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Optimizing the preparation of cooked chickpea

Optimerad bearbetning av kokt kikärta

Julia Engsner

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Optimerad blötlägning av kokt kikärta

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Abstract

The demand of processing pulses (dry beans, lentil, and peas) into various foods has increased over the recent years as they are considered a sustainable and healthy food. Thus, a sustainable processing of them is equally important for the future. A sustainable processing should be both financial, time and energy efficient for manufactures, safe and nutritious for consumers and have a low environmental impact. Hence, an optimization of the preparation of pulses is needed and constitute the main goal of this study.

In this study the optimal soaking conditions (time and temperature) and cooking time of chickpea (*Cicer arietinum L.*) was studied and analyzed by a Circumscribed Central Composite Design (CCC), allowing estimation of two-way interactions as well as quadratic terms. The intervals studied during soaking were 60-80 °C during 50-70 min and a cooking time of 50-90 min. Application challenges were also identified by observation of a large-scale test.

The results indicated that the water content and the amount of solid loss increased with increasing temperature or time. During soaking the temperature had a greater effect on the amount of solid loss than the water content. During cooking the cooking time had an even greater effect on the water content and the solid loss than the other variables studied. In the two-way interactions obtained no synergetic effect existed, meaning that changing one variable is more efficient than changing both. When performing the response optimization, the solid loss was set to be minimized, the water content maximized, and no core was detected. The outcome of the response optimization showed an optimal condition of 80 °C during 69 min during soaking with a following cooking time of 59 min. Furthermore, application challenges were observed. The main challenge identified was that the temperature was hard to regulate affecting time efficiency. Thus, the obtained optimal condition was not directly applicable to a larger scale.

Furthermore, the conclusion of this study indicate that the cooking time is the factor needed to be limited and is efficiently reduced by increasing the soaking temperature. This will improve the time efficiency, financial and nutritional value of the final product and reduce waste within the production.

Keywords: chickpeas, pulses, legumes, boiling, cooking, soaking, treatment, preparation, optimization

Sammanfattning

Efterfrågan på bearbetning av legymer (bönor, linser och ärtor) till olika produkter har ökat under de senaste åren. Detta eftersom de anses vara bra för miljön och hälsosamma för den som konsumerar dem. Således bör även bearbetningen av de, vara hållbar för framtiden. En hållbar bearbetning ska både vara ekonomiskt, tids- och energi effektiv för producenten, säker och näringsrik för konsumenten och ha en låg klimatpåverkan. Därav bör bearbetning av legymer optimeras, vilket ugör denna studies huvudsyfte.

I denna studie studerades och analyserades de optimala blötläggningsförhållandena (tid och temperatur) och koktiden av kikärter genom en Circumscribed Central Composite Design (CCC) vilket möjliggör uppskattning av två-vägsinteraktioner såväl som kvadratiska termer. Intervallen som studerades var en blöltäggningstemperatur på 60-80 °C under 50-70 min och en koktid mellan 50-90 min Applikationsutmaningar identifierades även, genom observation av ett storskaligt testförsök.

Resultaten indikerade att vatteninnehållet och förlusten av massa vid blötläggning ökade med ökad temperatur eller tid. Vid blötläggning hade temperaturen en större effekt än tiden på massaförlusten. Under kokningen hade koktiden en ännu större effekt än de andra vaiablarna som studerades. I två-vägs interaktionerna som hittades påvisades ingen synergetisk interaktion, vilket antyder att det är effektivare att ändra endast en variabel än att ändra båda.Vid utförandet av responsoptimeringen i Minitab, var förlusten av massa minimerad, vatteninnehållet maximerat och ingen hård kärna i mitten av kikärtan var tillåten. Detta ledde fram till en optimal behandling på 80 °C under 69 min under blötläggning med en efterföljande koktid på 59 min. De applikationsutmaningar som identidierades var att temperaturen var svår att reglera vilket i sin tur påverkar tidseffektiviteten. Således var den erhållna optimala behandlingen inte direkt överförbar i större skala.

Slutsatsen av denna studie tyder på att koktiden är den variabel som behöver begränsas. Detta görs effektivast genom att öka blötläggningstemperaturen. På så vis förbättras tidseffektiviteten, höjs det finansiella och nutritionella värdet av slutprodukten och minskas svinnet inom produktionen.

Nyckelord: kikärta, legymer, kokning, blötläggning, förädling, bearbetning, optimering, tidseffektivitet

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CCC	Circumscribed Centeral Composite Design

1 Introduction

Food production stands for one of the largest pressures that humans put on the Earth, threating vital eco-systems and the stability of the planet. This as the production of foods causes green-house gas emissions, pollutions, biodiversity loss and require water and land use. Although, we are not able to meet the needs of the human population of healthy foods. It is estimated that about 820 million people suffer from insufficient foods and several more consume an unhealthy diet. Thereby a dietary shift and the need for sustainable food systems is crucial for the future of our planet and people's health (Willett *et al.*, 2019).

Pulses is suggested to be one of the healthy and sustainable foods that should be consumed to a larger extent (Willett *et al.*, 2019). This as they can be grown worldwide and can be consumed in all stages of their growth. Pulses do also have the advantage of fixing nitrogen in the ground where they are grown, which make them require less nitrogenous fertilizers. Furthermore, pulses are economically affordable for consumers and can provide a livelihood for small scale farmers (Chigwedere *et al.*, 2019a).

Today pulses are contributing to the diet significantly in developing countries while in developed countries the consumption is still low (Chigwedere *et al.*, 2019a). However, in the recent years the awareness of pulses nutritional properties and them making a suitable alternative to meat have increased the demand for research about processing pulses into various foods (Yildirim *et al.*, 2011). A traditional way of processing pulses is through boiling them in hot water, herein referred to as cooking.

However, the long cooking time is considered a drawback of utilization of pulses, affecting the time efficiency at manufactures. Furthermore, how the cooking is performed do also affect the energy consumption as well as the leakage of nutrients, herein referred to as solid loss. It is therefore of interest for manufactures, from a financial and sustainable perspective, to optimize the preparation process of pulses.

2 Background

In this chapter definitions and previous research are presented to build a deeper understanding regarding soaking and cooking of pulses, with a special interest of chickpea. The first section is a review of the characteristics of chickpea. The second section is a review of soaking and cooking of pulses were the hydration and swelling process, texture and flavour and potential improvements are presented. Following sections will deal with the loss of solids during preparation of chickpeas, anti-nutritional compounds and finalizing with reviewing aspects of sustainable development.

2.1 Chickpeas

Chickpea (*Cicer arietinum* L.) is the third most cultivated crop in the world and is cultivated worldwide. The largest producer is India, but large amounts are also cultivated in Pakistan, Turkey, Mexico, Australia, Canada and USA (Costa *et al.*, 2018). The chickpea is approximate spherical in shape with a mean radius of 4 mm ± 1 mm (Yildirim *et al.*, 2011).

Moreover, the chickpea is generally divided into two types, “Kabuli” and “Desi”, whereas the difference is primarily based on their size and colour. The Desi type is dark in colour, ranging from black to tan, is small (>100 seeds/~28,34 g) and have a thick seed coat. The Kabuli type is generally larger with a wider range in size of >100 seeds/~28,34 g to >50 seeds/~28,34 g and is lighter in colour, from cream to white. The Kabuli chickpea, also called Garbanzo bean, is the most preferred chickpea among consumers (Xu *et al.*, 2014).

Furthermore, chickpeas are consumed fresh, roasted, fermented, fried, cooked, canned, mashed, germinated into sprouts or milled into flour and added into baking goods, pasta or in supplements (Buhl *et al.*, 2019; Wood, 2017; Xu *et al.*, 2014; Jukanti *et al.*, 2012). Its characteristics provides many opportunities in processed foods (Asif *et al.*, 2013).

As a food, the chickpea contributes with nutrients as they consist of essential vitamins and minerals. It does also contain carbohydrates (54.4-70.9 %), whereas the majority is starch (37.2-50,8 %). Chickpeas is also a good source of proteins as it has a high protein content (12.6-30.5 %) (Wang *et al.*, 2010; Frias *et al.*, 2000a). The protein profile of chickpea is also important as it contains lysine, an amino acid lacking in cereals (El-Adawy, 2001). In developing countries, chickpea is thereby a central source of protein while in developed countries they are mostly consumed as an alternative to meat (Chigwedere *et al.*, 2019a). Below the nutritional value of dried and cooked chickpea is presented in **Table 1**. The data is taken from the Swedish National Food Agency (SNFA, 2019).

Table 1. Nutritional properties of dried and cooked chickpeas, value per 100g (SNFA, 2019)

Nutrient	***Unit***	***Dried***	***Cooked (with salt)***
Energy	Kcal	352	133
Water	g	10.0	62.8
Protein	g	20.50	8.13
Fat	g	4.80	2.90
Carbohydrate	g	51.00	12.60
Fibre	g	10.00	12.30
Sugars	g	4.60	0.7
Saturated fats	g	0.50	0.36
Monounsaturated fats	g	1.04	0.81
Polyunsaturated fats	g	2.16	1.15
Vitamin D	µg	0.00	0.00
Vitamin C	mg	3.0	0.00
Folate	µg	557.0	93.5
Iron	mg	6.90	1.72

From this table (**Table 1**) a change in the available nutrient from dried to cooked chickpea can be observed. However, to be considered is that the moisture content of the two, dried and cooked chickpea, differs. Moreover, the fibre content of the cooked chickpea is extremely high in the table and can be questioned if it is true.

Furthermore, it is reported that available carbohydrates (monosaccharides, disaccharides and starch) decrease during soaking by 19-20 % and if cooking succeeds soaking the available carbohydrates decrease by 23-24 % (Frias *et al.*, 2000b). The proteins, concentration of tryptophan, lysine, total sulphur and aromatic-containing amino acids decreases during cooking. However, the tryptophan (4.1g/16 g N), lysin (7.75/16 g N) and aromatic amino acids (9.4/16 g N) content was reported to still be higher than the FAO/WHO reference (4.0/16 g N, 5.50 /16 g N, 6.0 /16 g N respectively) (El-Adawy, 2001). Vitamins and minerals are also decreased during cooking of chickpea (Wang *et al.*, 2010; Alajaji & El-Adawy, 2006; El-Adawy, 2001).

2.2 Soaking and cooking of pulses

Chickpea among many pulses is traditionally stored dried. They can be long-termed stored if the conditions are favourable with a low humidity and cold temperature (Chigwedere *et al.*, 2019a). However, dried pulses are not edible as they become hard and can be even dangerous to eat in large amounts as they contain anti-nutritional compounds. Thereby they need to be processed to become edible (Hajos & Osagie, 2004).

Commonly, whole pulses including chickpeas are processed by cooking, often in combination with a pre-treatment of soaking. During cooking and soaking the chemical and physical properties change (Xu *et al.*, 2014). A cooked pulse is characterized by a soft seed where the starch has gelatinized. To obtain a cooked seed hydration needs to occur before or during cooking (Wood & Harden, 2006).

2.2.1 Hydration and swelling processes

The major structural change during soaking is the hydration leading to swelling of the chickpea (Aguilera *et al.*, 2009). The soaking is thereby characterized by weight gain and volume gain (soaking capacity). The weight gain can be measured by maximum hydration and rate of hydration while the volume gain can be measured in maximum swelling and rate of swelling (Wood & Harden, 2006).

As pulses are biologically constructed to absorb water, they are considered to have specific structural parts that consist of a complex water absorption system. The permeability of water into the seed is also known to take place through pores and cracks in the seed coat (Chigwedere *et al.*, 2019a). A damage seed coat thereby results in a lower density and gives rise to a higher hydration ratio and solid loss (Pan *et al.*, 2010). Hence, the seed coat is proposed to act as a barrier in the beginning of the hydration process. The water absorption is driven by the moisture gradient and strong capillary forces (Chigwedere *et al.*, 2019a).

Furthermore, when the water is entering the seed during soaking, it is transported to the periphery of the cotyledons and the void space between them before the absorption into the cotyledons begins. This is illustrated in **Figure 1**. The water absorption happens until the cotyledons are fully hydrated. For un-soaked pulses the same hydration process occurs during cooking, the only difference is that the hydration only start from the outer parts (Chigwedere *et al.*, 2019a). Hence, the hydration process of chickpea is characterized by a rapid water absorption were water is filling the capillaries at the surface of the seed coat and hilum. The process is then followed by a water uptake of the intercellular matrix before entering an steady equilibrium phase, where the chickpea is reaching its full soaking capacity (Chigwedere *et al.*, 2019a; Yildirim *et al.*, 2011; Wood & Harden, 2006).

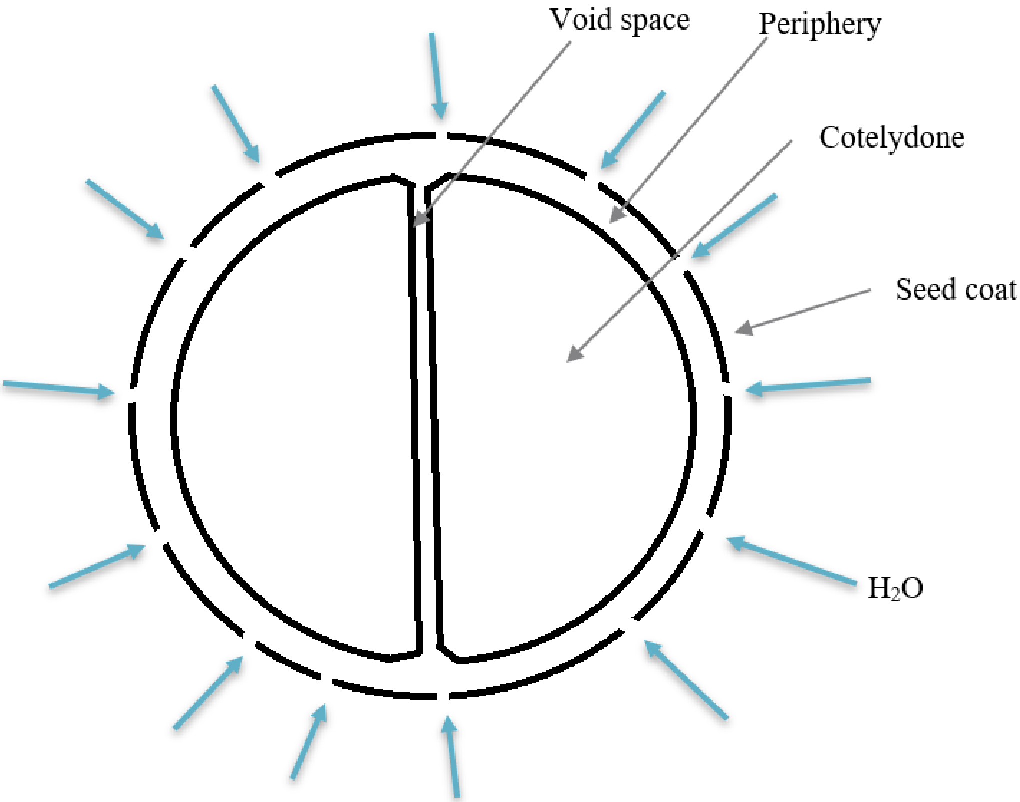

Figure 1.Illustration of the hydration process of chickpeas where water enters the chickpea through cracks and holes in the seed coat

The swelling is suggested to be caused by gases that are displaced by the water as it enters the matrix. The water surrounds the gasses in the matrix who thereby become pressurized. As the gases expands, the matrix becomes damaged and the seed starts to swell, making space for more water to enter. Eventually the gases become solubilized to facilitate their escape (Chigwedere *et al.*, 2019a). However, if increasing the temperature, as during cooking, the solubilization of gases decreases and the gas expands. This leads to that the matrix becomes more damaged, changing the texture further. Thus, the swelling depends on physical laws such as strong capillary forces.

The hydration and the swelling process is important as it enables starch gelatinization during cooking (Yildirim *et al.*, 2011).

2.2.2 Texture and flavor development

As mentioned earlier, the major change during processing of pulses is the change of physical and chemical properties (Xu *et al.*, 2014). During cooking softening of the chickpea takes place and desirable aroma, flavour and texture are developed (Wood, 2017). The development is dependent on the composition, maturity level at harvest, post-harvest conditions and in a later stage the processing conditions (Chigwedere *et al.*, 2019a).

To achieve softening the cells in the cotyledons need to be separated sufficiently (Wood, 2017; Paredeslopez *et al.*, 1991) During the cooking process thermal degradation is taking place causing the cotyledon cells to be less tightly bound. This degradation includes solubilization and weakening of intracellular cohesive materials (Wood, 2017). The denaturation of proteins, starch gelatinization and pectin solubilization have an influence on the softening (Chigwedere *et al.*, 2019a; Wood, 2017).

Furthermore, earlier obtained results indicate that pectin solubilization is the rate limiting factor for softening of pulses. Protein denaturation and starch gelatinization are shown by calorimetry to happen within 30 min in beans while the beans remained hard (Chigwedere *et al.*, 2018). However, starch gelatinization is seemed to still be a common evaluation method for cooking of pulses (Wood, 2017).

In terms of sensory properties, the texture of pulses has received most attention. The texture is however also contributing to the flavour development (van Ruth *et al.*, 2004) as the structure and composition influence the release of volatile compound. Thereby alternations in the food matrix changes the perception (Guichard, 2002). To be considered is that not all volatile compounds are flavour-active (van Ruth *et al.*, 2004).

As the chemical properties are changing during processing of chickpea (Xu *et al.*, 2014), volatile compounds are changing as well (Chigwedere *et al.*, 2019b). Enzymatic reactions during soaking will also contribute to the formation of volatile compounds (Shi *et al.*, 2017). In a study volatile profiles of beans were studied as beans were cooked to different extent. The influence of cooking time on volatile compounds could hence be demonstrated. The volatile compounds included aldehydes, ketones, sulphur compounds, an ester, a furan compound and a benzopyran derivate. Most of the compounds were linked to the Maillard reaction and lipid oxidation (Chigwedere *et al.*, 2019b).

2.2.3 Improvements of soaking and cooking

To process pulses before human consumption is crucial to utilize its health benefits. However, the long cooking time is inconvenient and expensive for manufactures and end consumers (Wood, 2017). By improve the cooking time a faster, cheaper and more convent processing would be achieved.

Different methods to decrease the cooking time of pulses have been studied. Methods as germination, fermentation, autoclaving, microwaving (Yin *et al.*, 2018), dehulling (Siva *et al.*, 2018) and enzyme treatment before cooking (Singh *et al.*, 2000) are some. However, as this report studies soaking and cooking only soaking and cooking improvements are reviewed in this section. Such improvements are mostly regulated by conditions during soaking and usages of additives.

Traditionally chickpea is soaked in ambient temperatures over a day, but soaking can be performed in a variety of conditions and temperatures. By soaking pulses in a higher temperature, the soaking time is reduced (Chigwedere *et al.*, 2019a). This is demonstrated (Yildirim *et al.*, 2011) in chickpea soaked in 20, 30, 40, 50, 60, 70, 87, 92, and 97 °C. At temperatures above 55 °C starch gelatinization occurs in pulses (Sayar *et al.*, 2011), and if soaking is done above the starch gelatinization temperature it may lead to significant loss of solids (Frias *et al.*, 2000b).

Furthermore, different solutions containing inorganic salt have been a traditionally used as processing aids to improve the cooking time, since the long cooking time is considered to be a drawback of utilization of pulses (Clemente *et al.*, 1998). The long cooking time is both inconvenient and requires energy (Wood, 2017). It is reported that alkaline salts contribute to an increased solubilization of polyphenols and thereby reduce hardening (Mubaiwa *et al.*, 2019).

Common salt to add during soaking and cooking is sodium bicarbonate ($NaHCO_3$) (Singh *et al.*, 2000; Clemente *et al.*, 1998) and sodium carbonate (Na_2CO_3) (Mubaiwa *et al.*, 2019; Coskuner & Karababa, 2003), but other salts such as $CaCl_2$ and NaCl are also reported to have an effect. However, $NaHCO_3$ is shown to have a more efficient decrease of cooking time than $CaCl_2$ and NaCl (Clemente *et al.*, 1998). It is also reported that soaking in NaCl together with $NaHCO_3$ or just in $NaHCO_3$ are considerably reducing the cooking time (Paredeslopez *et al.*, 1991). By adding NaCl (1 % w/v in distillated water) and Na_2CO_3 (1 % w/v in distillated water) during soaking of chickpea for 16 h the cooking time was reduced by 41 % and 82 %, respectively (Coskuner & Karababa, 2003).

2.3 Loss of solids during soaking and cooking

During cooking and soaking there is a considerable loss of solids into the water as the structure is changing. The factors affecting solid loss are the type of processing, temperature and seed damage (Chigwedere *et al.*, 2019a). The solids are mainly known to be carbohydrates (pectin) and proteins (Mubaiwa *et al.*, 2019; Sayar *et al.*, 2011). It is suggested that <5 % of the solids consists of minerals and other low molecular weight compounds, such as sugars and amino-acids (Mubaiwa *et al.*, 2019). Hence, the loss of solids decrease the financial and nutritional value of the final product as the water of both soaking and cooking often is discarded (Mustafa *et al.*, 2018; Sayar *et al.*, 2011). On the other hand, the advantage of solid loss is the loss of anti-nutritional compounds (see section 2.4 below).

In chickpea the solid loss is reported to be 0.81-2.80 % during soaking in ambient temperatures for 24 h and a total loss of 8.19-12.95 % after complete cooking (Xu & Chang, 2008). Besides the amount of solid loss, the rate of solid loss also increases with temperature (Sayar *et al.*, 2011). At 20°C the solid loss was reported to be 2.3 % and the rate $4.7x10^{-5}g\ s^{-1}$, while at 100°C the total solid loss became 10.2 % and the rate $240.3x10^{-5}g\ s^{-1}$ in a study by Sayar *et al.* (2011). In the same study the results indicated that the amount of solid loss is more sensitive to temperature change than the amount of water absorbed.

Furthermore, the permeability of the pulse is dramatically changed at temperatures above 60 °C due to starch gelatinization, leading to a three to fourfold solid loss if soaking at such temperature (Kon, 1979).

The explanation behind the solid loss is the leakage of water-soluble substances into the soaking and cooking water as the structure is changing (Haileslassie *et al.*, 2019). Another explanation is hydrolysis of large high molecule weight polymers into smaller compounds (Embaby, 2010).

Hence, if solid loss could be minimized it would be beneficial both for the manufacture, consumer and environment. This as more mass would increase the financial value of the final product for the manufacture, the consumer would retain more nutrients in the product and less solids would be discarded.

2.4 Reduction of anti-nutritional compounds

Anti-nutritional compounds limit the positive health effects of pulses by different mechanisms. Some decrease the bioavailability of nutrients by forming complexes with micro and macro nutrients, some inhibit digestive enzymes while others are harmful for humans in large amounts (Mikic *et al.*, 2009; Sandberg, 2002). Anti-nutritional compounds can be categorized into three groups depending on their chemical composition: proteins, glycosides and other substances (Muzquiz *et al.*, 2012). Below are some anti-nutritional compounds and their effects on human health are presented. How and if they are reduced by soaking and cooking is also mentioned.

Proteins

Among the category proteins, protease inhibitors, alfa-amylase inhibitors and lectins can be found. Protease inhibitors and alfa-amylase inhibitors decrease the digestion of protein and carbohydrates respectively, in the intestine (Muzquiz *et al.*, 2012).

Moreover, lectins are one of the more dangerous anti-nutritional compounds found in pulses as they can bind to specific carbohydrate structures on proteins and human cells. They are thereby able to affect the digestion and absorption and agglutinate red blood cells (Nasi *et al.*, 2009). Chickpea is reported to contain 2.73-2.74 HU (hemagglutinin activity)/mg of lectins, which is the lowest measured amount among common beans, peas and lentils (Shi *et al.*, 2018). The protein based anti-nutritional compounds are heat sensitive and decrease during cooking, due to denaturation (Shi *et al.*, 2018; Embaby, 2010).

Glycosides
To the group of glycosides, saponins and α-galactosides belong. Saponins are known to form complexes with specific minerals as calcium, iron and zinc which decreases their bioavailability. Furthermore, α-galactosides are oligosaccharides that the human digestive enzymes cannot hydrolyse which can cause stomach ache and bloating as they enter the colon intact (Muzquiz *et al.*, 2012). Soaking is reported to reduce α-galactosides by 16-27 % and 45-58 % if soaking is proceeded by a cooking period of chickpea. Saponins are also reported to be reduced by cooking (Wang *et al.*, 2010).

Other substances
To the group of other substances oxalate and tannins belong. They both have different mechanisms that inhibit the digestive enzymes and decrease the bioavailability of minerals, proteins and carbohydrates (Serrano *et al.*, 2009; Quinteros *et al.*, 2003). Tannins and oxalate are reported to be reduced by cooking and are known to leak out in the cooking water and form non-soluble complexes with other substances (Embaby, 2010; Quinteros *et al.*, 2003).

Phytate is also categorized among other substances and decrease the bioavailability of di-valent minerals as zinc and iron. It can be degraded by enzymatic activity of phytase, which is active at conditions of 45 °C and around pH 5. Soaking at such conditions is thereby advantageous before entering the cooking phase. During cooking phytase is denaturized leading to no degradation of phytate (Sandberg, 2002). However, soaking in 45°C is associated with microbial risks. Only a short period of time at such condition would hence be possible.

Thus, the reduction of anti-nutritional compounds is necessary for consumption of pulses both from a nutritional and food safety perspective (Hajos & Osagie, 2004). However, not all anti-nutritional compounds will be possible to eliminate, but a reduction of the most severe ones is needed. A successful reduction could be accomplished mainly by cooking, but soaking will enhance the effect (Shi *et al.*, 2018; Shi *et al.*, 2017).

2.5 Sustainable development

Today sustainability is more than eco-efficiency even though at businesses level it is often associated to only environmental aspects (Dyllick & Hockerts, 2002). However the concept of sustainability is built on three dimensions which are economic, social and environmental aspects which aim to create long-term sustainable development (Seuring & Müller, 2008; Dyllick & Hockerts, 2002). Sustainable development is defined as

‘‘a development that meets the needs of the present without compromising the ability of future generations to meet their own needs’’(WCED, 1987).

Nevertheless, to gain a long-term sustainability the world leaders agreed in year 2015 upon 17 global goals (Global Goals for Sustainable Development) aimed to guide governments, businesses, civil society and the general public to build a better future for everyone. Furthermore, within the 17 global goals number 2 entails hunger and number 12 entails responsible consumption and production (UNDP, 2019). Food producers have a large impact on the mentioned goals and are thereby responsible to take actions towards fulfilling these goals. The targets of main interest considering this study are the targets 2:1 *Universal access to safe and nutritious food*, 2:4 *Sustainable food production and resilient food agricultural practices* and 12:3 *Halve global capita food waste*.

2.6 Aim

This study aims to (1) facilitate an upscale of preparation of chickpeas and to (2) investigate the optimal preparation of chickpea, by studying the time and temperature during soaking and the time for cooking.

The following research questions are thereby answered:

- What is the optimal soaking time and temperature of chickpea?
- What is the optimal cooking time of chickpea?

3 Methods and material

3.1 Literature research

Information has been collected from scientific articles from databases as *PubMed*, *Web of science* and *Google scholar*. The search topic has been within the subject of soaking and cooking of pulses, with a special interest of preparation of chickpea. Examples of search words in different combinations are: *pulses*, *chickpea, garbanzo bean, boiling, cooking, soaking, pre-treatment, processing, texture, softening* among more.

3.2 Material

3.2.1 Chickpea

Chickpea of Kabuli-type (Sierra) with a size of 7-9 mm cultivated in United states have been used. The chickpea is not blanched before drying.

3.2.2 Equipment

In order to study the soaking and cooking of chickpea the following equipment have been used:

- Water bath, 10 L
- Pot, 5 L
- Electric single burner
- Three decimal scale
- Strainer
- Vacuum sealer
- Vacuum plastic bags, 11×30 cm
- Metal barbecue sticks

- Plastic cups for weighing chickpeas and water

Both the water bath and the pot has been filled with tap water to its recommended limit. The barbecue sticks have been used to fixate the plastic bags in the pot during the treatments. The burner, where the pot was placed on, has been on full speed while performing the treatments.

In order to study the solid loss an oven and aluminium moulds were used as well as a scale with four decimals.

3.3 Cooking of chickpeas

3.3.1 Experimental design

In this project tree variables were studied. The effects of the variables time (x1) and temperature (x2) during soaking and time (x3) during cooking, was determined by a Circumscribed Central Composite Design (CCC) (**Figure 2**) allowing estimation of two-way interactions as well as quadratic terms.

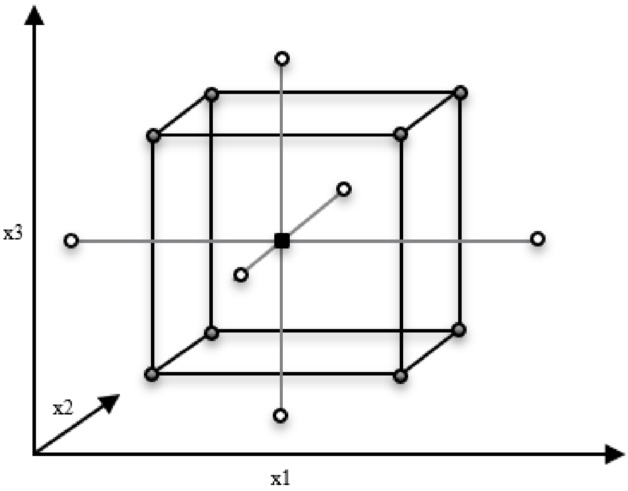

Figure 2. Circumscribed Central Composite design for optimization of three variables, factorial design (●), axial points (○) and central point (■).

The intervals studied are based on earlier experience and discussions with experts within the area. Previous research mentioned in the background has been used to adjust the intervals further. Thereby the optimal treatment is believed to lie within the studied intervals. All combinations are predicted to be possible. The levels studied in the design are determined according to the model (**Figure 2**), the axial points (○) are mentioned as *High+* and *Low–*, the factorial points (●) are mentioned as *Low* and *High* and the central point (■) is mentioned as *Centre* in **Table 2**. The intervals are presented in **Table 2** below.

Table 2. Interval given by the Central Composite Design applied on the range of the variables studied

	Low -	**Low**	**Centre**	**High**	**High +**
Temperature, soaking (°C)	60	64	70	76	80
Time, soaking (min)	50	54	60	66	70
Time, cooking (min)	50	58	70	82	90

The optimal treatment is defined as where the chickpea has absorbed as much water as possible (maximized water content) and minimal solids have been lost in the fastest way possible and without compromising with the softness of the chickpea. The performance of the soaking and cooking, the equipment and method used is determined and evaluated in tests performed in advance.

Based on the variables studied 20 experiments was given by the design. No replicate was made due to lack of time. The treatments and the run order can be seen in **Appendix 1 – All treatments**.

3.3.2 Soaking

Chickpea samples of 40 g were soaked in 90 g of tap water in open plastic bags (11×30 cm). The bags were placed in a water bath. The set temperature and time was given by the experimental design explained in previous paragraph (3.3.1). The chickpea samples were then drained and weighed. The soaking water was kept and weighed and was put back in the bags, sealed and saved in a freezer for further analysis.

3.3.3 Cooking

After soaking the chickpea samples were placed in new plastic bags (11×30 cm) together with 65 g of tap water. The bags were sealed, with as little air left as possible, and put in a pot with boiling water. The set time was given by the experimental design (see paragraph 3.3.1). As for the soaking, the chickpea samples were drained and weighed after finished cooking. The cooking water was kept and weighed and put back in the bags, sealed and placed in a freezer for further analysis.

3.4 Evaluation methods

3.4.1 Determiniation of solid loss

The frozen plastic bags with the soaking water and the cooking water were thawed overnight in a refrigerator. Approximately 3.5 ml of each water sample was weighed in aluminium moulds that had been dried and weight in advanced. Duplicates were made. The samples were dried in 105 °C for 16 h. After incubation the samples were weighed to determine the solid loss.

3.4.2 Determination of water absorption

By weighing the chickpea samples before and after soaking and cooking respectively the water absorption could be calculated. The increase in weight corresponded to the additional water the chickpeas gained.

3.4.3 Determination of sensory factors

To determine the texture and how well-cooked the chickpea became after different treatments the chickpea samples were evaluated by a sensory test. The sensory test was designed to determine the absence of core by separating the cotyledons and visually detect if any core was present. Chickpeas of each samples were also tasted and smeared in the palm to detect gritty parts. For the sensory test 4 chickpeas were controlled from each treatment.

3.5 Statistical analysis

The data analysis was carried out by Minitab® 18. Both regression analysis and a response optimization were performed. For the response optimization no core was targeted and the ratio between water content and solid loss was set to be minimized. A significant level of 95 % was used.

3.6 Large scale observation

To identify application challenges a large-scale test was performed. The test was meant to evaluate large-scale equipment and not primary processing challenges with an optimization perspective. However, by observing the large-scale process, potential application challenges could be identified which may interfere with the result of this study. The test was performed under conditions of soaking in higher temperatures followed by cooking.

4 Result and discussion

In this chapter the results are presented, and a discussion is held in correlation to the reviewed literature and practical challenges. The first section has a more theoretical approach and makes the basis for the second section were a more practical view is applied. All results are gathered from the small-scale experiments of this study.

4.1 Effects of water content and solid loss

This section presents and discusses the obtained small-scale results from the soaking and cooking of chickpea. The factors studied are water content and solid loss. The water content of the chickpea is supposed to work as a measurement of the hydration and swelling of the chickpea. The more water the chickpea can gain the higher is the financial value of it. This is important for the manufacture and their ability to maximize its profit. Furthermore, to add a wider and important perspective for the future of the processing of pulses the solid loss is also studied. The solid loss enables a discussion about sustainable development as nutrients and mass can be retained in the final product and less solids will be discarded, if it is minimized. The discarded solids in a second stage becomes pollutions and can cause over fertilization. Fees for discarding solids into the drain needs to be considered by manufactures. Thus, the loss of solids is an important factor to study in together with the water content when finding the optimal preparation of pulses, and in this case the preparation of chickpea.

The intervals of the variables studied in the statistical design were the following:

Temperature during soaking	60-80 °C
Time during soaking	50-70 min
Time during cooking	50-90 min

Why not a lower temperature during soaking was studied is both due to the time efficiency perspective and microbial risks associated with temperatures below 60 °C. A long processing time is associated with higher costs and low efficiency.

Moreover, the statistical design enabled to study the main effect of the studied variables as well as two-way interactions between them. The statistical design is illustrated in **Figure 3** in the chapter *Methods and materials*. The main effect is the overall effect of one variable, independent of the other variables studied. The two-way interaction enables to study the interactions between two variables. Hence, the design allows to study how one variable affects the effect of another variable. An overview of the obtained p-values of both the main effects and two-way interactions during soaking and cooking can be seen in **Table 2** below.

Table 3. P-values of main effects and two-way interactions on water content during soaking and cooking, solid loss during soaking and cooking, and the total solid loss

	Main effect	***p-value***	***2-Way Interaction***	***p-value***
Water content, soaking	Time soaking	0.000	Temp soaking – time soaking	0.157
	Temp soaking	0.001		
Water content, cooking	Time cooking	0.000	Temp soaking – time soaking	0.154
Solid loss, soaking	Time soaking	0.000	Temp soaking – time soaking	0.154
	Temp soaking	0.000		
Solid loss, cooking	Time cooking	0.000	Temp soaking – time cooking	0.185
			Time soaking – time cooking	0.118
Total solid loss	Time soaking	0.000		

The p-values of the main effects of both the soaking and the cooking variables are statistically significant ($p<0.05$). Furthermore, the two-way interactions found are not statistically significant. However, they are still likely to be true as the p-values obtained are low.

4.1.1 Water content

How much the chickpea can gain in weight is directly linked to its maximum hydration and maximum swelling. How fast it can gain weight is hence linked to the rate of hydration and rate of swelling (Wood & Harden, 2006). By study the main effect of the water content for different treatments the increase in weight can be analyzed for each variable.

This study showed an increase in water content during soaking for both the variables time and temperature. This can be seen in **Figure 3** below. Both variables are statically significant ($p<0.05$). The main effect of the both variables are shown to have similar effect on the water content as the levels between the starting point and the end point are approximately the same. Hence, by increasing the time or the temperature a higher water content can be obtained during soaking. To combine the variables to obtain an even higher water content thus may be beneficial.

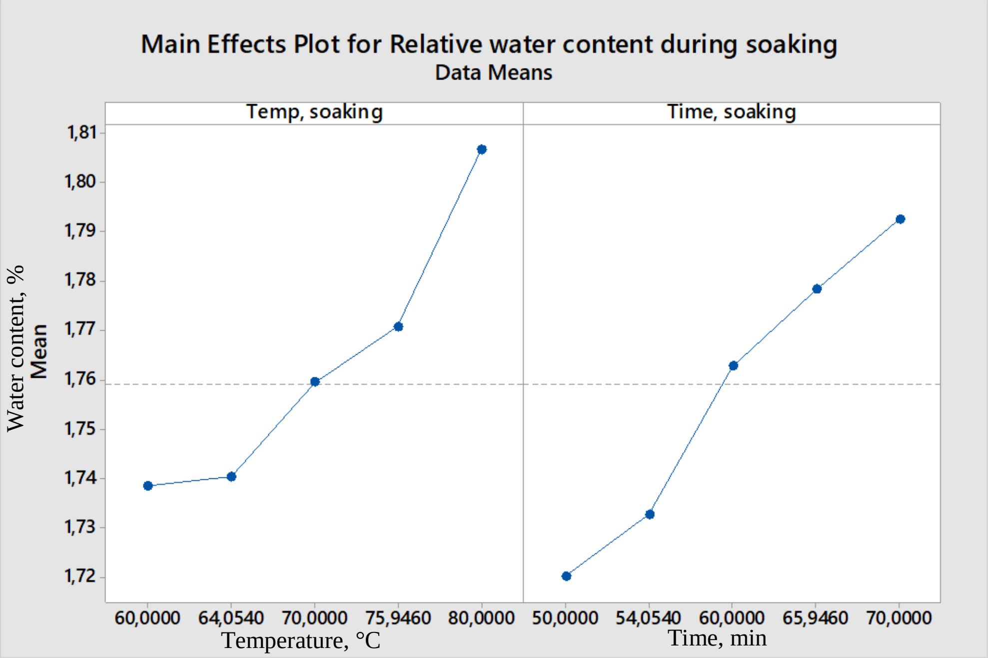

Figure 3. Main effect plot for relative water content during soaking with regards to temp soaking and time soaking.

During cooking the soaking variables have an increasing effect on the water content of the chickpea as they make the basis for the cooking. However, the variable time during cooking have an even greater effect increasing the water content of the chickpea as it is the primary variable during cooking affecting the chickpea. This can be seen in **Figure 4** as the levels between the starting point and the end point are higher than the levels between the soaking variables starting and end points. Thus, increasing the time during cooking are shown to be more beneficial than increasing the soaking variables.

To consider is however that the soaking variables only makes the basis for the cooking and still have a large effect even if it is not the primary variable affecting the water content. To combine the soaking variables and the cooking time in order to achieve a high water content may hence be possible. The main effects of each variable have a statically significant effect ($p<0.005$). The main effect for each variable during cooking on the water content can be seen in **Figure 4** below.

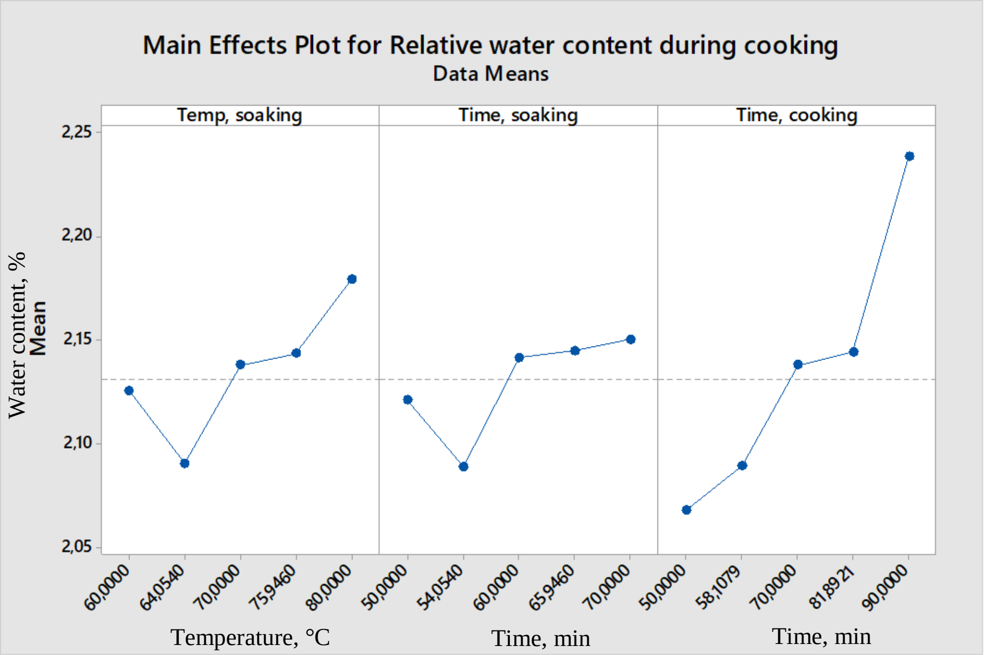

Figure 4. Main effect plot for relative water content during cooking with regards to temp soaking, time soaking and time cooking.

To know if an additionally effect on the water content would be obtained if increasing all variables two-way interactions were studied. From the data obtained two-way interactions were found between the soaking variables (time and temperature) both during soaking and during cooking (**Figure 5**). The interactions are however not statically significant (p=0.154 and p=0.157 respectively).

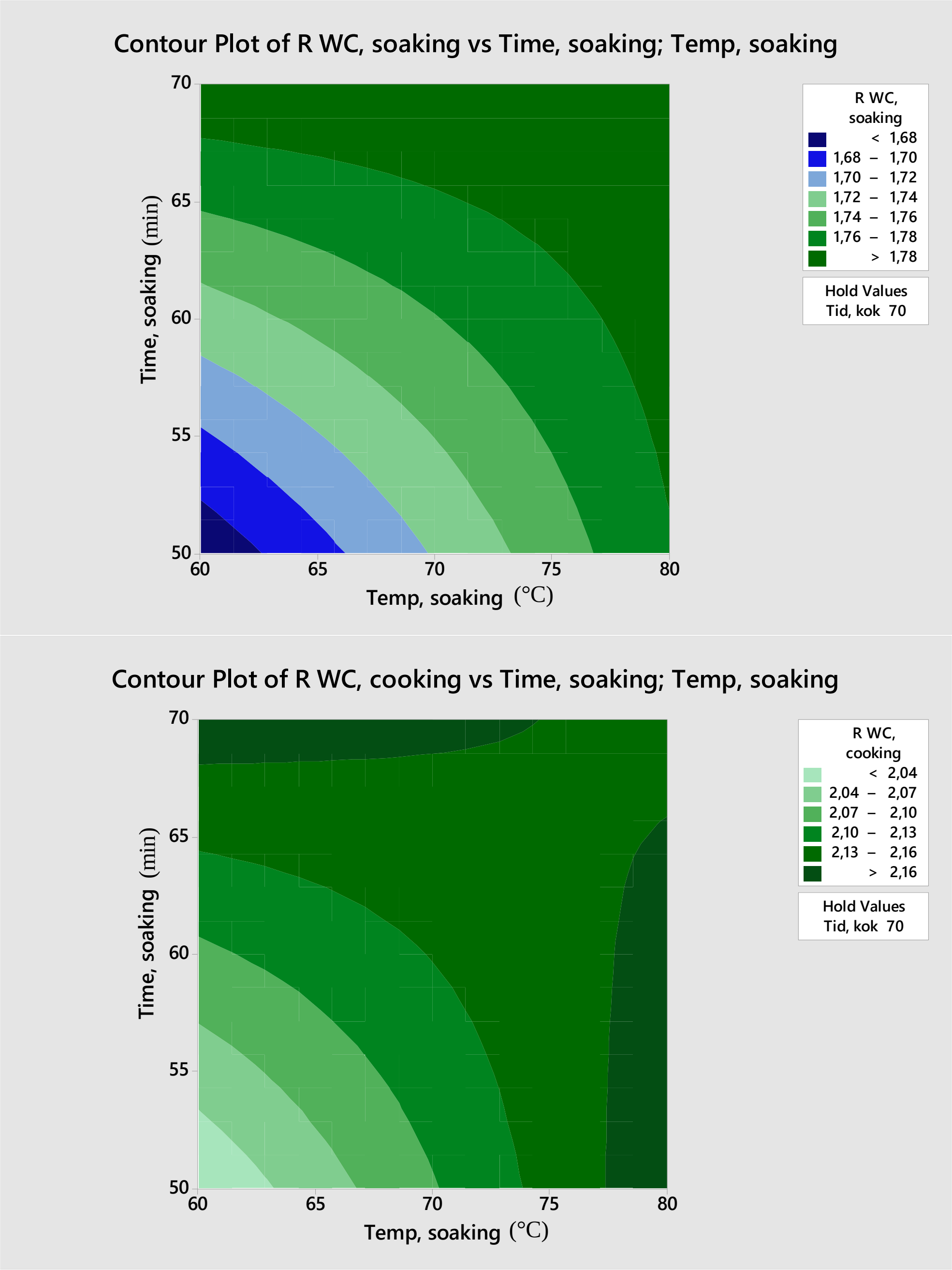

Figure 5. Contour plots for relative water content during soaking and cooking vs time soaking and temp soaking.

The contour plots show negative interactions between the soaking variables time and temperature. An increase in soaking temperature will increase the water content of the chickpea without the time needed to be increased to obtain the same result and vice versa. This means that to obtain the maximum water content of the chickpea the temperature or the time can be increased. But if increasing both the soaking time and temperature, there will be no additional effect since the combined effect levels out at a maximum level.

4.1.2 Solid loss

The amount of solid that often is discarded with the soaking and cooking water is mainly known to be pectin and proteins and is affected by type of processing, temperature and seed damage (Chigwedere *et al.*, 2019a; Mubaiwa *et al.*, 2019; Sayar *et al.*, 2011). The main effect of the temperature is shown in this study to increase the solid loss more than the time during soaking. This can be seen in **Figure 6** below. However, both the time and the temperature increase the solid loss during soaking. The main effects are statically significant ($p<0.05$).

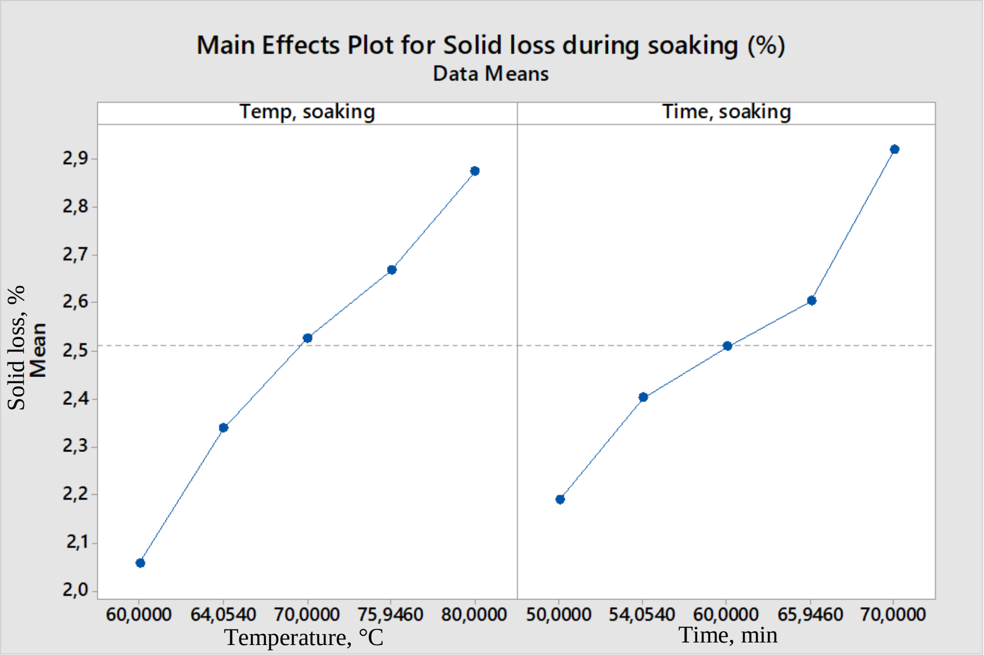

Figure 6. Main effect plot for relative water solid loss during soaking with regards to temp soaking and time soaking.

During cooking the soaking variables time and temperature have a main effect. However, as for the water content the cooking time still have a larger effect as it is the variable that primary affects the solid loss during the cooking phase. This can be seen in **Figure 7** below. But if the temperature during cooking would also have been studied, it is likely to believe that the temperature would have had a larger effect than the time as for soaking, during the cooking phase. However, 100 °C are easy to maintain during the cooking process, otherwise other equipment allowing pressure would be needed. That the temperature has a larger effect on the solid loss than the water content supports earlier obtained results (Sayar *et al.*, 2011; Clemente *et al.*, 1998). Thus, the time during cooking and the temperature during soaking are the factors needed to be limited to minimize the loss of solids.

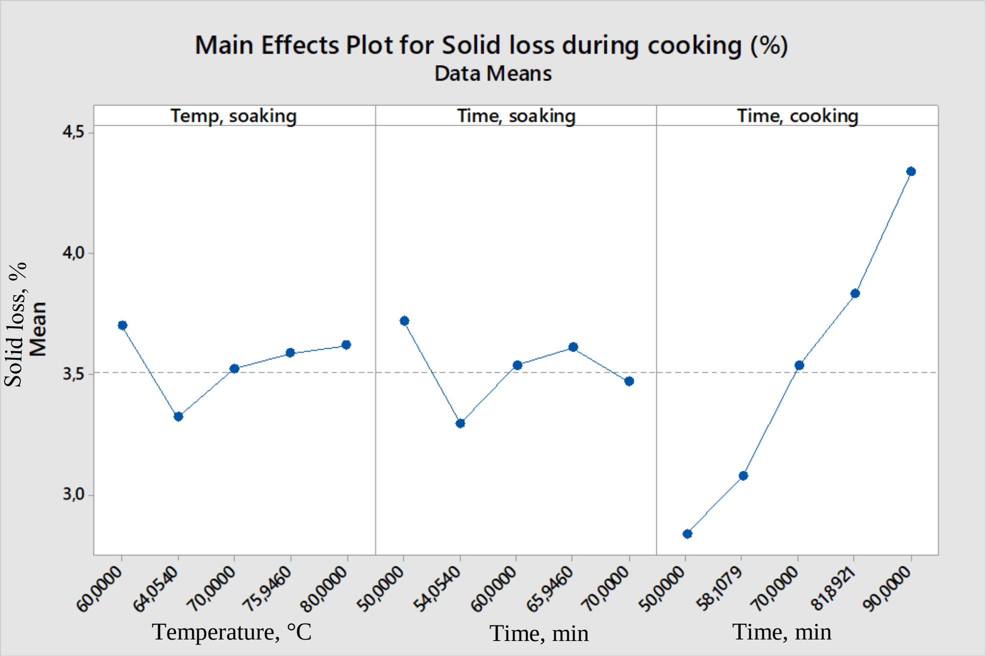

Figure 7. Main effect plot for solid loss during cooking with regards to temp soaking, time soaking and time cooking.

Why the curves are not linear in the main effect figures are likely to be caused by the human factor when performing the treatments. It is more likely that the curves would have been flack in the beginning and then increased more rapidly over time or temperature. To consider is also the intervals studied as the amount and rate of solid loss are lager above the gelatinization temperature which happens in the beginning of the studied interval and the hydration is slower in the beginning of the process.

Furthermore, the data from this study does indicate that there is a two-way interaction (p= 0.154) between soaking temperature and soaking time during soaking where the amount of solid loss is increases with increasing temperature or time. No synergistic effect exists (**Figure 8**). It can also be seen that the soaking temperature has a greater effect on the solid loss than the soaking time have since maximum solid loss is reached at lower levels than for soaking temperature. This means that it is advantageous to have a lower temperature during soaking and compensate by soaking during a longer time to minimize the solid loss during soaking.

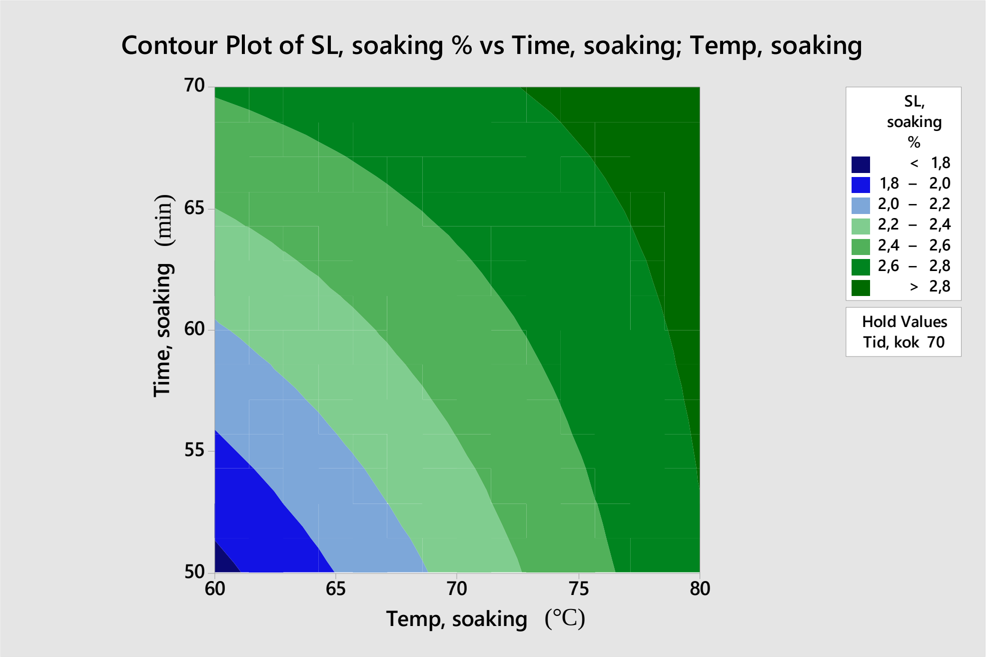

Figure 5. Contour plot for solid loss during soaking vs time soaking and temp soaking.

During the cooking phase two-way interactions could be assumed between cooking time and soaking temperature (p= 0.185) and between cooking time and soaking time (p= 0.118). The contour plots in **Figure 9** below indicate that the cooking time have a larger effect increasing he solid loss if the soaking have been performed during a long time or at a high temperature. However, it is also likely that if not the soaking has been done under such conditions, the cooking time would have been longer to obtain a soft chickpea and thereby more solids would be lost as it has the largest main effect on the solid loss. Thus, a short cooking time is advantageous to minimize the solid loss during cooking.

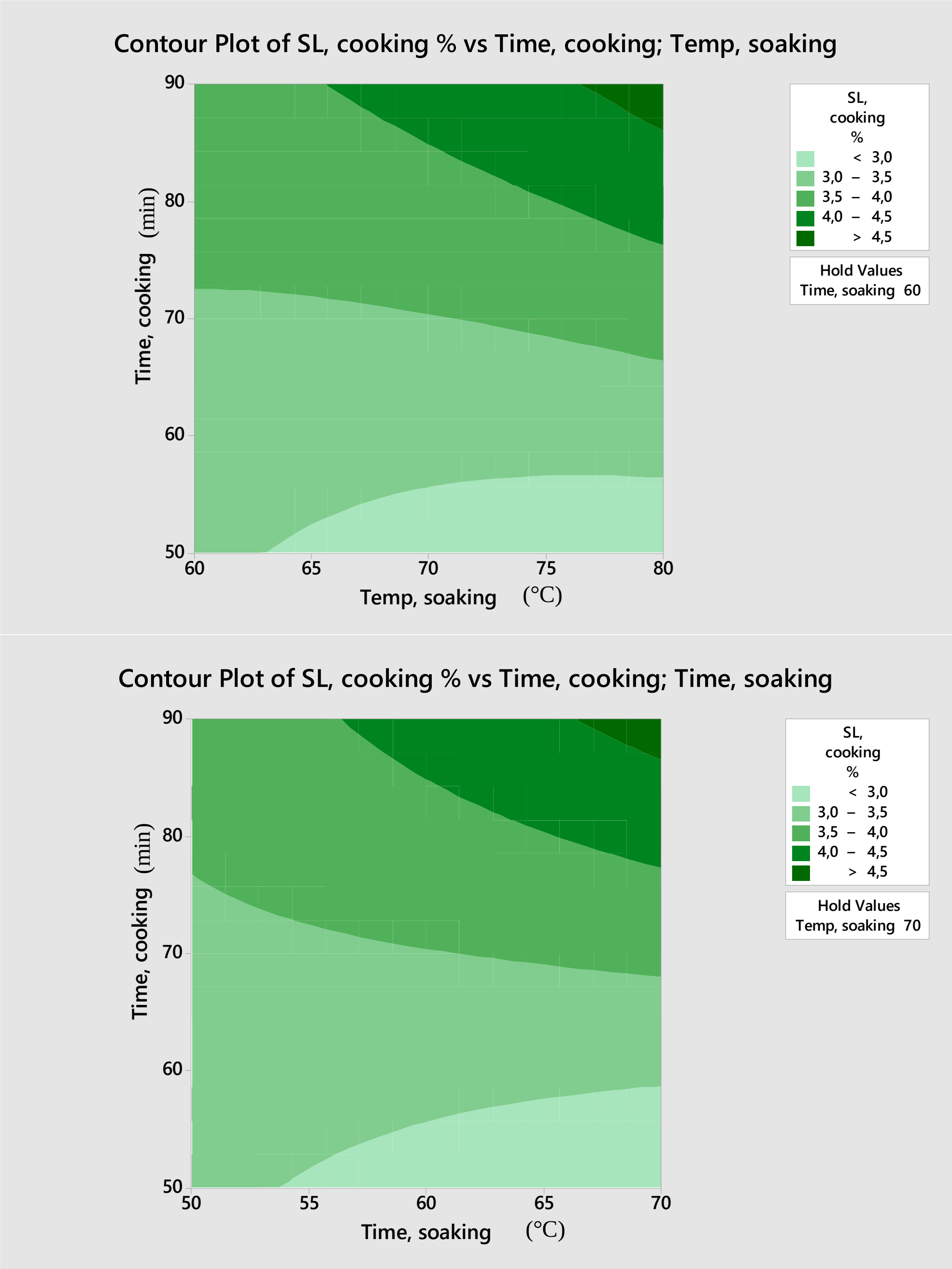

Figure 6. Contour plots for solid loss during cooking vs time cooking and time soaking and temp soaking.

Hence this study indicates that increasing one variable is more effectful than changing all. Furthermore, the result shows that the water content and solid loss are contradictable to each other form a financial perspective. Even if the water content is increased with increasing temperature or time the solid loss will also be increased. Hence, an increase in water content will increase the financial value but an increase in solid loss will have the opposite effect. However, the solid loss is more affected by temperature changes than the water content. Thus, it causes a discussion whether it is more beneficial to increase the time to minimize the solid loss and still remain a high water content even if it is not maximized. However, the time efficiency at manufactures are a limiting factor and solid loss is likely to be cheaper than energy and time for manufactures. However, if solid loss is associated with fesses in the future it might be the opposite way around. Hence, an evaluation of financial aspects of time and energy consumption would be complementary to this study.

4.1.3 Sensory analysis

When finding the optimal treatment, it is important that the treatment fulfil all requirements, in this case the chickpea should obtain maximal water content during processing were minimal solid loss is obtained. It should also be softened to a state were no core can be detected. The softness of pulses is mainly limited by the pectin solubilization (Chigwedere *et al.*, 2018). The presence of core can be observed when separating the cotyledons, splitting the chickpea in to two halves. In this study the unsoftened and harder part in the middle of the chickpea is referred to as core. Hence no core is accepted and thus limit the potential optimal combinations. Below, in **Figure 10**, samples with no core and a sample with core are shown to visualize the difference between no core and core.

Figure 7. Samples of chickpea without core (left) and with core (right).

Out of the 20 treatments done six fulfilled the requirements of no visible core. These can be seen in **Table 4** below. The levels are based on the studied intervals which consists of five levels (**Table 2**). All the treatments with no visible core had two *High* levels and one *Low* or consisted of one *High* + and two *Centre* levels were the high levels were either a high temperature during soaking or a long time during cooking. The time did not have the same effect on the softness as the temperature during soaking and the time during cooking had. All treatments and their result can be seen in **Appendix 1– All treatments**.

Table 4. The treatments* with approved sensory tests and their effects on total time, solid loss during soaking and cooking, total sloid loss, relative water content during soaking and during cooking

StdOrder	***4***	***6***	***7***	***8***	***10***	***14***
Temperature during solid loss, (°C)	High	High	Low	High	High +	Centre
Time during soaking, (min)	High	Low	High	High	Centre	Centre
Time during cooking, (min)	Low	High	High	High	Centre	High +
Total time, (min)	124	136	148	148	130	150
Solid loss during soaking, (%)	2.9	2.7	2.4	2.5	2.9	2.6
Solid loss during cooking, (%)	3.2	4.0	4.1	4.2	3.6	4.3
Total solid loss, (%)	6.0	6.7	6.5	6.7	6.5	7.0
Relative water content during soaking, (g)	1.8	1.8	1.8	1.8	1.8	1.8
Relative water content during cooking, (g)	2.1	2.2	2.2	2.2	2.2	2.2

* The levels are according to the studied intervals, see **Table 2**.

Table 4 indicate that if a higher temperature or a longer time during soaking are performed the cooking time will be reduced (compare treatment StdOrder 4 & 6 and treatment StdOrder 10 & 14). A high temperature during soaking does also seem to reduce the total time (see treatment StdOrder 10 & 4). Furthermore, the solid loss is seen to be more sensitive to temperature changes than the amount of water absorbed as the same water content were obtained for all treatments in **Table 4** while the solid loss differed more between the treatments. This supports earlier obtained results (Sayar *et al.*, 2011).

Thus, it can be thought that the temperature is the variable needed to be increased during soaking to reduce the cooking time and the overall processing time. This, as discussed in the previous section, due to that the solid loss might be cheaper for the manufacture than the time and energy consumed. The importance is that the cooking time is reduced as it affects the solid loss to a larger extent and does likely consume more energy than the soaking does.

The amount of solid loss is in the lower area of those who were obtained in earlier studies (Sayar *et al.*, 2011; Xu & Chang, 2008). This is probably explained by the sensitive handling performed, sample size used and how intact the chickpea used have been. The lowest total amount obtained in the approved sensory samples was 6.0 % w/w and the highest 7.0 % w/w. The difference between them can be thought to be little, but in a larger scale, or even if looking at the world production, 1 % less total solid loss is a lot of saved nutrients, money and environmental impact.

However, the benefits of losing solids is the loss of anti-nutritional compounds (Jukanti *et al.*, 2012). Hence, it is a balance between which solids needed to be lost and which have nutritional benefits. Nevertheless, many anti-nutritional compounds are reduced or eliminated by the processing steps (Hajos & Osagie, 2004) and will hence not be an issue for consumption even if less solids are lost.

4.1.4 Response optimization

Finding the optimal processing conditions is challenging and a complex problem due to that solid loss and water content are contradictable to each other. When considering an optimal treatment, the solid loss should be minimized to not loose financial and nutritional value of the final product and at the same time the chickpea needs to become maximally hydrated and softened. When performing the response optimization, no core was targeted.

By calculating a ratio between the total solid loss and the water content obtained after cooking (that depends on the soaking) a value that would indicate the balance between minimized solid loss and a maximized water content through the whole process would be obtained. This value should hence be minimized.

Given this the optimal conditions are predicted to be soaking at 80 °C for 69 min during soaking with a following cooking time of 57 min. The total required time would hence become 126 min. The response optimization function in Minitab, thus indicates as predicted a high temperature during soaking is beneficial to minimize solid loss and maximize water content thorough the process. Additionally, the cooking and overall processing time is reduced which makes the process more time efficient.

The literature also indicates that the processing time can be further decreased if processing aids as sodium bicarbonate ($NaHCO_3$) or sodium carbonate (Na_2CO_3) is added. Earlier results show a decrease of 82 % using Na_2CO_3 but the treatment is done in denaturized water (Coskuner & Karababa, 2003). It would hence be interesting to know how much the cooking time would be reduced in tap water.

However, there are more factors to be considered when applying this to the industry.

4.2 Application to the industry - practical considerations and challenges

When applying a theoretical, small scale result to a large scale or even an industry there will be application challenges. In this section practical considerations are discussed, and suggestions are presented.

4.2.1 Time and energy efficiency

The main application challenge that was identified during the large-scale test were the time and temperature gradients. The time and temperature gradients interfered with the optimal treatment of this study due to practical considerations as maneuvering, pumping, energy losses and other human and equipment limiting factors. Those factors will make it hard to implement the obtained optimal treatment directly. Hence processing steps, which is dependent on the equipment used, is needed to be consider when applying a small-scale test into a large scale. The small-scale test should hence be constructed to mimic the large-scale as much as possible. However, this is not always easy and even doable or feasible. Thereby a large-scale test can be of use before a startup of the production to identify limitations.

A time-line is illustrated in **Figure 11** below were the process time and temperature gradients can be observed.

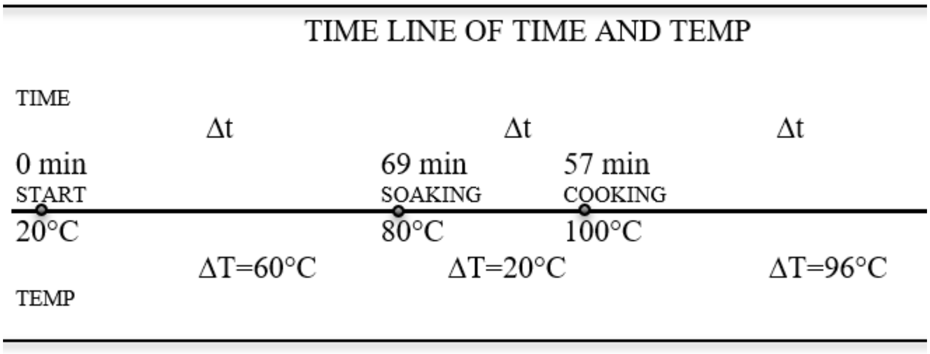

Figure 8. Time-line from start of process – soaking phase, cooking phase and cooling phase with temperature and time gradients.

Hypothetically, the starting temperature would be about 20 °C as the chickpea will be room tempered, the water will then be added. As the water is added the soaking phase starts. The temperature gradient becomes 60 °C, but if pre-heated water of 100°C could be added to the process the temperature of the chickpea will become approximately 80 °C at the beginning of the soaking. This would be beneficial as the response optimization suggested a soaking temperature of 80 °C. The temperature, depending on the equipment used and physical laws, will decrease due to energy losses. Hence heating during the soaking would be beneficial to regulate the temperature and prevent a decrease.

However, after completed soaking the water should be drained, and the cooking phase will begin. Furthermore, when starting the cooking process after 69 min of soaking the temperature will not immediately become 100 °C even though 100 °C of hot water could be added as equipment allowing pressure hence would be needed. The temperature gradient will become 20 °C. Thereby the cooking process will start on a lower temperature and work its way up to 100 °C. Hence the time of 57 min will not be applicable. Depending on how fast the temperature can be increased the shorter time cooking is needed. How fast the temperature can be increased is dependent on the energy input.

Hence, the energy required is also of interest as it plays an important role together with time efficiency on the financial aspects of the process. A higher temperature at soaking would theoretically require more energy than soaking in lower temperatures. Soaking in ambient temperatures would thereby be most advantageous as it does not require any energy, but in correlation it would take longer time.

However, if the soaking could be done during night (not taking active time) it may be economically beneficial and less solids would be lost. Contradictory it could be discussed if it could be an advantage to have an increased starting temperature of the chickpea when starting the cooking process if not the chickpea is meant to be cooled down in between the soaking and cooking process. Hence an energy consumption evaluation of the process could be complementary when finding the optimal soaking and cooking process.

5 Summary

In this chapter the results and discussion are summarized. The variables studied during soaking and cooking of chickpea were the time and temperature during soaking and the time during cooking. The factor measured in order to study the optimal preparation of chickpea were water content and solid loss. The water content is important as it effects the financial value of the final product. Furthermore, the solid loss is an important factor to study in together with the water content as less solid loss is associated with saved nutrients and financial value, less discarded solids affecting the environment. Furthermore, the drawbacks of utilization of pulses is its long cooking time. Hence, maximizing the water content and minimizing the solid loss in the shortest processing time is beneficial to obtain a sustainable production of cooked chickpea and other pulses.

All variables studied had an increasing main effect on both the water content and the solid loss. All main effects were significant ($p<0.05$). The main effects indicated that the temperature during soaking had a greater effect on the solid loss than the water content. For the water content both the time and the temperature during soaking had a similar increasing effect. Moreover, during the cooking phase the cooking time had an even larger main effect than the soaking variables on both measured factors. This is explained by that the cooking time have a primary effect while the soaking variables only make the basis for the start of the cooking. Hence, the effect of the soaking variables has a large effect on the cooking.

Furthermore, due to the statistical design used, two-way interactions between the studied variables could be studied. The result showed that there are possible two-way interactions between the soaking variables time and temperature both during soaking and during cooking for the water content. The interactions indicate that it is more beneficial to increase one variable than increasing both, to obtain a higher water content. A two-way interaction between the soaking variables could also be seen for the solid loss during soaking. It indicated that it was more beneficial to decrease the variable temperature than the soaking time. None of the two-way interactions were statically significant ($p>0.05$) but were still likely to be true.

When study the solid loss a two-way interaction between the cooking and the soaking variables could also be assumed. The interaction indicated that the time during cooking had a larger effect on the solid loss if the soaking had been performed at a higher temperature or during a longer time. However, the results from the sensory test did correspondingly indicate that the longer and the higher the temperature have been during soaking the shorter did the processing time become. Thus, it is beneficial to have a well performed soaking in order to minimize the cooking time were more solids are lost. The amount of water content was shown to not be as sensitive to temperature changes as the solid loss.

Furthermore, when performing the response optimization, the optimal conditions came to be 80 °C for 69 min during soaking with a following cooking time of 57 min. The total required time hence became 126 min. However, there are more factors to be considered when applying an optimal treatment to the industry.

The observation of a large-scale test identified that the time and temperature were hard to regulate which make the change in temperature to take time. The delay in temperature caused the optimal treatment to not be directly applicable to the industry. For the producer the heating is also a question of financial aspects, as it affects the energy consumption. However, the literature does indicate that the usage of processing aids as sodium bicarbonate or sodium carbonate would decrease the cooking time further, saving time for the producer.

6 Conclusion and future outlooks

To reduce waste and to be able to meet our needs for sustainable food systems in the future, processing of pulses has an important role. To combine time efficiency with factors that affect the profitability of manufactures, health benefits of consumers and environmental aspects a more sustainable production would be achieved. In this study the water content and the solid loss have been in focus to do so. However, this study brightens the contradictions involved between the two factors when finding the optimal processing condition of cooked chickpea. It has also allowed to study application challenges at a large-scale.

The conclusions are that the cooking time needs to be limited and to do so the results indicates that it is advantageous to have a soaking performed at a higher temperature. This will also reduce the overall processing time. The results of this study hence predict an optimal soaking at 80 °C for 69 min with a following cooking time of 59 min. At such condition the water content is maximized, the solid loss minimized, and the chickpea softened to a state where it is ideal for further processing or consumption. However, a soaking in ambient temperatures during non-active time would still be an option to consider as less energy would be required and less solids would be lost at such condition. Hence, future studies should include such alternative. Furthermore, additional studies on how to reduce the cooking time further and how to make the processing more sustainable, factors as energy consumption, equipment, processing aids and other techniques is of relevance.

This study contributes with useful information to industries who are planning on optimizing preparation of cooked chickpea or other pulses. The findings of this study could also be used to address the Global Goals 2:1 (*Universal access to safe and nutritious food*), 2:4 (*Sustainable food production and resilient food agricultural practices)* and 12:3 (*Halve global capita food waste*).

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Appendix 1

All treatments

StdOrder	***RunOrder***	***Temp, s (°C)***	***Time, s (min)***	***Time, c (min)***	***Total time (min)***	***SL, s (%)***	***SL, c (%)***	***Total SL (%)***	***WC, s (g)***	***R WC, c (g)***
1	19	64	54	58	112	2.4	3.1	5.5	1.7	2.1
2	20	76	54	58	112	2.6	3.0	5.6	1.7	2.1
3	16	64	66	58	124	2.6	3.0	5.6	1.8	2.1
4	14	76	66	58	124	2.9	3.2	6.0	1.8	2.1
5	8	64	54	82	136	2.0	3.1	5.1	1.7	2.0
6	7	76	54	82	136	2.7	4.0	6.7	1.8	2.2
7	15	64	66	82	148	2.4	4.1	6.5	1.8	2.2
8	11	76	66	82	148	2.5	4.2	6.7	1.8	2.2
9	9	60	60	70	130	2.1	3.7	5.8	1.7	2.2
10	1	80	60	70	130	2.9	3.6	6.5	1.8	2.2
11	10	70	50	70	120	2.2	3.7	5.9	1.7	2.1
12	4	70	70	70	140	3.0	3.5	6.4	1.8	2.2
13	6	70	60	50	110	2.4	2.8	5.3	1.8	2.1
14	12	70	60	90	150	2.6	4.3	6.9	1.8	2.2
15	13	70	60	70	130	2.6	3.6	6.2	1.8	2.2
16	3	70	60	70	130	2.5	3.6	6.1	1.8	2.2
17	18	70	60	70	130	2.5	3.1	5.7	1.7	2.1
18	5	70	60	70	130	2.5	3.5	6.0	1.8	2.1
19	2	70	60	70	130	2.6	3.7	6.3	1.8	2.2
20	17	70	60	70	130	2.5	3.1	5.7	1.8	2.1