Sveriges lantbruksuniversitet
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Faculty of Natural Resources and Agricultural Sciences

An analysis of capability in a bread making industry

En analys av kapabilitet i en brödtillverkningsindustri

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Abstract

In large scale industrial baking, problems with continuity are not uncommon and specification demands are used to keep produced units equal. Many factors may affect the bread making process including status of raw-material, temperatures in production area and the fermentation process. In this thesis, the production of hot dog buns has been investigated. Lantmännen Unibake detected variations in size among buns produced from the same production line. The aim of this thesis is to find what causes these variations and investigate the capability of the production line. This was done by measuring factors such as temperature, relative humidity, dough temperature, the fermentation process, oven temperatures etc. The measured parameters were compared to measurement of buns produced and analysed with principal component analysis. The results were further analyzed with ANOVA and compared with Tukey's comparison. Result from this showed that 1.6 % of the produced buns reaches the set specifications. Most variations in measurements are in width of the buns. Weather changes and temperature drops affect the relative humidity within the bakery and that may cause some variations of the produced units. Furthermore, this investigation shows that the production line could be improved in proving chamber and ventilation to optimise the process. Increasing the dough weight of every bun leads to greater percentage of produced units within set specifications. By adjusting the specifications with ±1 mm in every dimension more buns would be approved.

Keywords: Industrial bread making, hot dog buns, bread size variations, capability, principal component analysis

Sammanfattning

Problem med kontinuitet i storskalig brödtillverkning är inte ovanligt och specifikationer på bröd används ofta för att slutprodukterna ska vara jämna. Olika faktorer kan påverka brödtillverkning, kvalitet på råvaror, temperaturer i produktionslokalen och jäsningsprocessen är några. I den här uppsatsen har en produktionslinje som producerar korvbröd undersökts. Lantmännen Unibake upptäckte att deras korvbröd skiljer sig från varandra storleksmässigt även fast de produceras på samma produktionslinje. Syftet med den här studien är att hitta vad som orsakar dessa variationer. Detta gjordes genom att undersöka kapabiliteten på linjen och mäta parametrar som temperatur, luftfuktighet, degtemperatur och jäsningsprocessen. Alla parametrar utvärderades med principalkomponentanalys. Resultaten av detta utvärderades med ANOVA och jämfördes med hjälp av Tukey-jämförelser. De resultat som hittades visar att enbart 1,6% av de producerade bröden uppfyller specifikationskraven. De mesta variationerna är i brödens bredd. Väderförändringar och sjunkande temperaturer påverkar luftfuktigheten i produktionslokalen, vilket orsakar en viss del av problematiken med storleksvariationer. Vidare visar den här undersökningen att produktionslinjen kan förbättras, framförallt i jässkåpet och ventilationssystem för att optimera tillverkningsprocessen. Med högre degbitsvikt visar sig ge ett högre procentantal av bullar inom de satta specifikationsramarna. Genom att justera specifikationerna med ± 1 mm i varje riktning blir betydligt fler bröd godkända.

Nyckelord: Industriell brödtillverkning, korvbröd, storleksvariation bröd, kapabilitet, principalkomponentanalys

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1 Introduction

1.1 Problem description

Lantmännen Unibake produces hot dog buns and hamburger bread in large extent under the brand Lantmännen Unibake to households and restaurants distributed all over Sweden.

The buns produced in this bakery are regulated to specifications when it comes to appearance and quality. The appearance specifications include size measurements and weight of the buns. Specification limits are set so that the consumers can know what to expect when they buy the products, they are always the same. Variations in appearance among the buns are wanted in some extent, as it makes them look "homemade" and rustic which is a good sales argument.

At the baking plants packaging area, all operations are controlled by robots. Differences in shape, weight and size among the buns are causing trouble since the robots have difficulties to pack buns properly into plastic bags, which leads to stops in the production and unnecessary waste of product. Within the bags, buns are more easily misplaced if the measurements vary and when the plastic bags are packed together into cardboard boxes before storing, the misplacing continues. When a bag or a box comes out of place in the production line it often requires a short stop in the production. This is both inefficient and uneconomical for the bakery plant and must be reduced.

Buns from the production line are not baked in form, variations are therefore normally occurring. But there may be several other factors that potentially cause the unwanted differences among the buns. By thoroughly analysing the production line from raw material through all steps of the production and measuring the finished product the cause of the variations may be found.

1.2 Aims and Purposes

This thesis aims to answer the following questions

- To what extent does the bakery plant produce units within specifications?
- Is it possible to increase the yield of units within specification limits?
- Can one or several factors be found within the bakery plant that affects the size of finished products? Is it possible to link the potential factors and size variations?

The purpose of this thesis is to find a possible source causing the irregularities in size and weight among hot dog buns of a specific production line in Lantmännen Unibake's bakery plant. By investigating how doughs are being treated during production, what parameters separates them and compare the treatment to measurements of buns from that specific dough, correlations between handling during production and size of the buns may be found.

If successful, this thesis will provide suggestions for an improved capability of the production line. That would result in improved quality, increased efficiency of the production line and lower production costs, which is of interest for Lantmännen Unibake. The thesis could also contribute to a better knowledge of the baking industry.

2 Literature Background

2.1 Capability

Capability indices are quantified by investigating the relationship between set demands and process actual performance (Wu *et al.*, 2009). One capability index is C_P. A large value of C_P implies a high process yield and low process loss is expected (Chen *et al.*, 2001).

By investigating the deviations during a process, capability of the production can be increased (Motorcu & Güllü, 2006). The process capability can be used to understand and estimate a process ability when specification limits are pre-set (Chan *et al.*, 1988). By knowing a process capability its potential is also understood (Zhang & Datta, 2006; Kane, 1986). Capability analysis is based on statistics and is frequently used in manufacturing industry. A process with capability statistics under control does not need to be changed, since its potential meets specifications and requirements. The principle of capability is that instead of checking finished product units and comparing them to specifications, the product and process is evaluated at every step of the process (Motorcu & Güllü, 2006). Increased insight and understanding in a process and its details, leads to higher efficiency and productivity compared to if focus is just on the final product and its defects (Dolinšek & Kopač, 2001).

In a short-term investigation, like this thesis, the use of capability as method may give indications of problems in the process (Kane, 1986). In this investigation, factors such as raw material, bakers etc. that may have influence on the production process were also taken into consideration.

2.2 Bread making

One of the worlds most consumed processed food products is bread and technology where principles of bread making are some of the oldest known (Selomulyo & Zhou, 2007). Yet there is no true definition of what a bread really is but the unique gluten network that bread has is one of the aspects defining the product (Cauvain, 2016).

Saccharomyces cerevisiae, known as baker's yeast is an important ingredient in bread making (Bell *et al.*, 2001). To obtain perfect bun it is important that the dosage of yeast is adequate, too small amount causes an inactive fermentation and the dough appears sticky. Whereas too much of yeast can end up in a dough that is porous and more prone to early staling (Wieser, 2003) Baking plants generally requires stiffer dough, compared to homemade, to prevent the dough from getting stuck in the machinery during baking (Baardseth *et al.*, 2000). The dosage of yeast is therefore regularly changed to obtain optimal baking properties. Without kneading, no air bubbles would incorporate the dough. There would not be any developing of gluten network (Amend & Belitz, 1991).

During bread making, proving is a crucial step. The yeast's ability to ferment glucose into carbon dioxide contributes to the expansion of the viscoelastic dough and give rise to a bread product rather than dough (Birch *et al.*, 2013).

The yeast activity of *Saccharomyces cerevisiae* is inactivated at temperatures above 55 °C. The stability of the dough is maintained when the bread is warm and the cell pressure is positive (Cauvain, 2016). With a higher proving temperature, the time required to heat the dough is decreased. This eventuate in lower product quality since the gas production become uneven which causes uneven cell structure and texture in the buns (Cauvain, 2016).

Physiochemical changes occur during bread making as dough is formed and transformed into bread. An important factor, as mentioned, dominating these changes is temperature. It is important to keep oven temperature constant in order to achieve optimal results of baking (Mondal & Datta, 2008).

2.3 Flour

Flour is the most abundant ingredient in hot dog buns. For large scale baking it is important that every dough receive the same properties. Therefore, the flour quality must be constantly the same, good quality. Flour is delivered with certificate of analysis, flour outside specifications are not delivered. Parameters of interest to Lantmännen Unibake includes protein content and falling number.

Wheat flour from *Tritcum aestivum,* mainly consists of starch (Yasui *et al.*, 1996). One of the important attributes of starch is its excellent capacity of adsorbing water. Starch adsorbs 46 % of added water during dough preparation, contributing to the formation of dough (Goesaert *et al.*, 2005).

Starch is one of the constituents of importance, gluten proteins are another. Gluten proteins, gliadins and glutenins interact with other components in flour, contributing to a viscous and at the same time elastic dough, that contributes to gas holding (Veraverbeke & Delcour, 2002). In a study performed by Escalante-Aburto *et al.* (2017) the gliadins stood for 45.7 % of the total viscosity in a dough whereas gliadins together with albumin contributed to 54% of the total dough elasticity.

Protein content in wheat flour is normally 10-12 % and contributes to the strength of the dough. The protein content vary with season and temperature (Nasehzadeh & Ellis, 2017). Further protein related qualities are dough expansion, higher content of protein gives a greater expansion in dough during baking (He & Hoseney, 1992). Good quality bread is obtained when there is balance between the viscosity and the strength of the dough. High dough strength increase the volume of the bread, however if it is too strong any dough rise will be hindered (Goesaert et al., 2005). Dough baked from wheat with poor quality in gluten protein gets less elastic yet more viscous than dough from wheat with good quality (Khatkar *et al.*, 1995).

Another quality parameter of flour used for bread making is falling number. Measuring falling number, gives an indication of α-amylase activity (Perten, 1964). A high α-amylase activity causes an enzymatic hydrolysis of starch interfering in the bread making process and leading to products with lower quality. α-Amylase activity depends upon weather and temperature during growing season (Lunn *et al.*, 2001) and is therefore presented in a quality certificate with every new delivery of wheat flour to Lantmännens bakery. α-Amylase activity is at its highest at temperatures of 60-70 °C and not inactivated until 85 °C is reached. Insufficient α-amylase activity contributes to less bread volume since the dough gets stiff with less ability to expand. However, a high α-activity is also not desirable since that contribute to collapsing of dough during baking (Cauvain, 2016).

At the bakery of this investigation, a change in flour occur in the autumn, that's when flour from the harvest is delivered instead of the flour from previous season. And according Hruškova and Machova (2002) storage affects the quality of the flour. Therefore, it is possible that the flour quality differs during the time of the change to new harvest. During the time for this investigation the change had been performed and the flour from the new harvest showed good quality and baking properties along with a high enzymatic activity.

2.4 Baking and color

At large scale bakery plants, the most frequently used oven type are tunnel ovens. That means that baking units are transported on production bands throughout a long oven (Mirade *et al.*, 2004). Within the ovens several heating sources are incorporated, dividing the oven into several zones or sections. Temperature in the different zones are important factors contributing to browning among other characterisations of a bread (Therdthai & Zhou, 2003). During baking, chemical, physical and biochemical changes occur within the bread, contributing to the final quality of the baked bread. One important factor of oven baking is that activity of *S. cerevisiae* is reduced when temperature exceed 55°C (Wieser, 2003).

Heating starts at the surface of buns and transfers into the crumb. This means that the crumb of the buns continues to expand, since it takes longer time for it to reach the temperature that inactivate yeast. When crumb has been formed, that work as hindrance for further expansion of the buns (Cauvain, 2016; Vanin *et al.*, 2009). Position of the buns within oven must be carefully considered since it can affect the flow patterns of hot air and thereby change quality of the bread (Anishaparvin *et al.*, 2010). Browning of the crust is due to caramelization and Maillard reactions, where amino acids react with reducing sugar under acidic and heated conditions (Ajandouz & Puigserver, 1999). Maillard reactions contributes to flavour and aroma in several food items, including baked goods (and hot dog buns) (Martins *et al.*, 2000). The color development is only depending of temperature during baking (Purlis & Salvadori, 2007). Crust browning occur at low water content and temperature >110 °C since that activates non-enzymatic browning reactions, Maillard reactions and caramelization. At higher temperature, the crust obtain a darker color (Therdthai & Zhou, 2003). Therefore, measuring color can be used to ensure that browning and baking is sufficient (Ameur *et al.*, 2007).

Identifying color in baked goods is easily done with a Minolta BC 10 plus. Minolta BC 10 Plus are frequently used in industrial baking as a step of self-inspection. The value it gives is Baking Contrast Unit (BCU) and is a value of darkness or lightness of the product where 0 is the darkest and 5,25 the lightest. The human eye notes shades corresponding to 0,1 BCU. By identifying the rate of browning for the buns and connect that with which position it has had in the pan, temperature differences and unevenness may be found (Therdthai & Zhou, 2003).

Color variations of baked buns are often derived from diversiform heating. Reductions of these variations are possible with a proper design and processing of the oven. The processing include factors such as air temperature, heating power, baking time and size of the bread (Anishaparvin *et al.*, 2010). According to Purlis and Salvadori (2007) there is a clear relationship between oven temperature and lightness. With increased temperature, color of the crust does get darker.

However, ovens are complex and it is difficult to find one that bake identical buns. It is very common that there are significant differences in temperature depending on position in oven. Controlling the procedure is of importance to gain information about the ovens eventual defects in order to continue producing buns in large extent (Cauvain, 2016).

2.5 Freezing

Efficiency is very important in the production, packing oven hot buns in plastic bags there can cause quality problems. Since a lot of condensation will gather within the bag, soaking of the buns and problems with quality can occur. A cooling step is interposed between oven and packaging of the buns. Cooling with a fast freezing step is done for several reasons. Partly, it slows the heat flow, making it possible to immediately wrap the baked products without quality defects (Cauvain, 2016). The fast freezing also contributes to a more convenient handling for operating personal in the sorting area (Reynolds & Young-Bandala, 1982).

In a study from Zeleznak and Hoseney (1986) not all starch is gelatinized during baking. Freezing a baked product may have effect of the starch gelatinization process. According to Patel *et al.* (2005) bread baked at high temperatures gives a decreased water holding capacity. An investigation of the size before and after the cooling step was included in this thesis to clarify if this step affects the final size of the buns.

2.6 Temperatures and relative humidity

Several factors during bread making has impact on the quality of the finished bread product. All of the factors are of importance and they are often coupled to each other. Zhang and Datta (2006) describes one distinct example; Core temperature of bread gives an indication of when the bread is ready baked and is strongly linked to the breads volume expansion. Volume expansion in turn depends on circumstances such as temperature, which is the dominant factor regulating yeast activity. This is just one example illustrating the obviously complex bread making process.

During start-up of this thesis, some of the bakers working at the bakery plant requested information regarding whether the in- and outdoor temperatures and humidity, proposing it as aspects for the quality attribute differentials. Both temperature and relative humidity factors contributing to a proper proving (Therdthai *et al.*, 2007) since dough sometimes rest before kneading, if the funnels are filled up. Extra proving occurs to some extent. Humidity in production space is a parameter that have great impact of bread quality and it affects water evaporation (Le Bail *et al.*, 2005).

3 The bakery

All information regarding the bakery are based on conversation with the staff of the plant and my own experiences that I gathered during the investigation. A lot of the information is due to secrecy reduced.

3.1 Recipe and specification requirements

The hot dog buns in this thesis are made out of wheat flour dough. The major constituents of the dough are wheat flour, water and yeast. The specific recipe includes mixing times and dough temperature.

Changes in recipes occur when the baker experience minor quality defects of the dough or baked units. Changes in water and yeast consumption are the most abundant and are made by adding or removing kilos or half kilos from original recipe.

The bakery plant produce buns with set specifications. In the daily routines for every shift, one task is to measure size of the buns with a volume meter (Tex Vol BVM-L 190, Perten instruments). The specifications include length, height, width, and weight and they are presented in Table 1. For appearance there are no set specifications but experienced sorting personal sorts buns that are out of shape damaged, and with irregular coloration etc.

3.2 Description of the production line

The investigated production line is automated and includes several work stations, similar to what Tsarouhas (2009) describes. At the first station, dry ingredients from silos and water are mixed in a movable bowl. Mixing times varies with recipe and two different gears are often needed (Tsarouhas, 2009). After mixing, the movable bowl is moved by the baker into an elevator and the dough is discharged into funnels. The dough is kneaded automatically within the funnels; a new batch is added every 10 minutes. The prepared dough is split into five funnels that ends up in three, almost identical production lines. After working station 4, the oven, the lines are incorporated again before the freezing step. A schematic overview of this can be seen in Figure 1. The three lines keep different speed and in this thesis the focus lies in investigating one out of these three lines.

Second working station is where the dough is kneaded and cut into smaller pieces. After that, station 3 in Figure 1 the forming is operated by moulders. The transfer of dough in the production line is mechanically driven and after forming by moulders and rounder, the pieces of dough are placed on pans that holds 16 buns each before proving. The prover of this production line is a chamber with the pans moving up and down contributing to an even proofing of the buns. Time for this is constant but can be changed if needed. By changing the speed of the track, proving time can be specified (Cauvain, 2016). Within the chamber the relative humidity is set to hold 62 % and the temperature to 37°C. The chamber is equipped with two doors at each long side, which can be opened to regulate temperature and humidity if needed. One critical point of the baking process is in the proving chamber; it sometimes occurs that dough falls of the pan. That creates stops in the process. It is included in the baker's daily routines to check the chamber every half an hour. This may include opening of doors.

Next step of the line is the oven. A process aiming to transform dough to sponge, where temperatures should be in the range 220-250 °C and to obtain preferable quality of the bread, the core should obtain 92-96 °C (Campbell, 2003). Oven temperatures and speed are therefore controlled daily so that right baking properties are gained. The oven in the production line is electrical driven with four section heating sources, each with three power steps in both bottom and top heating. Heating source from several directions helps to contributes to an even heat spread. The four sections of the tunnel oven are equipped with three power steps individually. The power steps are regulated automatically, depending on the capacity at the moment. If the oven is empty, as in start-up of a shift, maximum power will be switched on for a quick heating. Temperature adjust automatically and decrease, with lower power when buns enter the oven. To keep temperature at certain temperature, the power steps are either on or off, making the overall oven temperature unstable.

After oven, buns from three separated lines are merged together before freezing and packaging. The pans are transported back to mixing step underneath the oven and proving cell. This enables them to cool down to approximately 40 °C before new dough is put on them.

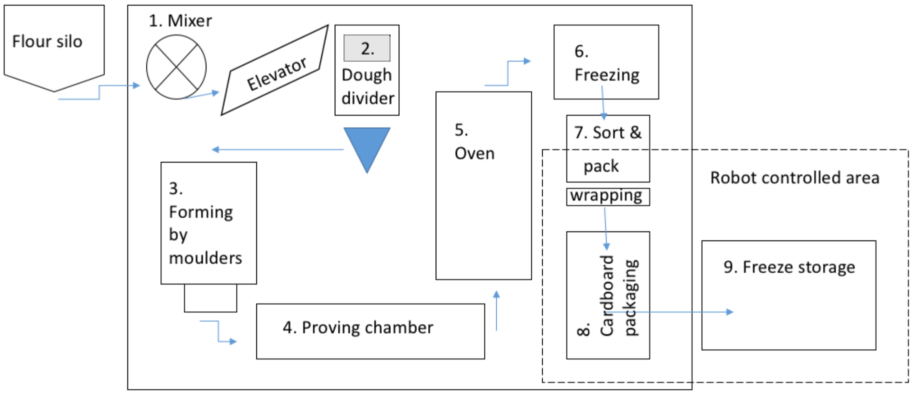

Figure 1. The bread production line in schematic overview. Numbers indicate the direction and order of different working stations. The silo with flour is shared among other production lines within the bakery. Within the dashed lines, all operations are handled and controlled by robots

3.3 Capacity

Out of one dough a total of 6307 hot dog buns can be prepared. The dough is divided into three almost identical lines, each with different speed and capacities. In this thesis, focus has been on production line 3, which consumes 42 % of one dough. Throughout proving and oven the buns are placed on pans. A full pan carries 16 buns. The production line bakes with a speed of 21 pans per minute, equals 336 finished buns per minute. The hot dog bun production is operated in two or three 8 hour shifts during a 24-hour period of time. Maintenance and cleaning is done when no shift operates. High season for hot dog buns is during spring and summer time and there may be extended production including weekends during that period of year.

4 Method

In total, the described analysis was performed 20 times during several days in October-November 2017. The aim was to gain all information about changes, environmental factors and disturbances that occurred during bread making, from dough to finished product that can correlate with the product quality according to specification. The method was practiced by following the production line during the process and includes collecting data from several steps, presented in table 1.

Table 1. *The measuring and methods used for them. Most measuring included reading thermostats that exists within the bakery.*

Analysis	Method
Temperature (°C) inside and outside	Checked with available thermometers
Relative humidity (%) inside and outside	Checked with available measurement
Recipe changes & dough temperature	Answered by the baker in charge
Proving chamber, temperature & RH	Checked Viasala transmitter every 5 minute
Proving chamber, disruption	Monitored and noted when doors open and the time for it
Oven temperature	Temperature checked at every section during baking
Color of crust	Measured in BCU by Minolta BC 10 Plus
Product assessment	Callipers in height, length and width. Weight with 0.5 g accuracy
Freezer	Comparison in measurement and weight between 15 buns before and after freezing

4.1 Existing data

As a part of securing good quality at the bakery, several self-inspections are performed. The inspections include measuring size of produced products and controlling raw materials by their certificates. Results from the measuring could be used as indicators of the process capability of a longer period of time. But today the results are not further analyzed at the bakery.

To get an idea of the spread of variations, existing data, registered by the volume meter, Tex Vol BVM-L190 was evaluated. The volume meter measures the product with laser sensors moving in a half circle around the bun, giving measurements in height, weight and length (Cauvain, 2016). The data, gained every day from January to August 2017 was compiled (total number of 3167 buns) presented in Table 2. It was noticed that the volume meter does not make difference between height or width, those measurements are therefore not credible. The existing data comes from measuring buns after the oven step. That is the reason why buns of this investigation also was measured after the oven step.

Existing data were compared to measurements of hot dog buns collected during the thesis. Instead of measuring with volume meter, callipers were used further in the investigation. Measuring bread with callipers is a good method to assure that size measurements are adequate (Curic *et al.*, 2008). This was made to see if there were any differences between measuring with volume meter and callipers, result presented in Table 2.

4.2 Surroundings - Temperature and humidity

Temperature and relative humidity outside as well as inside the production were read just before a new batch of dough was manufactured. The sensors measured both temperature and relative humidity and were updated constantly. Temperatures measured in the production area are average values from two sensors, since none of them were positioned exactly were the investigated production line was.

4.3 Baker - dough properties

The collection of data occurred continuously during the production of hot dog buns, with the thought to follow dough throughout the process until it is a finished product. This requires an insight in quality of raw material, changes in recipe and dough temperature, that will be gathered in the first step of data collection. By asking the baker in charge about the dough's properties a first perception about the dough quality was obtained, this was used as basis for the first parameter that is thought to have an impact of final product. In the mixing step, information about temperature and humidity is collected for the premises but also outdoor conditions.

4.4 Proving chamber - temperature and relative humidity

In the proving chamber, temperature and relative humidity (%) was measured by Viasala humidity and temperature transmitter every 5th minute. The transmitter is at a fixed position in the proving chamber. The position of the measuring point is in the ceiling, 3 dm from the wall and approximately 1dm down. Disturbed proving, when bakers open doors to the proving chamber for any kind of control were noted as well as the time, in seconds the door stood open (Table 4).

4.5 Oven - temperatures

Temperature of the four section oven was read one time per section during baking of the specific followed dough. Both under and over heat are taken into account. The color of each of the collected buns were measured by Minolta BC 10 plus, 20 minutes after they were finished in oven. Color measuring was in this thesis investigated to see if there is a correlation between the position in oven and BCU. The values gained were compared to each other, to investigate if any of the 16 positions of the pan is exposed to more uneven heating than other. The BCU values are compared with size of the buns. Replicated sampling were done at the centre of the top of the, presented as an average. Temperatures of the four sections of oven will be taken into consideration in correlation with the overall size and color distribution of 32 buns of a dough, since, according to Therdthai and Zhou (2003) the temperatures of each zone contributes to the browning of the baked product units.

4.6 Product dimensions

The collection of buns included in this investigation was made directly after they exit the oven. Two buns from every of the 16 positions were taken from every dough that had been investigated. From every dough, 32 buns were collected and measured individually by callipers in height, length and width, callipers with 0.5 mm accuracy. The measurement of length was taken at the longest part of the bun, height and width was assessed in the centre of the bun. The buns were weight on a scale with 0.5-gram accuracy, 10 minutes after they exit the oven. After weighing the buns, they were measured in color by Minolta BC-10. The color measuring was performed at the centre of the bun in duplicates.

4.7 Freezing

The everyday self-inspection includes measuring of the buns. That step is performed by the baker and the buns measured are gathered after the oven step. However, all the buns undergo the incorporated fast freezing step before packaging. Therefore, the effect of fast freezing the buns was measured. This was done by comparing buns before and after the freezing, the total freezing time is approximately 15 minutes. Three buns were collected after the oven exit. They were measured in height, length, width by callipers and weight before they were put back on a marked area of the production band. The markings made it possible to collect the same three buns after freezing and measuring them again with the same methods. This step was performed five times, total number of buns in the investigation, n=15. The result is presented as average and differences before and after freezing in Table 3.

4.8 Statistical design

The sampling in this thesis is gathered from 20 different doughs, baked on various days, shifts and with different variations in recipes. Out of the 20 doughs, 16 buns were taken in duplicates, total number of buns per dough n=32. The samples were collected from different positions of the production band, which carries 16 buns in a row. Position 1 and 16 are furthest from each other, at the very ends of the production band.

The main goal with this thesis was to find relationships between size of the different buns and the investigated doughs. To find the relationships, Principal component analysis (PCA) was used. PCA is a statistical method with main goal of to find relationships between objects and grouping them due to their characteristics (Wold *et al.*, 1987). Using PCA gave a good understanding and interpretation of variables, since they correspond in a linear manner to the component. The analysis must followed up by another statistical technique to detect the significance (Rousseeuw & Hubert, 2011). In this investigatioin it was followed up with analysis of variance (ANOVA) and Tukey’s comparsion. By using PCA it is possible to find out if any samples are outliers i.e. that the samples deviate from others in a way that is not relevant. The analysis indicates whether or not there were any correlated variables (Filzmoser *et al.*, 2009). Knowing this, PCA as method could be used to separate samples and group them depending of their characteristics and similarities in variables (Wold *et al.*, 1987).

In this thesis the measurements and weight of the buns vary, by finding including several affecting factors and group the samples possible conclusions may be drawn.

To see if there are any connections between the different means in this investigation and analyzing the PCA plots the use of ANOVA and Tukey's comparisons were interpreted.

5 Result and Discussion

An important source of knowledge during the work with this thesis has been contact and conversations with the bakers at the plant. Even though most of the baking process is more or less mechanically driven, the bakers possess knowledge from many parts of the production chain and can with small adjustments change parameters that may affect the result of final product. These adjustments were not taken into consideration during the investigation but they cannot be excluded as parameters that affect the size of the final products.

5.1 Existing data and raw materials

Measuring of buns from the self-inspections performed by the bakers two times per hour was include in this study. The data was compiled and measurements are presented in Table 2 as average values for data collected during January to August 2017. Table 2 also include measuring of buns used in this thesis, the number of buns n=640. These were measured by callipers and the specification demands are also presented in Table 2. It can be seen that the average numbers deviate from specifications. It is mainly in height and width for the samples measured with volume meter. That can be explained by the performance of measuring, where the machinery does not sense the difference in those dimensions during scanning. Those result are therefore not trustworthy.

Buns measured by the baker during the year were also examined if they followed any trend. Since abnormalities among the buns happened occasionally and did not follow any trends, conclusions were hard to draw. Temperatures are not measured at the time for measuring with volume meter. But with the seasons in Sweden, the results should have varied with them if they depended on outside temperature. No results pointed at seasonal variations or weather as cause of the size variations.

For samples measured by callipers the most outliers are in width, average values differ with 5.1 mm from specifications. However, by looking at average values, the distribution of size is not that big.

Table 1. *Set specification dimensions for hot dog buns at Lantmännen Unibake. n=3167 are measured with a volume meter from data collected every day Jan-Aug 2017 The volume meter cannot make difference between height and depth and those results are misleading. The 640 buns were measured by callipers during October 2017*

	Height (mm)	Length (mm)	Width (mm)	Weight (g)
Specification Demands	39±2	123±2	49±2	27
Average measured n=3167	45.6	124.7	45.9	26.8
Average measured n=640	36.7	124.9	43.9	26.9

Rate of flour consumption varies at the plant, but new deliveries occurred several times a week. New deliveries come with a certificate of analysis. These were checked for the cause of this study and no abnormalities were detected. The certificates of flour batches ensured that quality of raw material were under control. According to Hruškova and Machova (2002) quality characteristics of flour are affected during short term storage and therefore this is a source of error. Further investigations are needed to exclude the impact of flour on the final quality of the buns. Another flour related problem, described by Wong *et al.* (2007) is that status and quality of raw material is not fully evaluated until it is baked of. So even if the bakery has certificated in place, the impact of flour and raw material are hard to fully exclude.

5.2 Factors affecting buns

Since the main goal with this thesis was to find potential sources that cause the size variations they are presented below. The investigated sources were as mentioned compiled and analyzed with PCA, ANOVA and Tukey's comparison.

5.2.1 Temperature, relative humidity and dough properties

The strive to achieve same bread attributes of every finished product turns out to be almost impossible. There are factors that cannot be controlled in the industry, such as weather and temperatures. In table 3, indoor and outdoor temperatures and relative humidity are listed along with changes from original recipe, weight of dough pieces and the temperature of dough after kneading for every of the investigated 20 doughs. Interruptions in Table 3 have to do with the proving chamber, where bakers open the door to verify the status of proving.

The changes are considered possible as precursors to the problem with size variations and the temperature outdoors affects the relative humidity indoors. It could be seen during the investigations that low outside temperature decreased the indoor relative humidity. The ratio of yeast in original recipe did not have to be decreased when relative humidity is lowered. However, with an increased relative humidity, yeast was removed from original recipe.

Table 3. *Temperatures (°C) and relative humidity (%) inside the plant and outside, interruptions i.e. times that doors to proving chamber and seconds the doors were open. Weight of dough pieces before moulding and dough temp of the dough after mixing was measured by the baker in charge. Changes in recipe by adding (+) or reducing (-) yeast (Y) or water (W). All these conditions are noted for every of the 20 investigated doughs The bold numbers are outliers. The bold numbers indicate clear differences in temperatures among the dough groups.*

Dough	Outside		Indoors		Interruptions		Changes in recipe	Weight of dough (g)	Temp dough (°C)
	°C	%	°C	%	Times	Sec.			
1-6	7.4	97.4	20.6	39.8	3	109	- W - Y	31.0	21.9
7-14	**3.5**	**62.1**	20.4	**27.2**	4	67.5	- W	30.8	21.8
15-20	7.3	96.4	22.0	37.0	7	101.3	- Y	30.6	22.2

When looking at Table 3, most bun size variations seem to be due to temperatures and recipe changes. A partition can be made among the dough, where dough 1-6 are described with changes in both yeast and water and in outside temperature between 4.7 – 9.8 °C. Dough number 6-14 is modified in recipe with decreased level of water and the outside temperatures were slightly lower during these investigations. The differences made it possible to group doughs, and therefore the numbers in Table 3 are presented as means.

The impact on level of interruption, i.e. opening the doors, within proving chamber has nothing to do with temperatures or recipe changes. It was noted during the investigation that employed bakers approached their tasks different. It cannot, from this investigation be seen that the opening of doors to the proving chamber did affect the bread size of the finished products. However, it might be a good idea to look over this procedure, since the methods is uncontrolled. Another thing is the filling of the funnels with dough. Due to the fact that the dough is divided into three identical lines the bakers can divide different amounts of dough into funnels. When one funnel is filled up to a maximal level, the fermentation of it may start before it is divided into pieces and formed into buns. That may impact on the final quality of the bun and their sizes. However, by not filling up funnels there is a risk of emptying them, which causes troubles in the proving chamber when it is not filled, temperatures and relative humidity is more likely not in balance with target settings.

During resting period in funnels before moulding, it was noted that some bakers were cautious with adding too much dough at one time, while other bakers added much since they were afraid of the consequences if it runs out of dough. The resting time may contribute to a stiffer dough since the gluten network develops over short time, that may have impact of the size of end-products. This was not measured or noted during the time of the investigation but is one thing that for sure may influence the baking. To produce units of the same size, not only the machinery must be uniformed but also the bakers. And since there are several bakers within this bakery they may need to be trained together so that they perform their tasks in similar ways.

5.2.2 Proving chamber

The proving chamber seems to be a critical point in the production line of this bakery plant. By modifying temperature and relative humidity, the strive for maximal effect of fermentation can be achieved. When investigating the proving chamber, it would have been favourable if the distribution could be seen in the whole chamber, measuring where the pans transfer the dough. This was not possible at the time of data collection and therefor temperature and relative humidity was read from the chambers integrated logging system every 5th minute. The only measuring point in the chamber, was located in the ceiling three decimetres in from the wall. With more measuring points for relative humidity and temperature the result may be more representable.

The investigation of the proving chamber indicates that there have been some changes during proving for the 20 doughs. Most clearly this is seen for as the difference between dough 14 and 15, in Figure 2 where the temperature decreased significantly while relative humidity increased from 61 % to 65 %. That specific change in both temperature and relative humidity is explained by the fan within the chamber. During collection of data it was noted that there were a lot of condensation on the windows of the chamber, whereas relative humidity and temperature did not correspond to the settings. During the baking of dough 1-14, the internal fans in the proving chamber had been accidently turned off which explained the lack of circulation of air in the chamber. Dough number 15-20 is thus baked with the fans turned on.

Another temperature drop in the proving chamber can be seen in Figure 2, after dough number 5. Outside temperature was lower during investigation of dough 6-

14 than for the other doughs. Therefore, a division into three groups were made and the result of size for the dough groups are presented in Table 5.

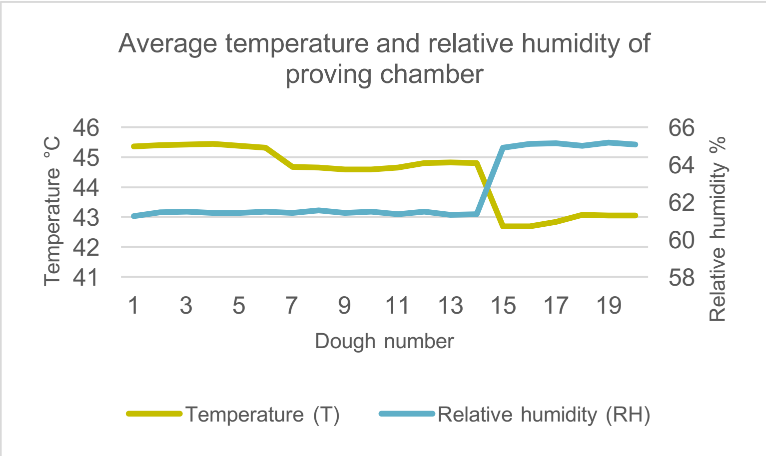

Figure 2. Temperature and relative humidity of the proving chamber. The values are represented as average for every dough. The relative humidity is constant until dough 14, where the fan was turned on. Due to the significant changes in temperature, the doughs are divided into three groups.

5.2.3 Oven temperature

The four sections in the oven holds different temperatures to obtain wanted quality of the buns. It is known in the bakery plant that at section 1 heating from underneath does not reach the set temperature. However, when the fans in the proving chamber were fixed, temperature of oven section 1 did rise, almost to set temperature (230 °C) as seen in Figure 3. An explanation of this could be that fans within the proving chamber blew hot air into the oven, since the over-heating in section one also rise after the fans were fixed. This gives an indication of the sensitivity of the process, where the oven temperatures are of importance to gain the right size of the buns and represent one step toward the perfect hot dog bun.

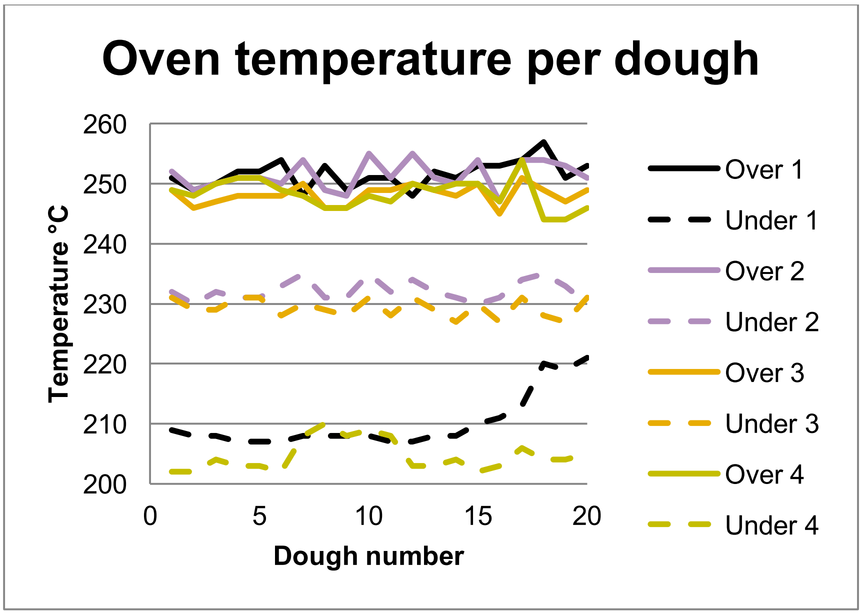

Figure 3. Oven temperature measured at every of the four sections distributed over the doughs. Under temperature 1 is set to 230°C but does not reach it. An increase in oven temperatures can be seen in section 1 when fans were turned on.

5.3 Principal Component Analysis

By the PCA chart in Figure 4 and 5, the distribution in measurements are explained by 40 % and it is shown that the dough group 15-20, marked in green deviates from the other doughs. The properties that explain group 15-20 are length and width and can be seen by PCA Figure 5.

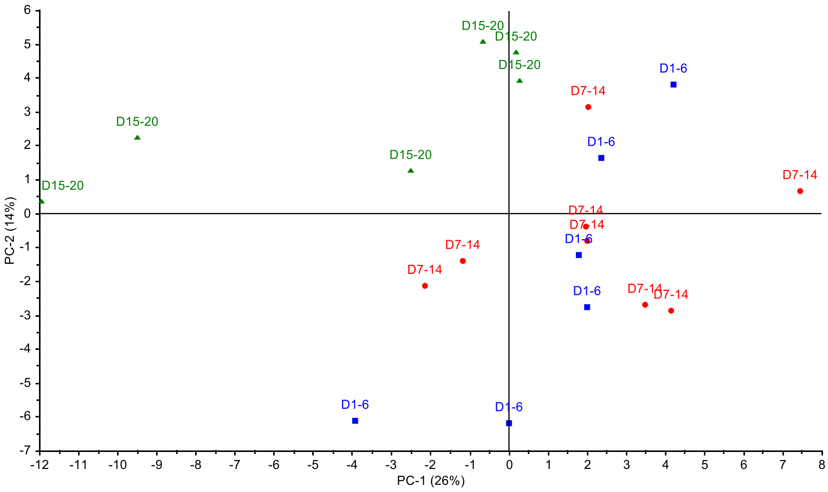

Figure 4. Dough groups sectioned due to all measurements of the buns. Dough number 15-20, in green, are grouped close to each other, charring similar properties. The properties describing buns in sectioning are presented in Figure 5.

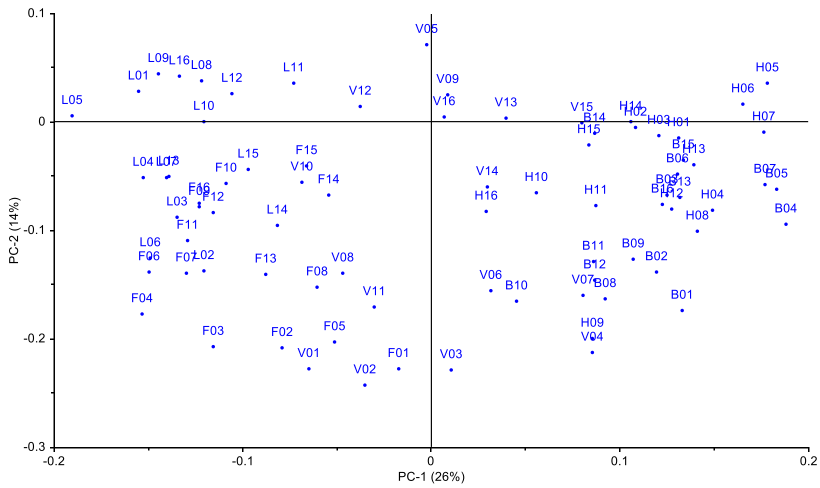

Figure 4. Variables describing all buns in length (L), height (H), width (B), weight (V) and color (F). Numbers denote positions in the oven. The figure describes the measurement and figure 4 distributes dough groups with those properties.

The PCA does only describe 40 % of the connections found between dough groups and the measured properties. This is therefore used as indications but does not give a description to the reality. When looking at the Tukey comparison in Table 4, length in dough group 15-20 does not differ from group 1-6. In width, differences are seen among all of the groups and the characteristics distinguishing group 15-20 are height and weight. By comparing BCU it can be concluded that there are differences among positions in the oven. Though they are minimal and therefore not taken into further consideration for the group comparison.

Table 4. *The means and result of Tukey comparison of measurement of the investigated doughs, divided into groups.* Measurements sharing the same letter are not significantly different.

Group	Length (mm)	Width (mm)	Height (mm)	Weight (mm)	Colour (BCU)
1-6	126.2 A	44.8 A	36.9 A	27.0 A	3.41 B
7-14	122.8 B	44.2 B	37.0 A	27.0 A	3.42 AB
15-20	126.3 A	42.7 C	36.0 B	26.7 B	3.43 A

5.4 Measured buns - dimensions

From Figure 4 it is read that group 14-20 deviates from the others. The main characteristics that deviate group 15-20 from the others are in width. By confirming that with Tukey's comparison it was showed that all groups deviate from each other in width. Table 5 shows the Tukey's comparison for the buns collected form the same position of the production band, where only position 15 and 16 distinctly differs in width from the rest of the buns. A grouping of the positions was made in order to simplify and find correlations within the oven. Three groups were made (the five positions most to the right, left and six positions in the middle) and no no signs of differentiation in width were detected among them. However, none of the average values represented in table 5 measures within specifications.

Table 5. *Result of Tukey comparison and mean of measurement for the 16 positions and grouped positions, Right, R=position 1-5, Middle, M = position 6-11 and Left, L= position 12-16.* Sharing the same letters (A, B, C, D, E) means that values within the group are not significantly different from each other

Position	Length (mm)	Width (mm)	Height (mm)	Weight (mm)	Color (BCU)
1	124.2 CDE	43.6 AB	37.0 A	27.0 A	3.44 ABC
2	124.2 CDE	43.7 AB	37.0 A	27.1 AB	3.39 CDE
3	125.2 ABCDE	434 AB	36.8 A	27.0 AB	3.35 E
4	123.7 DE	44.3 AB	37.0 A	26.8 B	3.40 CDE
5	123.3 DE	43.9 AB	36.6 A	26.7 B	3.36 DE
6	123.5 DE	43.9 AB	37.0 A	26.8 B	3.42 ABC
7	125.8 ABCDE	43-7 AB	36.4 A	26.7 B	342 ABCDE

Position	Length (mm)	Width (mm)	Height (mm)	Weight (mm)	Color (BCU)
8	126.7 ABC	44.1 AB	36.5 A	27.0 AB	3.46 ABC
9	127.2 AB	44.1 AB	36.5 A	27.4 A	3.47 A
10	126.1 ABCD	43.9 AB	36.3 A	27.1 AB	3.48 AB
11	123.4 DE	44.3 AB	37.0 A	26.9 AB	3.46 ABC
12	123.0 E	44.3 AB	36.4 A	26.8 B	3.45 ABC
13	127.2 AB	43.5 AB	36.4 A	27.0 AB	3.42 ABCD
14	124.7 BCDE	44.0 AB	36.9 A	26.8 B	3.41 CDE
15	128.1 A	43.2 B	36.1 A	26.6 B	3.41 ABCDE
16	125.5 ABCDE	44.6 A	36.3 A	26.9 B	3.41 BCDE
R	124.1 b	43.8 a	36.9 a	26.9 ab	3.41 c
M	125.5 a	44.0 a	36.6 ab	27.0 a	3.45 a
L	125.7 a	43.9 a	36.4 b	26.8 b	3.42 b

By looking at position and measurements indication of variances in width of the production band could be detected. Variations in length are frequently occurring and positions were length is out of specifications are 3, 7, 8, 9, 10,13 and 15. However, when grouping positions, as presented in Table 3 with R, M and L - the differences among them are significantly smaller.

The set specifications, presented in Table 2 are tight, with ± 2 mm in every dimension (height, length and width) and 27g of every bun. When comparing the 640 buns included in this thesis only 1.6 % are within the set specification demands. Since the remaining 98.4 % buns are not discarded, the specifications should be adjusted. That wouldn't solve the problems with the size differences but is an easy way to increase yield of approved size. With a further investigation, the deviations in measurement differences between the three dough groups, divided after parameters affecting them is presented in Table 3. More thoroughly, checking what dimension most of the buns vary (Table 6) it is showed that buns with right measurement in width was as low as 1% for group 15-20 and 13% in group 1-6, which was the group with most buns within specifications when it measures the width.

When looking at BCU, there are very small differences between the positions. Since 0.1 BCU is what the human eye can see, it can be said that the buns are evenly baked within the oven, no matter on what position they were baked.

Table 6. *Percentage of buns within set specifications. Tot=total buns within specification, included weight of 27 grams. L=length, H=height, W= width. Notable that 0% of the buns produced in group (G) 15-20 could be classified within specifications*

	G 1-20	G 1-6				G 7-14				G 15-20			
	Tot	L	H	W	Tot	L	H	W	Tot	L	H	W	Tot
Within (%)	1,56	36	57	13	3,13	51	66,5	10	1,56	28	35,4	1	0

	G 1-20	G 1-6				G 7-14				G 15-20			
	Tot	L	H	W	Tot	L	H	W	Tot	L	H	W	Tot
Over (%)		59	0	0		24	0	0		59,5	0	0	
Under (%)		5	43	87		25	33	90		12,5	64,6	99	

From table 6, it can be read that the width is the parameter were least percentage achieve the demands of specifications. This problem is present even after dividing the dough into groups. In length, it seems that most of the buns are too long and in height, they are mostly too small. This could give an indication of that the kneading process should be taken into consideration. By decreasing the length, same amount of dough may cover up the height and width so that the measurements get closer to specification demands.

In this study, after grouping the doughs, it shows that 0 % of the buns in group 15-20 met the specification demands, significant for that group is that the fan was on during proving. As noted in Table 6 buns baked in dough 15-20 are longer than they should but smaller in height and width. The same properties describe buns from group 1-6, where the fan was not properly operating, which indicates that the fan did not impact on the process that much, size of the buns depend on something more. Even though temperatures and relative humidity were changed after switching on the fan they had not impact on final size and measurement in great extent.

The greatest proportion of buns within specifications is from group 1-6, where 3.13 % could be approved. What signifies that dough group can be found in Table 3, it has reduced amount both water and yeast and the average weight of dough is slightly higher than within the other groups. Additionally, fans in the proving chamber were not on, which deviated that group from 14-20. The measured parameters included in this study gives an indication of the problem in this production line but cannot describe the whole picture. Even if the fan should be turned on in the proving chamber, the statistics in this thesis cannot prove that it would impact of the final products. When the weather outside is colder that affect the relative humidity within production space buns are still measuring smaller than the demanded specifications.

5.5 Freezing

In Table 5, the average size and weight of 15 buns measured before and after the freezing step are presented. If the products lie within set limits after oven is of importance. But the freezing step in the production line also needs to be taken under consideration, since the buns that are sold and consumed undergo this step. The set specifications are accordingly measured on buns after the freezing step.

Result from the average, presented in Table 7, shows a small decrease in weight and size, except from length that increased by 0.7 mm after the freezing step. This is not favourable since the buns in this investigation already indicates that the measurements are too small in height and width whereas in length, they are too big.

The method of measuring oven hot buns must be improved since oven hot buns were soft and they sensitive to pinching. Compared to the frozen buns, they were harder in texture and the callipers did not pinch as far into the bun. This may be the explanation to why length increased after freezing, as seen in Table 7.

Table 7. *Average measurements and weight of buns before and after freeing step in mm and grams. Average of buns investigated. n=15. The difference presented and show a small decrease in width, height and weight. The length increased in 0,7 mm. Probable source of error is that the measuring by callipers more easily pinch oven hot buns than the frozen ones.*

	Width	Length	Height	Weight
Before (mm)	44.9	125.1	36.8	26.9
After (mm)	43.7	125.8	36.7	26.8
Difference (mm)	-1.2	+0.7	0.1	0.1

6 Conclusion

To find the cause of size variations among the buns more studies than this investigation is needed. A lot of factors that matters and by this investigation it cannot be found how and if the factors affect each other. However, this thesis can give an indication of what the problem in the process can be derived from. By making sure that all the included equipment of the production line operates adequately, a lot of the problems would probably be solved. The main aim of this study was to investigate the capability of the production line, and with as low as 1.6 % of the buns within specifications the conclusion is that the capability must be improved.

There are room for improvement of the methods in this thesis. One critical point is the proving chamber where only one measuring point is not sufficient to show temperatures and relative humidity within the whole chamber.

It was shown in this study that only 1.6 % of the produced buns measure within set specification demands and most of the buns measured in the study are too small. After the freezing step it was shown that the buns shrunk even more. By increasing the dough weight by 0.1 gram gives a greater yield of hot dog buns within set specifications.

It turns out in this investigation that the production space is not optimal since outside temperatures and relative humidity affect the indoor climate. The problem with size variations does occur in more than just the investigated production line within the bakery. However, when data from the whole year was analysed no obvious changes could be among seasons. At the time for this investigation it was still noted that recipe changes were partially controlled by the climate; with lower temperature the ratio of yeast is higher.

One of the purposes of this thesis was to give suggestions on how to increase the yield of produced units within set specifications. As it looks today the units often are too small in width and height whereas they are too long, one suggestion is to adjust the specifications. Since the buns are not discarded as they appear today, that may be one thing to consider - if the specifications are of importance for the bakery.

To get the explanation of what is causing the problem described in this study further investigations are required. The work with this study can be seen as a start up for a bigger project within the bakery. One thing of importance for further research is to compare the problem with other bakeries, that would give a bigger understanding of the issue.

7 Further aspects and suggestions of improvement

One factor, that is important but that was not taken into consideration in the investigation are the bakers influence. Even though the production is almost exclusively mechanically driven there are a few steps adjusted by the bakers. One is filling the funnels with dough, some of the bakers fills up the funnels, with the result that the dough ferment more since it takes longer time for it to be baked of. If the funnels are not filled up there is a risk of them to get empty, which also causes trouble since the proving chamber then will run half empty. Another thing, that could be seen at the bakery was the baker's attitude against opening the doors of the proving chamber. Some of the bakers open the doors more often than others. Though it cannot be seen as a factor contributing to size variations, it should be avoided. The more control the better and since the chamber is quite sensitive in temperature and relative humidity door opening should be avoided and a more controlled method of regulating these parameters are preferred.

By investigating the capability of the production line with other methods and more thoroughly, exclusions of the mechanical instruments may be done. That may increase the amount of buns within specifications even more. Another suggestion for improved ratio of buns within specifications could be to bake in pans. That can give product units with less differences in shape since that would be controlled. Pan baking may however take away the "home-baked" feeling.

References

Ajandouz, E.H. & Puigserver, A. (1999). Nonenzymatic browning reaction of essential amino acids: effect of pH on caramelization and Maillard reaction kinetics. *Journal of Agricultural and Food Chemistry,* 47(5), pp. 1786-1793.

Amend, T. & Belitz, H.-D. (1991). Microstructural studies of gluten and a hypothesis on dough formation. *Food Structure,* 10(4), p. 1.

Ameur, L.A., Mathieu, O., Lalanne, V., Trystram, G. & Birlouez-Aragon, I. (2007). Comparison of the effects of sucrose and hexose on furfural formation and browning in cookies baked at different temperatures. *Food Chemistry,* 101(4), pp. 1407-1416.

Anishaparvin, A., Chhanwal, N., Indrani, D., Raghavarao, K. & Anandharamakrishnan, C. (2010). An Investigation of Bread-Baking Process in a Pilot-Scale Electrical Heating Oven Using Computational Fluid Dynamics. *Journal of food science,* 75(9).

Baardseth, P., Kvaal, K., Lea, P., Ellekjaer, M. & Faergestad, E. (2000). The effects of bread making process and wheat quality on French baguettes. *Journal of Cereal Science,* 32(1), pp. 73-87.

Bell, P., Higgins, V. & Attfield, P. (2001). Comparison of fermentative capacities of industrial baking and wild-type yeasts of the species Saccharomyces cerevisiae in different sugar media. *Letters in applied microbiology,* 32(4), pp. 224-229.

Birch, A.N., Petersen, M.A., Arneborg, N. & Hansen, Å.S. (2013). Influence of commercial baker's yeasts on bread aroma profiles. *Food Research International,* 52(1), pp. 160-166.

Campbell, G.M. (2003). Bread Aeration In: Cauvain, S.P. (ed. *Bread Making Improving quality*. Cambridge, England: Woodhead publishing limited, pp. 352-371.

Cauvain, S. (2016). *Technology of Breadmaking*3). Perth, Australia: Springer International Publishing.

Chan, L., Cheng, S.W. & Spiring, F.A. (1988). A new measure of process capability. *Journal of Quality Technology,* 20(3), pp. 162-175.

Chen, K., Huang, M. & Li, R. (2001). Process capability analysis for an entire product. *International Journal of Production Research,* 39(17), pp. 4077-4087.

Curic, D., Novotni, D., Skevin, D., Rosell, C., Collar, C., Le Bail, A., Colic-Baric, I. & Gabric, D. (2008). Design of a quality index for the objective evaluation of bread quality: Application to wheat breads using selected bake off technology for bread making. *Food Research International,* 41(7), pp. 714-719.

Dolinšek, S. & Kopač, J. (2001). Linkage between quality assurance tools and machinability criteria. *Journal of materials processing technology,* 118(1), pp. 132-136.

Escalante-Aburto, A., Figueroa-Cardenas, J.D., Veles-Medina, J.J., Ponce-Garcia, N., Hernandez-Estrada, Z.J., Rayas-Duarte, P. & Simsek, S. (2017). Viscoelastic properties of tablets from Osborne fractions, pentosans, flour and bread evaluated by creep tests. *International Agrophysics,* 31(3), pp. 307-315.

Filzmoser, P., Hron, K. & Reimann, C. (2009). Principal component analysis for compositional data with outliers. *Environmetrics,* 20(6), pp. 621-632.

Goesaert, H., Brijs, K., Veraverbeke, W., Courtin, C., Gebruers, K. & Delcour, J. (2005). Wheat flour constituents: how they impact bread quality, and how to impact their functionality. *Trends in food science & technology,* 16(1), pp. 12-30.

He, H. & Hoseney, R. (1992). Effect of the quantity of wheat flour protein on bread loaf volume. *Cereal chem,* 69(1), pp. 17-19.
Hruškova, M. & Machova, D. (2002). Changes of wheat flour properties during short term storage. *Czech J Food Sci,* 20, pp. 125-130.
Kane, V.E. (1986). Process capability indices. *Journal of Quality Technology,* 18(1), pp. 41-52.
Khatkar, B., Bell, A. & Schofield, J. (1995). The dynamic rheological properties of glutens and gluten sub-fractions from wheats of good and poor bread making quality. *Journal of Cereal Science,* 22(1), pp. 29-44.
Le Bail, A., Monteau, J., Margerie, F., Lucas, T., Chargelegue, A. & Reverdy, Y. (2005). Impact of selected process parameters on crust flaking of frozen partly baked bread. *Journal of Food Engineering,* 69(4), pp. 503-509.
Lunn, G., Kettlewell, P., Major, B. & Scott, R. (2001). Effects of pericarp alpha-amylase activity on wheat (Triticum aestivum) Hagberg falling number. *Annals of applied biology,* 138(2), pp. 207-214.
Martins, S.I., Jongen, W.M. & Van Boekel, M.A. (2000). A review of Maillard reaction in food and implications to kinetic modelling. *Trends in food science & technology,* 11(9), pp. 364-373.
Mirade, P., Daudin, J., Ducept, F., Trystram, G. & Clement, J. (2004). Characterization and CFD modelling of air temperature and velocity profiles in an industrial biscuit baking tunnel oven. *Food Research International,* 37(10), pp. 1031-1039.
Mondal, A. & Datta, A. (2008). Bread baking–a review. *Journal of Food Engineering,* 86(4), pp. 465-474.
Motorcu, A.R. & Güllü, A. (2006). Statistical process control in machining, a case study for machine tool capability and process capability. *Materials & Design,* 27(5), pp. 364-372.
Nasehzadeh, M. & Ellis, R.H. (2017). Wheat seed weight and quality differ temporally in sensitivity to warm or cool conditions during seed development and maturation. *Annals of Botany,* 120(3), pp. 479-493.
Patel, B., Waniska, R. & Seetharaman, K. (2005). Impact of different baking processes on bread firmness and starch properties in breadcrumb. *Journal of Cereal Science,* 42(2), pp. 173-184.
Perten, H. (1964). Application of the falling number method for evaluating alpha-amylase activity. *Cereal chem,* 41(3), pp. 127-140.
Purlis, E. & Salvadori, V.O. (2007). Bread browning kinetics during baking. *Journal of Food Engineering,* 80(4), pp. 1107-1115.
Reynolds, M.M. & Young-Bandala, L. (1982). Freezing baked bread goods. Google Patents.
Rousseeuw, P.J. & Hubert, M. (2011). Robust statistics for outlier detection. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery,* 1(1), pp. 73-79.
Selomulyo, V.O. & Zhou, W. (2007). Frozen bread dough: Effects of freezing storage and dough improvers. *Journal of Cereal Science,* 45(1), pp. 1-17.
Therdthai, N. & Zhou, W.B. (2003). Recent advances in the studies of bread baking process and their impacts on the bread baking technology. *Food Science and Technology Research,* 9(3), pp. 219-226.
Therdthai, N., Zhou, W.B. & Jangchud, K. (2007). Modeling of the effect of relative humidity and temperature on proving rate of rice-flour-based dough. *Lwt-Food Science and Technology,* 40(6), pp. 1036-1040.
Tsarouhas, P.H. (2009). Classification and calculation of primary failure modes in bread production line. *Reliability Engineering & System Safety,* 94(2), pp. 551-557.
Vanin, F., Lucas, T. & Trystram, G. (2009). Crust formation and its role during bread baking. *Trends in food science & technology,* 20(8), pp. 333-343.
Veraverbeke, W.S. & Delcour, J.A. (2002). Wheat protein composition and properties of wheat glutenin in relation to breadmaking functionality. *Critical Reviews in Food Science and Nutrition,* 42(3), pp. 179-208.
Wieser, H. (2003). The use of redox agents. In: Cauvain, S.P. (ed. *Bread Making*1). Cambridge, England: Woodhead Publishing Limited, pp. 424-446.
Wold, S., Esbensen, K. & Geladi, P. (1987). Principal component analysis. *Chemometrics and intelligent laboratory systems,* 2(1-3), pp. 37-52.

Wong, S.-Y., Zhou, W. & Hua, J. (2007). CFD modeling of an industrial continuous bread-baking process involving U-movement. *Journal of Food Engineering,* 78(3), pp. 888-896.
Wu, C.-W., Pearn, W. & Kotz, S. (2009). An overview of theory and practice on process capability indices for quality assurance. *International Journal of Production Economics,* 117(2), pp. 338-359.
Yasui, T., Matsuki, J., Sasaki, T. & Yamamori, M. (1996). Amylose and lipid contents, amylopectin structure, and gelatinisation properties of waxy wheat (Triticum aestivum) starch. *Journal of Cereal Science,* 24(2), pp. 131-137.
Zeleznak, K. & Hoseney, R. (1986). The role of water in the retrogradation of wheat starch gels and bread crumb. *Cereal chem,* 63(5), pp. 407-411.
Zhang, J. & Datta, A. (2006). Mathematical modeling of bread baking process. *Journal of Food Engineering,* 75(1), pp. 78-89.

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Appendix 1 - Popular scientific summary

Did you ever notice that the hot dog bun in your hand looks a little out of shape? No, I didn't think so. That is probably because the buns often have to full fill some specifications before they are packed at the bakery plant and sold. Despite this there are problems with size variations within bakeries and the cause of that has been investigated at Swedens largest producer of sausage buns.

Several factors are thought to affect the bread size and quality among other, temperature and weather and quality of raw material. The size differences are unwanted, partly because of the consumers whom wants to know what they buy and to be guaranteed the same product every time they buy it. But it is also of economical matter, since at the investigated production the packaging is operated by robots. Bread of different sizes contributes to stops in the packaging since the robots are programmed to handle buns of a specific size. When a stop occurs in the packaging area buns are being discarded, that is an economical lost for the bakery.

Weather and relative humidity are thought to affect the activity of yeast and thereby the final size of the products since the yeast has optimum in which it is most active and gas-producing. At the investigated bakery, proving chambers are used. In the chambers, where the fermentation takes place is a critical stage in the production. Any kinds of interruptions are thought to lower quality of buns and influence the size of buns.

By a statistical designed analysis, considering several factors an investigation of these size differences were made. The result from this showed that several factors matters and that there is no easy answer to the question. However, making sure that equipment in the production line operates at its best is one way to achieve more uniform result. The investigated bakery plant did also have some issues with the ventilation, outside temperatures affect the indoor climate.

Important things that were found in the investigation was that only 1.6 % of the buns reached the set specification limits. The remaining ones were not discarded which indicates that the robots are not that sensitive and that a lot of “off-size” buns are being sold.