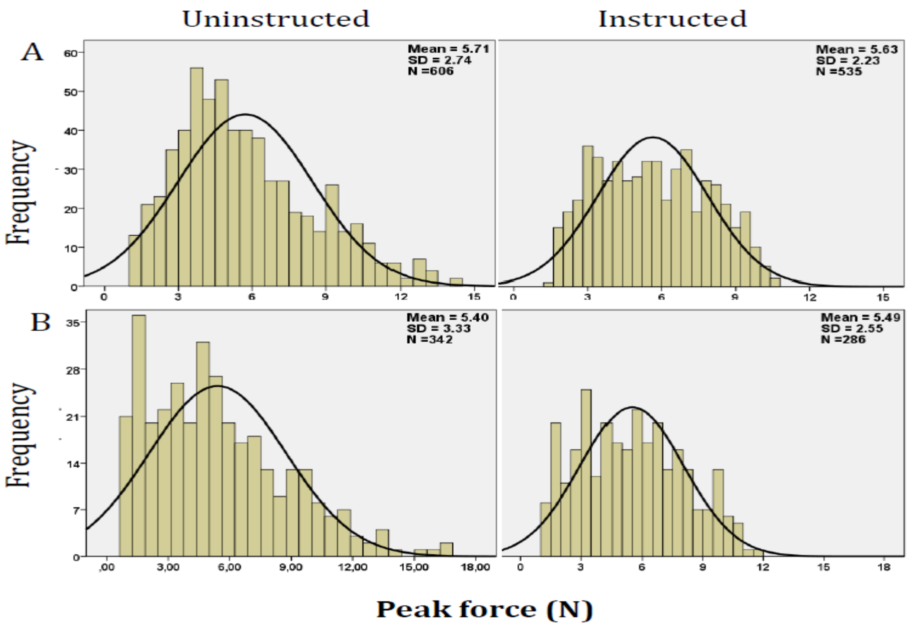


***Figure 5.4:*** *Histograms showing extent of variation in the raw data of peak force for thin FF, after implementation of frying instructions provided to the participants with A) scores between 21-40 and B) scores between 0-20 for their frying attitude. The relevant statistical parameters are indicated in the figure.*

## 5.4 Discussion

To our knowledge, the quantitative effect of instructions on the variation in control decisions and final quality attributes has not yet been studied. The present study indicated that providing detailed instructions and measuring tools, together with strict monitoring on actual compliance to instructions leads to a significant reduction in the variation in the applied frying conditions (frying time and portion size) and in the texture and colour data of French fries.

Before instruction, a large variation was found in the selected portion sizes (ranging from 116 to 491 g) and applied frying times (ranging from 78 to 534 seconds) by the participants; the food handlers. This variation apparently resulted in a considerable variation in the ln (peak force) and colour index data of thin FF; ranging from -0.25 to 2.82 and 1.0 to 5.0, respectively. This effect of variable frying conditions on the variation in texture and colour data was more obvious in the case of thin as compared to thick FF.

Romani et al. (2009) found that different portion sizes of frozen fries (expressed as product to oil ratio; 1/4 and 1/8, respectively), after 4 minutes of frying at 180 $^{o}$C, resulted in significantly different texture (expressed as F max; 3.53 and 6.81N, respectively) and colour (in terms of Lightness; 69.63 and 64.32, respectively) values of the French fries. The different portion sizes actually resulted in a different drop and subsequent recovery of the frying oil temperature that ultimately increased the final frying time to achieve similar colour and texture (Fiselier et al., 2006). In our study, in the first session food handlers used different frying times due to their personal preferences on final colour and/ or texture by visual judgement and sometimes taking a bite. In a previous study (chapter 3), it was demonstrated that variation in frying time can lead to large variation in the final texture and colour data of French fries, which explains the large variation in colour and texture values in the uninstructed situation. Sanny and co-authors (2011a, b) also reported that food handlers in different types of food service establishments used their own preferences on final colour of French fries to control the frying conditions, which resulted in large variation in acrylamide concentrations.

After providing instruction, in combination with strict monitoring on compliance to these instructions, variation in the control decisions of food handlers, on portion size and frying time, was significantly reduced, corresponding to a significant reduction in variation in the texture and colour datasets. Our study showed that the effect of the frying instructions had a larger impact on the thin as compared to the thick French fries. This difference might be attributed to the fact that heat and mass transfer will be faster in the thin FF with higher SVR resulting in the formation of crust in less time and harder texture and darker colour at higher temperatures with longer period of time as compared to thick FF (lower SVR) (Taubert et al., 2004; Hindra and Baik, 2006; Moyano, Troncoso, and Pedreschi, 2008).

Provision of instructions affected indeed decision-making behaviour of the food handlers, resulting in more similar control decisions on the crucial process parameters / conditions, which ultimately led to a reduction in variation in the final quality attributes, as previously hypothesised by Luning and Marcelis, (2006, 2007). However, in real life situations this effect of instructions is expected to be less obvious due to the difficulty of compliance to instructions and/ given procedures. Sanny et al. (2011b) indeed reported that, in small restaurants, mere instructions to the food handlers (without strict monitoring on compliance) did not result in an obvious reduction in the concentration and variation in acrylamide in French fries, only when the food handlers did comply strictly with the instructions.

Non-compliance behaviour may increase due to deficient procedures, complicated procedures; and operator's experience and belief rather than what is stated in the procedure (Park and Jung, 2003). Other factors that can also influence compliance behavior of food handlers include motivation (Azanza and Zamura-Luna, 2005) appropriateness of training, culture of organization (Clayton et al., 2002; Griffith, 2006), and adequacy of equipment (Clayton, et al., 2002; Sanny, et al., 2010; Seaman & Eves, 2006).
Moreover, several studies describing knowledge and food handlers practice emphasised the importance of training programmes for increasing awareness, knowledge and motivation of food handlers. However, increased knowledge does not always result in positive change in the food handling behaviour (Angelillo, Viggiani, Greco, & Rito, 2001; Bas, Ersun, & Kivan, 2006; Gomes-Neves, Arau˘ jo, Ramos, & Cardoso, 2007; Tokuc, Ekuklu, Berberog˘lu, Bilge, & Dedeler, 2009). Therefore, provision of clear and adequate frying instructions to the food handlers, in combination with strict check on compliance

to these instructions, can result in significant reduction in variation in control decisions, ultimately resulting in reduction in variation in the final quality out put.

In the present study, differences in food handler's characteristics like knowledge, food safety consciousness and attitude were also taken in to account while analysing the impact of instructions on the variation in the final quality attributes. Data showed that before instruction, variation in the datasets of peak force was significantly larger in case of respondents scoring 0-20 as compared to those scoring 21-40, for the different personal characteristics. However, after providing the instruction, these differences were not significant anymore. For example, Clayton and Griffith (2008) showed that hygiene practices cannot be merely improved by providing information to individuals handling food, although they identified inadequate attitude as one of the significant predictors for hand hygiene malpractice.

The present study shows that variation in the food handlers' control decisions on process and product parameters can reduce variation in the data set when strictly monitored and measuring equipment is provided. However, actual compliance in real life situations will be affected by the efficacy of instructions (Teigland and Wasco, 2009), awareness of food handlers (Gauci and Gauci, 2005; Luning et al., 2008; Jevsnik, Hlebec, and Raspor, 2008), appropriateness of attitude (Azanza and Zamora-Luna, 2005) and control of compliance (Crowther, Herd, and Michels, 1993; Uen, Wu, and Huang, 2009). These factors may be controlled under food manufacturing conditions, but is much less controllable under domestic conditions. Also, in food service establishments (FSE) dealing with high turnover, low levels of competence and motivation of the personnel compliance to safety procedures maybe more difficult (Chinchilla and Lee, 2009). In the situation of FSE, one could apply typical technological measures, like time-temperature controlled frying equipment, to reduce the effect of variable control decisions or consider strict monitoring on compliance in daily practice (a typical managerial approach).

## 5.5 Conclusion

The study demonstrated that variation in the control decisions on frying practices by food handlers, leads to large variation in the texture and colour of French fries. Variation in these attributes can be reduced considerably by implementing instructions and measuring tools, along with strict monitoring on compliance to these instructions, to the food handlers.

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# Appendix

## Questionnaire

The questionnaire was organized in four sections 1: Socio-demographic characteristics of the participants (gender, age, nationality, education level / professional category; 2: characteristics related to safety consciousness; 3: knowledge; and 4: attitude. Three human characteristics, namely knowledge, food safety consciousness, and attitude were analysed. Based on the response to this questionnaire, participants were categorized into levels (higher and lower) of above mentioned human characteristics.

## Questionnaire

Q1) Gender: Female / Male

Q2) Age:

Q3a) Nationality:

Q3b) Education / professional category

Q4) How often do you consume French fries at home or elsewhere?

- More than once per week
- Once per week
- Once per month
- Never

Q5) How often do you fry French fries at home?

- More than once per week
- Once per week
- Once per month
- Never

Q6) I always wash my hands prior to the preparation of food.

- Agree
- Disagree

Q7) I always check the expiration day of a product before I buy it.

- Agree
- Disagree

Q8) The quality of the oil remains the same after frying many times with the same oil.

- Agree
- Disagree

Q9) The fresh products (vegetables, meat, fish, etc.) tend to get spoiled easier than the processed ones (processed cheese, canned food, etc).

- Agree
- Disagree

Q10) What is acrylamide?

- It is a probable human carcinogen composed in fried French fries.
- It has nothing to do with French fries.
- It is a health promoting compound formed in fried French fries.
- I do not know.

Q11) If frying temperature increases beyond 180$^{o}$C, then the formation of acrylamide is decreased.

- Agree
- Disagree

Q12) Do you always read the instructions written on the package prior to frying?

- I always read the instructions written on the package prior to frying.
- Only the first time that I fried I read the instructions written on the package.
- I never read the instructions written on the package prior to frying.

Q13) When you read, do you fully understand the instructions written on the package?

- The instructions written on the package are always clear to me.
- Sometimes it is difficult for me to understand the instructions written on the package.
- I never understand the instructions written on the package.

Q14) Do you believe that following the instructions, your food will be cooked properly?

- I am fully convinced that following the instructions, my food will be cooked properly.
- I believe that the instructions are useful but I also use my own judgment.
- I am not convinced that following the instructions my food will be cooked properly, so I use my own judgment.

Q15) Do you always follow the instructions?

- I always follow exactly the instructions written on the package.
- Sometimes I follow the instructions written on the package.
- I never follow the instructions.

# Chapter 6

# General Discussion

## 6.1 Scope and major findings of the research

Although food quality (FQ) is of utmost importance for agri-food business, little attention has been paid to systematic, science-based assessment of points to control quality attributes. Quality control aims at reducing unacceptable variation in final product quality. Understanding variation is a key issue for the control of quality attributes of a food product. In the current research, the techno-managerial research approach, the *food quality-relationship* and *food quality-decisions* model were used as basic concepts to analyse and assess the contribution of technological and managerial factors to variation in major quality attributes of a final product. The production of French fries has been taken as a case. The insights obtained for the French fries case, are used as input for the development of an approach towards a systematic and science based assessment of critical quality points (CQPs) as a basis for designing an effective quality control system. The following research questions were formulated to achieve the aim of the thesis:

1. Which product and process factors, along the whole production chain, can affect variation in final quality attributes of French fries?

2. How much can these factors contribute to the variation in quality attributes at the final preparation step and at the preceding step, blanching?

3. What is the contribution of variation in food handler's decisions on frying conditions to variation in quality attributes of French fries? Can administrative conditions reduce variation in this decision-making and affect variation in the quality attributes?

4. How to use the obtained insights to propose a systematic approach to assess critical quality points (CQPs)?

**Question 1: which product and process factors, along the production chain, can affect variation in final quality attributes of French fries?**

Study 1 (chapter 2) aimed at getting insight in causes of variation in the major quality attributes of French fries based on a comprehensive literature analysis. Based on key studies on French fries production (summarized in table 2.2), the analysis showed that

1) selection of suitable cultivars with appropriate levels of reducing sugars, 2) time-temperature (t-T) settings during bulk storage, 3) adjustment of t-T blanching conditions, and 4) t-T frying conditions were indicated as major potential sources of variation in final quality attributes of French fries.

A Monte-Carlo simulation using data from literature demonstrated that slight variation in frying time and temperature induced considerable variation in the colour index. This Monte Carlo analysis, despite not having specific quantitative information about quality attributes of French fries, provided a first quantitative hint towards the possible effect of variation in time and temperature on variation in final quality attribute of French fries. To our knowledge, studies showing such data are not yet available in the current literature, which was the reason for performing experimental studies to characterize variation.

**Question 2: How much do these product and process factors contribute to the variation in quality attributes at the final preparation step and at the preceding step, blanching?**

***A Contribution of t-T frying settings to variation in texture and colour of French fries***

The first study (chapter 2) indicated that current literature does not allow to assess quantitatively the actual variation in texture and colour of French fries, which instigated the need for a quantitative analysis. Study 2 (chapter 3), aimed at investigating the contribution of different time-temperature settings, simulating food service establishment (FSE) conditions, to variation in texture and colour.

The study showed that increasing temperature and time (from 170 $^{o}$C for 4 min to190 $^{o}$C for 6 min) increased not only the mean values of peak force as a measure for texture (from 0.98± 0.54 to 1.51±0.71; for the log transformed data) but also resulted in a larger variation in the peak force datasets (0.55 ± 0.02 to 0.71 ± 0.02; for the log transformed data). Likewise, the mean value for colour index increased (from 2.3 ± 0.59 to 3.43 ± 0.83; colour scale ranged from 1-7) and a larger variation in colour index data (0.58 ± 0.09 to 0.82 ± 0.14) was found.

Initiation of crust formation is a crucial step as it accelerates the hardening and darkening of French fries with a faster rate of dehydration of the external cells of potato strips and of the Maillard reaction, respectively (Nouirian and Ramaswamy, 2003a and b; Pedreschi, Aguilera, & Pyle, 2001; Romani et al., 2008). Crust formation starts approximately at the end of the first stage of frying, (t > 80 seconds) as reflected in Figure 3.1, afterwards both peak force and colour index increase with a faster rate. Therefore, larger variation in ln peak force datasets for thin FF were observed at 170 °C after 6 minutes of frying (0.58 ± 0.01) comparing to 4 minutes of frying (0.55 ± 0.02). Similarly, in the case of colour index datasets of thin FF, variation increased significantly from 0.58 ± 0.09 to 0.63 ± 0.09 with frying time (from 4 to 6 minutes, respectively) at 170 °C. This progressive increase in hardness and darkness can be attributed to crust hardening, which usually accelerates at higher frying temperatures (Pedreschi et al., 2001; Nourian and Ramaswamy, 2003a and b; Moyano, Troncoso and Pedreschi, 2008). The extent of variation in the datasets further increased (0.71 ± 0.02 and 0.82 ± 0.17, respectively), when thin FF was subjected to 190 °C as compared to 170 °C for the same 6 minutes of frying. Thus, small deviations in temperature can lead to obvious differences in hardness and darkness of French fries causing more variation.

The effect of t-T settings on the hardness and darkness was more obvious in the case of thin French fries (FF) as compared to thick FF. This might be due to differences in the rate of moisture loss (drying) with increasing frying temperature for thin and thick French fries. Studies have shown that moisture loss is faster in thinner samples (Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001; Tajner-Czopek, Figiel, & Carbonell-Barrachina, 2008). This difference in drying rate is probably because of the larger surface to volume ratio (SVR) for thin FF as compared to thick FF (Taubert et al., 2004; Hindra and Baik, 2006; Moyano et al., 2007).

The study showed significant differences in variation in the data sets of peak force and colour index; 29% and 41%, respectively, when thin FF were subjected to frying at 190°C for 6 minutes as compared to setting with 170°C for 4 minutes. These findings confirmed our previous conclusions, quantitative analysis based on literature, (chapter 2) that t-T frying setting is a potential source of variation for texture and colour of French fries.

### B Process and product factors during blanching

In the study described in Chapter 3 it was concluded that t-T frying settings have a significant impact on the variation in texture and colour of French fries. However, variation in final quality attributes is due to the cumulative effect of all the sources of variation along the whole production chain.

The precursors like reducing sugars and other dry matter (DM) are affecting the formation of colour, in the Maillard reaction (Marquiz and Anon, 1986), and texture development, respectively (Van Loon, 2005). It is through blanching that sugars leach out, starch gelatinizes, and cell separation is achieved (Pedreschi, 2009). Therefore, it was investigated whether adjustment of t-T conditions at blanching, which is an indispensible step in the preparation of the par fried FF, is another source of variation that can contribute to variation in the final quality attributes.

Different t-T blanching settings were expected to contribute additionally to variation in the peak force and colour index datasets due to differences in initial distribution of precursors in the potato strips. These differences in the distribution of precursors were expected due to variation in removal/leaching of DM and reducing sugars at different blanching settings. However, different blanching settings did not result in obvious differences in variation for DM and reducing sugars. Likewise, no significant differences in the variation of texture and colour were observed after frying. Only a slight increase in variation in the peak force data (texture) was observed for the thin fries after blanching at 80 °C as compared to the blanching at 60 °C for 10 minutes. Apparently, the t-T blanching conditions are not a source of additional variation in texture and colour data of FF.

However, the adjustment of t-T blanching conditions does have an effect on the mean values of texture and colour. The study found that, for thin FF, peak force values were significantly lower when a higher blanching temperature was used (80 °C) as compared to the rest of the blanching temperatures and control. However, no significant change in peak force values was observed at the lower blanching temperatures (60 as compared to 70 °C) for all blanching times tested. These findings are in line with previous studies (Aguilera-Carbo, Montanez, Anzaldua-Morales, Reyes, Contreras-Esquivel, and Aguilar, 1999; Agblor and Scanlon, 2000; Canet et al., 2005; Liu and Scanlon, 2007). Agblor and

Scanlon (2000) found lower mean peak force values for the French fries subjected to high temperature (HTST) as compared to low temperature (LTLT) blanching and also control conditions. Peak force, at higher blanching temperatures, tends to increase with blanching times, while it tends to decrease (softening) with increasing blanching temperature. The swelling pressure of starch gelatinization, in combination with hydrothermal degradation of pectin results in softening of the texture (Andersson, Gekas, Lind, Oliveira, Öste, 1994). This swelling pressure exerted by the starch gelatinization during LTLT blanching settings, is probably not sufficient to breakdown the above mentioned linkages, strengthened by the activity of PME (Agblor and Scanlon, 2000; Liu and Scanlon, 2007).

The present study showed that the mean reducing sugar content was significantly lower at high temperature (80 °C) as compared to the low temperature blanching (60 and 70 °C). Previous studies have shown faster removal of reducing sugars at higher blanching temperature (Pedreschi et al., 2006 and 2007; Mestdagh et al., 2008). Mestdagh et al. (2008) found significant reduction in reducing sugar content with high temperature as compared to low temperature blanching settings. They indicated that blanching time is only important with lower blanching temperatures. It might be true for longer duration as observed by Aguilera-Carbo et al. (1999) and that might be the reason of non significant differences in reducing sugar content at lower blanching temperatures (60 and 70 °C) with blanching time was observed in this study.

The mean colour index values for both thin and thick FF were significantly ($p<0.05$) lower (resulting in lighter French fries) when higher blanching temperature were applied (80 as compared to 60 and 70 °C) (Figure 4.2 A and B). Similarly, previous studies have observed lighter final colour of French fries at higher blanching time (Aguilera-Carbo et al., 1999) and temperature (Agblor and Scanlon, 2000). Aguilera-Carbo et al. (1999) showed significant reduction in reducing sugar content of potato strips at lower blanching temperature (60°C) for longer duration (45 and 60 minutes) ultimately reduced browning of the French fries.

Although differences in blanching conditions are not reflected in more variation, the adjustment of the t-T blanching conditions has a considerable impact on the mean value of colour and texture formation after final frying. Therefore, selection of appropriate blanching settings is important to achieve certain mean values in quality attributes in the end product. That means that setting the target value (as part of the control system) is crucial at this stage.

**Question 3: What is the contribution of variation in food handler's decisions on frying conditions to variation in quality attributes of French fries? Can administrative conditions reduce variation in this decision-making and affect variation in the quality attributes?**

Study 2 (chapter 3) showed that small deviations in t-T frying settings resulted in large variation in texture and colour profiles of French fries. The variation in decision-making of food handlers in setting actual frying conditions was expected to be another potential source of variation for texture and colour of French fries. The study in chapter 5 aimed at getting insight in the effect of providing instructions (strictly checked on compliance to instructions) on the variation in decisions on portion weight and frying time, and variation in peak force and colour index.

The study demonstrated significant reduction in variation in ln (portion size) and ln (frying time) (from 0.32 to 0.003, and 0.45 to 0.003, respectively, for the log transformed data) when participants were provided with frying instructions in combination with strict control on compliance to these instructions. This reduction in variation ultimately resulted in a significant reduction in variation (Cal Var) in the ln (Peak force) and colour index data of thin FF (from 0.53 ± 0.16 to 0.44 ± 0.08 and 0.69 ± 0.13 to 0.53 ± 0.07, respectively, for the log transformed data).

Previously, Romani et al. (2009) demonstrated significant differences in the texture (expressed as $F_{max}$; 3.53 and 6.81N, respectively) and colour (in terms of Lightness; 69.63 and 64.32, respectively) of the French fries due to different portion sizes (expressed as product to oil ratio; 1/4 and 1/8, respectively) of frozen fries, after 4 minutes of frying at 180 °C. These variable portion sizes actually affect the drop and subsequent recovery of the frying oil temperature that ultimately increase the final frying time (Fiselier et al., 2006). In addition, in the present study food handlers also used variable frying times due to their personal preferences on final colour and/ or texture by visualising and sometimes taking a bite, respectively. In chapter 3 it was indicated that variation in frying time can lead to a large variation in the final texture and colour data of French fries. Sanny et al., (2011a) also observed significant variation in food handlers's control decisions on frying conditions like portion size and frying time, in different FSE, based on their visual perception about the final colour of French fries.

The present study showed drastic reduction in variation in food handlers control decisions, on portion size and frying time, after providing instruction to food handlers in combination with strict monitoring on compliance to the instruction, resulting in a significant reduction in variation in the texture and colour datasets. However, in real life situations, the above mentioned effect of instructions is expected to be less obvious due to the difficulty of compliance to instructions and/or given procedures. For example, under food service establishment (FSE) conditions, providing instructions to food handlers in restaurants without strict check on compliance resulted in variable effects on acrylamide concentrations in French fries. The food handlers only partly complied with the instructions and applied longer frying times than prescribed (Sanny et al., 2011b).

The study concluded that variation in the control decisions, as made by the food handlers, can lead to variation in texture and colour data of French fries. However, this variation can be significantly reduced by providing appropriate frying instructions to food handlers in combination with strict monitoring on compliance to these instructions.

**Question 4: How to use the obtained insights to propose a systematic approach to assess critical quality points (CQPs)?**

This question 4 is discussed in detail in the following section 6.2.

## 6.2 Towards an approach to assess control points for quality attributes as a basis for effective quality control systems

The data from the French fries case studies (chapter 2-5) provided insight in technological and managerial sources of variation that affect variation in the texture and colour of French fries upon consumption. Based on these insights, in this section, a systematic approach to assess control points for quality attributes in general is proposed. First, an analysis is made on the applicability of the commonly acknowledged approach for assessment of critical control points (in the Hazard Analysis and Critical Control Point concept) for quality attributes. Next, the definition for critical control points (in the HACCP concept) is adapted for quality attributes; called critical quality points (CQP's). Subsequently, a stepwise procedure is proposed to assess CQP's illustrated and inspired by data and experiences from the French fries case.

### 6.2.1 Applicability of HACCP principles to assess control points for quality attributes

Hazard Analysis and Critical Control Points (HACCP) is a widely acknowledged food safety management system that enables the systematic identification, evaluation and control of those steps in food manufacturing that are critical to food safety (Jacxsens, Devlieghere, and Uyttendeale, 2009; Luning & Marcelis , 2009). It has been suggested that the HACCP concept may also be applicable for quality attributes (Peters, 1998; Bertolini, Rizzi and Bevilacqua, 2007). However, these studies did not present a concrete methodology on how to assign critical control points for quality attributes, and it is questionable if the HACCP principles are simply applicable to other quality attributes. In this section, applicability of HACCP for control of quality attributes is analyzed. An overview of important aspects of the HACCP approach, with respect to food safety and food quality is given in table 6.1.

Food safety is a rather straightforward, one dimensional, concept with evident limits based on scientific risk assessment commonly established in legislative norms, which enables a systematic assignment of CCPs (Jacxsens, Devlieghere, and Uyttendeale, 2009; Luning and Marcelis, 2009). In contrast, quality is a complex and multidimensional concept (Luning and Marcelis, 2009).

**Table 6.1 Applicability of HACCP principles for controlling quality attributes**

| Criteria/Aspect | Safety | Quality attribute(s) |
|---|---|---|
| **Characteristics of the attribute(s)** | - Well defined concept<br>- One-dimensional<br>- Dissatisfier<br>- Similar consumer requirements | - No univocal concept<br>- Multidimensional<br>- Satisfier<br>- Distinct consumer requirements |
| **Identification of hazards** | - Classified quite clearly into physical, chemical and microbiological hazards<br>- Established lists with restricted numbers of agents, compounds and microbes.<br>- Can be find in many products<br>- Identification relatively straightforward | - No established classification of desired /undesired quality defects/compounds/processes<br>- No lists as many compounds and (or) processes (chemical, physical, physiological etc.) can be involved.<br>- Very product specific<br>- Complex |
| **Hazard evaluation** | - Acknowledged methods for systematic qualitative and quantitative evaluation of hazards characteristics<br>- Assessment of consequences for human health (in terms of risk on illness or injuries), e.g. risk assessment, systems and procedures for hazard evaluation etc. | - Methods available to evaluate impact of desired /undesired compounds/ processes on quality attribute(s)<br>- No established methodology to assess consequences of undesired compounds/ processes in terms of benefits or complaints. |
| **Assessment of critical control point** | - Rather straightforward identification of control points (CCP decision tree)<br>- If not controlled properly may lead to unacceptable level | - CCP decision tree needs modification to make it applicable to quality attribute(s)<br>- Unacceptability depends on consumer requirements. |
| **Standards and norms** | - Standards are set by legislations and can be further derived from risk assessment<br>- Usually for all consumers | - Standards / limits are commonly not established by legislation for specific attribute(s)<br>- Only for target consumers |

In case of quality attributes, hazards may include quality defects but there are many positive attributes like sensory attributes. How to deal with those? No lists containing desired and non-desired compounds /processes related to negative quality defects and positive attributes are available or even possible, as many compounds and processes may be involved in this context. Unlike food safety, identification of positive quality attributes is expected to be complex.

The core idea behind the HACCP concept is that one should focus on what is really critical to consumers/customers, and to take measures in production instead of final inspection. Luning and Marcelis (2009) stated that in order to comply with the conflicting requirements, i.e., assurance on the one hand and flexibility on the other hand, one should focus on critical quality points (CQPs). The points in the process that should be assessed are those that have a decisive influence on final quality. As a general requirement on food quality, quality attributes should be constant over time while complying with consumer desires (Deming, 1982). In view of these general concepts, a quality point (QP) can be defined as "a point in the process, where a relationship exists between the product and or process factors and the quality attributes of the final product". In other words, a QP is identified if changes in product and or process factors are indeed reflected in changes in quality attributes of the final product. In line with the CCP definition of HACCP, a critical quality point (CQP) can be defined as "a point in the process where variation in product properties and or processes result in unacceptable variation in required quality attributes of the final product, and when this variation cannot be reduced to acceptable variation further in the process" (Luning and Marcelis, 2009).

### 6.2.3 Approach proposed for the assessment of CQPs

This section describes a stepwise approach to assess CQPs in a food production system. Table 6.2 shows the steps of the proposed approach.

#### *Step 1 Identification of major quality attributes*

The first step comprises the identification of the most important quality attributes of a product as perceived by the consumers of that product, in order to select most desirable,

**Table 6.2 Approach proposed for the assessment of Critical Quality Points (CQPs)**

| Steps | What | Why | How |
|---|---|---|---|
| **Step 1** | Identification of major quality attributes | Focusing on most desirable attributes<br><br>Making the control system efficient and lean | Desktop literature search.<br><br>Sophisticated consumer research |
| **Step 2** | Identification of product & process factors underlying the formation of major quality attributes | Unraveling properties, reactions /mechanisms and technological conditions underlying formation of quality attributes | Basic literature in handbooks on food chemistry, food physics, etc. |
| **Step 3** | Identification of Quality Points (QPs) | First idea about relationships among above identified factors and final quality attributes at the location to be controlled<br><br>First insight on existence and extent of above mentioned relationships at certain locations in the chain | Specific literature search e.g., literature on effects of storage, frying conditions on final quality attributes<br><br>Own research |
| **Step 4** | Systematic verification of QPs | Quantitative assessment of product and process sources of variation in quality attributes at certain QPs | Conducting experiments, using statistical tools and methods, ANOVA, develop histograms, Sensitivity analysis based on experimental data |
| **Step 5** | Analysis of contribution of variable control decisions at QPs to variation in final quality attributes | Analysing additional effect of variable control decisions by food handlers at the QP's on variation in final attributes | Intervention experiments (comparing with and without instructions) |
| **Step 6** | Assessment of Critical quality points (CQPs) | Focusing on QPs critical to final quality attributes<br><br>Making systems lean and efficient | Comparing/matching company specifications with the observed data |

rather than all, consumer requirements on that particular food product, thus making the system lean and efficient. This is in line with the CCP approach where only hazardous compounds are identified for further assessment. Major quality attributes of products can be identified in different ways depending on availability of expertise, equipment, methods, tools, and financial resources (Grunert, 2005; and Bredahl et al., 1998). One can identify attributes based on searching in existing literature (desk-top) or one can apply more advanced methods to collect actual data on consumer demands, such as preference analysis techniques, which are among the most popular tools of market research (Urban and Hauser, 1993). These analysis techniques use two basic approaches, internal and external preference analysis; enable understanding which attributes of a product are driving consumer preferences. Internal preference analysis emphasises consumer preferences by capturing much of the consumer understanding, while external preferences analysis deals with perceptual or sensory information capturing much of product understanding. These analyses use Principal Component Analysis (PCA) as a statistical tool for interpretation (Van Kleef, Van Trijp, and Luning, 2006). The outcome of the first step is a list with a selected number of attributes to be further analyzed. In the case of the French fries production (Chapter 2), we used existing literature and concluded that the main desirable quality attributes of French fries include a light yellow to golden brown colour, and a crispy crust with homogenous mealy interior that does not separate from the crust, and a firm yet delicate shape that is not lump (Gould, 1999; Agblor and Scanlon, 2000; Scanlon, 2003; Van Loon, 2005).

***Step 2 Identification of product and process factors underlying the formation of the major quality attributes.***

The next step is the identification of product and process factors that are involved in the formation/ development of the major quality attributes identified in step 1. This step will help in unraveling the complexity of quality attributes by understanding which product components, reactions/mechanisms (physical, chemical), and / or technological conditions play a crucial role in the formation of desired quality attributes. These insights can be obtained through comprehensive literature search, consulting handbooks, like food chemistry, food physics, post harvest physiology etc., providing insights in established mechanisms and processes, Outcome of this step is a list of specific product components (reactants), mechanisms / processes, technological conditions that can affect the desirable quality attributes. In the case of French fries production chain (this thesis), reducing sugars, Maillard reaction, dehydration process, time-temperature, were identified as the most important product and process factors influencing development of colour and texture of French fries. An overview of these factors is given in table 2.2 (chapter 2).

### *Step 3 Identification of quality points (QPs)*

The next step is to identify where in the production chain, the above product and process factors can influence the major quality attributes in the final product. Such points/ locations in the chain where a relationship exists between variation in product and or process factors and variation in the major (desirable) quality attributes of the final product are referred to as quality points (QPs). The identification of QPs will provide a first idea about locations in the production chain where the identified product / process factors should be controlled. It will also provide a first insight in the impact of these identified factors, at these locations, on the final quality attributes. One can get these insights through specific literature search providing evidence for the existence and the extent of relationship between identified product / process factors at certain chain location and final quality attribute(s). Based on key studies on French fries production (summarized in table 2.2; chapter 2), 1) selection of suitable cultivars with appropriate levels of reducing sugars, 2) time-temperature (t-T) settings during bulk storage, 3) adjustment of t-T blanching conditions, and 4) t-T frying conditions were identified as potential QPs. It was indicated that minor change in t-T frying settings can lead to a big variation in the final texture and colour of the French fries. However, these conclusions were based on limited quantitative data in the existing literature, thus further thorough quantitative assessment of these QPs was required via own research.

### *Step 4 Systematic verification of QPs*

The next step is the systematic verification of identified QPs in order to get quantitative insight in the actual contribution of variation in product/process factors on variation in quality attributes. This step helps in selecting QPs that require attention, and should be controlled.

One can start this step with the location which was found to have, based on qualitative data, a major impact on the final quality attributes. In the next study it can be analysed whether a preceding step in the chain can give any additional contribution to variation in the final quality attributes. Different statistical tools and techniques can be used to get insight in variation in final quality attributes. For example by making histograms to show variation in the profiles of quality attributes and then analyzing extent of variation in these profiles. Sensitivity analysis can also be used to show whether small / minor deviations in the process/ product conditions can result in large/ major variation in the final quality attributes.

In the case of the production of French fries (this thesis), verification of identified QPs (based on literature analysis) started from final frying, as large variation in the final texture and colour of French fries was expected due to variation in the t-T settings. The study was conducted under strict experimental conditions where the effect of different fixed t-T frying settings on the variation in the final texture and colour of French fries was investigated. In the subsequent study, it was investigated whether or not variation in the t-T blanching settings, a crucial step proceeding the final frying, can result in additional variation in the texture and colour of French fries. Both the studies were conducted by the same person to avoid variation due to variable control decisions made by different people.

***Step 5 Analysing contribution of variable control decisions to variation in quality attributes***

The next step is analyzing the contribution of control decisions of food handlers, at QPs, to variation in the final quality attributes. It is assumed that food quality is also affected by the decision-making behavior of the people involved. Variation in the decisions on product and / or process conditions may result in significant differences in the final quality attributes. This can be achieved by measuring variation in the control decisions and also by measuring the effect of this variation on the variation in the final quality attributes with/ without providing administrative conditions like ‘control instructions’ and strict monitoring on compliance to these instructions.

Chapter 5 demonstrated that variation in decisions, made by food handlers, on frying conditions like portion size and frying time resulted in large variation in texture and colour of French fries. However, after providing instructions to food handlers, in combination with close monitoring on compliance to these instructions, significant reduction in variation was measured.

***Step 6 Assessment of critical quality points (CQPs)***

The next step is to assess critical quality points along the food production chain. Those quality points (QPs) where minor deviation in the applied process and / or product factors lead to a large (unacceptable) and / or irreversible variation in the major quality attributes of the final product are referred to as critical quality points (CQPs). One can assess CQPs by matching company's norms and tolerances with the observed findings. Here the aspect of unacceptability is crucial, as in contrast to safety, companies set specifications/standards for the desirable quality attributes of different food products for their target customer; tolerances may differ depending on product type and type of target group. In the case of French fries production, Chapter 3 provided quantitative insight in the contribution of higher temperature and longer duration to the variation in the peak force and colour index data. Lack of control of frying time and temperature, can lead to large (undesirable) variation in final product quality and can be considered as a critical quality point (CQP) depending on the companies' tolerances/specifications. Assessment of t-T frying settings as a real CQP needs a specific target value, for example, for peak force of thin FF along with the acceptable tolerable limits set by the particular company for their product. For example, if we take 1.1 N as a hypothetical target for a ln (Peak force) value set by a particular company with 0.25 to 1.8 N as acceptable tolerable limits, we can re-evaluate our experimental data for the assessment of CQP (chapter 3). Figure 6.1 shows a slight deviation of the values from the acceptable limits when subjected to 170 °C for 4 minutes. The deviation from the acceptable limits became larger when frying time increased from 4 to 6 minutes. This extent of variation further increased with frying temperature for example at 190 °C (Figure 6.2). Therefore, t-T frying settings under the given product specification can be considered as a (real) CQP.

The study conducted to investigate the contribution of blanching settings to final variation in the quality attributes of French fries, (Chapter 4) showed only a slight variation in the final quality attributes of French fries with blanching time and temperature. Consequently, t-T blanching settings need not be considered as CQP, as was first deduced from the qualitative analysis conducted in the first study (chapter 2). However, establishment of the appropriate t-T blanching setting should be an integral part of the control system when designing the process and product specification, because the blanching conditions do have a pronounced effect on the level of a quality attribute, rather than on variation in that attribute. Food handler's control decisions on different frying settings like portion size and frying time, in addition, can be considered as major source of variation in the texture and colour of French fries (chapter 5). However, strict monitoring on compliance to instructions provided to food handlers on frying time and portion size can ensure similar decisions on these conditions by the food handlers. Thus control decisions on frying conditions like portion size and frying time can also be considered as CQP.

We can conclude that by applying the proposed CQP approach to our case study (this thesis), frying temperature and food handler's control decisions on portion size and frying time can be considered as CQPs.

The question then becomes how to use these insights. Since it is not well possible to strictly monitor compliance to instructions with consumers doing home frying, less variation in quality attributes could be achieved through innovative automation of frying equipments, optimizing frying temperature throughout the frying process. For food service establishments on the other hand, strict managerial control could be possible through effective supervision of food handlers, on compliance to the frying procedures / instructions on applied frying conditions. Such measures can lead to production of French fries with more consistent final quality. Reducing sugar content of potato cultivar cannot be considered as CQP as larger concentration of reducing sugar due to poor selection can be overcome by optimizing blanching conditions accordingly, which is an essential design activity in French fries production.

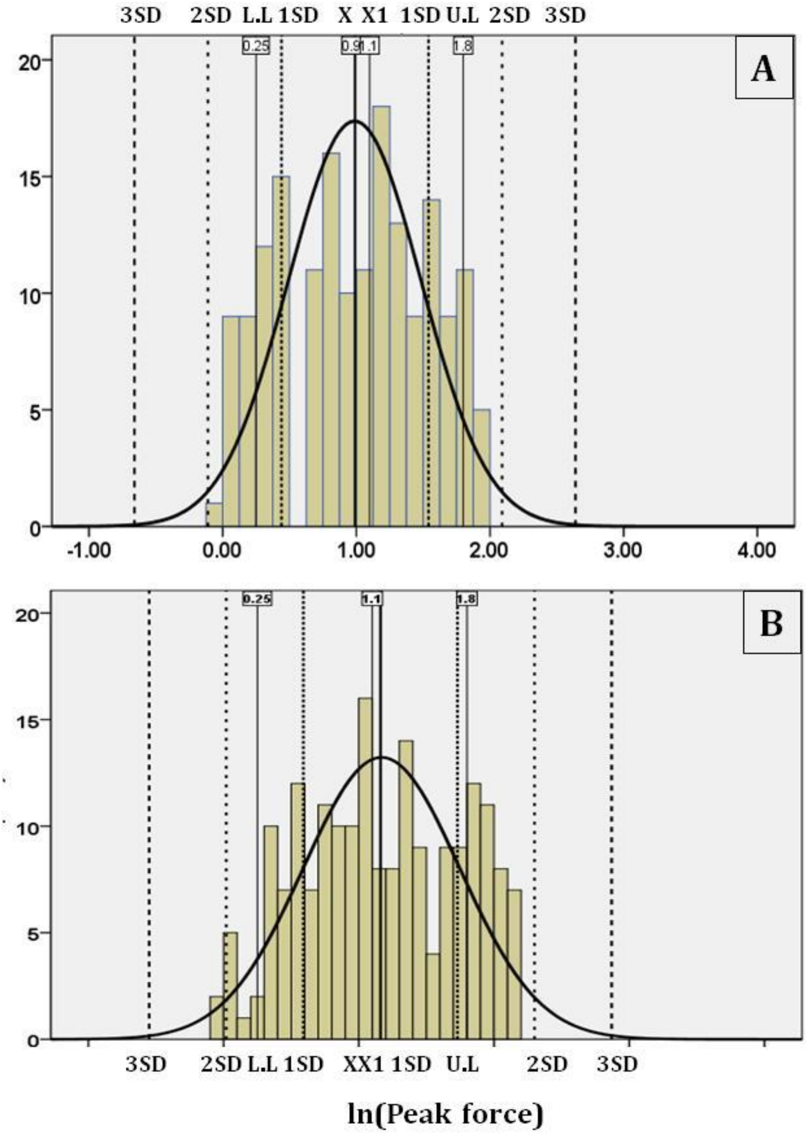


***Figure 6.1*** *Variation in the ln (Peak force) datasets of thin FF subjected to A: 170 $^{o}$C for 4 minutes and B: 170 $^{o}$C for 6 minutes. X1, L.L, and U.L express the target ln (Peak force) value, lower tolerable and upper tolerable limit, respectively. X, and SDs express the original mean and three standard deviations on both sides of mean ln (peak force) of thin FF.*

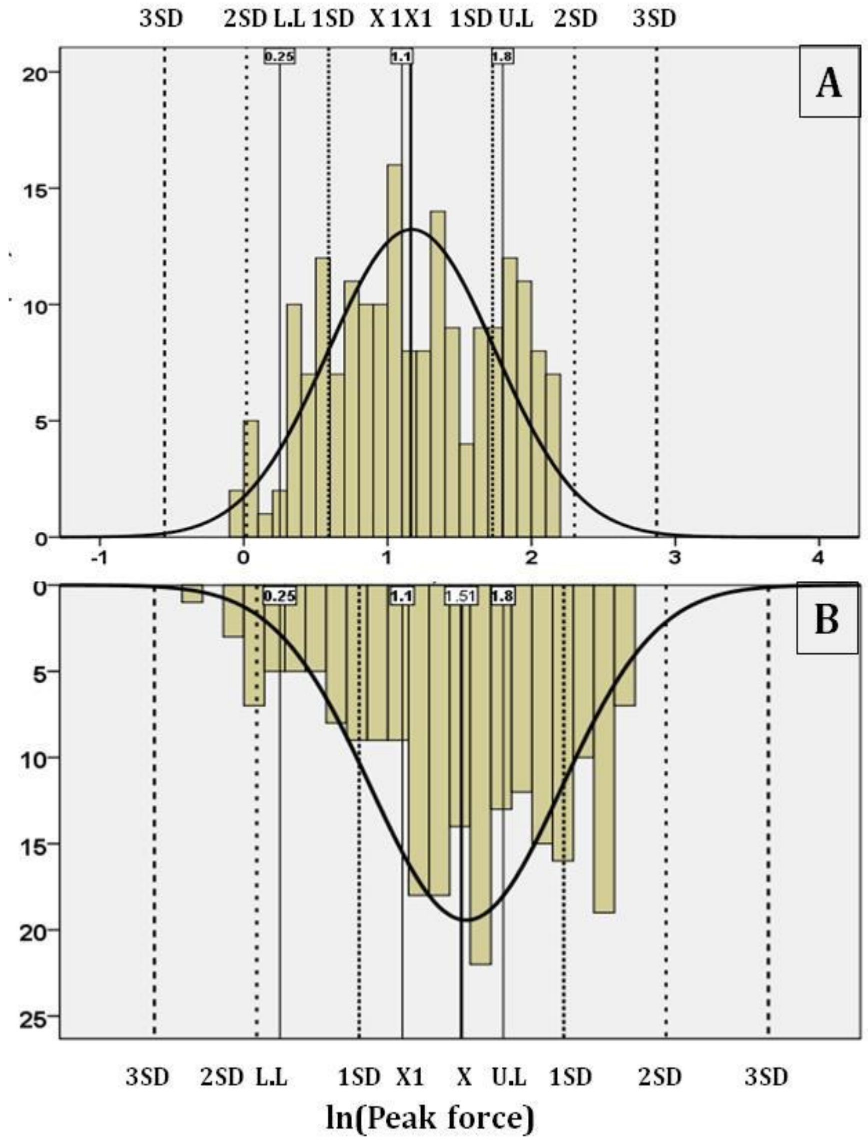


***Figure 6.2*** *Variation in the ln (Peak force) datasets of thin FF subjected to A: 170 °C for 6 minutes and B: 190 °C for 6 minutes. X1, L.L, and U.L express the target ln (Peak force) value, lower tolerable and upper tolerable limit, respectively. X, and SDs express the original mean and three standard deviations on both sides of mean ln (peak force) of thin FF.*

It was also observed in chapter 4 that different blanching settings did not result in considerable variation in reducing sugar such that it would result in a large variation in the colour profiles of the French fries. Therefore, selecting potato cultivars with appropriate reducing sugar content can be considered more as a company policy or design than as a control activity thus cannot be considered as CQP.

The proposed approach provides a basic structure/framework with main steps for the assessment of critical quality points in a food production system, based on our research on the production chain of French fries.

## 6.3 Future research

The thesis has taken the production of French fries as a case to investigate what it requires to assess CQPs. The case was chosen because of the heterogeneous nature of the potato as raw material and the many technological and managerial aspects that are involved, which allowed the assessment of variation in final quality attributes. Production of French fries is usually taking place in food service establishments and/or at the domestic level where companies have no control over food handlers/consumers making control decisions that can lead to additional variation in the final quality output. It would therefore be interesting as a follow up to this study, to investigate the production chain of food products that are prepared in the industry as ready-to-eat. Insight in the contribution of different technological and managerial factors in such cases to variation in the final quality leading to the assessment of CQPs will probably lead to better control. The resulting insights will allow making the proposed approach for CQP assessment even more general.

In the present research, results were interpreted in the light of available scientific literature where frying processes are mostly reported with respect to mean values of different quality attributes. However, these kinetic studies do not explain much about effect of different processing conditions, like t-T frying conditions, on variation in the datasets of these quality attributes. Therefore, kinetic studies with special reference to <u>variation</u> in the datasets of quality attributes of French fries are required to get further insight in the underlying reasons and to make more precise control measures to handle variation. Furthermore, our investigations about variation in the datasets of major quality attributes of French fries were based on real experimental data about different process and product conditions. In future, these studies can serve as a useful starting point for assessing the extent of variation in product and process conditions in relation to the impact on the profiles of final quality attributes of French fries.

It would be very useful to investigate via computer models how small deviations in the product and / or process parameters affect variation in the final quality attributes. In order to be able to do that, mathematical models are required that describe the effect of process and product parameters on final quality attributes. Such models are now widely available and can then be used to model the ensuing variation due to small variation of these processing and product conditions via Monte Carlo techniques (van Boekel, 2008).

The present research provided insight in the assessment of CQPs in a food production system as a first concrete step towards development of a lean and effective quality focused control system. It will result in a lean quality system as only few locations were focused for only those conditions/ properties which can critically affect final quality attributes which will save money, labour and time. It has been shown that it is possible to get an experimental grip on variation of quality attributes, and this information proved to be essential to establish CQPs. Moreover, the TM (Techno-Managerial) approach applied in this thesis proved to be essential as well, as the case study clearly showed the interconnection between human and technological factors on variation in quality attributes. It is suggested that this impact of human factors needs more attention in future studies next to the impact of technological factors.

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# Summary

This thesis investigated how to develop an approach for the systematic and science based assessment of those points in food production systems that have a critical effect on quality; such points could be designated as critical quality points (CQPs). There is an increasing interest in establishing effective and efficient control measures in the food industry to assure that quality requirements other than safety are met. One of the fundamental objectives of quality control is to reduce variation in the final quality attributes, which makes it essential to understand causes of variation in these quality attributes. In principle, variation in final quality attributes may result from the applied technological conditions (variation in the chosen raw materials, in process and storage conditions, in preparation methods) and from human behaviour (people handling the food at various points in the production chain). Therefore, a so-called techno-managerial approach was applied as the research framework to study both technological and managerial aspects. **Chapter 1** introduces the problem statement, the objectives and research questions. Furthermore, it is explained why the French fries (FF) production chain was chosen as a case study, namely because of the many points in the French fries chain where variation in conditions can lead to substantial variation in the final quality.

**Chapter 2** reviewed causes of variation in the major quality attributes of French fries based on a comprehensive literature analysis. Texture and colour were selected as major quality attributes of French fries, which are affected by one or more product factors (like compositional characteristics of the potatoes, chemical reactions) and process factors (such as the technological parameters in cultivation, harvesting, storage, and processing). The analysis focused on those studies that provided insight in the extent of variation in the product and process factors at various chain locations/ points and also their contribution to variation in the final quality attributes. Such points in the chain where minor deviations in the process and/ or product factors result in large (unacceptable) variation in the major quality attributes were considered critical to final quality attributes. It appeared not to be possible to firmly assign these critical control points, as a systematic approach appeared to be lacking to establish variation in the final quality attributes. Based on available quantitative data in literature, selection of suitable cultivar, time-temperature settings during bulk storage, blanching and final frying were indicated as potential critical control points (pCCPs). Moreover, Monte-

Carlo simulation demonstrated that a slight variation in frying time and temperature induced considerable variation in colour index. Lack of control over these critical control points may thus lead to unacceptable variation in quality attributes of the final product from a consumer perspective. The conclusion of the study was that further quantitative insight was required in the contribution of variation in process and product factors to the actual variation in the profiles of major quality attributes of French fries.

**Chapter 3** focused on quantitative assessment of variation in texture and colour profiles of French fries as a function of various fixed time-temperature (t-T) frying settings. The study indicated that increased frying temperature and time (from 170 to 190 $^{o}$C, and from 4 to 6 min) resulted not only in higher mean ln (peak force) values as a measure for texture (0.98± 0.54 to 1.51±0.71 as log-transformed values ) and colour index (2.3 ± 0.59 to 3.43 ± 0.83 on a scale from 1-7), but also in a larger variation in peak data force from 0.55 ± 0.02 to 0.71 ± 0.02 (29 %) and colour index data from 0.58 ± 0.09 to 0.82 ± 0.17 (41 %). These results were more obvious in the case of thin as compared to thick FF. The conclusion of this chapter was that lack of adequate control of these t-T settings during final frying can result in large variation in desired quality attributes of French fries.

Therefore, t-T frying-settings can be considered as potential critical control point (pCCP) for quality attributes. Companies, based on their established tolerances for product specifications, can decide whether or not to consider this pCCP as a real CCP. Thin French fries were found to be more susceptible to the above mentioned variation as compared to the thick FF, especially under domestic frying settings where lack of control over frying time due to variable food handler behaviour and frying temperature due to the frying equipment is nearly inevitable.

**Chapter 4** focused on blanching, a step preceding final frying, to investigate the effect of different blanching conditions like time-temperature (t-T) on variation in the texture and colour of thin and thick French fries (FF). Standard deviation of peak force and colour index data of each frying was used as measure of variation (Cal Var) in the datasets. Results showed no significant difference in variation in the datasets of peak force and colour index of thin and thick French fries as a function of different time and temperature blanching settings except for the blanching setting at 80°C for 10 minutes where slight increase in variation in the peak force datasets for thin FF was observed. In addition, peak force was significantly decreased with blanching temperature, whereas colour index of French fries was significantly lower with both blanching time and temperature. These results were found, again, more pronounced in case of thin FF as compared to thick FF.

The t-T blanching settings were not considered as potential critical control point because of the minor effect on variation, but selection of an optimum t-T blanching setting is to be considered as an important design activity while making process and product specifications because of the large effect on the actual value of a quality parameter.

**Chapter 5** focused on the managerial part by investigating the contribution of variable decisions of food handlers to variation in final quality attributes of French fries. The study analysed the effect of instructions to food handlers, making decisions on frying time and portion size, on variation in the texture and colour of French fries. Food handlers were closely monitored on compliance to these instructions. The extent of variation in the datasets of ln (peak force) and colour index was measured as calculated variation (Cal Var). The results indicated that implementation of frying instructions, sharply reduced variation in ln (frying time) and ln (portion size) (from 0.45 to 0.003 and 0.32 to 0.003 as log transformed data, respectively). This reduction in variation ultimately resulted in significant reduction in variation (Cal Var) in the ln (Peak force) and colour index data of thin FF (from 0.53 ± 0.16 to 0.44 ± 0.08 and 0.69 ± 0.13 to 0.53 ± 0.07 as log-transformed values, respectively). Furthermore, results of a secondary data analysis showed that these instructions, in combination with strict monitoring on compliance to these instructions, significantly reduced variation due to differences in the food handler's characteristics, like safety consciousness and appropriate attitude.

**Chapter 6** discusses the main findings and puts them in a general perspective. The data from the French fries case studies (chapter 2-5) provided insight in technological and managerial sources of variation that affect variation in the texture and colour of French fries upon consumption. First, it was discussed whether or not the well-known HACCP approach is suitable for establishing CQPs. The conclusion was that this is not the case because of the multidimensional and multifactorial of quality attributes as compared to hazards. Nevertheless, the HACCP approach was taken as the starting point and based on these insights, a systematic approach to assess CQPs is proposed in chapter 6. The proposed approach has provided a basic procedure consisting of six global steps for the assessment of critical quality points in a food production system, based on our research on the production chain of French fries.  Each of these steps is discussed in detail with respect to the applicability to food chains. A general picture emerged but it is also clear that in some details further research is needed for specific food chains, Moreover, the TM (Techno-Managerial) approach applied in this thesis proved to be essential as well, as the case study clearly showed the interconnection between human and technological factors on variation in quality attributes. Whether or not this is also the case for other food chains remains to be established, but it is certainly a point to give attention to.

This approach could be the base for further studies with different foods by investigating the production chain of other food products, to further evaluate and improve this approach as structured guidelines for the food industry to control and assure quality of the food products.

Finally, based on general considerations about CQPs, future research recommendations have been discussed.

# Samenvatting

Dit proefschrift beschrijft onderzoek verricht met de doelstelling om tot een systematische en wetenschappelijk gefundeerde benadering te komen voor beheers punten voor kwaliteit in een voedselproductie systeem, aangeduid als kritische kwaliteit beheers punten (in het Engels: *Critical Quality Points, CQPs*). Er is een toenemende behoefte om effectieve en efficiënte maatregelen te hebben in de levensmiddelenindustrie om naast voedselveiligheid ook voedselkwaliteit te kunnen beheersen. Een belangrijke doelstelling in de kwaliteitskunde is om ongewenste variatie in kwaliteit te kunnen verminderen tot binnen een bepaalde bandbreedte, en dat betekent dat het belangrijk is om de variatiebronnen goed te leren kennen. De uiteindelijke variatie in kwaliteitsattributen kan de resultante zijn van de gebruikte technologische condities (variatie in de grondstoffen, in proces- en opslagcondities, in bereidingsmethoden) maar ook van menselijk gedrag (veroorzaakt door menselijk handelen op verschillende plaatsen in de voedselproductieketen). Om hier grip op te krijgen is de zogenaamde *techno-managerial* benadering gekozen in de onderzoeksopzet. Dit houdt in dat technologische inzichten over gedrag van levensmiddelen gecombineerd worden met bedrijfskundige inzichten over gedrag van mensen om grip te krijgen op de uiteindelijke kwaliteit die aan het eind van een voedselketen wordt afgeleverd. **Hoofdstuk 1** introduceert de probleemstelling, de doelstelling en de onderzoeksvragen van het onderzoek. Verder wordt uitgelegd waarom de productieketen van frites gekozen is als onderzoeksobject, namelijk omdat er veel stappen plaatsvinden in de keten die invloed kunnen hebben op kwaliteit, omdat kwaliteit van frites door meerdere attributen bepaald wordt en omdat menselijk handelen een belangrijke rol speelt vooral in de eindfase van de productie van gebakken frites.

**Hoofdstuk 2** beschrijft een uitgebreid literatuuroverzicht aangaande variatiebronnen die invloed hebben op de belangrijkste kwaliteitsattributen van frites, namelijk textuur en kleur. Deze kwaliteitsattributen komen tot stand als gevolg van één of meer producteigenschappen (chemische samenstelling, chemische reacties) en van heersende condities tijdens de groei van aardappelen, oogst, opslag, verwerking, en het uiteindelijke frituurproces. Gefocust werd op die studies die inzicht gaven in de mate van variatie in de product- en procesfactoren op verschillende punten in de keten die van invloed zijn op de uiteindelijke productkwaliteit. Die punten in de keten waar kleine afwijkingen in de proces- en productfactoren leiden tot grote, onacceptabele variaties in kwaliteitsattributen werden beschouwd als kritische beheers punten (CQPs). Het bleek echter niet goed mogelijk op basis van de literatuur zulke kritische punten ondubbelzinnig vast te stellen; de reden daarvoor is dat er nog geen systematische benadering te vinden bleek te zijn in de literatuur om variaties in kwaliteitsattributen vast te stellen. Gebaseerd op wat er dan wel beschikbaar is zijn potentiele kritische beheers punten vastgesteld, namelijk de keuze voor een bepaalde aardappelcultivar, de tijd-temperatuur conditie tijdens aardappel opslag, tijdens blancheren, en tijdens het uiteindelijke frituren. Simulaties werden gedaan met de Monte Carlo techniek bij afwezigheid van echte data; deze lieten zien dat kleine variaties in frituurtijd en temperatuur leiden tot onacceptabele variaties in kleur vanuit consumentenperspectief. Geconcludeerd werd dat experimenteel kwantitatief onderzoek vereist is om de bijdrage van variatie in product- en procescondities en activiteiten in de keten op variatie in kwaliteitsattributen te kunnen vaststellen. Dit is het onderwerp van Hoofdstukken 3, 4 en 5.

**Hoofdstuk 3** bestudeert in detail en kwantitatief de variatie in textuur en kleur van frites als functie van de verschillende tijd-temperatuur combinaties bij het frites bakken. Textuur werd instrumenteel gemeten m.b.v. een '*texture analyzer*' waarbij de gemeten kracht om tot breuk te komen van een frietje als maat voor textuur werd genomen: hoe hoger de kracht, hoe steviger de textuur. Kleur werd gemeten met een kleurkaart bestaande uit schalen; een dergelijke kaart wordt standaard gebruikt in de levensmiddelenindustrie. Het bleek dat een hogere temperatuur (gaande van 170 naar 190°C) en een langere tijd (van 4 tot 6 minuten) resulteerde in een grotere benodigde kracht en een meer intense kleur, maar minstens zo belangrijk was dat ook de variatie in deze twee parameters toenam. Dit was duidelijker voor dunne frietjes dan voor dikke. De conclusie uit het werk beschreven in dit hoofdstuk was dat een niet goede beheersing van tijd-temperatuur combinaties bij het frituren leidt tot een grote ongewenste variatie in belangrijke kwaliteitsattributen. Deze variatie bleek goed experimenteel vast gelegd te kunnen worden, en is daarmee een instrument om het effect van kritische factoren op kwaliteitsattributen vast te leggen. Daarom kan het instellen van tijd-temperatuur combinaties bij het frituren beschouwd worden als een potentieel kritisch beheers punt, zeker voor dunne frietjes. Het wordt een reëel beheers punt op het moment dat een fabrikant besluit tot bepaalde toleranties waarbinnen kwaliteitsattributen mogen variëren.

**Hoofdstuk 4** concentreerde zich op de effecten van de blancheer stap in het productieproces van frites op de variatie in de kwaliteitsattributen textuur en kleur, waarbij blancheer tijd-temperatuur combinaties werden bestudeerd. Het bleek dat deze processtap geen noemenswaardige invloed had op de variatie in de bestudeerde kwaliteitsparameters (behalve voor één instelling, namelijk 10 minuten 80$^{o}$C, waar een lichte toename in variatie in textuur werd waargenomen). Wel werd, uiteraard, een duidelijk effect gevonden op de waarde van de kwaliteitsattributen; de benodigde kracht voor breuk nam af met zowel blancheer tijd als temperatuur. Ook hier waren de effecten duidelijker voor dunne frietjes dan voor dikke. Hoewel de variatie dus niet sterk werd beïnvloed door de blancheer instellingen, worden de waardes van de kwaliteitsparameter wel sterk beïnvloed en blancheer instellingen zijn dus wel een belangrijk instrument om op gewenste kwaliteitsattributen te sturen, maar het is niet kritisch voor de variatie in kwaliteitsattributen.

In **Hoofdstuk 5** werd de invloed van menselijk gedrag onder de loep genomen. Bestudeerd werd in hoeverre variatie in kwaliteitsattributen beïnvloed werd door beslissingen die mensen nemen t.a.v. frituurinstellingen en de portiegrootte om te frituren. Daartoe werden de proefpersonen al dan niet geïnstrueerd t.a.v. de aan te houden tijd-temperatuur van het frituren. Degenen die geïnstrueerd werden nauwkeurig geobserveerd om te zien of de instructies daadwerkelijk gevolgd werden. De instructies bleken grote invloed te hebben op de waargenomen variatie in de kwaliteitsattributen: de variatie nam sterk af met instructies. Dit toont dus aan dat de effecten van menselijk gedrag kwantitatief gemeten kunnen worden in de variatie van kwaliteitsattributen. Een bijkomend onderzoeksresultaat was dat karakteristieken van de proefpersonen t.a.v. bewustzijn van het belang van voedselveiligheid enige invloed hadden: minder variatie bij meer bewuste mensen.

In **Hoofdstuk 6** zijn de gevonden resultaten bij elkaar gebracht en in perspectief gezet in de algemene discussie. Dit proefschrift heeft, als eerste, aandacht aan zowel technologische factoren als ook de effecten van menselijk gedrag als bronnen van variatie op kwaliteitsparameters van levensmiddelen. Het hoofdstuk bediscussieert vervolgens of de bekende HACCP methodologie, ontworpen om negatieve effecten tegen te gaan in relatie tot voedselveiligheid, ook geschikt zou kunnen zijn voor positieve, d.w.z. gewenste kwaliteitsattributen. De uitkomst van de discussie is dat

HACCP daar niet toe geschikt is vanwege het multi-dimensionele en multi-factoriele karakter van kwaliteitsattributen; voedselveiligheidsparameters zijn veel eenduidiger. Wel werd de HACCP methode geschikt bevonden als startpunt voor het ontwikkelen van een methodologie voor het vaststellen van kritische beheers punten voor kwaliteit. Gebaseerd op het in dit proefschrift beschreven onderzoek werd een zes-stappen plan voorgesteld om tot een voor kwaliteitsattributen geschikt management systeem te komen. Hierbij werden ook de punten voor verder onderzoek vastgesteld die nodig zijn om een dergelijk systeem van de grond te tillen voor andere producten dan frites. Geconcludeerd werd dat de *techno-managerial* benadering nieuwe inzichten geeft in de kwaliteitskunde door de combinatie van technologisch inzicht enerzijds en het gedrag van mensen anderzijds die beslissingen nemen in voedselproductie en –bereiding. Een belangrijke genomen stap is dat deze factoren rechtstreeks terug te meten zijn in de variatie van kwaliteitsattributen, en dat geeft een handvat tot beheersing.

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How can I forget the multicultural room 211B with wonderful colleagues? I would like to start from my immediate neighbour for at least 4 years, Dr. Gao Ran. Dear Gao, thanks for your very pleasant company and very nice and useful ideas and suggestions whenever required. I am also grateful to Dr. Hettinga Kasper for his considerate support. Dear Kasper, I can never forget the day when I was feeling very sick and you very kindly commuted me to Nijmegen (my home). I would also like to thank Dr. Kathia Broce for a very nice company during her post doc at PDQ.

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I feel myself fortunate that I found very nice friends. I am extremely grateful to Mr. Aamir Ilyas Rana for his great support. Dear Aamir, our 25 years friendship is a real asset for me. You are a human version of the saying “friend in need is a friend indeed”.

My life in the Netherlands was divided into two parts: life in Nijmegen and life in Wageningen. However, I can never forget Nijmegen and my friends in Nijmegen. I would like to thank Waqar, Faisal, Wasim, Kaleem, Aamir, Zahid, Saidan, Rabbani, Zafar, Ansar, and Waqas for their remarkable company. I will really miss that company, especially our cricket team. Dear Waqar, you were the first person who received us at Schiphol airport and helped me (with my family) to reach our home in Mook near Nijmegen. Your support and friendship during all these days is highly commendable. Dear Faisal, I would like to appreciate you for the respect and care you have given me and my family throughout these years. I would also like to thank Ms. Sadia Saeed for her cooperation. Dear Sadia, from your first day in Nijmegen you became our family member and we as family share very pleasant memories. I wish you all the best for the final stage of your PhD.

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*"AAFTON KE DOR MEIN CHAIN KI GHARI HAI TU MERE ZINDAGI HAI TU" (Nasir Kazmi).* My lovely little princess Minahil, your entry at the end of my PhD was just like Faiz said "*JAISEY WEERANE MEIN CHUPKE SE BAHAR AA JAEY*" (like swift onset of spring). Your smile is just enough for all day's stress.

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*"Pakistan Zindabad".*

***(Muhammad Ali)***

# Curriculum Vitae

# &

# List of publications

Muhammad Ali was born on 20th of August 1971 at Bhakkar, Pakistan. He graduated as B.Sc. (Hons.) and later on M.Sc. (Hons.) in Food Technology from the University of Agriculture Faisalabad, Pakistan. He performed his M.Sc. thesis in the Laboratory of cereal technology. Afterwards, he worked for the Pakistan Agriculture Research Council (PARC) as an Assistant Director Research Coordination. Later on he joined University of Arid Agriculture Rawalpindi as a Lecturer in Food Technology in April 1998. In 2005 he won a fellowship for PhD abroad financed by Higher Education Commission (HEC), Govt. of Pakistan. He started his PhD in 2006 under the supervision of Dr. Martinus van Boekel and Dr. Pieternal Luning in the Product Design and Quality Management group in Wageningen University, the Netherlands. In 2011, he completed his PhD project titled "Towards an approach to assess critical quality points (CQPs) in food production systems: A case study on French fries production".

He is married to Dr. Afsheen Tabassum, who after completing her PhD in Dental Implants from Radboud University Nijmegen, now working as ITI Fellow in the dental Implantology department of Dentistry institute Amsterdam (ACTA). He is a happy father of one brilliant son and one lovely daughter.

# List of Publications

## Research Articles


1 Ali, M., Luning, P. A., Marcelis, W. J., & Van Boekel, M. A. J. S. 2012. Assessment of critical quality points (CQP): A case study for the French fries production chain. *Submitted in Food Reviews International*.

2 Ali, M., Luning, P. A., Bakker, E., & Van Boekel, M. A. J. S. 2012. A quantitative assessment of variation in major quality attributes of French fries during frying. *Submitted in Food Control*.

3 Ali, M., Luning, P. A., Andrikopoulos, G., & Van Boekel, M. A. J. S. 2012. Impact of frying practices on variation in texture and colour of French fries. Ready for *submission in Food Control*.

4 Ali, M., Luning, P. A., Siyi, W., & Van Boekel, M. A. J. S. 2012. A quantitative assessment of variation in major quality attributes of French fries during blanching. *In preparation for submission in LWT: Food Science & Technology.*

5 Ali. M, Saeed, M. K., Asif, A., & Nasreen, A. 2000. Stabilization and Preservation of Yoghurt Drink. *Pakistan Journal of Arid Agriculture*, 3(1-2).

6 Hassan. M., Ali, M., & Nasreen, A. 2000. Formulation of Ice Cream for Weight Watchers, *Pakistan Journal of Arid Agriculture*, 3(1-2).


## Conference proceedings


1 Ali, M., Luning, P. A., Bakker, E., & Van Boekel, M. A. J. S. 2011. Effect of varying frying conditions on variation in color and texture of French fries: A quality control perspective" at 4th International congress on food and nutrition, held in Istanbul, Turkey.

2 Ali, M., Luning, P. A., Andrikopoulos, G., & Van Boekel, M. A. J. S. 2012. Impact of frying practices on variation in texture and colour of French fries" 3rd FOOD Denmark PhD Congress held in Copenhagen, Denmark.

# Overview of Training Activities

***Discipline specific***

*Courses*

Reaction kinetics in food science, VLAG, 2006

Food perception & food preference, VLAG, 2007

Workshop on ISO 22000, Wageningen, 2006

Management of microbiological hazards in foods, VLAG, 2010

Bayesian Statistics, Wageninegn, 2010

*Conferences and meetings*

4th International congress on food and nutrition, held in Istanbul, Turkey from 12-14th October, 2011.

3rd FOOD Denmark PhD Congress held in Copenhagen, Denmark, from 22-23 November, 2011.

***General courses***

Philosophy and ethics of food science and technology, VLAG, 2007

Techniques for writing and presenting scientific papers, 2008

Information literacy, including introduction End Note, 2009

Career perspectives, 2010

Scientific publishing, 2011

Writing grant proposal, 2011

***Optionals***

Preparation of research proposal, 2006

Advanced course of food quality management, 2007

Presentation and mini poster for study trip to USA, 2007

PDQ strategy meeting (two yearly), 2006

Presentation on PDQ strategy meeting (two yearly), 2008

PDQ group presentations 2006-2011

## Colophon

The research described in this thesis was financially supported by The Higher Education Commission (HEC), Govt. of Pakistan.