Shelf-life study of rice pudding: Differences in assorted rice varieties and how they change in texture over time

By

Johanna Bengtsson

In collaboration with Orkla Foods Sweden

A Master Thesis performed during spring 2023

Department of Food Technology, Engineering, and Nutrition at Lund University.

LUND UNIVERSITY | LTH FACULTY OF ENGINEERING

Supervisor at Lund University: Jeanette Purhagen

Supervisor at Orkla Foods Sweden: Annasofia Grönqvist

Examinator at Lund University: Karolina Östbring

Abstract

This master thesis was performed in collaboration with Orkla Foods Sweden AB. The aim of the study was to investigate rice pudding and how storage time affects the texture properties of the rice grains inside the pudding, and if this could be related to some of the properties of the raw rice. Rice pudding is produced by Orkla Foods under the label Risifrutti and is a popular in-between meal snack in Sweden. Six different rice varieties with different origin or harvest date were selected for investigation and boiled into rice pudding according to a recipe mimicking the factory production process. The texture of the rice grains inside the rice puddings were analyzed on selected days during a 29-day storage period, with the result that all rice varieties increased in firmness over time to different extent. To investigate what could be the reason for the differences in firmness increase, differential scanning calorimetry (DSC) measurements was performed in parallel with the texture analysis. This was to determine if starch retrogradation could be the cause for the increased grain firmness. It was expected for the DSC to detect endothermic peaks due to starch gelatinization around the starch gelatinization temperature, it was expected for the peaks increase in size over the studied storage period. The starch gelatinization temperature was measured through DSC measurements of the raw rice samples, giving gelatinization temperatures between 66°C and 76°C. Unfortunately, the DSC measurements of the cooked rice pudding grains only detected endothermic reactions around the starch gelatinization temperature in very few of the samples, and then the peaks were very small in size generating rather inconclusive results. Starch could therefore not be said to be the cause for the increased firmness of the cooked rice grains. For the raw rice samples also water absorption, water content and a microscopy study were performed. The water absorption test gave the results that the rice varieties absorbed between 228%-264% of their initial dry weight, and that the rice variety with the highest increase of firmness in the cooked rice grains also had the greatest water absorption. The water content measurements gave that all varieties had between 11.5%-12.7% water content, and the rice variety with the highest water content also had the highest firmness increase in the cooked rice grains.

In conclusion, a rice variety with good water absorption, high water content, and high gelatinization temperature showed the lowest firmness of the cooked rice grains. These are all factors that indicate that the rice variety has a rather low amylose content. To avoid high firmness of the cooked rice grains in the rice pudding, amylose content was deemed to be an important factor when choosing rice variety. However, the firmness of the cooked rice grains is not only dependent on the amylose content but on complex interactions between water, amylose, amylopectin, proteins, and lipids. Factors that all need to be considered to get the wanted rice pudding properties.

Popular abstract

When we eat, we usually don't think of the chemistry behind the food that we have in front of us, or do you? Every ingredient in your ready meal is carefully selected and tested to fit the taste and texture of the product and to make the product last until its expiration date. The same applies for rice pudding, an in-between meals snack that is easy to consume on the go. Orkla Foods Sweden AB have been producing the Swedish beloved rice pudding under the label Risifrutti since 1992. This thesis was performed in collaboration with Orkla Foods where the aim was to see how the boiled rice grains changed in texture during storage, and if it could be connected to properties of the raw rice. Six rice varieties that differed in origin or harvest date were selected for analysis, these were compared by cooking rice pudding from each variety and measure textural changes over one month's storage time. It was expected that the cooked rice grains should increase in firmness over time, which they did, but to what extent differed between the different rice varieties. It is important that the rice grains inside the rice pudding don't get to firm before the expiration date since then there is a possibility that the consistency of the rice pudding no longer is pleasant to the consumer. Textural changes within the rice depends on complex interactions between the present water, fat, protein, and carbohydrates, and there are a lot of factors that needs to be considered in order to choose the right raw material. However, measurements performed in this study indicated that the ratio of certain types of carbohydrates present inside the rice was an important factor to be considered when choosing what rice variety to use for the rice pudding production.

Table of content

1 INTRODUCTION 6

1.1 BACKGROUND 6
1.2 OBJECTIVE 6
1.3 LIMITATIONS 6

2 THEORETICAL BACKGROUND 7

2.1 RICE 7
2.1.1 Rice grain appearance 7
2.1.2 Rice water content 8
2.1.3 Rice starch 9
2.1.4 Rice Proteins 9
2.1.5 Rice lipids 9
2.2 STARCH 9
2.2.1 The starch molecule 9
2.2.2 Starch gelatinization and retrogradation 11
2.3 ANALYSES 12
2.3.1 Water Absorption 12
2.3.2 Texture Analysis 13
2.3.3 Differential Scanning Calorimetry 13

3 METHODS AND MATERIALS 16

3.1 MATERIALS 16
3.2 MICROSCOPY STUDY 16
3.2.1 Texture analysis of the microscope studied rice grains. 16
3.3 WATER CONTENT 16
3.4 WATER ABSORPTION 17
3.5 SHELF-LIFE STUDY 17
3.5.1 Kitchen boil of rice pudding 17
3.5.2 Texture Analysis 17
3.5.3 Differential Scanning Calorimetry 18
3.6 STATISTICAL EVALUATION 19

4 RESULTS AND DISCUSSION 19

4.1 MICROSCOPY STUDY 19
4.2 WATER CONTENT 22
4.3 WATER ABSORPTION 23
4.4 SHELF-LIFE STUDY 24
4.4.1 Texture Analysis of the kitchen-boiled rice pudding 24
4.4.2 Texture analysis of the factory-produced rice pudding 29
4.4.3 Comparison of kitchen-boiled rice variety 5 and factory-produced rice pudding 32
4.4.5 Differential Scanning Calorimetry 34

5 CONCLUSION 38

6 SUGGESTIONS FOR FUTURE STUDIES 38

REFERENCES 39

APPENDIX **42**

A.1 WATER CONTENT 42
A.2 WATER ABSORPTION 42
A.3 TEXTURE ANALYSIS ON THE KITCHEN-BOILED RICE PUDDING 44
A.3.1 Three-point bend test 44
A.3.2 Compression test 46
A.3.3 Penetration test 47
A.4 TEXTURE ANALYSIS ON THE FACTORY-PRODUCED RICE PUDDING 48
A.5 DSC MEASUREMENTS 49
A.6 PERTEN INSTRUMENT METHOD DESCRIPTION 51-01.02 52

List of abbreviations

DSC	Differential Scanning Calorimetry
kcal	Kilocalories
kDA	Kilodalton
DIAAS	Digestible indispensable amino acid score
Mm	Millimeter
pps	Data points collected per second
min	Minute
J	Joule
g	Gram
°C	Degree Celsius
h	Hour
kg	Kilogram
s	Second
mg	Milligram

1 Introduction

1.1 Background

Rice has been around for over eight thousand years and nowadays about half of the world's population relies on rice as a staple crop. The majority of the world's rice is grown in southeast Asia, but something many may not know is that rice is also grown in Europe. The yield from rice farming is much higher above a latitude of 30°, making the south of Europe a more efficient growth place than the south of Asia. Rice is grown in several areas of Europe but mainly in Spain and Italy (Bhattacharya, 2011c). Two-thirds of the rice grown in Europe is of Japonica-type which general characteristics are shorter and thicker grains with a rounder shape. A rice variety that is commonly used in risotto due to its great adhesiveness (Hansjoerg Kraehmer, 2017). When the rice is ready in early autumn it is time to harvest. Upon harvest the rice crop is separated into the straw and paddy rice grains. The paddy rice is then dried for a couple of months before being milled to remove the outer shell, the husk. The rice is then polished giving the white rice we recognize from the supermarket (Muhammad Riaz et al., 2017).

It is not only risotto that is made from Japonica-type rice, and one out of many other possible uses for this type of rice is rice pudding, which from now on will be the focus of this report. Orkla Foods Sweden AB is a Swedish company that has been producing the Swedish popular rice pudding as an in-between meal snack under the label Risifrutti since 1992. A ready-to-eat snack with rice pudding together with a jam that today is available in many different flavors and varieties. With today's environmental changes affecting the quality of raw material Orkla Foods wants to actively work towards gaining a better understanding regarding rice to ensure a good quality end product. (Orkla, 2023)

1.2 Objective

The thesis examines the rice inside the rice pudding with a focus on starch retrogradation and texture analysis. By following six different varieties of rice pudding for a month's time, the aim was to study how the storage time affects the texture properties of the rice grains inside the rice pudding and investigate how and if it is related to some of the properties of the raw rice. Measurements performed were texture analysis, differential scanning calorimetry (DSC), water absorption test, water content analysis, and microscopy study, combined with data gained from Orkla Foods Sweden. One batch of rice pudding produced in the factory was examined with the same analysis in addition to the kitchen-boiled rice pudding, to see if the behavior of the kitchen-boiled rice pudding corresponded to the factory-produced pudding. This master thesis will answer the following research questions:

1. Is there a measurable difference between the different rice puddings when it comes to texture of the cooked rice grains? How will the texture difference change throughout one month's storage time?
2. If the firmness of the rice grain inside the rice pudding wants to be kept low, what rice properties of the raw rice are the most important to look for in the future selection of raw material?

1.3 Limitations

There are many pieces of equipment that could be used and measurements that could be performed, to gain a better and deeper understanding of the changes in rice grain texture over time, than what is included in this thesis. For time management reasons there had to be a limitation and the selected methods will be described in more detail later. Delimitations were also made when choosing the number of rice varieties to be examined due to limited time. All rice varieties that were analyzed were selected by Orkla Foods coming from different batches collected over time. The differences in processing and storage of the rice before arriving at Orkla Foods will be kept in mind but not examined further since it would be too difficult to track the full process chain that far back.

2 Theoretical background

2.1 Rice

Looking at the Swedish authority Livsmedelsverkets database for nutritional values for rice used in rice pudding it is stated that it contains 361kcal per 100g (wet weight based). It has a protein content of 6.4g, a fat content of 0.8g, and a carbohydrate content of 80.2g, all presented per 100g wet weight of rice, which confirms that rice is mainly a source for energy and carbohydrates (Livsmedelsverket, 2023). When milling the rice most of the dietary fibers from the husk are lost resulting in a fiber content of only 1.1g per 100g of wet-weight of rice (Juliano, 2015). The rice pudding rice has very similar fat and overall energy content to rice types like jasmin and basmati rice but has a slightly higher amount of carbohydrates and a bit lower amount of protein. Cereal grains have a protein content of between 7-18% of dry weight and rice has one of the lowest spans of 7-8% protein of dry weight (Poutanen et al., 2022).

2.1.1 Rice grain appearance

When starch granules inside the rice grain are loosely packed the grain appears opaque since the starch granule then scatters light. This opacity is called chalkiness and can be divided into subcategories depending on how large part of the rice grain that is chalky. If only the center of the grain is opaque, it is called white center or white core. This phenomenon is mostly genetically controlled and can be a characteristic property of a rice type (Bhattacharya, 2011e). Another subcategory is white belly in which the grain has a chalky area on the germ side of the grain. White belly is dependent on the width of the grain and a threshold value of about 2.4mm is set, above this width it is normal for most of the grains to have white belly and below this width white belly is absent (Murugesan & Bhattacharya, 1991). The other two subcategories are milky white and opaque grains, and in both cases the chalkiness is spread within the grain. The difference is that milky white grains are not fully chalky on the outer edges while the opaque grain is completely chalky. Milky grains and opaque grains are affected by growth temperature after flowering, the higher the temperature the more of the grains tend to be chalky due to hasty grain filling (Bhattacharya, 2011e). Milky and opaque grains are mostly unfavorable since it will affect the yield, the chalkier the grain is the weaker it gets, and are more susceptible to breaking. But also, since it affects the grain filling it can lead to lower amylose content, less proteins, and less minerals inside the rice kernel (Lin et al., 2016). Figure 1 shows a white belly grain and a milky white grain.

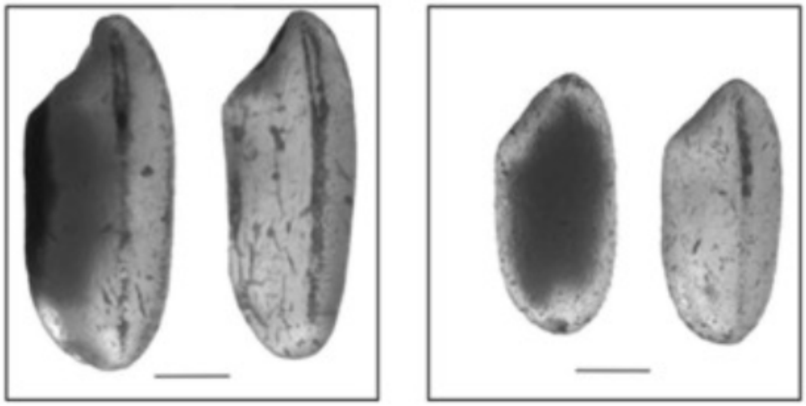

Figure 1: Picture of chalky grains. White belly grain to the left and milky white grain to the right.(Tao et al., 2022)

Grain hardness is a measurement of how tough and resistant the grain is to outside pressure. Using a Kiya grain hardness tester a single healthy milled grain should be able to uphold a pressure of about 7-10kg before it breaks (Bhattacharya, 2011e). If the grain has a chalky area that covers more than 20% or the grain the resistance to forces is almost halved to between 3-6kg/grain (Bhattacharya, 2011e).

A quick change in moisture content usually leads to the cracking of the rice grain. Today the rice processing is carefully selected to avoid this, but some cracks might still occur. Transverse cracks go across the rice grain unlike the longitude cracks that go from top to bottom; the more cracks the rice grain has, the more defective it is (Bhattacharya, 2011d). The main reason for cracked rice grains lays within harvest time and handling of the rice, where reapplied moisture to a dried grain is the biggest cause. This can occur when the rice is harvested too late, thus the grain has already started to dry on the field and if the humidity goes up in the surrounding the rice grains can crack. A controlled drying step is needed to prevent cracking. Cracked rice grains mainly affect the yield, since cracked grains break more easily and go to waste before reaching the end product. Cracks within the rice might marginally affect the cooking time, but not in enough manner to make it an issue (Bhattacharya, 2011d).

2.1.2 Rice water content

Before storage, the rice grain needs to have optimal water content to avoid spoilage. If the water content is too high there is a risk for fungal infections, and if the water content is too low there is a risk for the grain to be brittle and break. A water content of between 11-14% is optimal to preserve the rice quality during storage (Mohd Ramli et al., 2021). The water content is related to the water activity in the rice, it is considered that below a water activity of 0.65 it is very difficult for spoilage microorganisms to grow and the product is safe for long time storage (Pitt, 1975). For rice grains stored at 25°C this corresponds to a water content of 13% and the water content should be kept below this (Abdullah et al., 2000).

2.1.3 Rice starch

Starch consists of numerous glucose units joined together into the bigger molecules' amylose and amylopectin. In rice the amylose content varies from 0-35% of the total starch amount and the rest is amylopectin (Corke, 2016). However, the starch composition is the same inside all starch granules within a certain rice variety. Rice that contains 0% amylose is called waxy rice and becomes very sticky when cooked (Chen et al., 2022). Rice grain gets firmer when cooled down after cooking due to starch retrogradation where a higher amylose content leads to a firmer rice grain (Yu et al., 2009). This will be explained further in chapter 2.2.

2.1.4 Rice Proteins

The protein inside the rice grain consists of a mix of different types of proteins. The majority, about 60-80% of the proteins are glutelins (Hoogenkamp et al., 2017). Rice glutelins have several different polypeptide sizes where all are of high molecular weight ranging from 45-150kDa, they are extensively aggregated, are only soluble in dilute alkali or acid solutions and have a denaturation temperature of 82.2°C (Ju et al., 2001). The second biggest fraction of rice proteins are albumins which vary between 4-22% of the total protein content (Hoogenkamp et al., 2017). Albumins are water-soluble and have a denaturation temperature of 73.3°C (Ju et al., 2001). The two remaining types of proteins are globulins and prolamins, with a fraction of the total protein content of 5-13% and 1-5%, respectively (Hoogenkamp et al., 2017). Globulins are soluble in salt solutions and have a denaturation temperature of 78.9°C while prolamins are soluble in alcoholic solutions and have a denaturation temperature of less than 35°C (Ju et al., 2001). The protein content within the husk looks different with higher levels of albumin and globulins, lower levels of glutelins, and similar levels of prolamins. The exact protein composition, of both the husk and the inner grain, is determined by the genetics of the rice variety (Hoogenkamp et al., 2017). When it comes to the protein profile, rice contains all the essential amino acids, where lysin is the limiting one. Looking at the digestibility of each individual essential amino acid and combining this with a digestible indispensable amino acid score (DIAAS) rice has a better DIAAS than other common grains such as wheat, barley, maize and rye (Poutanen et al., 2022).

2.1.5 Rice lipids

There are two types of lipids in rice, starch lipids and non-starch lipids. About 50% of the non-starch lipids in rice are present in the outer layers of the rice grain that are polished away when producing white rice (Tong & Bao, 2019). In the white rice the starch lipids are present inside the starch granule while the non-starch lipids are free lipids that are absorbed to the surface of the starch granules. The starch lipids inside the starch granule interact with the starch amylose to form amylose-lipid complexes, complexes that interfere with starch retrogradation and have a positive effect on lowering rice grain firmness (Chang et al., 2021).

2.2 Starch

2.2.1 The starch molecule

Glucose is a six-carbon monosaccharide that is the building block of starch polymers. In starch the glucose appears in its pyranose ring structure with its reactive hydroxyl groups are linked together through α-linked bonds (Stoddard, 2015). As seen in Figure 2 the glucose molecules are linked together from carbon atom number one to the neighboring glucose carbon number four by a so called α-$(1 \rightarrow 4)$ bond. The monosaccharides link together into long and almost linear starch molecules called amylose. The amylose molecules can then be further linked together into branched amylopectin structures by α-$(1 \rightarrow 6)$ bonds (Stoddard, 2015). These bonds connect carbon atom number one to a neighboring glucose carbon number six, which gives the molecule its branched structure. The branched structure leads to much larger and less soluble molecules.

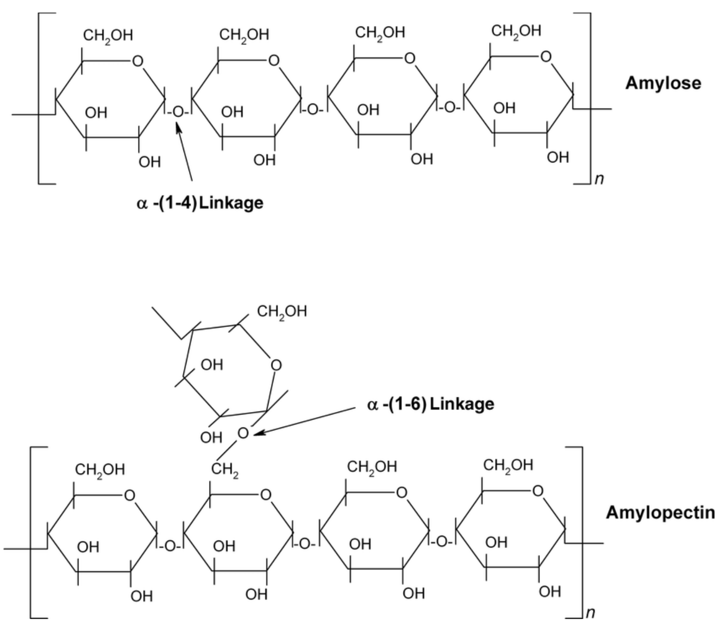

Figure 2: The molecular structure of amylose and amylopectin. (P Mathew et al., 2014)

Starch is the main component in rice and is located inside the white rice in the shape of 2 - 4μm wide polygonal granules (Corke, 2016). A schematic picture of the starch's different levels of organization can be seen in Figure 3. The amylose polymer is not fully linear since it contains of between 2-11 glucose chains linked together through α-$(1 \rightarrow 6)$ bonds making the amylose structure a bit branched. The general amylose polymer consists of about 1000-5000 glucose molecules linked together forming a single helix structure (Stoddard, 2015). It is still considered as a "linear" molecule since its structure is less branched and much less complex than the amylopectin polymer. The amylopectin polymer is one of the largest known polymers in nature, with a possible size of up to 100 000 glucose molecules (Li et al., 2019). The amylopectin complex is starting with a single central C-chain in the middle, there is only one C-chain in each amylopectin molecule, and it acts as a backbone (Stoddard, 2015). This chain is then branched out into multiple longer B-chains. On the B-chains the shortest and outer chains, the A-chains, are attached. An A-chain is a linear and unbranched chain that contains of only 15-30 glucose units (Stoddard, 2015). Together the A-chains and B-chains form double helix structures that align together into crystalline regions, also called lamellae, inside the starch granule. Between the crystalline lamellae in the starch granule, there are amorphous lamellae that consist of branched regions of the amylopectin together with single helix amylose chains. The amorphous lamellae are a non-crystalline region that is much freer in structure.

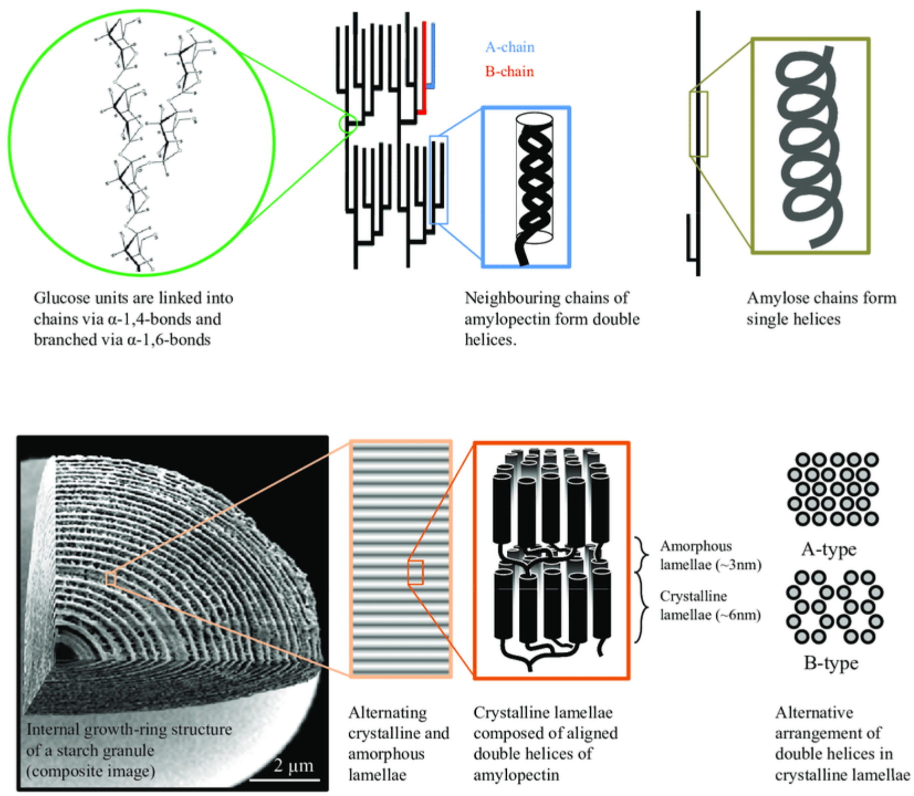

Figure 3: Starch different levels of organization. (Streb & Zeeman, 2012)

2.2.2 Starch gelatinization and retrogradation

When starch is exposed to high temperature in excess water, the starch granules start to swell, and amylose is leaching out of the starch granule. Water is moving into the starch granule and the strong crystalline structure is starting to melt and a gel is formed. This process occurs during boiling and is irreversible. During this process the bonds between the glucose molecules in the polymer chain rupture during an energy-demanding endothermic process (Stoddard, 2015). The temperature where this happens is called the gelatinization temperature and is specific for different types of starch. It is related to the length of the starch chains, the ratio of amorphous and crystalline regions, and to how it is packed inside the starch granule. More specifically, the definition of when the gelatinization temperature occurs is when 98% of the starch granules within the sample have undergone birefringence loss (Muñoz et al., 2015). The rate and loss of birefringence differ depending on starch composition which is why the gelatinization temperature differs between different starches. Birefringence is the phenomenon where a material can split incoming light into two separate rays, and this ability is lost during gelatinization (Yukako Kato, 2018). Starches with a high amylose content generally have a higher starch gelatinization temperature (Yu et al., 2009). During gelatinization, the starch polymer can also form complexes by binding to other components such as proteins and fat which affects the starch properties (Stoddard, 2015).

As the carbohydrate starts to cool down after boiling the starch inside is beginning to reassociate its polymer chains back into a more orderly structure. This process is called retrogradation. Retrogradation of the amylose chains happens fast, about the same time it takes for the starch to cool to room temperature most of the amylose is retrograded. Its linear structure and its small size make the reassociation of the glucose molecules occur faster. In contrast the amylopectin molecule, which is larger and more complex in structure and can take days or weeks to fully retrograde. Retrogradation leads to a thicker viscosity of the starch with a change from soft to more solid properties. During the retrogradation water is expelled from the polymer network which is called syneresis. (Stoddard, 2015)

During gelatinization the amylose molecules can form complexes with lipids. These complexes change the gel strength and can interfere with the retrogradation process and delay staling or hardening of the starch. Dissociation of lipid from amylose absorbs energy and shows as an endotherm reaction that occurs between 102°C and 120°C. Also, interactions between protein and starch can affect the starch retrogradation both positively and negatively. Mainly glutelins can retard the retrogradation process by interfering with its long chain size. (Chang et al., 2021)

Even if amylose is responsible for the immediate retrogradation it creates a start to the crystalline network that affects the crystal growth towards an overall faster retrogradation. It can be seen as if the immediate and fast amylose retrogradation creates a higher baseline generating a firmer consistency already from the start and then the hardening of the starch correlates to the amylopectin retrogradation. The rate and extent of retrogradation is however decided by complex interactions between amylose, amylopectin, protein and lipids and is difficult to estimate. (Yu et al., 2009)

2.3 Analyses

2.3.1 Water Absorption

If rice is boiled until the hard center disappears it is said to be boiled until its optimum time. When this time is reached it is a fact that all rice varieties have absorbed roughly 2.5 times their dry weight in water (Bhattacharya & Sowbhagya, 1971; Juliano et al., 1981). This has been proved in several different studies and is a constant regardless of the other properties of the rice. Generally, the amylose content within the starch correlates positively with good water absorption (Juliano, 2015).

The rate of water-absorption is mainly determined by the amount of surface area available per weight unit of the rice but also the gelatinization temperature plays a role, especially when rice is cooked at lower temperatures. The higher gelatinization temperature of the starch the less water will be absorbed at lower temperatures. Cooking rice in boiling water, at 100°C, means that the temperature is well above the starch gelatinization temperature and therefore the differences in water-absorption rate will not be easily seen. When lowering the temperature to 70°C there will be greater differences in water-absorption rate since some varieties have higher gelatinization temperature than the boiling temperature (Bhattacharya, 2011b).

To measure the true water uptake of a rice variety, the moisture content of the rice needs to be measured before and after boiling. This is made by drying the rice in an oven. A quicker way of measuring the water uptake of rice is by boiling a small sample of rice in a test tube and weighing the sample before and after boiling (Bhattacharya, 2011a). However, this method does not take into consideration the moisture that is already present in the rice before boiling nor the loss of solids that occurs during boiling. However, this method is quick and easy and gives a relative value of apparent water uptake that can be used for comparison between varieties.

2.3.2 Texture Analysis

Sensory properties of a food are closely related to its texture and therefore texture is an important parameter to consider within product development. For measuring texture, a texture analyzer can be used, a machine that uses force to deform a sample and then measures its response against time or distance. One example of a texture analyzer is a TVT 300XP (Perten Instruments, Stockholm, Sweden). This instrument is very versatile and by using different rigs and probes it can be programmed to measure the texture of many different kinds of products. To enable replicability there are also standardized methods available for many types of measurements (TexVol-Instruments).

Single-cycle measurements is the most used for texture analysis while multiple-cycle measurements can be used to test the persistency of a sample towards several compressions (TexVol-Instruments). Cylindrical probes can be used to measure the strength and firmness of a sample, one example is a penetration test. A penetration test can be used to measure the hardness and gel-strength of a product, if the product has a flat surface, a flat cylinder probe between 2-20mm in diameter is a good choice (Stable-Micro-Systems, 2023d). By performing a single-cycle penetration measurement the probe measures the force needed to break through the sample. On the way back the probe can also measure adhesiveness which is the workforce needed to overcome the attractive force between the sample and the probe (Stable-Micro-Systems, 2023c). To measure fracturability a wide but thin blade probe is used together with a three-point bend rig to fracture the sample. The texture analyzer measures the force needed to fracture the sample, the fracture starts when the applied force is greater than the cohesive force within the sample and the sample breaks or shatters (Stable-Micro-Systems, 2023b). A compression test exposes the sample for great forces to a large degree of deformation. The degree of deformation can be set to a certain percentage of the initial sample height and then the amount of force that is needed to deform the sample to the decided degree of deformation, the compressibility, is measured. The graph generated from this type of compression test will go higher and higher as more force is applied and then stop at the selected degree of deformation, the maximum force applied is the wanted value. Compression tests are performed with a flat probe that has a large surface area, either with a wide cylinder probe or a compression plate that matches the size of the sample (Stable-Micro-Systems, 2023a).

2.3.3 Differential Scanning Calorimetry

Calorimetry is used for determining the thermal properties of a reaction process. Differential scanning calorimetry (DSC) is a commonly used type of calorimeter. It is a thermal analysis instrument with the purpose of measuring heat energy change as a function of temperature and time. The sample is heated together with a reference sample inside a small furnace where the amount of heat required for a certain temperature change is measured. This allows to examine how the physical changes and chemical reactions of the sample changes along with the temperature. Both the reference and sample are heated simultaneously at a set linear heating rate. The DSC measures the difference in energy input needed to obtain the same temperature in the sample as in the reference. For example, when a sample of starch is gelatinizing it requires energy and the DSC detects that more energy is needed to be put into the sample pan to match the temperature of the reference pan. This is translated into peak curves that indicates how much and at what temperature the extra energy input was needed. (Gill et al., 2010)

The temperature of where the peak will appear is a function of the heating rate. When measuring on starch it is important to not have a too high heating, not above 15-20°C/min, this because starch gelatinization is time-dependent since swelling of the starch granule during gelatinization takes time to be completed (Xing et al., 2018). Also, the aluminum pan is taking some of the heat and will delay the peak appearance in the results, and with a too high heating rate the peak cannot catch up with the speed and will be further off from the true temperature, giving the result that the higher heating rate the higher the peak temperature will appear (Yu & Christie, 2001). When analyzing starch in a DSC the observed peaks will not only be dependent on heating rate but also on moisture content in the sample and the equipment sensitivity. Nonetheless the factor that mainly determines the starch gelatinization temperature is the starch composition and the ratio of amorphous and crystalline regions inside the starch granule. Therefore, the peaks shown through the DSC measurements should be identical for samples within the same rice variety. Due to differences in growth conditions the ratio of amylose and amylopectin can slightly change making it possible for the DSC results to somewhat differ from batch to batch (Cooper et al., 2008). The software used for the DSC measurements in this thesis makes peaks that go downwards to indicate energy-demanding endothermic reactions such as starch gelatinization. A picture of this can be seen in Figure 4. Peaks that go upwards indicates crystallization, which is the opposite, an exothermic reaction that releases energy. Such reactions in starch could be the formation of hydrogen bonds between the amylopectin molecules or the formulation of amylose-lipid complexes. Sometimes no peaks will show up, indicating that no reactions occurred during the heating that was big enough for the DSC to detect. A picture of a graph with no peaks can be seen in Figure 5. After the measurement the enthalpy is calculated by the area under the peak and translated into J/g of sample. It is wanted to obtain a peak of above 1J/g to know that the reaction had an effect on the sample. For peaks below 1J/g it is difficult to distinguish between noise and actual results, therefore theses small peaks are seen as more coincidental. However, if peaks smaller than 1J/g are seen at the same temperature for multiple replications of the sample these should still be considered, but then a greater knowledge of the sample is required before determining if the peaks are true results.

Water is the volatile compound in a DSC sample and is evaporated around water boiling temperature, therefore it is important that the pan is properly sealed to avoid leakage of water. A picture of a leaked sample pan can be seen in Figure 6. It is wanted to have a closed pan to trap the moisture and ensure that water is present for the starch to gelatinise. When examining dry non-pregelatinized starch samples it is needed to add water to ensure enough water is present for gelatinization. When examining pregelatinized starch water is not always needed to be added since it is can already be present within the sample in adequate amounts. DSC measurements of pregelatinized starch such as boiled rice will indicate if there is any non-gelatinized or retrograded starch present in the sample (Rangelov et al., 2017). When measuring starch, it is normal to use aluminum pans with a heating rate of 10°C/min, where the reference is an empty aluminum pan. The heating temperature interval usually goes from room temperature up to about 185°C to also include dissociation of complexes. (Yu & Christie, 2001).

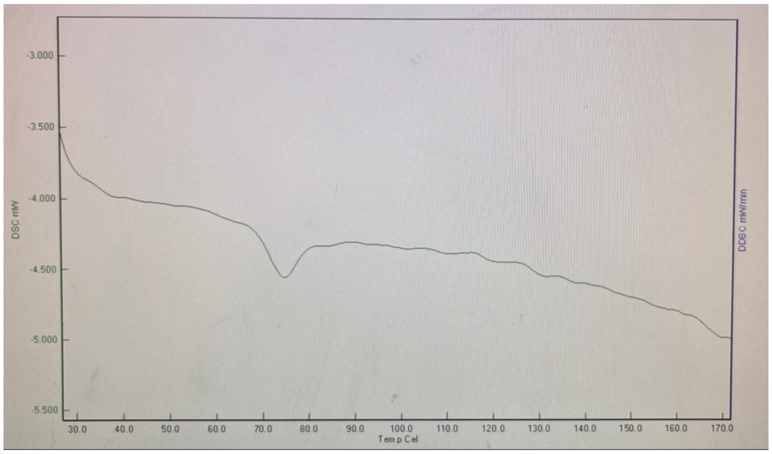

Figure 4: Picture of a DSC graph showing a distinct peak. The x-axis shows temperature in °C and the y-axis shows the heat flow in mW.

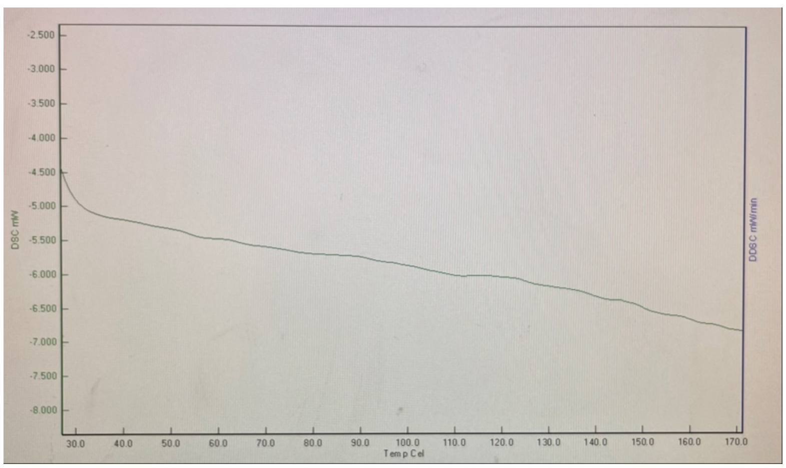

Figure 5: Picture of a DSC graph without any peak. The x-axis shows temperature in °C and the y-axis shows the heat flow in mW.

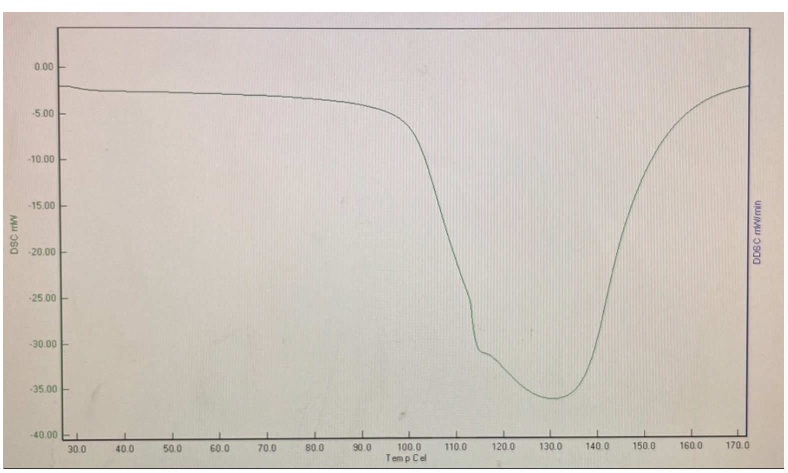

Figure 6: Picture of a DSC graph of a leaked pan. The x-axis shows temperature in °C and the y-axis shows the heat flow in mW

3 Methods and Materials

3.1 Materials

During this work a total of six different polished white rice varieties of Japonica rice were examined, named 1, 2, 3, 4, 5 and 6. The rice varieties differed in country of origin, or time when harvested. The ingredients used for the kitchen-boiled rice puddings were rice, milk, heavy cream, sugar, water, carrageenan, and vanillin. One factory-produced batch of rice pudding produced in January 2023 in the factory of Orkla Foods in Örebro, Sweden, was also examined.

3.2 Microscopy study

To take a closer look at the grains a microcopy study was performed. An Olympus Optical Co. Ltd microscope produced in Japan was used, the lamp inside was a Philips type 7388 with 6V/20W strength that was able to shine through the rice grains. The zoom was set to 1 which was the lowest setting and picture were taken of each rice variety. A group of about 30 rice grains were randomly selected by taking a spoon of rice grains from each bag. The rice was put on a microscope slide and then put in the microscope. An overviewing picture of the 30 grains was taken and from the picture, the overall number of chalky grains within the rice sample was determined. Then five grains of interest from each variety were selected containing of a mix of healthy, chalky, and cracked grains, for more focused pictures and to evaluate their characteristics. These five selected grains included the chalkiest grain, one health grain, another chalky or cracked grain and two randomly chosen grain, all selected from the group of rice grains in the overviewing picture.

3.2.1 Texture analysis of the microscope studied rice grains.

The five selected grains of interest, from each rice variety, were kept separated and put into carefully labeled containers and transported to the texture analyzer (Perten Instruments, Stockholm, Sweden) to fracture the grains. These raw rice grains were broken according to the same settings used for the three-point bend rig test performed on the boiled rice grains during the shelf-life study, that will be described later. Each grains respective hardness was measured and noted down.

3.3 Water content

To determine the water content within the raw samples of the different rice varieties an international standard method from the American Association of Cereal Chemist approved methods (AACC) was used. The method was the 44-19 air-oven method, drying at 135°C, which is applicable to grains such as rice. The polished rice grains were grinded into pieces smaller than 1mm in diameter, the size was controlled by straining the sample, and then 2g (±1mg) of sample was weighted into an aluminum pan. Then the samples were put in a Termarks drying oven at 135°C for 2h. The timer was set once the oven regained a temperature of 135°C after opening the door to put in the samples. After 2h the samples were put in a desiccator to cool for 1h before getting weighted again. The moisture content was then calculated according to equation 1 using the original sample weight and then the weight loss after drying.

$$\% \, moisture = \frac{loss\ of\ moisture \times 100}{weight\ of\ sample} \qquad (1)$$

3.4 Water absorption

The different rice variety's ability to absorb water was determined through a laboratory cooking test, as described by Bhattacharya (Bhattacharya, 2011f) with a slight modification, using 20 rice grains from each variety instead of 1-2g. The rice grains were weighed before being placed into a test tube. The test tube was filled with boiling water to approximately 50% of its volume before a lid was put on. The test tubes were then put into a water bath which held a temperature of 90-95°C. The tubes were in the water bath for 30 minutes (± 15 seconds) with one stirring with a spatula after half the time. After 30 minutes the excess water from the tubes was drained using a sieve and the rice grains were immediately weighted again. The weight gain was calculated as a percentage gain from the original dry weight. For each variety the tests were performed in triplicates and a mean value and standard deviation was calculated.

3.5 Shelf-life study

3.5.1 Kitchen boil of rice pudding

The kitchen-boiled rice pudding was cooked according to instructions received from Orkla Foods. Milk, sugar, and heavy cream were put to boil before rice and a mixture of vanillin and carrageenan was added. All ingredients were then boiled for a total of 30 minutes ± 30 seconds, and every 5 minutes there was manual stirring with a non-stick coated spoon. In the end, water was added to a pre-set total weight of the boiled rice pudding to compensate for the evaporated water during stirring. The pudding was then allowed to cool in room temperature inside the pot with lid on, before being put into sealed and labeled containers in the refrigerator. All batches were boiled in identical pots on the same stove to ensure as equal results as possible. The boiling was performed on two different days, with three rice varieties each day giving in total twelve different batches of rice pudding. The rice puddings were stored in a refrigerator until examined day 1, 5, 10, 15, 22 and 29 after being produced.

3.5.2 Texture Analysis

On the specific days of analysis the samples were taken out from the refrigerator and brought into the texture lab. All texture analyses were performed using a TVT-300XP texture analyzer (Perten Instruments, Stockholm, Sweden) equipped with a 7kg load cell. The results were measured in gram-force where 100 grams is equal to 0.98 newton. During the first and last day of examining the kitchen-boiled rice batches (day 1 and day 29), the first measurements taken were a penetration test of the entire rice pudding, while still being in the container. This was performed while the pudding was still cold from the refrigerator while all other tests were performed on room temperature rice pudding. The analysis was performed in duplicates by a 45mm high and 20mm wide cylinder probe penetrating the pudding while measuring firmness and stickiness. The compression distance was set to 20mm with both initial speed and test speed to 1mm/s and the retract speed to 10mm/s. The trigger force was set to 10g and adhesiveness was measured to a distance above the trigger of -5mm. For the second analysis (the first analysis for days 5, 10, 15, and 22) a three-point bend test was used to measure the firmness of cooked individual rice grains taken form the rice puddings. The whole container of rice pudding was poured into a glass beaker then washed and drained with water 3 times to remove the pudding around the grains. Five grains from each batch were randomly selected and analyzed using a 20mm wide and 2mm thick break probe perfectly fitting in a three-point bend rig setting specially made for rice, see Figure 7. The compression distance was set to 2mm, and both the initial speed and the test speed were set to 1mm/s with a retract speed of 5mm/s. The trigger force was set to 10g and the data collection rate to 200pps, no adhesiveness was measured. After the test, all five grains were put into labeled small containers for further analysis and their respective firmness was written down. The last texture analysis method to be performed was a compression test of the rice grains. Where three randomly selected cooked rice grains from the rice pudding were put on a heavy-duty stand with a plastic table insert and squeezed under a 45mm high and 35mm wide cylinder probe. This was performed according to the Perten instrument method description 51-01.02 (Perten-Instruments) of how to measure firmness for cooked rice, where the rice grains were compressed to 90% of their height with an initial speed and test speed of 0.5mm/s. The retract speed was set to 10mm/s and the trigger force to 5g. Adhesiveness was measured to the trigger distance and the data collection rate was set to 333pps. The method description can be found in Appendix A.6. This measurement was performed in triplicates.

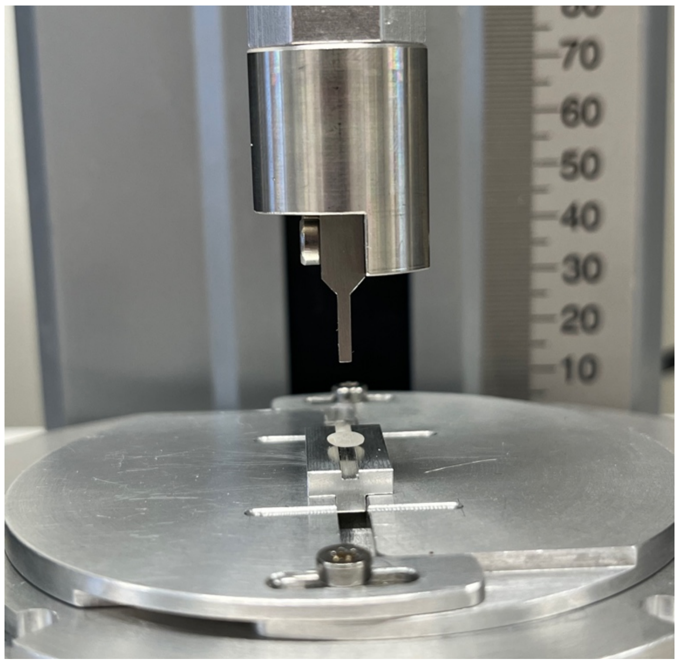

Figure 7: The three-point bend rig for the rice break test

The same analyses were performed on the factory-produced pudding on day 21, 28, 36, 43, 50, and 57 after production. The initial plan was to measure the factory-produced pudding on the same days after production as the measurements for the kitchen-boiled pudding. However, due to the late arrival of the factory-produced pudding in combination with the possibility to only schedule measurements on weekdays this was not possible, and days were chosen as close as possible to the analysis days for the kitchen-boiled pudding. During the tests a duplicate of 2 cups of factory-produced rice pudding was examined. It followed the exact same measurements as the kitchen boiled pudding with the exception that all samples were going through the first pudding penetration test.

3.5.3 Differential Scanning Calorimetry

Three out of the five rice grains from each rice pudding batch that was measured for texture hardness using the three-point bend method were used for DSC analysis. The selected grains were the grain with the lowest firmness, the one with the highest firmness, and the one with the median firmness. From each of the rice grains a small sample of about 5-10mg was collected using spatulas, carefully weighted, and put into the

DSC aluminum pans before being sealed. An empty pan was used for reference. The DSC was programmed to ramp up from 25°C to 200 °C, with a heating rate of 10°C/min. After the DSC run the sample was cooled down before being switched out to the next sample to be analyzed. Then the sample pans were punctured and dried overnight in an oven at 105°C. The day after the pans were weighted again to get the dry weight of the samples.

To get a reference of where the starch gelatinization peaks were expected, DSC analysis was also performed on the raw rice grains. This was performed in the same way with the exception that rice grains were grounded using a mortar with a sample weight of 2mg and 6mg of Milli-Q water.

3.6 Statistical evaluation

The standard deviation was calculated for all obtained results according to equation 2. σ indicates the standard deviation of the examined group and μ is the mean value of the same group, N is the size of the population and x_i represents each value from the population.

$$\sigma = \sqrt{\frac{\Sigma(x_i - \mu)^2}{N}} \qquad (2)$$

For the texture analysis of the raw rice grains outliers were determined by taking the mean value of the population $\pm 3\sigma$. If the examined value was outside of this interval it was deemed an outlier.

The relative standard deviation was calculated for all results from the three-point bend test and the compression test, and was calculated according to equation 3. σ indicates the standard deviation of the examined group and μ is the mean value of the same group.

$$Relative\ standard\ deviation = \frac{\sigma}{\mu} \times 100 \qquad (3)$$

By taking the mean value of the studied population into account the difference in size of the values was eliminated, and the deviation was instead presented as a percentage compared to the value size. Which made it possible to compare deviation between the tests even though the value size was largely different.

For some of the data from the three-point bend test the p-value with 95% confidence level was calculated to see if there was any statistical difference between the measured data.

4 Results and discussion

4.1 Microscopy study

According to the specific analysis reports that arrived with rice types 1, 2, 3, and 4 all had a chalky grain ratio of 1.3-1.5% where the maximum allowed was 6%. For rice varieties 5 and 6 the analysis report from the supplier was not available. Looking at Figure 8 together with the summarized data in Table 1 the level of chalky grains seen in the microscope was slightly higher than what was stated in the supplier analysis report. In this study a chalky grain was calculated as a grain where the opaque area covered 50% or more of the grain. It was not known how the rice supplier counted the chalky grains in the analysis report and therefore the results could differ due to different methods. However, in the industry it is common to calculate rice chalkiness using an image analysis device that calculates the total chalky area compared to the translucent area of the entire rice sample, usually containing about 100g of rice (Lisle et al., 2000). This microscopy study only highlighted a selected group of about 30 rice kernels, which is about 0.5g. The group was randomly selected but could still have given a deceptive picture of the truth. To draw any distinct conclusion that the chalkiness is higher than was given by the supplier a microscopy study on larger volumes needs to be performed. An interesting discovery is that in rice variety 1 there were lot of grains with cracks, which was rarely seen in the other rice varieties. The cracks were mainly transverse cracks that went across the rice grain. This should not affect the end product since it does not significantly affect cooking time or water absorption, but demonstrates that somewhere along the production chain handling of the rice, regarding moisture and drying, had not been perfect (Bhattacharya, 2011d).

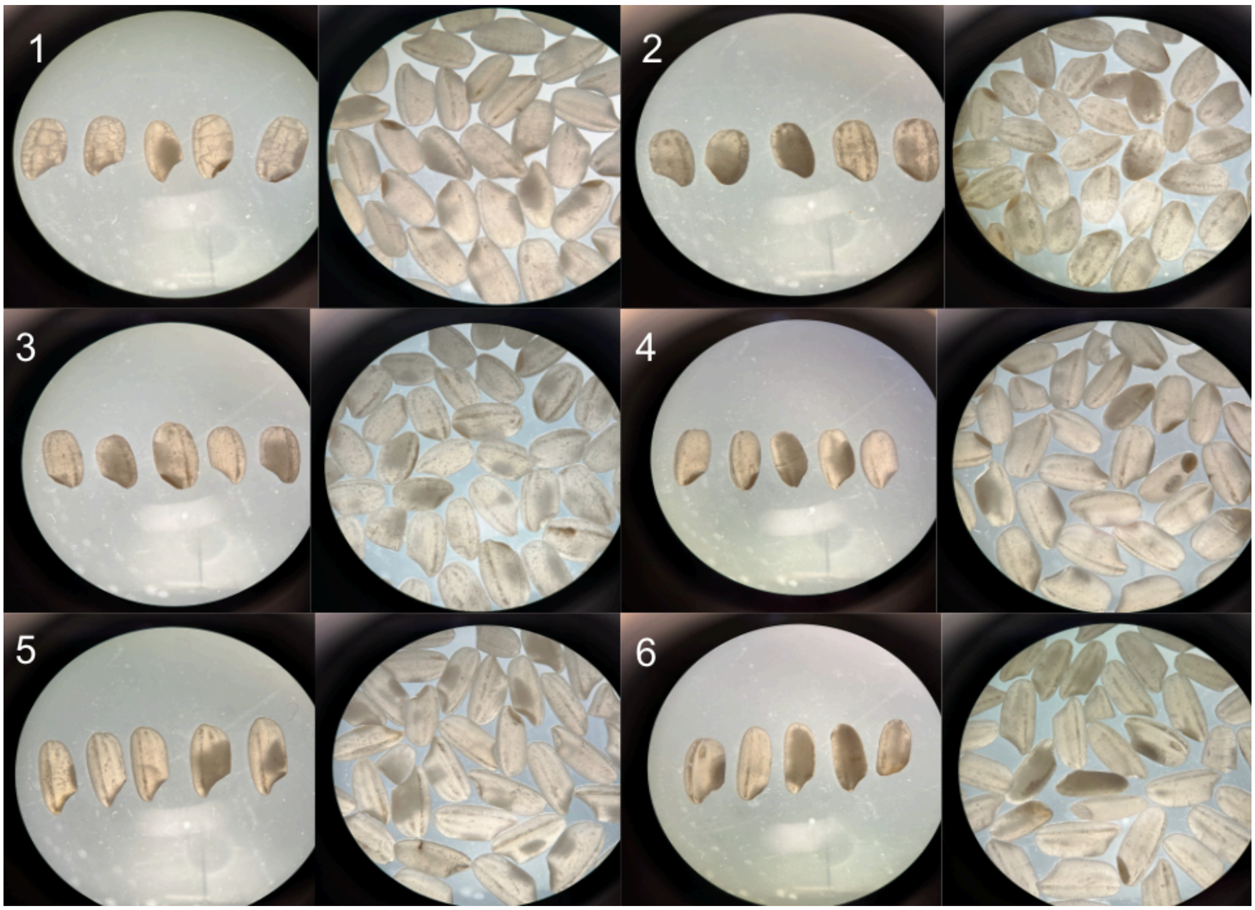

Figure 8: Microscopic pictures of the different rice varieties with light transmission. The number in the corner indicates the number of the rice variety. The right picture of each rice variety is an overall picture of the grain appearance, and the left picture of each variety is of the five selected grains for texture analysis.

Table 1: Summarized table of the number of chalky grains in each rice variety. Chalkiness that covers 50% or more of the grain area, as seen in the microscopic picture, is counted as a chalky grain.

Rice variety	**1**	**2**	**3**	**4**	**5**	**6**
Chalky grains	3	2	2	3	3	3
Total grains	33	33	32	31	32	34

Percentage chalky grains	9%	6%	6%	10%	9%	9%

Comparing the rice grain appearance with the hardness of the respective grain presented in Table 2 there were some correlations. The overall hardness values were lower than what was described in the theory but around the same percentual differences between chalky and healthy grains. The grains were labeled from the left to the right, so the grain furthest to the left in each picture was grain number 1. The five grains were selected so that at least one chalky and one healthy grain were chosen. In rice variety 1 it could be seen that grain 1.3 was the chalkiest one, and it was also the one with the lowest value. When chalkiness was plotted against hardness for each rice variety, rice variety 1 had a linear R^2 value of only 0.40 which does not indicate a good correlation between chalkiness and hardness. This was due to that rice grain 1.4 had a low hardness without any chalkiness, possibly due to the extensive cracking. For rice variety 5, grain 5.2 seemed like a healthy grain under the microscope but only measured 1217g in the hardness test, compared to the highest value within the same variety of 3876g in grain 5.1. Also, in rice variety 4 grain 4.2 seemed healthy but had a low value of hardness compared to the other grains within the same variety. There seemed to be no particular reason for this other than that the grains had some weakness that could not be seen under a microscope. It was not possible to deem any of these as outliers, possibly because of that too few rice grains were tested, which lead to low R^2 values for both rice varieties 4 and 5. Rice varieties 2 and 3 had the highest R^2 values and were said to have a correlation between hardness and chalkiness. Figure 9 shows the graph over chalkiness plotted against hardness for rice variety 3. Correlations between grain appearance, water absorption and water content will be further discussed in the next section.

Table 2: Results from the three-point bend test of raw rice grains. 5 grains from each batch were analyzed. The last column shows the R^2 value obtained when plotting grain chalkiness against grain hardness for each rice variety.

Sample	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	$\mathbf{R^2}$
Hardness (g)	3753	3769	2107	2267	3250	0.40
Sample	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	$\mathbf{R^2}$
Hardness (g)	2698	2805	2098	3424	3017	0.89
Sample	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	R^2
Hardness (g)	5411	2665	5145	3738	2699	0.68
Sample	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	$\mathbf{R^2}$
Hardness (g)	2398	1895	2299	2843	2101	0.20
Sample	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	$\mathbf{R^2}$
Hardness (g)	3876	1217	3232	2048	2873	0.01
Sample	**6.1**	**6.2**	**6.3**	**6.4**	**6.5**	$\mathbf{R^2}$
Hardness (g)	5200	3491	1615	1391	1788	0.54

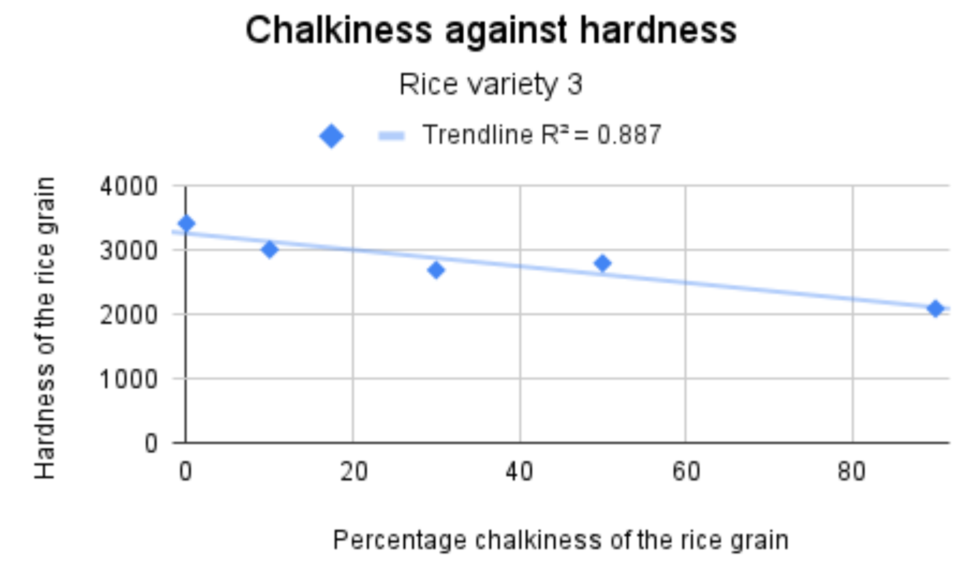

Figure 9: Graph showing grain chalkiness plotted against grain hardness for rice variety 3. Including a trendline showing the R^2 value.

4.2 Water content

The results from the water content measurement are presented in Table 3 as mean values with standard deviation from the triplicates performed on each rice variety. The raw data can be found in Table 13 in Appendix A.1. All rice varieties presented a water content of below 13% which is within the optimal storage range indicating a water activity below 0.65 that is very unfavorable for growth of spoilage microorganisms. According to the specific analysis report available for rice varieties 1, 2, 3, and 4 all varieties presented lower water content than stated by the supplier.

Table 3: Water content within the different rice varieties presented as mean values together with standard deviation. Obtained from drying raw rice samples in an oven at 135°C for 2h.

Rice variety	**1**	**2**	**3**	**4**	**5**	**6**
Water content	12.71% ± 0.11%	11.54% ± 0.07%	12.08% ± 0.09%	12.62% ± 0.06%	12.57% ± 0.05%	12.14% ± 0.57%

The microscopy study showed that rice varieties 2 and 3 had the lowest number of chalky grains and these two types also showed the lowest water content. Chalky grains have loosely packed starch molecules that could allow water to easier penetrate the rice grain and allow for higher water content. The other rice varieties had similar ratios of chalky grains to each other, where variety 4 had the highest number of chalky grains but only the second-highest water content. The only rice variety with higher water content was variety 1, this could be explained by that this was the only rice variety that showed a lot of cracks in the grains. Cracks within the rice allow for water to easier penetrate the grain and resulting in a higher water content. The water content within the rice was therefore said to be positively correlated to grain chalkiness and cracking.

4.3 Water Absorption

The amount of water absorbed by the rice batches correlated to the firmness of the rice kernels. In this test the rice was boiled in 90-95°C water which differed from the cooking of the rice pudding which was boiled in slightly higher temperatures. This due to that the water bath couldn't hold a higher temperature. For next time maybe another boiling media inside the water bath should be used. During the test the rice was boiled in water, which also differed from the milk mixture in the rice pudding recipe. Even if the parameters were not the same as in full-scale production, all batches were examined using the same method and the results should still be comparable to each other. The results from the water absorption test are shown in Table 4, raw data can be found in Table 14 in Appendix A.2. As mentioned according to Bhattacharya (2011f) it is a fact that all rice absorbs about 2.5 times their weight of water when the rice is fully cooked. This corresponds to 250% in the water uptake measurements performed in this study, and all rice varieties seemed to be fully cooked since all values were around 250%. Rice variety 1 had the lowest water absorption of 228%. Amylose content correlates with the rice's ability to absorb water and the results indicates that rice variety 1 had the lowest amylose contents while rice varieties 2 and 3 contained the most amylose (Juliano, 2015).

Table 4: Results from the water absorption test obtained by boiling raw rice samples in test tubes for 30min. The test was performed in triplicates and the mean values are presented together with standard deviation.

Rice variety	Mean water absorption
1	228% ± 4.0%
2	264% ± 7.6%
3	264% ± 9.3%
4	237% ± 18%
5	259% ± 9.6%
6	252% ± 9.3%

The higher the water uptake, the higher firmness could be seen during storage. Figure 10 shows a plot of water absorption against the highest obtained mean firmness of the boiled rice grains of each rice variety from the three-point bend test. The trendline gives a R^2 value of 0.95 and an evident correlation between firmness and water uptake could be seen. Higher amylose content leads to increased firmness of the rice grain which confirms the hypothesis that rice variety 1, which had the lowest water absorption and the lowest firmness of the boiled rice grains, would have the lowest amylose content (Yu et al., 2009).

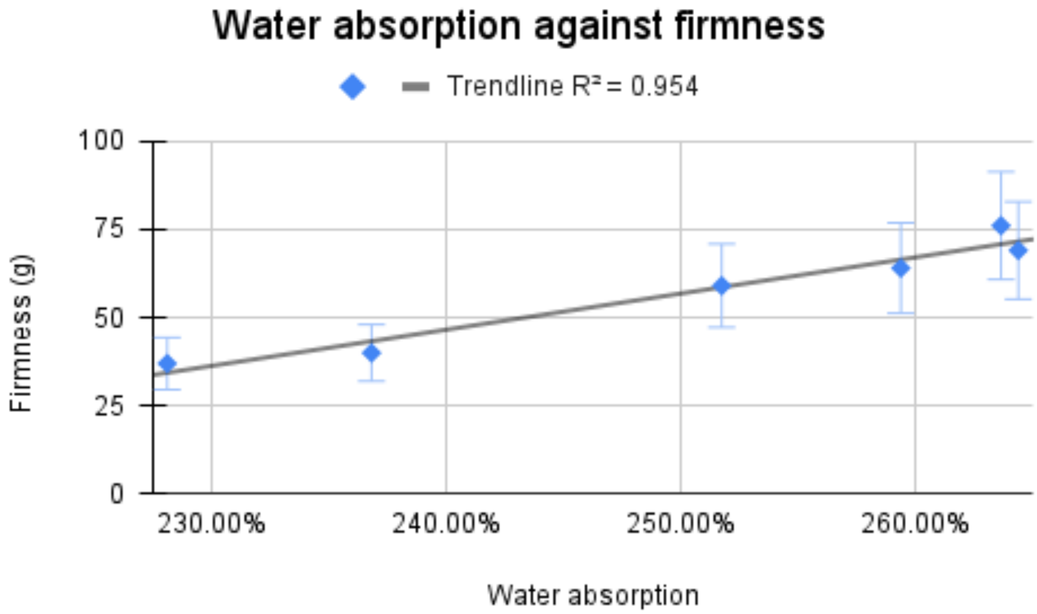

Figure 10: Plot over water absorption against firmness. Trendline showing correlation between water absorption and the highest mean firmness value from each rice variety for the three-point bend test.

It should be noted that the results are showing the apparent water uptake and not the true water uptake. To get the true water absorption, the moisture contents of the cooked and dried rice must be compared, and not only their respective weight. The difference is that the apparent water uptake does not take into consideration the dry rice's original water content nor the loss of solids during cooking. The apparent water uptake gives a value that is different from the truth but still comparable between the rice varieties.

Searching for correlations between water absorption and water content, rice varieties 1 and 4 had the highest water content while showing the lowest water absorbing ability. This also correlated with the other rice varieties where rice varieties 2 and 3 had the highest water absorption ability together with the lowest water content. Rice varieties 5 and 6 were in the middle on both tests. Water content in the raw rice was therefore said to be negatively correlated to water absorption ability.

4.4 Shelf-life study

4.4.1 Texture Analysis of the kitchen-boiled rice pudding

The results from the pudding penetration test performed on day 1 and 29 are presented in Table 5. The raw data can be found in Table 17 in Appendix A.3.3. This test was performed to see if there would be any differences in the overall firmness of the pudding after 29 days of storage. Looking at the mean values for each rice variety, all varieties get lower firmness with time. As a comparison the percental lowering of firmness was calculated according to equation 4 below.

$$((texture\ day\ 1 - texture\ day\ 29\ )/texture\ day\ 1\ )\ \times\ 100 \qquad (4)$$

The highest reduction of firmness was seen in rice variety 6 while rice variety 1 had the lowest reduction of firmness. On day 29 puddings from rice varieties 5 and 6 had indications of mold on the pudding surface, which not the other varieties had, therefore the reason for the greater reduction in firmness could be due to degradation caused by spoilage microorganisms. The added stabilizer, carrageenan, was added as a powder combined with the vanillin. The powder was well mixed before adding but there was a possibility that the ratio of carrageenan could differ between the different varieties of rice pudding and then give a difference in the stability of the pudding, which could affect the penetration test results. Also, due to syneresis water is released from the rice grains into the pudding which migrates upwards in the container. Since the penetration test only measured the first centimeters of the rice pudding it was a possibility that reduction of firmness could be because of the migrated water.

Table 5: Mean values from the pudding penetration test measuring firmness, a higher value indicates higher firmness. The data is presented per rice variety together with the standard deviation. All values are presented in grams. The last row shows the percentual decrease of pudding firmness from day 1 to day 29.

Variety	1	2	3	4	5	6
Day 1	267 ± 43.0	271 ± 24.0	259 ± 47.4	253 ± 14.2	215 ± 4.6	257 ± 14.7
Day 29	260 ± 13.1	257 ± 37.2	239 ± 33.1	243 ± 15.9	174 ± 17.5	198 ± 15.9
% Decrease	2.35%	5.26%	7.81%	4.05%	19.21%	22.71%

The three-point bend test results are shown in Figure 11. The figure shows the mean value of all five replicates of both batches within that rice variety, together with bars of standard deviation. The raw data is presented in Table 15 in Appendix A.3.1 together with Figure 21 showing all batches.

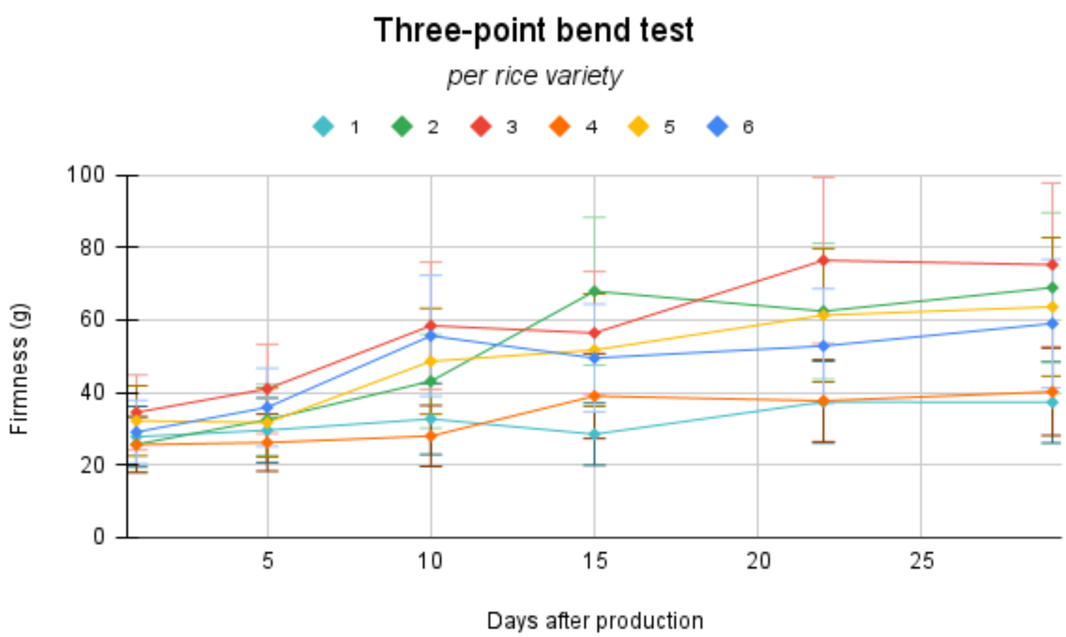

Figure 11: Results from the three-point bend test presented per rice variety. The data are presented as mean values with standard deviation bars, each color represents a different rice variety.

Figure 12 display the results from the compression test. The values are mean values from the triplicates of both batches within the rice variety. The raw data of all batches can be seen in Table 16 and Figure 22 in Appendix A.3.2.

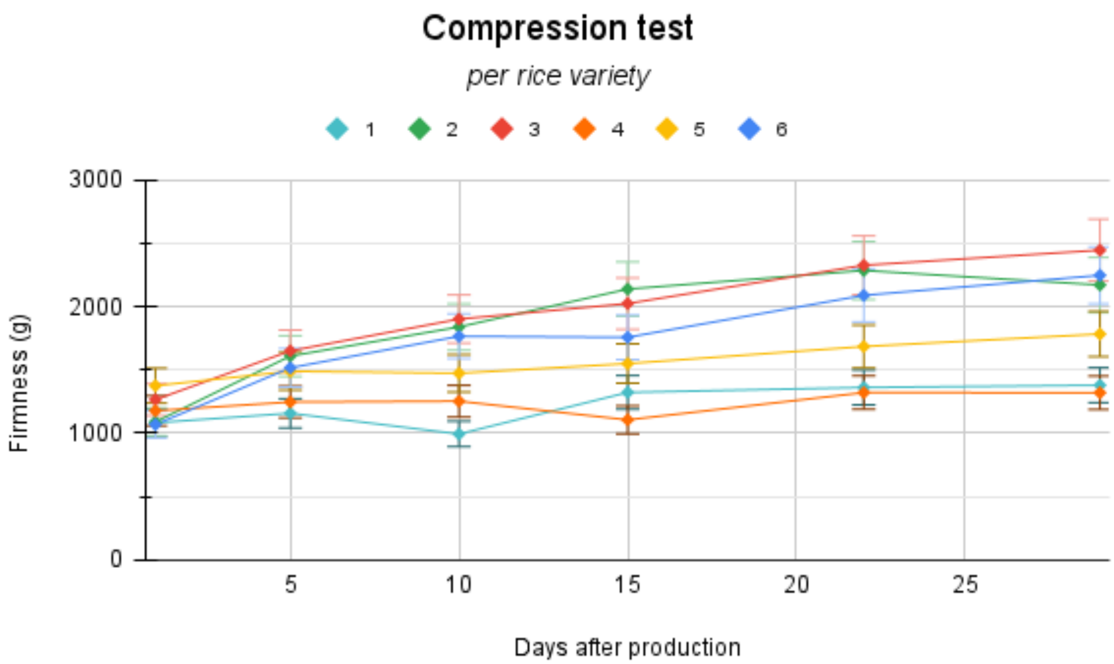

Figure 12: Results from the compression test presented per rice variety The data are presented as mean values with standard deviation bars, each color represents a different rice variety.

Looking into the graphs over the texture analysis results in Figure 11 and Figure 12, all samples increase in firmness over time, something that was also expected. The firmness values for both the three-point bend test and the compression test, together with the standard deviation and a percentual increase of firmness, can be seen in Table 6 and Table 7. There were differences in the firmness increase between the samples, where varieties 2 and 3 were resulting in a firmer pudding than varieties 1 and 4, while varieties 5 and 6 were somewhere in between. This correlated well with the results that Orkla Food had seen in the factory. Even if it was not fully investigated within this project it could also be mentioned that the only rice varieties that clearly showed syneresis during the shelf-life study were varieties 2 and 3. With a layer of water on top of the pudding when the container was opened.

Table 6: Firmness results from the three-point bend test presented together with standard deviation. Data are presented as the mean value per rice variety and the bottom row includes the percentual firmness increase over the entire storage period.

	1	2	3	4	5	6
Day 1	28 ± 12	26 ± 9	35 ± 15	26 ± 9	32 ± 9	29 ± 5
Day 5	30 ± 9	33 ± 15	41 ± 10	26 ± 8	32 ± 1	36 ± 10
Day 10	33 ± 14	43 ± 20	58 ± 25	28 ± 7	49 ± 16	56 ± 12
Day 15	29 ± 8	68 ± 25	56 ± 16	29 ± 6	52 ± 14	50 ± 23
Day 22	37 ± 10	62 ± 25	76 ± 28	38 ± 8	61 ± 24	53 ± 16
Day 29	37 ± 14	69 ± 25	75 ± 22	40 ± 11	64 ± 21	59 ± 19
Percentual increase in firmness	34.2%	168.1%	118.0%	57.0%	97.5%	102.7%

Table 7: Firmness results from the compression test presented together with standard deviation. Data is presented per rice variety and the bottom row includes the percentual firmness increase over the entire storage period.

	1	2	3	4	5	6
Day 1	1083 ± 129	1090 ± 94.0	1265 ± 66.0	1178 ± 132	1375 ± 153	1069 ± 115
Day 5	1158 ± 129	1609 ± 164	1650 ± 103	1247 ± 112	1489 ± 224	1516 ± 83.0
Day 10	994 ± 49.0	1838 ± 112	1900 ± 213	1253 ± 165	1473 ± 139	1765 ± 160
Day 15	1322 ± 134	2137 ± 170	2023 ± 142	1106 ± 41.0	1550 ± 250	1757 ± 297
Day 22	1361 ± 225	2284 ± 256	2325 ± 178	1321 ± 107	1684 ± 152	2088 ± 135
Day 29	1379 ± 114	2169 ± 242	2444 ± 147	1320 ± 106	1783 ± 112	2246 ± 129
Percentual increase in firmness	27.3%	99.0%	93.2%	12.1%	59.6%	87.0%

The relative standard deviation for the firmness values from the three-point bend test and the compression test is seen in Tables 8 and 9. The reason for calculating the relative standard deviation was to be able to compare the three-point bend test and the compression test for the boiled pudding rice grains. The relative standard deviation for the three-point bend test was much greater than for the compression test indicating that the compression test was more stable and reliable. This was expected since the three-point bend test only examined one rice grain at a time while the compression test squeezed three rice grains at once, distributing the inequalities over more samples. The big numbers in relative standard deviation for the three-point bend test clearly show that there was a big individual difference in firmness between the rice grains within the same variety. To lower the relative standard deviation for the three-point bend test a large number of replicates would be needed. This would make it a rather time-consuming test and not very appropriate for a quick estimation of the grain firmness in a rice pudding batch. The compression test gave more replicable values and fewer replicates were needed to obtain a stable value with a low relative standard deviation.

Table 8: Firmness results from the three-point bend test presented together with relative standard deviation. Data is presented per rice variety.

	1	2	3	4	5	6
Day 1	28 ± 43%	26 ± 33%	35 ± 43%	26 ± 33%	32 ± 28%	29 ± 17%
Day 5	30 ± 30%	33 ± 46%	41 ± 24%	26 ± 31%	32 ± 34%	36 ± 29%
Day 10	33 ± 42%	43 ± 47%	58 ± 43%	28 ± 25%	49 ± 32%	56 ± 22%
Day 15	29 ± 28%	68 ± 37%	56 ± 28%	29 ± 15%	52 ± 27%	50 ± 47%
Day 22	37 ± 26%	62 ± 40%	76 ± 37%	38 ± 21%	61 ± 39%	53 ± 31%
Day 29	37 ± 36%	69 ± 36%	75 ± 30%	40 ± 27%	64 ± 33%	59 ± 32%

Table 9: Firmness results from the compression test presented together with relative standard deviation. Data is presented per rice variety.

	1	2	3	4	5	6
Day 1	1083 ± 12%	1090 ± 9%	1265 ± 6%	1178 ± 11%	1375 ± 11%	1069 ± 11%
Day 5	1158 ± 11%	1609 ± 10%	1650 ± 6%	1247 ± 9%	1489 ± 15%	1516 ± 5%
Day 10	994 ± 5%	1838 ± 6%	1900 ± 11%	1253 ± 13%	1473 ± 9%	1765 ± 9%
Day 15	1322 ± 10%	2137 ± 8%	2023 ± 7%	1106 ± 4%	1550 ± 16%	1757 ± 17%
Day 22	1361 ± 17%	2284 ± 11%	2325 ± 8%	1321 ± 8%	1684 ± 9%	2088 ± 6%
Day 29	1379 ± 8%	2169 ± 11%	2444 ± 6%	1320 ± 8%	1783 ± 6%	2246 ± 6%

Overall, the results from the three-point bend test and the compression test correlated well and gave the same general picture. Looking at the percentual increase of firmness in Table 6 and Table 7 rice variety 2 had the highest increase in firmness even if rice variety 3 showed the highest value of firmness by storage day 29. Retrogradation leads to increased firmness in rice, which could indicate that rice variety 3 had more immediate retrogradation, since this variety also had the highest firmness already on day 1, while rice variety 2 had an overall higher retrogradation over the storage period. Since amylose is responsible for both the immediate retrogradation and an overall higher retrogradation, both varieties 2 and 3 shows indications of high amylose content (Yu et al., 2009). The rice variety giving the highest value of firmness is the least wanted in the rice pudding production. The firmness increase is the greatest for variety 2 which should be taken into consideration since the shelf-life of factory-produced rice pudding is longer than 29 days and the firmness of variety 2 could increase to above the values for variety 3. Since it was not studied what happened past day 29 anything could occur but looking at both the firmness values and the tendencies for firmness increase, rice varieties 1 and 4 was considered the best option for rice pudding production. If firmness is connected to retrogradation this would indicate a lower amylose content in varieties 1 and 4 compared to varieties 2 and 3 (Yu et al., 2009). Or that variety 1 and 4 have more free lipids present for the formation of amylose-lipid complexes, or contains higher amounts of glutelin, both of which can limit retrogradation and result in less firm grains (Chang et al., 2021).

Both varieties 5 and 6 showed tendencies for further increase in firmness on the last day of storage. However, variety 5 was deemed to be a better option for rice pudding production than rice variety 6 due to its overall lower increase in firmness. Also, variety 5 shows lower firmness values in the compression test which was said to be the more trusted method.

Looking at the three-point bend test results some data points stood out where the first data point generated a higher value than the later data point which indicated that the firmness of the grains decreased until the next week. This was not a likely result and was more likely due to errors or that the method was not good enough. The data points that had this pattern were examined using a p-test with a 95% confidence level, all showed a p-value > 0.05 and were therefore considered not significantly different. The results were likely affected by that sometimes the random selection of five grains resulted in overall firmer grains and sometimes in softer grains. A likely theory when looking at the big spread in firmness from the overall high numbers for standard deviation.

4.4.2 Texture analysis of the factory-produced rice pudding

The results from the pudding penetration test for the factory-produced rice pudding are presented in Table 10. The raw data can be found in Table 20 Appendix A.4. The pudding stayed stable during the entire period and there was no change in firmness from day 21 to day 57. Compared to the penetration results that were obtained for the kitchen-boiled pudding the factory-produced pudding was much more consistent in firmness. Most likely because the pudding was packed in a controlled environment inside a filling machine with limited contamination that could increase the degradation rate. The added amount of the stabilizing factor, carrageenan, during factory production, was more controlled than during the kitchen boil, which could affect the pudding's ability to stay stable. Also, the recipe, boiling temperature and boiling time differs. The recipe for the kitchen-boiled pudding was made as similar as possible to the factory production process but there were still some differences between both productions that could affect the pudding's stability.

Table 10: Mean value from the pudding penetration test performed on the factory produced pudding, the left column indicates storage day after production.

	Firmness (g)
Day 21	129 ± 6
Day 28	126 ± 9
Day 36	126 ± 3
Day 43	129 ± 4
Day 50	124 ± 3
Day 57	128 ± 1

The results from the three-point bend test of the cooked rice grains inside the factory-produced pudding are presented in Figure 13. The presented results are mean values from the five replicates performed on each of the puddings, the raw data can be found in Table 18 in Appendix A.4.

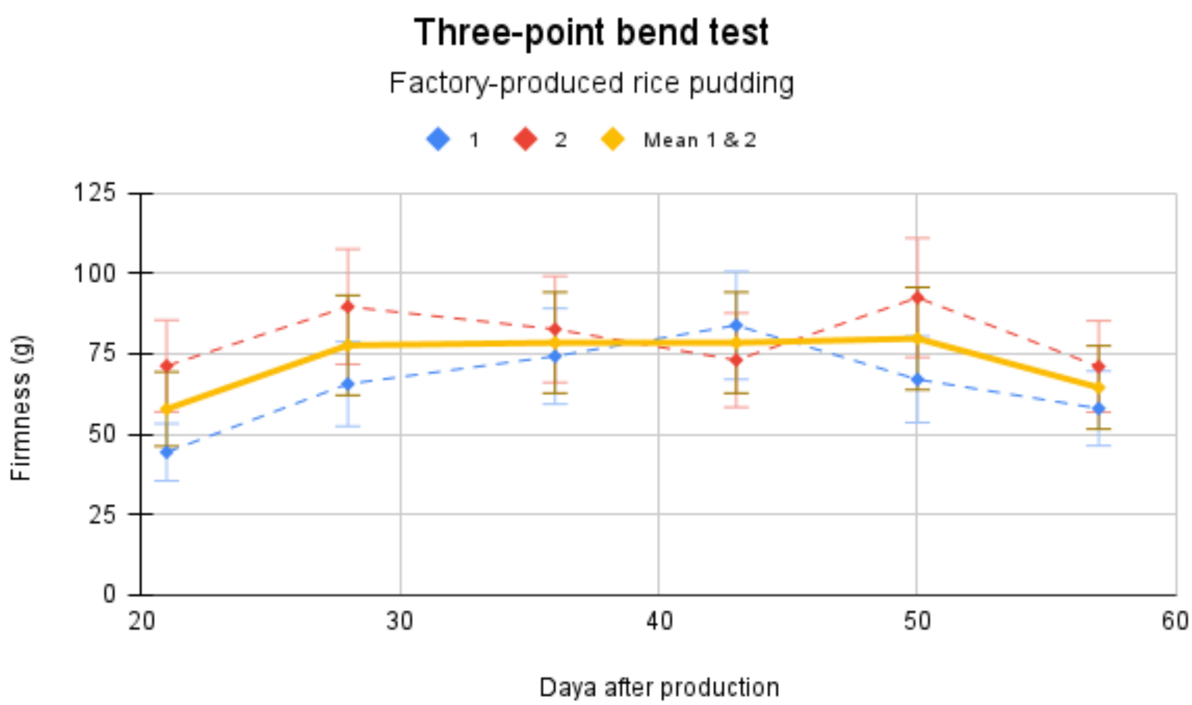

Figure 13: Results from the rice three-point bend test on the cooked rice grains of the factory produced rice pudding. The dotted lines represent the different replicates, the full yellow line is a mean value of both.

The results from the compression test for the cooked rice grains inside the factory-produced pudding are shown in Figure 14. The data are mean values from the performed triplicates from both puddings 1 and 2. The raw data from the compression test can be found in Table 19 in Appendix A.4.

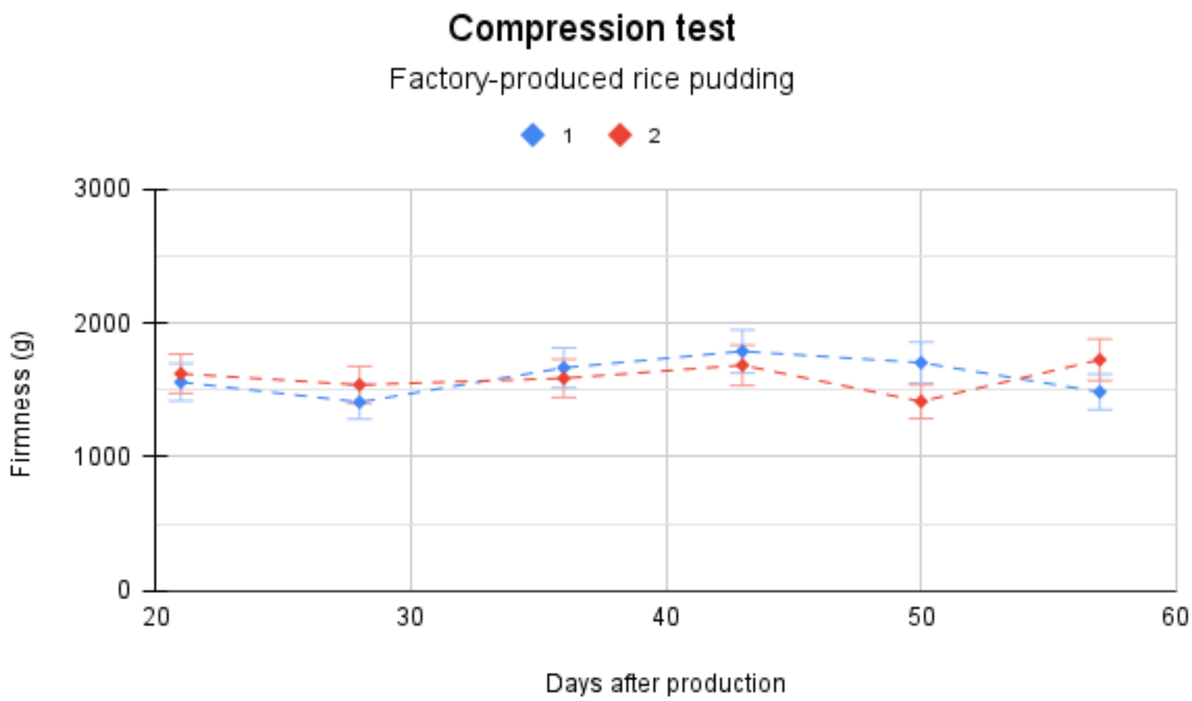

Figure 14: Results from the compression test on the cooked rice grains from the factory produced rice pudding. The dotted lines represent the different replicates.

Due to the late analysis start the results only shows firmness of the grains from storage day 21 to day 57. In Figure 13 the yellow line shows the mean firmness value of both sample 1 and 2 for the three-point bend test. It highlights that even if the two replicated did not follow each other perfectly, the overall firmness was rather constant throughout the studied storage period. The firmness results from the compression tests also gave a rather constant firmness. The shelf-life of the factory produced rice pudding had already expired during the last day of storage. The expiration date was set there for a reason and after this date, it is not a surprise if the grains start to lose their structure and begin to degrade, which could be a reason for the lowering in firmness seen in both tests around this time.

Looking at the values from both the three-point bend test and the compression test shown in Table 11 the firmness values from storage day 21 did not differ much from the firmness values from day 57. This indicates that the rice pudding already after 21 days had reached a rather stable firmness of the rice grains. Which, when putting firmness in relation to retrogradation, could be an indication that most starch was already retrograded by day 21 and the retrogradation rate after that was slowed down.

Table 11:Firmness results from both the three-point bend test and the compression test for the factory produced rice pudding. Data is presented in grams together with the standard deviation.

	Three-point bend test	Compression test
Day 21	58 ± 22	1590 ± 114
Day 28	78 ± 26	1474 ± 172
Day 36	78 ± 21	1626 ± 133
Day 43	78 ± 22	1736 ± 276
Day 50	80 ± 21	1559 ± 232
Day 57	65 ± 19	1605 ± 352

4.4.3 Comparison of kitchen-boiled rice variety 5 and factory-produced rice pudding

The factory-produced rice pudding was made from rice variety 5. A comparison of the results from the three-point bend test for the boiled rice grains from rice variety 5 and the factory-produced rice pudding can be seen in Figure 15. A comparison of the results from their respective compression test results can be seen in Figure 16. This is to see if conclusions from tests performed on the kitchen-boiled rice grains could be applied to the factory-scale production. Both rice puddings showed similarities with each other, especially in the three-point bend test where the results from the factory-produced pudding looked like an extension of the results from rice variety 5. For the triple compression test, the analysis of the rice grains from the kitchen-boiled pudding tended to result in slightly higher firmness values than for the factory produced pudding. However, due to short overlap in storage time and the fact that both tests had rather high standard deviations it was not possible to conclude if the kitchen-boiled pudding behaved in a similar matter as the factory-produced pudding or not. To do so it would be suggested to do another test on the factory-produced pudding starting from day 1after production to really see if the trends were matching.

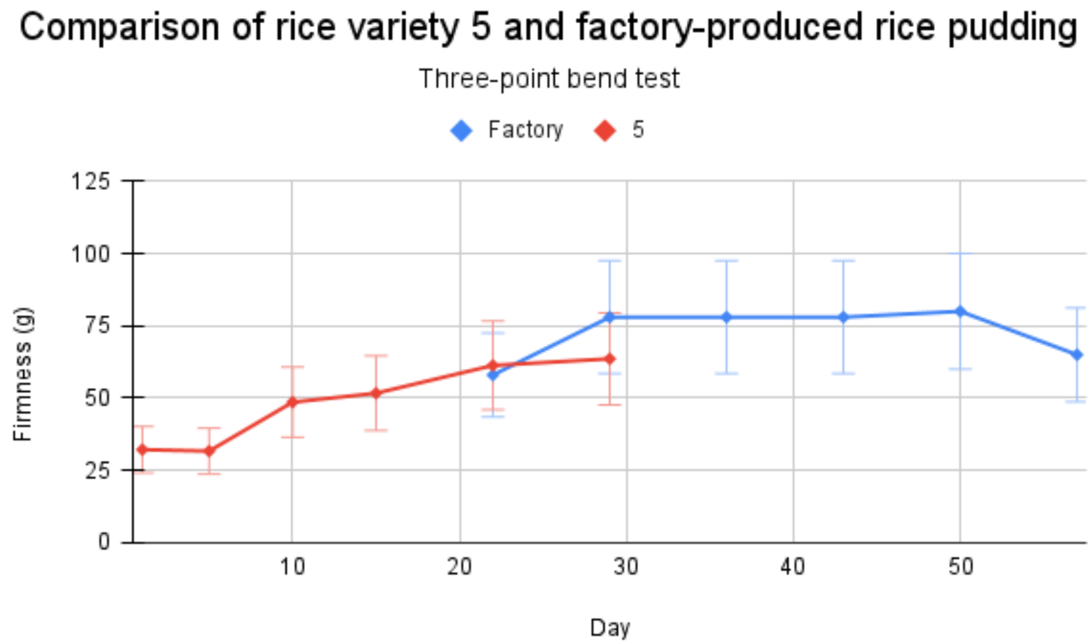

Figure 15: Comparison of the three-point bend test results between factory-produced pudding and kitchen-boiled pudding from rice variety 5, performed on single rice grains. The data is presented as mean values from the tests together with standard deviation bars.

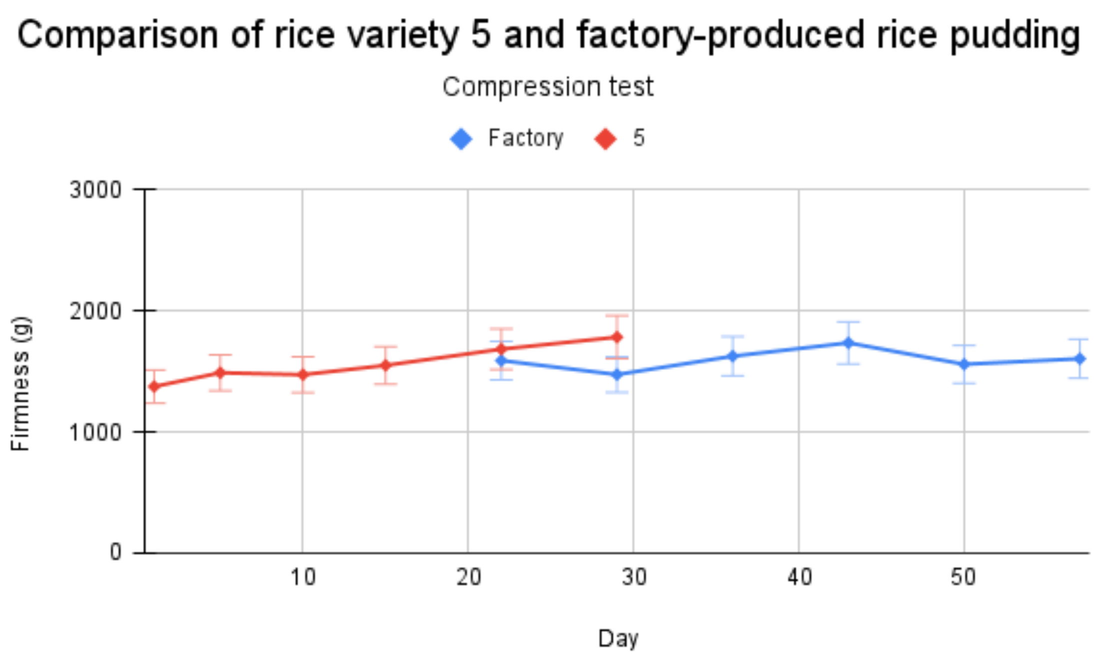

Figure 16: Comparison of the compression test results between factory-produced pudding and kitchen-boiled pudding from rice variety 5, performed on single rice grains. The data is presented as mean values from the tests together with standard deviation bars.

4.4.5 Differential Scanning Calorimetry

Table 12 show peaks from the DSC measurements performed on the raw rice, where all samples showed a distinct peak for starch gelatinization. The mean peak temperature of each rice variety was calculated, and around this temperature it was expected to see peaks in the DSC measurements for the boiled rice grains as well. It was known that amylose gave a tendency towards a higher gelatinization temperature (Yu et al., 2009). According to this test then rice varieties 2, 3, and 6 would have a higher amylose content, and varieties 1 and 4 would have the lowest, while variety 5 would have an amylose content somewhere in-between, which correlates to the conclusions drawn earlier.

Table 12: Results from DSC measurements performed on raw rice grain samples showing gelatinization temperatures (Tp) and enthalpies (ΔH) together with standard deviations.

Rice variety	ΔH (J/g)	Tp (°C)
1	2.24 ± 1.48	67.4 ± 0.6
2	4.86 ± 1.24	74.7 ± 0.1
3	5.83 ± 1.35	73.3 ± 0.2
4	4.43 ± 1.10	66.9 ± 0.9
5	5.27 ± 0.32	70.1 ± 0.3
6	4.21 ± 0.93	76.7 ± 0.7

The protein that was present in the rice had denaturation temperatures below 100°C, but since the pudding had been boiled and reached temperatures of about 100°C before the test these should already have been denatured and not shown as a peak. The starch inside the boiled rice puddings were expected to be mostly gelatinized during the first day of the shelf-life study and no peaks were expected in the DSC measurements. The size of the peaks around the starch gelatinization temperature was expected to increase in size with increased storage time due to the re-crystallization of the amylopectin. Looking at Figure 17, which represents the number of peaks detected below 100°C for all samples, there were only a few and then very small peaks detected and there were no clear indications of starch retrogradation in any of the rice varieties. All peaks that had an enthalpy above 0.5J/g were counted as true peaks to evaluate all retrogradation tendencies. It should also be mentioned that of the total 28 peaks detected below 100°C less than one-third (8 peaks) had an enthalpy value above 1J/g. Meaning that possible conclusions should be drawn with caution. A total of six samples were analyzed for each rice variety on every day of analysis. Towards the end of the shelf-life study it was therefore expected to have a result with six peaks from each rice variety, indicating retrogradation in all samples, to compare against each other. This was not the case since most samples did not give any peaks at all. The samples that gave a peak during day 1 could indicate that the rice variety was not completely gelatinized during the boiling and would need longer boiling time to fully gelatinize. Only rice variety 2 showed peaks on every day of analysis, however, the biggest peak size occurred during day 10 with a value of 1.45J/g, while all the other peaks below 100°C were smaller in size and the majority with a size below 1J/g. Although the texture analysis indicated an increase in firmness during storage, it could not be confirmed for any of the rice varieties that this depended on starch retrogradation, due to inconsistency in the DSC results. A possible source of error that could have led to the overall weak DSC results could be the small sample size. Since only some of the starch present within the sample would be retrograded this amount could be very low and difficult to detect. What part of the rice grain selected for the measurement was randomized since the grain was already broken it was difficult to sample from the same part. What part of the grain the sample was taken from could affect the DSC results by depending on the amount of water and retrograded starch present in the sample.

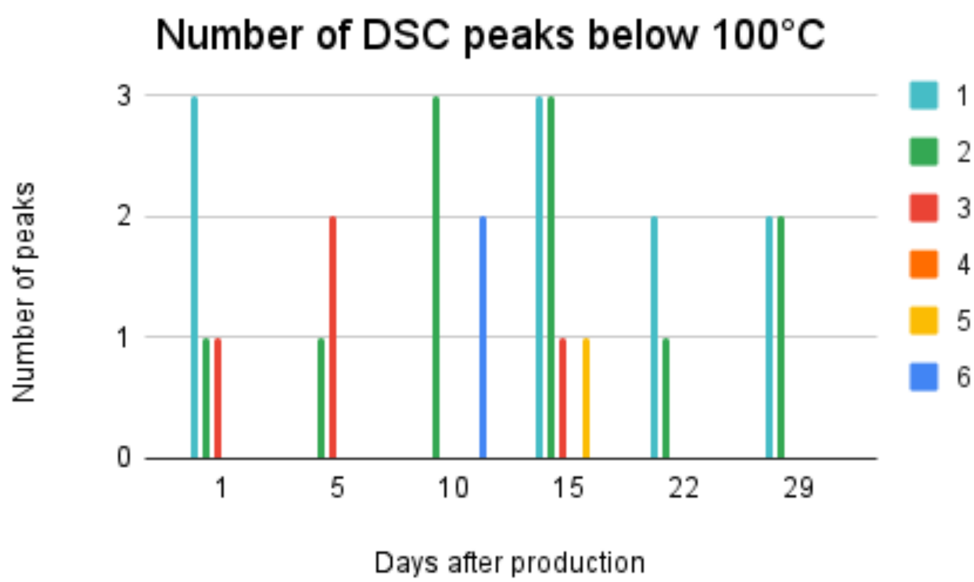

Figure 17:Number of DSC peaks detected below 100°C for each rice variety on each analysis day. Each color represents a different rice variety.

Amylose-lipid complexes melts between 102-120°C (Chang et al., 2021). Figure 18 shows the number of peaks detected between 100-120°C for all samples and indicates the melting of amylose-lipid complexes. About one third (16 peaks) out of the total 49 peaks detected for all samples between 100-120°C had an enthalpy higher than 1J/g. The rice variety with the highest number of samples showing peaks within the temperature range was variety 5 with a total of 12 peaks throughout the entire shelf-life study period, while rice number 3 had the fewest with only 6 peaks. Indicating that rice variety 5 had more amylose-lipid complexes than rice variety 3. Amylose-lipid complexes delay retrogradation (Chang et al., 2021). Looking at the compression test results in Table 7 the rice grains from variety 5 stayed rather stable in firmness for the first two weeks of storage, while rice kernels from variety 3 started to increase in firmness rather heavily already from the first day. This could be an indication that rice variety 3 had faster retrogradation while rice variety 5 had a more delayed retrogradation process. This was in line with the DSC results that rice variety 5 had a better ability to form amylose-lipid complexes which could give a more delayed retrogradation process. However, there are many factors affecting the retrogradation process with complex interactions and the formation of amylose-lipid complexes cannot be seen as the sole reason for differences in retrogradation rate.

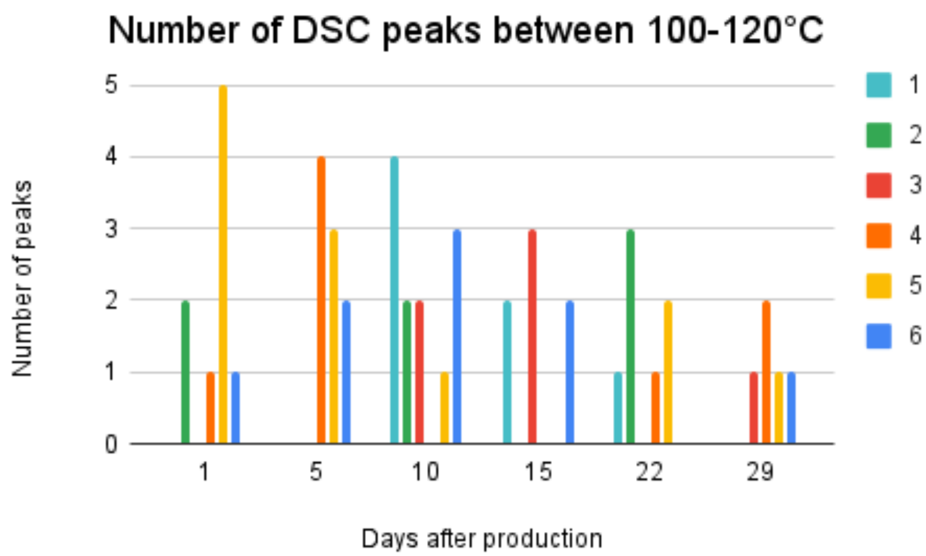

Figure 18: Number of DSC peaks detected between 100-120°C for each rice variety on each analysis day. Each color represents a different rice variety.

Figure 19 show the number of peaks above 120°C detected within all samples. The peaks at these high temperatures were the strongest DSC results obtained. Out of the total 172 peaks, 60% (101 peaks) were above 1J/g and many of them were presenting higher values of up to 11J/g. Some of these peaks were very sharp and most likely due to the desorption of water that could be caused by the aluminum pan slightly opening from the increased vapor pressure (Mettler-Toledo, 2000). Peaks detected at a temperature slightly above 120°C could indicate dissociation of amylose-lipid complexes.

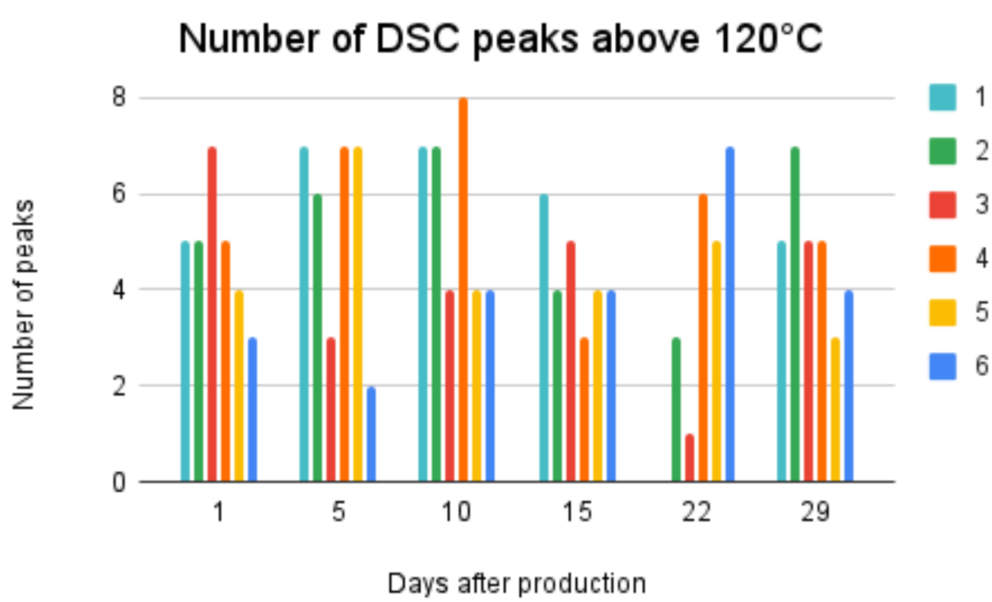

Figure 19: Number of DSC peaks detected above 120°C for each rice variety on each analysis day. Each color represents a different rice variety.

In Figure 20 the number of DSC peaks for the factory produced pudding is shown. No peaks below 100°C were detected for any of the samples throughout the storage time, showing no indication of retrograded or un-gelatinized starch. On day 36 after production two peaks between 100°C-120°C were detected, these had an enthalpy of 0.5J/g and 0.55J/g respectively. Giving weak indications of amylose-lipid complex dissociation. Peaks above 120°C were occurring on every analysis day. And as mentioned above this could also be amylose-lipid complexes or due to water desorption.

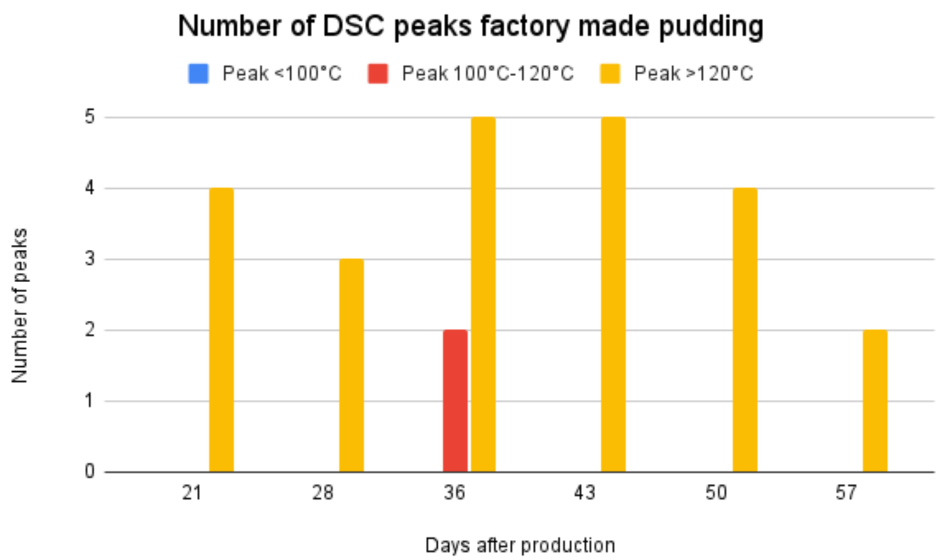

Figure 20: Number of DSC peaks detected for the factory produced pudding on each analysis day.

All raw data for the DSC figures are presented in Table 21 in Appendix A.5. When comparing the enthalpy values for peaks below 100°C with the firmness of each rice kernel, there were no conclusions to be drawn. As an example, the firmness values for rice variety 2 on day 10; Rice grains 1, 2, and 3 had peak enthalpy of 0.84J/g, 1.45J/g and 0.9J/g respectively. While their firmness value was 28g, 18g, and 64g respectively, resulting in that the softer rice grain had the highest enthalpy. To draw conclusions that the firmness in the rice grain were related to starch retrogradation, the harder rice grain would have the highest enthalpy. Looking at the water content of each DSC sample and comparing to the peak enthalpy the results were like the comparison between enthalpy and firmness. All over the collected data, correlations between water content and enthalpy, and firmness and enthalpy, were coincidental rather than definite. This allows for no conclusions to be drawn between neither water content nor firmness of the sample against enthalpy detection.

5 Conclusion

This study clearly shows that there are differences in the firmness of the cooked rice grains inside rice puddings produced out of different rice varieties. A difference that is noticeable already from the start but gets more prominent during storage. To avoid these firm rice grains when producing a rice pudding the measurements performed in this report points towards some important rice properties to aim for. Out of the six rice varieties studied during the 29 days storage period, a rice variety with low water absorption, high water content, and low gelatinization temperature showed the lowest firmness of the cooked rice grains, which corresponds best to rice variety 1 and 4. These are all factors that indicates that the rice variety has a rather low amylose content. Even if the increased firmness of the cooked rice grains could not be concluded to be due to starch retrogradation, starch and specifically amylose still seemed to be an important factor to consider. Amylose which is the starting step to starch retrogradation creates a crystallized starch baseline that amylopectin continues to retrograde on during storage. The higher amylose content, the higher baseline, which leads to an overall higher retrogradation rate and firmer rice grains. Amylose content is an important factor, but with that in mind the firmness of the cooked rice grains is not only dependent on the amylose content but on complex interactions between water, amylose, amylopectin, proteins, and lipids. Factors that all need to be considered when choosing rice variety for rice pudding production.

6 Suggestions for future studies

It would have been of great interest to examine the nutritional values of the different rice varieties, to really be able to determine differences. This was something on the agenda for this project but due to lack of time these tests were never conducted. Since starch retrogradation plays a role in the firmness of the rice grains it would be most interesting to investigate the differences in amylose and amylopectin content. This is likely to give a better fundamental insight of the rice varieties different textures and would be interesting to perform to see if the results are linear to the conclusions from this report.

A study of the process parameters, like cooking temperature and time, would also be of interest to see how it affects the texture of the cooked rice pudding grains over time.

References

Abdullah, N., Nawawi, A., & Othman, I. (2000). Fungal spoilage of starch-based foods in relation to its water activity (aw). *Journal of Stored Products Research*, *36*(1), 47-54.

Bhattacharya, K., & Sowbhagya, C. (1971). Water uptake by rice during cooking. *Cereal Science Today*, *16*(12), 420-424.

Bhattacharya, K. R. (2011a). Analysis of rice quality. In *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Bhattacharya, K. R. (2011b). Cooking quality of rice. In *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Bhattacharya, K. R. (2011c). An introduction to rice: its qualities and mysteries. In *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Bhattacharya, K. R. (2011d). Milling quality of rice. In *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Bhattacharya, K. R. (2011e). Physical properties of rice. In *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Bhattacharya, K. R. (2011f). *Rice Quality: A Guide To Rice Properties And Analysis [Electronic resource]*. Woodhead Publishing.

Chang, Q., Zheng, B., Zhang, Y., & Zeng, H. (2021). A comprehensive review of the factors influencing the formation of retrograded starch. *International Journal of Biological Macromolecules*, *186*, 163-173.

Chen, Y., Yao, Y., Gu, Z., Peng, Y., Cheng, L., Li, Z., Li, C., Chen, Z., & Hong, Y. (2022). Effects of different waxy rice varieties and their starch on the taste quality of zongzi. *Journal of Cereal Science*, *108*, 103571. https://doi.org/https://doi.org/10.1016/j.jcs.2022.103571

Cooper, N., Siebenmorgen, T., & Counce, P. (2008). Effects of nighttime temperature during kernel development on rice physicochemical properties. *Cereal Chemistry*, *85*(3), 276-282.

Corke, H. (2016). Grain: Morphology of Internal Structure. In C. Wrigley, H. Corke, K. Seetharaman, & J. Faubion (Eds.), *Encyclopedia of Food Grains (Second Edition)* (pp. 41-50). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-394437-5.00010-3

Gill, P., Moghadam, T. T., & Ranjbar, B. (2010). Differential scanning calorimetry techniques: applications in biology and nanoscience. *Journal of biomolecular techniques: JBT*, *21*(4), 167.

Hansjoerg Kraehmer, C. T., and Francesco Vidotto. (2017). Rice Production in Europe. In B. S. Chauhan, K. Jabran, & G. Mahajan (Eds.), *Rice Production Worldwide*. Springer International Publishing :. http://dx.doi.org/10.1007/978-3-319-47516-5

Hoogenkamp, H., Kumagai, H., & Wanasundara, J. (2017). Rice protein and rice protein products. In *Sustainable protein sources* (pp. 47-65). Elsevier.

Ju, Z., Hettiarachchy, N., & Rath, N. (2001). Extraction, denaturation and hydrophobic properties of rice flour proteins. *Journal of food science*, *66*(2), 229-232.

Juliano, B. O. (2015). Rice: Overview. In C. W. Wrigley (Ed.), *Encyclopedia of Food Grains [Electronic resource]*. Elsevier Science.

Juliano, B. O., Perez, C. M., Barber, S., BLAKENEY, A. B., IWASAKI, T. A., Shibuya, N., KENEASTER, K. K., Chung, S., Laignelet, B., & Launay, B. (1981). International cooperative comparison of instrument methods for cooked rice texture. *Journal of Texture Studies*, *12*(1), 17-38.

Li, H., Lei, N., Yan, S., Yang, J., Yu, T., Wen, Y., Wang, J., & Sun, B. (2019). The importance of amylopectin molecular size in determining the viscoelasticity of rice starch gels. *Carbohydrate polymers*, *212*, 112-118. https://doi.org/https://doi.org/10.1016/j.carbpol.2019.02.043

Lin, Z., Zheng, D., Zhang, X., Wang, Z., Lei, J., Liu, Z., Li, G., Wang, S., & Ding, Y. (2016). Chalky part differs in chemical composition from translucent part of japonica rice grains as revealed by a notched-belly mutant with white-belly. *Journal of the Science of Food and Agriculture*, *96*(11), 3937-3943.

Lisle, A., Martin, M., & Fitzgerald, M. (2000). Chalky and translucent rice grains differ in starch composition and structure and cooking properties. *Cereal Chemistry*, *77*(5), 627-632.

Livsmedelsverket. (2023). *Näringsinehåll; Ris grötris rundkornigt okokt*. Retrieved April 20 (2023) from https://soknaringsinnehall.livsmedelsverket.se/Home/FoodDetails/2485?sokord=ris&soktyp=1&kategoriId=

Mettler-Toledo. (2000). Interpreting DSC Curves Part 1: Dynamic measurements. In *UserCom 1/2000*.

Mohd Ramli, N. A., Fazalul Rahiman, M. H., Kamarudin, L. M., Mohamed, L., Zakaria, A., Ahmad, A., & Rahim, R. A. (2021). A New Method of Rice Moisture Content Determination Using Voxel Weighting-Based from Radio Tomography Images. *Sensors*, *21*(11), 3686.

Muhammad Riaz, Tariq Ismail, & Akhtar, S. (2017). Harvesting, Threshing, Processing, and Products of Rice. In B. S. Chauhan, K. Jabran, & G. Mahajan (Eds.), *Rice Production Worldwide*. Springer International Publishing :. http://dx.doi.org/10.1007/978-3-319-47516-5

Muñoz, L. A., Pedreschi, F., Leiva, A., & Aguilera, J. M. (2015). Loss of birefringence and swelling behavior in native starch granules: Microstructural and thermal properties. *Journal of Food Engineering*, *152*, 65-71.

Murugesan, G., & Bhattacharya, K. R. (1991). Basis for varietal difference in popping expansion of rice. *Journal of Cereal Science*, *13*(1), 71-83. https://doi.org/https://doi.org/10.1016/S0733-5210(09)80028-3

Orkla. (2023). *Om Risifrutti*. Orkla. Retrieved April 19 (2023) from https://www.risifrutti.se/om-risifrutti/

P Mathew, A., Oksman, K., Thomas, S., Habibi, Y., & Lucia, L. (2014). *STARCH-BASED BIONANOCOMPOSITES: PROCESSING AND PROPERTIES Polysaccharide Building Blocks: A Sustainable Approach to the Development of Renewable Biomaterials, First Edition. Edited By*.

Perten-Instruments. Perten Instruments Method Description; TVT Method 51-01.02. In.

Pitt, J. I. (1975). Xerophilic fungi and the spoilage of foods of plant origin. *Water relations of foods*, 273-307.

Poutanen, K. S., Kårlund, A. O., Gómez-Gallego, C., Johansson, D. P., Scheers, N. M., Marklinder, I. M., Eriksen, A. K., Silventoinen, P. C., Nordlund, E., Sozer, N., Hanhineva, K. J., Kolehmainen, M., & Landberg, R. (2022). Grains – a major source of sustainable protein for health. *Nutrition Reviews*, *80*(6), 1648-1663. https://doi.org/10.1093/nutrit/nuab084

Rangelov, A., Arnaudov, L., Stoyanov, S., & Spassov, T. (2017). Gelatinization of industrial starches studied by DSC and TG. *Bulgarian Chemical Communications*, *49*(2), 422-429.

Stable-Micro-Systems. (2023a). *Compression Tests*. Stable-Micro-Systems. https://www.stablemicrosystems.com/compression-testing.html

Stable-Micro-Systems. (2023b). *How to Measure Fracturability and Brittleness*. Stable Micro Systems. Retrieved May 19 (2023) from https://www.stablemicrosystems.com/MeasureFracturability.html

Stable-Micro-Systems. (2023c). *How to Measure Stickiness/Adhesiveness*. Stable Micro Systems. https://www.stablemicrosystems.com/MeasureStickiness.html

Stable-Micro-Systems. (2023d). *Penetration Tests*. Stable Micro Systems. Retrieved May 19 (2023) from https://www.stablemicrosystems.com/penetration-testing.html

Stoddard, F. L. (2015). Starch: Chemistry. In C. W. Wrigley (Ed.), *Encyclopedia of Food Grains [Electronic resourse]*. Elsevier Science.

Streb, S., & Zeeman, S. (2012). Starch Metabolism in Arabidopsis. *The Arabidopsis book / American Society of Plant Biologists*, *10*, e0160. https://doi.org/10.1199/tab.0160

Tao, K., Liu, X., Yu, W., Neoh, G. K., & Gilbert, R. G. (2022). Starch molecular structural differences between chalky and translucent parts of chalky rice grains. *Food Chemistry*, *394*, 133471.

TexVol-Instruments. Texture products: TVT-300 series. In. Viken, Sweden.

Tong, C., & Bao, J. (2019). 5 - Rice lipids and rice bran oil. In J. Bao (Ed.), *Rice (Fourth Edition)* (pp. 131-168). AACC International Press. https://doi.org/https://doi.org/10.1016/B978-0-12-811508-4.00005-8

Xing, J.-j., Li, D., Wang, L.-j., & Adhikari, B. (2018). Temperature thresholds and time-temperature dependence of gelatinization for heat-moisture treated corn starch. *Journal of Food Engineering*, *217*, 43-49. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2017.08.019

Yu, L., & Christie, G. (2001). Measurement of starch thermal transitions using differential scanning calorimetry. *Carbohydrate polymers*, *46*(2), 179-184.

Yu, S., Ma, Y., & Sun, D.-W. (2009). Impact of amylose content on starch retrogradation and texture of cooked milled rice during storage. *Journal of Cereal Science*, *50*(2), 139-144.

Yukako Kato, T. T. (2018). 4 - Key technologies for device fabrications and materials characterizations. In S. Koizumi, H. Umezawa, J. Pernot, & M. Suzuki (Eds.), *Power Electronics Device Applications of Diamond Semiconductors* (pp. 219-294). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-102183-5.00004-2

Appendix

A.1 Water content

Table 13: Raw data from the water content measurements. The raw sample was weighted before and after drying in an oven at 135°C for 3h.

Rice variety	Sample weight (g)	weight of aluminum cup + sample before oven	weight of aluminum cup + sample after oven	Lost weight/ amount of water	water uptake	Mean
1	2.0030	8.3652	8.1081	0.2571	12.84%	12.71%
	1.9997	8.3192	8.0661	0.2531	12.66%	
	1.9998	8.2348	7.9822	0.2526	12.63%	
2	1.9996	8.3759	8.1439	0.2320	11.60%	11.54%
	2.0002	8.3521	8.1210	0.2311	11.55%	
	2.0002	8.2820	8.0526	0.2294	11.47%	
3	2.0006	8.2979	8.0540	0.2439	12.19%	12.08%
	1.9994	8.4414	8.2011	0.2403	12.02%	
	2.0002	8.3934	8.1526	0.2408	12.04%	
4	2.0007	8.3497	8.0960	0.2537	12.68%	12.62%
	2.0007	8.2647	8.0122	0.2525	12.62%	
	2.0002	8.3883	8.1370	0.2513	12.56%	
5	1.9993	8.3152	8.0635	0.2517	12.59%	12.57%
	2.0009	8.3414	8.0891	0.2523	12.61%	
	1.9998	8.4031	8.1529	0.2502	12.51%	
6	1.9992	8.3732	8.1435	0.2297	11.49%	12.14%
	2.0002	8.3673	8.1189	0.2484	12.42%	
	1.9994	8.3508	8.1004	0.2504	12.52%	

A.2 Water absorption

Table 14: Raw data form the water absorption test. Weight of 20 rice grains measured before and after boiling in water for 30 minutes.

Sample	Weight before boiling	Weight after boiling	Wateruptake	% wateruptake	Mean
1.1	0.38	1.25	0.87	229%	228%
1.2	0.38	1.26	0.88	232%	
1.3	0.38	1.23	0.85	224%	
2.1	0.36	1.34	0.98	272%	264%

2.2	0.35	1.25	0.90	257%	
2.3	0.36	1.31	0.95	264%	
3.1	0.35	1.31	0.96	274%	264%
3.2	0.35	1.26	0.91	260%	
3.3	0.37	1.32	0.95	257%	
4.1	0.38	1.20	0.82	216%	237%
4.2	0.37	1.29	0.92	249%	
4.3	0.37	1.28	0.91	246%	
5.1	0.39	1.40	1.01	259%	259%
5.2	0.40	1.40	1.00	250%	
5.3	0.39	1.44	1.05	269%	
6.1	0.37	1.29	0.92	249%	252%
6.2	0.36	1.24	0.88	244%	
6.3	0.37	1.34	0.97	262%	

A.3 Texture analysis on the kitchen-boiled rice pudding

A.3.1 Three-point bend test

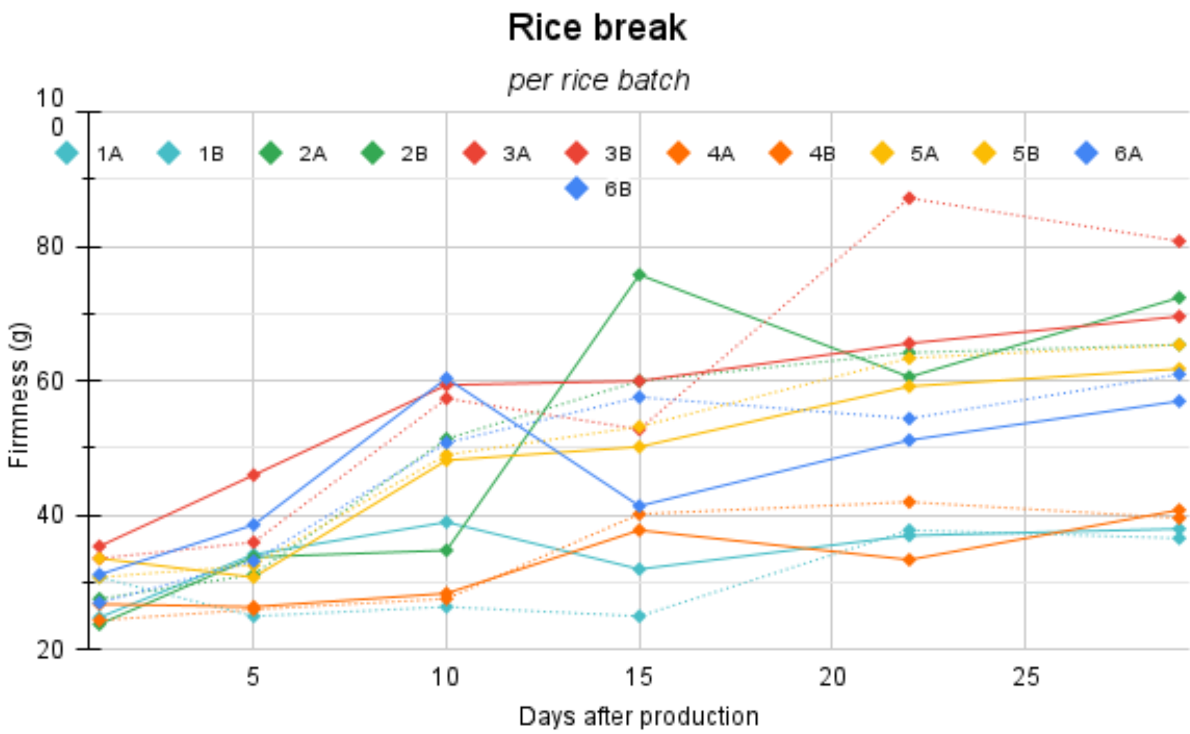

Figure 21: Results from the three-point bend test presented per batch. Every color represents a rice type, where batch A is presented by a full line and batch B by the dotted line.

Table 15: The raw data from the three-point bend test performed on boiled rice grains from the kitchen-boiled rice pudding. Data presented in grams.

Batch	1A					1B					2A					2B				
Day 1	17	27	26	16	38	48	46	19	21	20	28	23	37	13	18	35	30	26	33	14
Day 5	36	34	42	26	33	20	22	14	31	38	26	58	46	15	24	43	40	41	16	16
Day 10	26	21	54	59	35	24	21	36	23	28	28	37	18	64	27	49	41	77	24	66
Day 15	22	28	30	46	34	21	22	20	31	31	86	63	109	43	78	78	30	83	75	34
Day 22	31	33	50	27	44	37	37	54	38	23	49	36	54	110	54	87	27	55	82	70
Day 29	23	46	48	16	57	35	46	21	46	35	108	42	54	71	87	50	69	35	71	102
Batch	3A					3B					4A					4B				

Day 1	32	28	25	37	55	24	66	33	21	24	14	23	38	38	21	30	27	14	29	22
Day 5	50	38	43	41	58	25	33	47	29	46	14	28	27	34	29	41	18	21	20	30
Day 10	58	56	96	22	65	33	92	80	50	32	31	24	23	33	31	23	38	23	37	17
Day 15	72	50	52	76	50	51	43	31	56	83	40	35	42	40	32	37	48	35	49	32
Day 22	70	63	50	98	47	50	123	56	106	101	20	39	35	35	38	41	50	47	37	35
Day 29	68	78	104	54	44	87	61	53	102	101	48	25	39	39	53	47	45	32	22	52
Batch	5A					5B					6A					6B				
Day 1	24	46	23	37	38	39	42	20	26	27	37	29	28	31	31	27	20	36	28	24
Day 5	24	24	27	46	33	44	17	43	20	39	43	37	23	45	45	34	23	37	22	50
Day 10	33	38	40	66	64	37	62	68	25	53	48	53	65	81	55	38	60	55	42	59
Day 15	46	56	43	59	47	45	26	52	73	70	31	35	62	55	24	33	89	85	29	52
Day 22	55	55	39	67	80	34	29	79	68	107	29	49	52	76	50	70	67	32	39	64
Day 29	61	62	19	78	89	87	49	65	74	52	72	44	59	64	46	51	21	73	77	83

A.3.2 Compression test

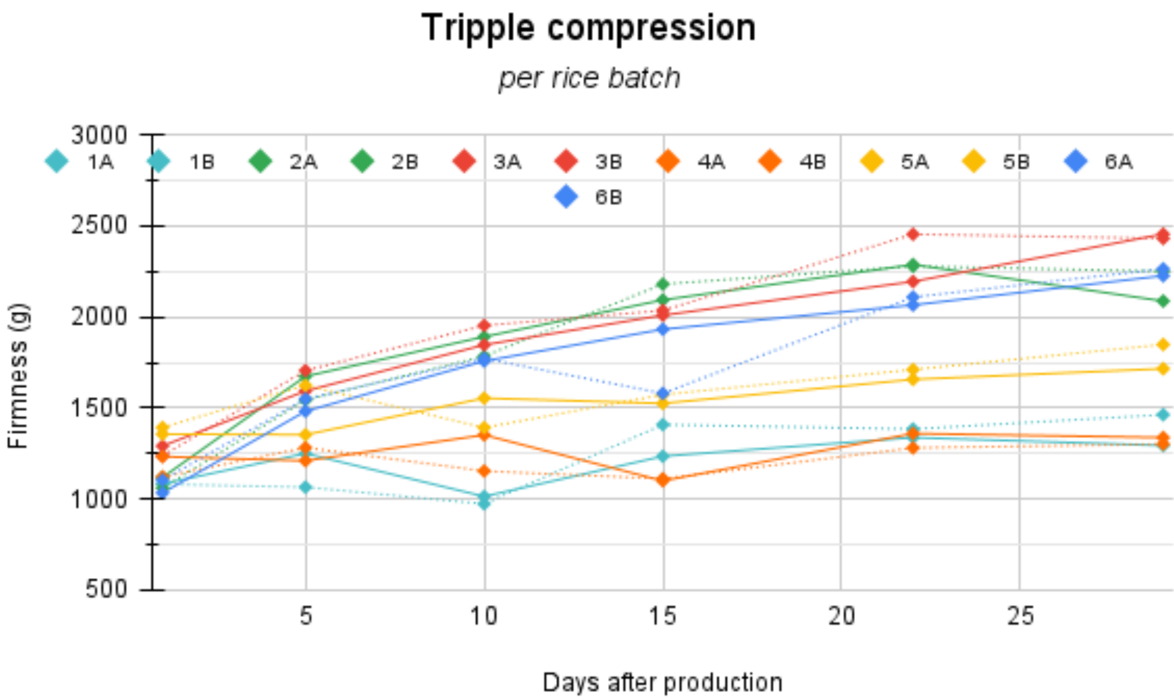

Figure 22: Results from the triple compression test presented per batch. Every color represents a rice type, where batch A is presented by a full line and batch B by the dotted line.

Table 16: Raw data from the triple compression test. All results are presented in grams

	1A			1B			2A			2B		
Dag 1	1254	946	1051	1232	1017	998	1098	1067	1193	1194	952	1036
Dag 5	1257	1373	1122	1085	1059	1053	1655	1744	1624	1420	1407	1804
Dag 10	994	1049	1001	930	1045	947	1815	1856	2004	1739	1702	1913
Dag 15	1321	1300	1085	1332	1415	1480	2114	1952	2215	2247	1933	2361
Dag 22	1520	1368	1126	1393	1089	1672	2322	2401	2141	2174	1961	2702
Dag 29	1198	1334	1352	1481	1394	1516	2181	1714	2368	2383	2167	2203
	3A			3B			4A			4B		
Dag 1	1088	1192	1172	1186	1260	1268	1166	1370	1164	1199	1210	958
Dag 5	1634	1512	1635	1716	1592	1810	1415	1268	1306	1441	1131	1276
Dag 10	1955	1871	1715	1688	2280	1893	1203	1323	1531	1036	1183	1244
Dag 15	1830	2109	2090	2192	2043	1873	1035	1153	1113	1084	1123	1129

Dag 22	2181	2132	2271	2611	2303	2450	1219	1494	1368	1298	1202	1344
Dag 29	2431	2622	2314	2627	2305	2362	1346	1202	1466	1205	1404	1298
	5A			5B			6A			6B		
Dag 1	1574	1347	1150	1263	1463	1454	1049	1113	940	1092	964	1257
Dag 5	1283	1435	1343	1856	1353	1665	1532	1499	1417	1435	1622	1593
Dag 10	1706	1528	1429	1328	1347	1502	1788	1548	1938	1760	1937	1618
Dag 15	1798	1225	1554	1642	1278	1801	2108	1897	1793	1396	1950	1396
Dag 22	1573	1531	1868	1700	1570	1864	2250	1917	2030	2010	2068	2250
Dag 29	1808	1645	1696	1888	1931	1728	2189	2122	2369	2167	2443	2183

A.3.3 Penetration test

Table 17: Raw data from the pudding penetration test on the kitchen boiled rice pudding. All data is presented in grams

	1A		1B		2A		2B		3A		3B	
Day 1	248	235	330	253	281	245	258	299	309	290	225	213
Day 29	247	278	255	261	210	259	301	256	264	266	230	196
	4A		4B		5A		5B		6A		6B	
Day 1	265	249	264	235	210	212	220	217	256	258	274	238
Day 29	260	223	250	239	169	159	199	167	216	206	191	180

A.4 Texture analysis on the factory-produced rice pudding

Table 18: Raw data from the three-point bend test during the retrogradation study on the factory produced pudding. All data is presented in grams.

	1					2				
Dag 21	50	57	34	36	45	62	44	61	93	96
Dag 28	61	64	87	51	65	53	89	141	83	82
Dag 36	85	84	42	75	85	73	91	92	47	110
Dag 43	42	90	105	89	93	76	93	84	39	73
Dag 50	41	85	85	65	59	91	111	91	71	98
Dag 57	39	58	52	66	75	61	60	109	77	48

Table 19: Raw data from the compression test during the retrogradation study on the factory produced pudding. All data is presented in grams.

	1			2		
Dag 21	1374	1639	1661	1574	1694	1595
Dag 28	1585	1302	1340	1752	1488	1374
Dag 36	1577	1558	1860	1509	1704	1547
Dag 43	1663	2214	1486	1873	1482	1698
Dag 50	1551	1978	1580	1329	1358	1555
Dag 57	1453	1486	1517	2315	1499	1360

Table 20: Raw data from the pudding penetration test of the factory produced rice pudding. All data is presented in grams.

	1		2	
Dag 21	131	130	134	121
Dag 28	136	122	129	115
Dag 36	126	121	127	128
Dag 43	124	133	127	131
Dag 50	124	120	127	124
Dag 57	129	127	129	128

A.5 DSC measurements

Table 21: The raw data from the DSC measurements. Showing peak temperature (Tp) and peak enthalpy (ΔH) for all peaks observed above an enthalpy of 0.5J/g.

Day after production	1A Tp (°C)	1A ΔH (J/g)	1B Tp (°C)	1B ΔH (J/g)
Day 1	150.7	1.78	56.9	0.99
	153.0	0.70	61.0	0.82
	166.2	1.73	73.0	0.91
			154.0	2.89
			159.5	2.29
Day 5	143.3	1.62	128.9	1.64
	154.0	0.81	132.4	1.81
			138.6	1.35
			142.8	2.30
			152.0	3.24
Day 10	105.0	0.60	113.8	0.65
	111.2	1.30	118.0	0.77
	144.5	4.76	135.9	0.54
	146.9	1.03	138.0	0.51
	152.7	0.58	161.5	0.55
	156.8	0.61		
Day 15	113.1	0.99	67.9	0.62
	149.8	7.01	80.5	0.71
	156.4	2.76	83.6	0.94
	169.4	1.46	112.0	1.10
			138.7	1.65
			142.2	0.67
			167.2	0.91
Day 22	53.6	2.44	92.5	1.19
	110.3	0.66		
Day 29	53.1	3.22	139.6	0.55
	56.3	1.01	145.3	1.56

Day after production	2A Tp (°C)	2A ΔH (J/g)	2B Tp (°C)	2B ΔH (J/g)
Day 1	70.3	1.06	150.7	2.08
	107.8	1.39		
	119.6	0.69		
	142.7	0.70		
	146.4	2.96		
	146.9	0.51		
	161.8	0.55		
Day 5	60.5	0.54	143.0	0.83
	156.4	0.93	151.5	1.00
	161.2	0.99	154.5	0.75
	163.3	8.32		
Day 10	61.1	1.45	133.6	0.89
	83.7	0.90	168.2	0.53
	108.0	0.55	171.0	0.60
	112.1	1.56		
	145.1	1.51		
	150.3	2.13		
	152.2	0.59		
Day 15	57.4	1.09	87.8	0.84
	151.7	3.58	92.7	0.54
			145.2	1.49
			156.0	12.20
			169.2	1.19
Day 22	110.6	0.97	54.7	1.13
	110.7	1.15	111.7	0.62
	152.3	0.93	147.8	0.83
			155.0	0.75

	147.9	1.42	154.4	0.50	Day 29	83.3	0.86	94.7	0.69
	148.3	2.94				135.7	1.79	138.4	1.20
						142.5	1.80	155.1	1.95
						158.4	1.01	161.6	0.65
	3A		3B			4A		4B	
Day 1	84.4	0.81	150.8	1.06	Day 1	139.4	3.39	86.8	0.48
	153.7	0.84	150.0	1.44		143.4	0.72	135.5	0.59
	157.0	1.25						143.8	3.50
	157.2	3.56						146.0	1.29
	159.6	2.60			Day 5	110.1	0.53	110.7	1.08
	162.6	0.62				114.8	1.03	121.9	1.04
Day 5	156.3	0.71	60.8	0.83		139.7	2.72	130.0	1.00
			61.0	0.59		143.3	0.54	136.2	0.90
			158.9	1.07		143.7	3.02	145.1	0.75
			168.6	10.30		154.8	0.84		
Day 10	1110.7	1.17	111.0	0.57	Day 10	136.4	1.67	137.7	1.53
	121.3	0.53	150.1	1.10		140.2	3.79	142.0	1.55
	145.2	3.54	158.7	0.91		141.4	2.36	149.6	2.64
Day 15	92.2	0.66	92.0	0.32		146.1	2.63		
	109.2	0.59	113.0	0.85		148.6	2.54		
	141.3	1.96	113.1	0.85	Day 15	Nothing		132.9	0.53
	147.2	1.69	151.8	0.43				134.8	0.85
	157.6	0.60	155.8	0.72				141.8	1.37
			158.0	2.55	Day 22	142.9	0.65	101.2	0.64
Day 22	Nothing		156.9	3.10		152.9	0.64	144.8	1.04
						156.4	6.30	148.0	3.48
Day 29	129.2	2.56	111.9	0.65				150.5	3.48
	141.5	0.83	128.7	1.03	Day 29	112.1	0.69	112.2	0.64
			147.4	1.59		129.8	1.16	148.7	11.70
			152.6	7.36		135.9	2.31	151.2	0.68
						151.8	0.85		
	5A		5B			6A		6B	
Day 1	110.6	1.47	110.5	0.65	Day 1	Nothing		116.2	0.97

	113.8	1.38	111.9	1.29
	162.3	2.13	0.7	154.30
	167.7	0.70		
Day 5	112.2	0.55	109.9	0.80
	126.4	1.44	110.8	1.40
	144.3	1.40	128.8	3.36
	149.0	0.77	138.7	1.46
	153.2	0.95	148.1	3.54
Day 10	161.7	1.26	113.4	0.80
	167.0	0.55	145.1	0.84
			158.1	1.07
Day 15	129.8	1.23	73.4	0.79
	148.6	0.58	153.4	1.08
	153.8	5.39	159.0	1.42
Day 22	119.3	0.83	111.1	0.62
	132.2	1.27	137.5	0.99
	151.8	2.68	140.3	2.33
			147.5	0.79
Day 29	118.4	0.77	155.8	7.04
	129.9	2.50		
	146.9	2.77		

			143.3	1.47
			154.7	0.52
			157.8	1.68
Day 5	119.1	0.91	110.5	0.66
			132.8	3.01
			137.4	0.76
Day 10	76.8	0.62	112.3	1.31
	94.0	0.55	114.1	0.63
	111.5	1.56	152.7	0.90
	126.8	0.65	153.2	0.71
	157.0	1.20		
Day 15	128.2	0.98	110.6	0.52
	160.6	2.22	111.3	1.44
			132.4	0.70
			157.9	0.84
Day 22	139.8	0.78	150.3	0.56
	144.1	0.86	166.0	3.43
	150.4	3.31		
	154.7	1.11		
	160.0	0.86		
Day 29	111.2	0.70	127.1	2.75
	151.7	0.50	128.3	0.59
			157.0	0.67

A.6 Perten instrument method description 51-01.02

Perten Instruments Method Description
TVT Method 51-01.02

Cooked Rice Firmness & Stickiness, by Compression

TVT Texture Analyzer

The TVT Texture Analyzer (Figure1) offers rapid and objective analysis for different products. The following parameters can be characterized for your product category:

- Firmness
- Stickiness

Both international standard methods as well as customer tailor-made profiles are available.

Figure 1: TVT Texture Analyzer

Scope

- Determination of firmness and stickiness for cooked rice by single cycle compression.

Method Description

The recording of the measurement data commences once the probe reaches the pre-set trigger force. The probe will then compress the sample to a pre-defined distance. After compression, the probe returns to its starting position.

Calibration

Make sure the instrument is correct calibrated before the measurements. How to perform the calibration can be found in the User's Manual.

Load cell (recommended) 5 – 10 kg

Probe
P-Cy35S, Cylinder probe 35 mm diameter, stainless steel (Figure 2)
Part number: 67.30.35

Figure 2: P-Cy35S

Profile Settings

Setting Parameter	
Single Cycle Compression	
Sample height [mm]	3.0
Starting distance from sample [mm]	5.0
Compression [%]	90.00
Initial speed [mm/s]	0.5
Test speed [mm/s]	0.5
Retract speed [mm/s]	10.0
Trigger force [g]	5
Data rate [pps]	333
Adhesiveness	Marked ☑

Sample preparation

Cooking, cooling and other preparation and handling of the product are critical actions for the outcome of the results. In order to compare different samples, these procedures needs to be kept constant and well documented. Place the sample (3 grains of rice) on the measuring table centered below the probe and commence the test, Figure 3. Work quickly, since contact with air dries out the rice and increases the firmness.

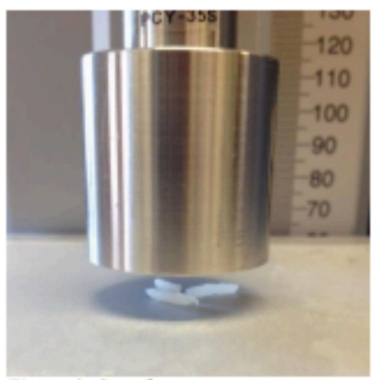

Figure 3: Sample set-up

Curve Description

In Figure 4 typical Force-Time curves are illustrated. The maximum positive peak force value is here used for the hardness while the peak value of the negative peak is the stickiness of the rice grains. Distance to maximum peak force give information about the size of the grains. As seen in the graph, variety A rice grains were smaller, slightly less hard and more sticky than the variety B rice grains.

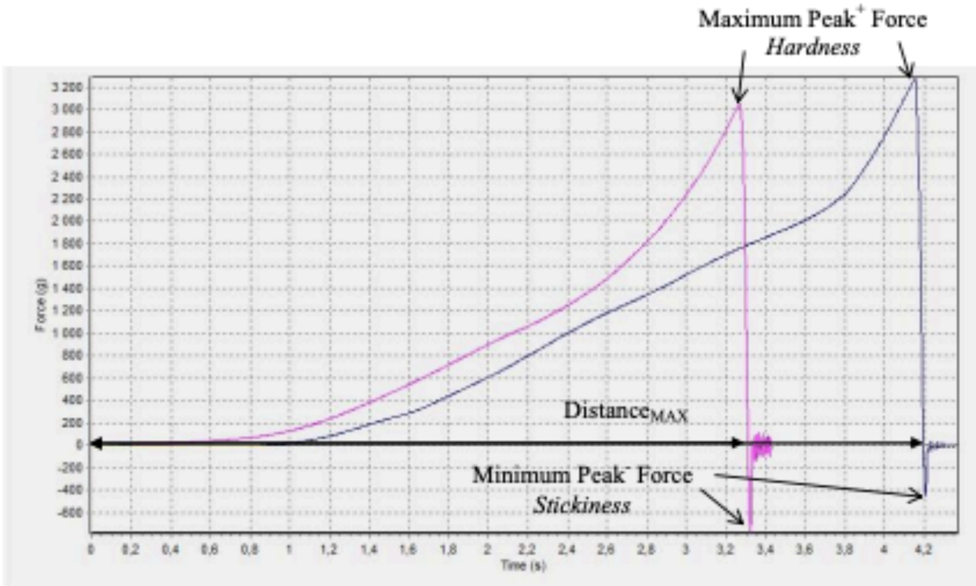

Figure 4: Pink curve: Variety A, Blue curve: Variety B.

Data Analysis

The force required to compress the sample to a certain strain of the sample height is here defined as hardness while the force required for withdraw of the probe is the stickiness. These parameters can be measured in the units [g] or [N]. In addition, the ratio between the positive and negative force gives a texture property often used within the rice industry. Except raw data (force, time and distance) the program also directly provides calculated results such as ***mean value*** and ***standard deviation***.