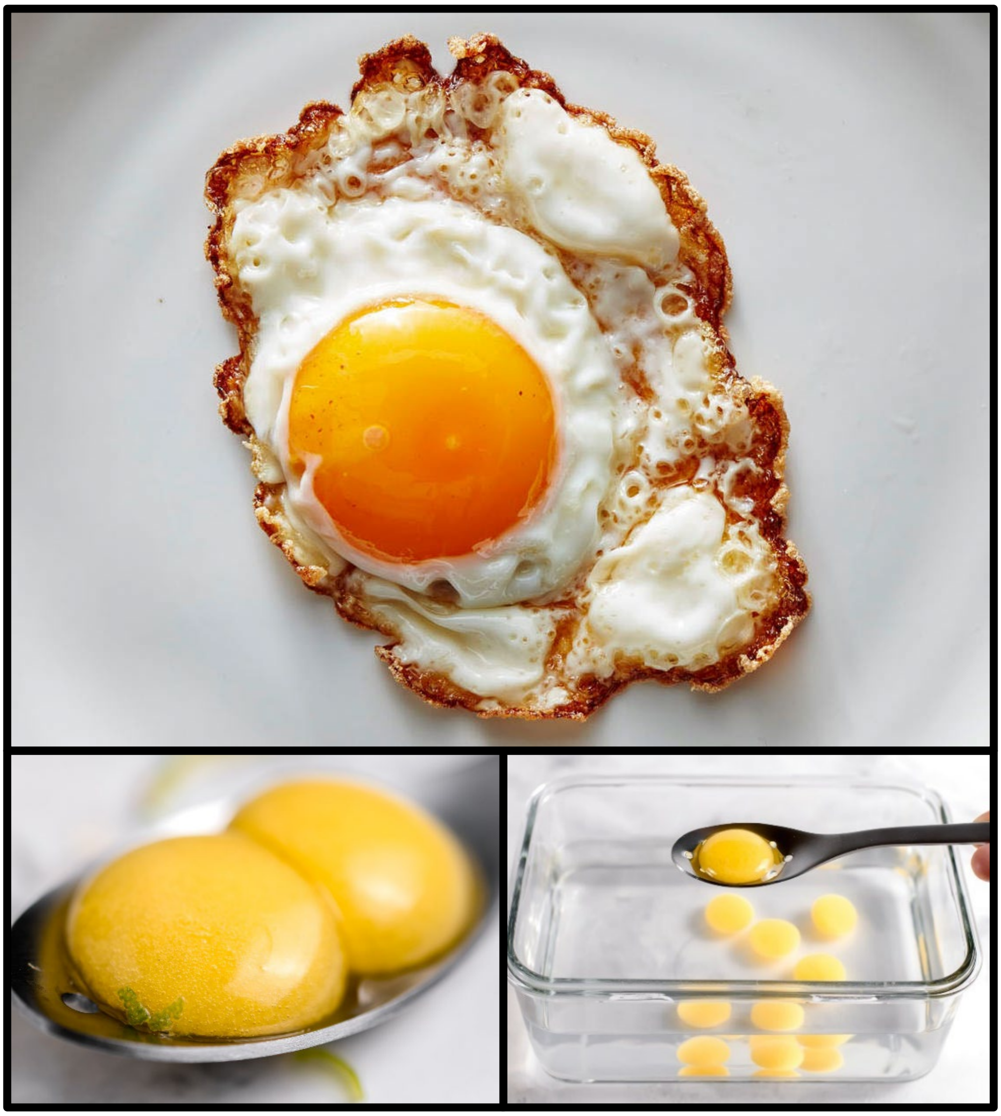


Creating a vegan fried egg using molecular gastronomy

Polina Ebnöther 6F

January 2023

Kantonsschule Zug

Chemistry, Urs Leisinger

1 Content

2 Preface 4

3 Abstract 5

4 Introduction 6

4.1 What is molecular gastronomy? 6

4.2 Alginate 6

4.2.1 Production of alginate 6

4.2.2 Structure of alginate 7

4.2.3 Structure of alginic acid 7

4.2.4 Use of alginate 9

4.3 Alginate gel 9

4.4 Spherification 11

4.4.1 Basic spherification 11

4.4.2 Reverse spherification 12

4.5 Xanthan gum 12

4.5.1 Production of xanthan gum 13

4.5.2 Structure of xanthan gum 13

4.5.3 Use of xanthan gum 14

4.6 Objective of the matura project 15

5 Experiments 16

5.1 Importance of the correct concentrations 16

5.1.1 Materials 16

5.1.2 Method 1 16

5.1.3 Results 1 17

5.1.4 Method 2 17

5.1.5 Results 2 17

5.1.6 Discussion 17
5.2 Does calcium lactate leave a bitter aftertaste ? 18
5.2.1 Materials 18
5.2.2 Method 19
5.2.3 Results 19
5.2.4 Discussion 20
5.3 Mango juice instead of water for the calcium solution 20
5.3.1 Material 21
5.3.2 Method 21
5.3.3 Results 21
5.3.4 Discussion 22
5.4 Frozen reverse spherification 23
5.4.1 Material 23
5.4.2 Method 24
5.4.3 Results 24
5.4.4 Discussion 24
5.5 Proving hypothesis 1 25
5.5.1 The idea behind the hypothesis 25
5.5.2 Designing a method to prove the hypothesis 25
5.5.3 Experiment 26
5.6 Implementing the results 29
5.6.1 Material 30
5.6.2 Method 30
5.6.3 Results 30
5.6.4 Discussion 30
5.7 Proving hypothesis 2 31

5.7.1 The idea behind the hypothesis 31
5.7.2 Designing a method to prove the hypothesis 31
5.7.3 Materials 32
5.7.4 Method 33
5.7.5 Results 33
5.7.6 Discussion 34
5.8 Creating the egg white using xanthan gum 34
5.8.1 Materials 34
5.8.2 Method 1 35
5.8.3 Results 1 35
5.8.4 Discussion 36
5.9 Using less xanthan gum 36
5.9.1 Materials 36
5.9.2 Method 2 36
5.9.3 Results 2 36
5.9.4 Discussion 37
5.10 Creating the vegan fried egg 37
5.10.1 Materials 38
5.10.2 Method 38
5.10.3 Result 39
5.10.4 Discussion 40
6 Conclusion 40
7 Table of Figures 42
8 Bibliography 44

2 PREFACE

I was introduced to the art of molecular gastronomy for the first time, through a TV series, I enjoyed watching as a child. This series was about a traditional French restaurant and the cooks working there. At some point in the series a new chef, who was a professional in molecular gastronomy, was employed. The other cooks were very conservative and at first did not like the new art of cooking. I believe that many people deny molecular gastronomy because they are not used to it. However, I was very intrigued when I saw the spectacular dishes that were produced with the help of molecular gastronomy. The idea of taking one ingredient and then transforming it into something else,which looks completely different, but still tastes the same, fascinated me. For example, in this TV series the chef made spaghettis by mixing basil, water and gelatin. I could not stop watching him cook.

When the time came to choose the topic for my matura paper, I realized that it would be a great opportunity to try molecular gastronomy myself. I wanted to test whether it is possible for a beginner like me to create such spectacular dishes and surprise my friends and family.

During this project my matura advisor’s and family’s help was very important to me. I would at first like to thank Urs Leisinger for guiding me, answering my questions and always having a useful tip for me. Then I would also like to thank my grandmother, who encouraged me to continue experimenting and not be satisfied with the bare minimum. At last I would like to thank my mother, who supported me throughout the project and allowed me to use our family kitchen for my experiments. It was a very challenging project and I would have not got through it without this support.

3 Abstract

The aim of this project was to create a vegan fried egg using molecular gastronomy. It was decided not to follow an existing recipe, but to create the egg relying only on some acquired basic knowledge.

Therefore research had to be conducted, before starting the actual production of the egg. It was important to gain an overview over the theoretical part of molecular gastronomy: the structure of alginate, alginate gel and xanthan gum. This knowledge was required to better understand the results of the experiments and adjust the approach to achieve the desired outcome.

The egg yolk and the egg white were produced separately and combined in the end to form the vegan fried egg. For the production of the egg yolk the reverse spherification technique was chosen. This technique is the most suitable, as it allows to create spheres that have a solid outside layer and a liquid inside, just like a real egg yolk. The process of creating the egg yolk was very long. Often experiments did not work out as desired; therefore, the approach had to be modified and the experiments repeated. With each new experiment the perfectly shaped sphere drew nearer. Using the frozen reverse spherification technique was the last step leading to a perfectly shaped sphere.

For the production of the egg white the thickening technique was chosen. This is a process where xanthan gum is dissolved in a liquid and thickens it. It is also used in traditional gastronomy and was therefore easier to master. Less experiments had to be conducted to receive the desired outcome.

After the reverse spherification technique and the thickening technique were mastered, the actual cooking was initiated. Both parts of the egg were produced and combined to form the final result: a vegan fried egg.

4 INTRODUCTION

4.1 What is molecular gastronomy?

Molecular gastronomy is a science that deals with texture changes and chemical transformations during cooking processes [1]. The Hungarian physicist Nicholas Kurti and the French chemist Hervé This invented the term “molecular gastronomy” in 1988 and therefore are the founders of this science. [2].

As a science molecular gastronomy is primarily used to highlight the reactions between different ingredients. This information can later be used in the process of cooking, as molecular gastronomy is also a cooking technique. As a cooking technique molecular gastronomy is used to discover new cooking mechanisms and to create fascinating dishes. This new and innovative cooking technique encourages cooks to combine unordinary flavors and to present them in a special way. There are many different techniques used in molecular gastronomy. The most frequently used techniques include spherification, turning liquids into foam and thickening [2]. Alginate plays a vital role in molecular gastronomy. The next chapter will provide more information to this substance.

4.2 Alginate

4.2.1 Production of alginate

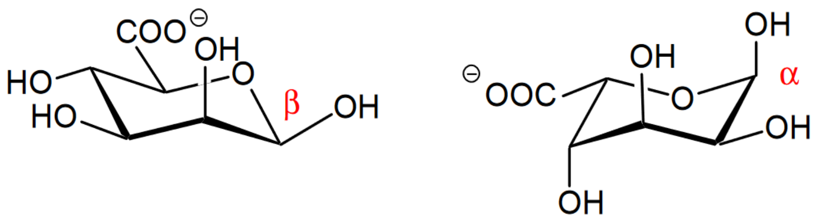
Alginate, which is sold on the market as a white powder, is usually obtained from brown algae, such as the *Phaeophycea* and *Laminaria hyperborean*. Right after the extraction alginate does not look like a white powder. Rather, alginate is present in a dissolved form in the algal extract. This extract has to be processed further in order to obtain pure alginate. For this purpose sodium chloride or calcium chloride is added to the extract to precipitate alginate. Only after further purification and transformation pure alginate powder is finally obtained [3].

4.2.2 Structure of alginate

Alginates are defined as salts of polyuronic acids. Salts always consist of an anionic and cationic part. In the case of alginates alginic acid represents the anionic part and counter-ions represent the cationic part. Alkali- and earth-metals, such as magnesium, potassium, calcium, sodium and barium, are the counter-ions most commonly present in brown algae. Depending on the counter-ion that is bound to the alginic acid, the alginates receive different names. For example, sodium alginate contains sodium-ions bound to the alginic acid as a counter-ion [4].

4.2.3 Structure of alginic acid

Alginic acid is an anionic polysaccharides that belongs to the linear copolymers family. The structure of alginic acid consists of two monomers that form long chains. The first monomer is the β-(1,4) linked D-mannuronic acid, also called ManAp or just M. The second monomer is the α-(1,4)-linked L-guluronic acid, also called GulAp or just G (Figure 1) [3] [5]. These two monomers differ in two aspects. The first difference is that one monomer is a β-anomer and the other one is an α-anomer due to the different configurations of the hydroxy-group (OH) attached to the first C-atom of the ring.



β-D-mannuronic acid α-L-guluronic acid

Figure 1: The two monomers of alginat [4]

The second difference is that one monomer is a D-configuration and the other one is an L-configuration. A D-configuration exists if the hydroxy-group attached to the lowermost chiral C-Atom, i.e the C-Atom with position 5 when looking at the Fischer projection, is located on the right. If it is located on the left, an L-configuration exists [6].

Both monomers have in common that they form a covalent bond between the first C-Atom one monomer and the fourth C-Atom of the second monomer. The numbers (1,4) therefore stand for the positions of the C-Atoms to which the monomers are linked [6].

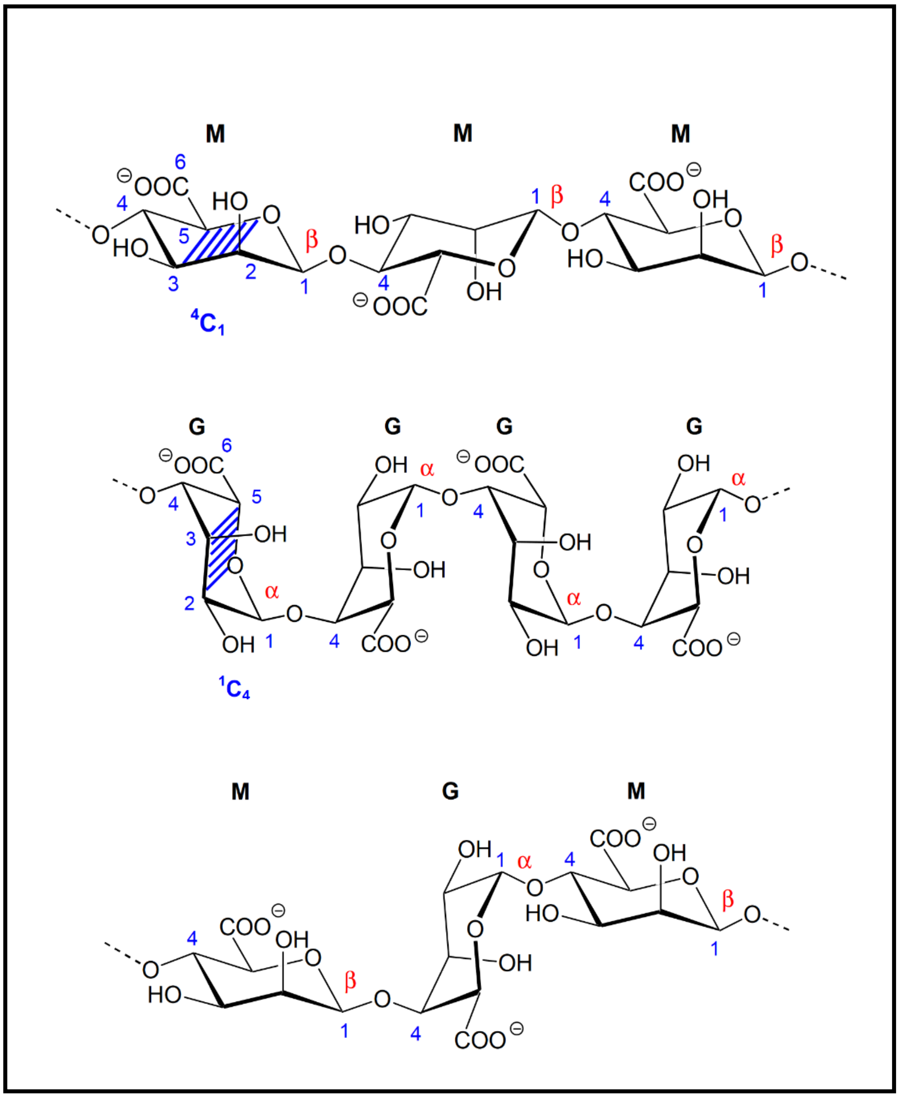


Figure 2: Structure of the three different blocks [4]

The M and G monomers can form three different blocks (Figure 2). GG blocks exist, when a G monomer is followed by several other G monomers. The second possible block, the MM block, exists when an M monomer is followed by multiple M monomers. Each of these two blocks form a homogenous pattern [5]. The third block that can be formed is the MG or GM block where a G monomer is followed by an M monomer. This block forms a heterogeneous pattern [5].

These three blocks can vary in length and are arranged differently on the alginic acid chains. As a result, all alginates have different M and G contents. Currently more than 200 alginate types with different properties are being extracted from algae. [3].

4.2.4 Use of alginate

Alginates are widely used in different areas due to their biocompatibility, low health risk and not too high cost. The food industry uses alginate as a thickening and gelling agent, but also as an emulsifier, stabilizer and texture-improver [7]. Specifically, sodium alginate is used as a stabilizer in ice cream, yogurt and cheese. As an emulsifier it is knowns as the food additive E401that can be spotted on the ingredients list of many food products [8].

Another area where alginate, respectively, alginic acid is used, is the pharmaceutical industry. In the process of making tablets alginic acid is added as a carrier to speed up tablet disintegration. As a result, the medical component of the tablet is released faster and can therefore start to affect the human body after a shorter period of time [7].

Alginate is a substance that rarely causes an allergic reaction and is therefore hypoallergenic. For this reason alginate is used in dentistry to take precise teeth impressions for many oral devices, such as braces or dental crowns [9].

4.3 Alginate gel

Alginate is capable of forming gels independent of temperature. If cations, such as, Ca^{2+} are present, a coordination occurs between the ions and the carboxylate (COO^-), acetal (-O-) and hydroxyl (OH^-) groups of the G monomers. A metal-ion is then surrounded by four G monomers from two adjacent chains, which results in a three-dimensional structure that cannot be reversed (Figure 3). As more and more such three-dimensional structures are formed, the viscosity increases until a gel is created [5,10]. In the structure of this gel the calcium-ion is embedded as a complex between the zigzag structures of the GG-blocks like an egg in the egg box. Therefore, this structure received the often used term the “egg box”.

Cross-linking between calcium ions and alginate, which leads to the formation of the gel, occurs mostly due to the existence of GG blocks [5].

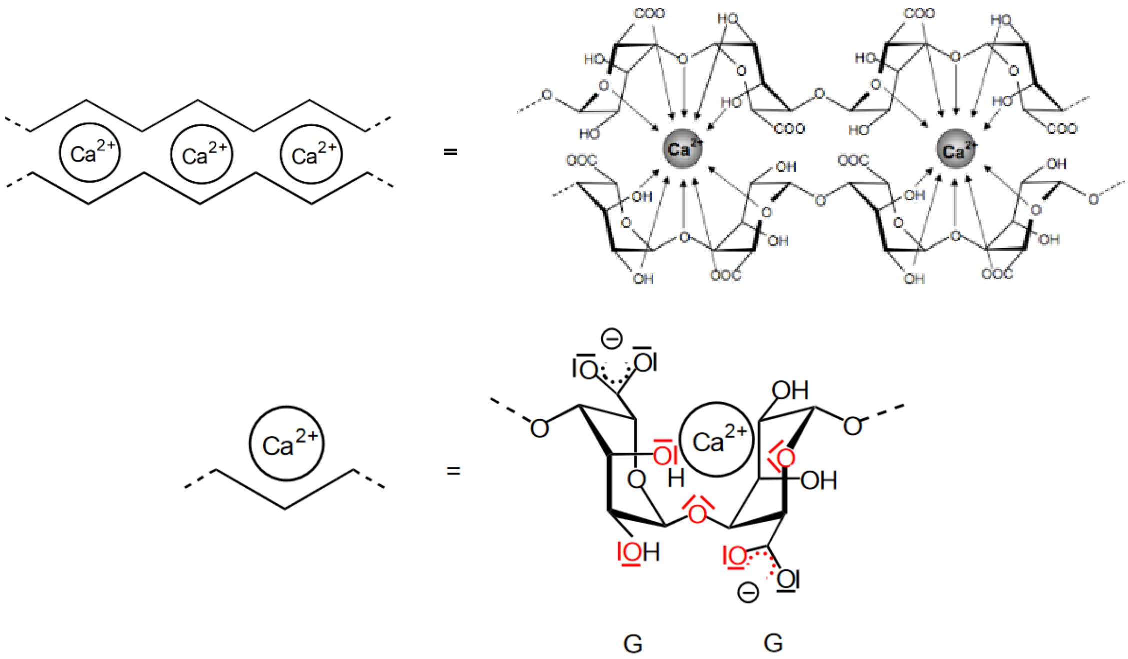


Figure 3: The structure of alginate gel; O-atoms that are coordinated with the calcium- ion are marked red [4, 11]

The formation of alginate gels depends heavily on the type of alginate that is used, or more precisely on the ratio between the M and G monomers. If an alginate contains a high amount of mannuronic acid, the gel turns out elastic, as the M monomers; therefore also the MM blocks, are soft and flexible. A high amount of M monomers also causes a delay in gel formation. The more guluronic acid is present in the alginate, the harder and more compact the gel turns out. The chain stiffness is the highest in the GG blocks due to their zigzag formation. The stiffness decreases in MM blocks and is the lowest in MG blocks [5].

Alginate gel is used in many areas, but is especially very important for molecular gastronomy. It is created with the spherification technique which will be described in the next chapter.

4.4 Spherification

Spherification is the most widespread technique in molecular gastronomy. This technique is used to create spheres that burst when they are eaten. These spheres consist of a liquid enclosed by a gel layer. The wow-effect that comes with eating this sphere, is what makes spherification such an attractive technique [12]. In spherification the concentration of the solutions is very important. The alginate solution has to have a 0.5% concentration and the calcium solution - a 2% concentration. If these conditions are not met, the sphere will not be able to form [13]. There are two types of spherification: basic and reverse.

4.4.1 Basic spherification

Basic spherification is a technique that creates spheres with a very thin gel layer. These spheres pop easily in one's mouth, making the eating experience very special. To give the sphere a desirable taste a corresponding flavored liquid (e.g. juice) is used. The first step is to mix calcium with water to create a calcium solution. Alginate in a form of a white powder is added to the flavored liquid to produce the alginate solution. Droplets of this alginate solution are then dropped into the calcium solution. As soon as the alginate gets in touch with calcium, they start to form a gel layer inside the sphere. The gel layer is formed inside because the calcium-ions from the calcium solution diffuse from the outside to the inside of the sphere, where they get in touch with alginate. While the alginate, which forms the basis of the alginate gel, is dissolved in the flavored liquid, the alginate gel takes on the flavor of the liquid and is therefore not flavorless. Consequently, the eating experience becomes more enjoyable [13].

However, there are also negative aspects about basic spherification. Once the sphere is taken out of the calcium solution, it needs to be consumed immediately and therefore, cannot be stored. This is due to the fact that the jellification process does not stop when the sphere is withdrawn from the calcium solution. If not consumed immediately, the sphere, which now contains ions, that diffused into it, will completely turn into a gel clump. Additionally, basic spherification will not be successful, if the flavored liquid contains calcium or has a pH under 3.6. This is due to the fact that calcium and a low pH have the same effect on the alginate solution: it begins to gel too early, the calcium solution cannot penetrate it and ,therefore, the reverse spherification will not work [13].

4.4.2 Reverse spherification

In reverse spherification the exact opposite is done: the calcium is added to the flavored liquid and the alginate is mixed with water to create an alginate solution. When the calcium solution is dropped into the alginate solution, a gel layer is formed on the outside surface of the sphere. In reverse spherification calcium is added to the flavored liquid instead of alginate. Therefore nearly any type of flavored liquid can be used, as calcium cannot form a gel prematurely. Reverse spherification technique is especially good for liquids that cannot be used for basic spherification, such as milk (contains calcium) or alcohol (pH often below 3.6). Another advantage of reverse spherification is, that the jellification process stops immediately after the sphere is withdrwan from the alginate solution and rinsed. This is due to the fact that alginate cannot diffuse into the sphere, therefore there is no alginate available to form the gel when the sphere is taken out of the alginate solution. That is why the sphere remains liquid inside and can be stored [13].

Nevertheless reverse spherification also has disadvantages. The gel layer is formed outside of the sphere, using the flavorless alginate solution and not the flavored liquid. This results in a less pleasant eating experience because when the sphere pops, one can feel the flavorless gel in the mouth [13].

4.5 Xanthan gum

There are many techniques in molecular gastronomy, which do not require alginate as their main ingredient. Techniques like thickening or turning liquids into a foam require a different substance. This substance that thickens liquids is called xanthan gum and is sold on the market as a white powder.

4.5.1 Production of xanthan gum

Xanthan gum is produced by aerobic fermentation of carbohydrates, such as glucose [14]. Aerobic fermentation occurs only in the presence of oxygen and only when a microorganism is involved [15,16]. In the case of xanthan gum carbohydrates are fermented by the microorganism called *Xanthomonas campestris*. This microorganism is a gram-negative bacterium that is responsible for the black rot and other plant diseases worldwide [16].

Before fermentation can start a fermentation medium is created out of a carbohydrate, a nitrogen source and mineral salts. When the bacterium is finished with the fermentation, a fermentation broth remains. Xanthan gum is recovered from the broth with the use of isopropanol for alcohol precipitation. Due to the mineral salts, respectively ions, added to the fermentation medium, xanthan gum is obtained as a sodium, calcium or potassium salt. Afterwards the whole product is rinsed and dried. This is how the white power that is sold in shops is produced [14] .

4.5.2 Structure of xanthan gum

Xanthan gum is a high-weight branched polysaccharide. The word “branched” indicates that there are multiple interconnected chains in the structure of xanthan gum. The main chain, respectively the backbone of xanthan gum, is formed by repeating cellobiose units like a simple cellulose chain. Side chains, which branch off from the backbone, consist of a trisaccharide. This trisaccharide consist of β-(1,4) linked D-mannose, β-(1,2) linked D-glucuronic acid and α-(1,3) linked D-mannose. A side chain is connected from the D-mannose to every second D-glucose unit of the backbone by an α-(1,3) linkage (Figure 4). An acetyl group is linked to the 6^{th} position of the first D-mannose unit of the side chain. In addition, about a half of the terminal D-mannose units are cyclically linked to pyruvic acid residues at their 4^{th} and 6^{th} position via an acetal group formed from the pyruvic acid keto group (Figure 4) [17].

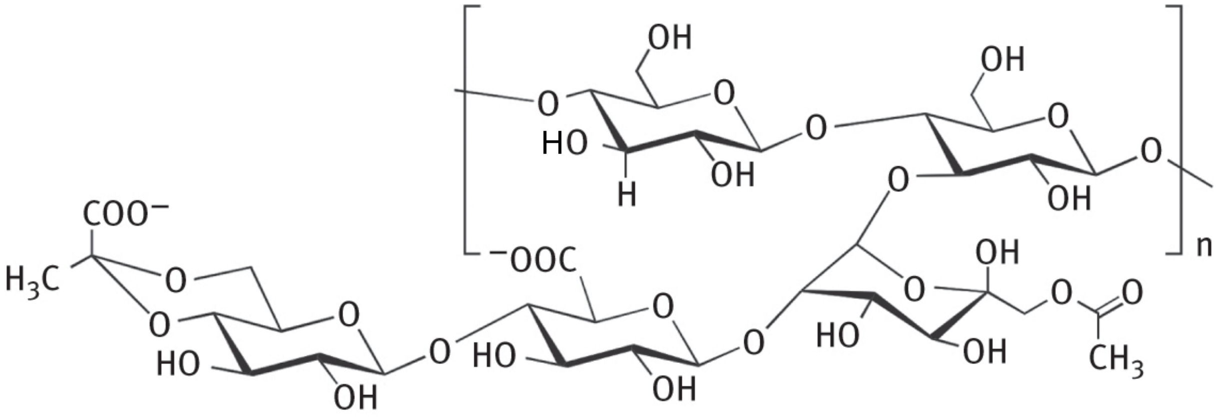


Figure 4: The structure of the anionic part of xanthan gum [18]

Both, the pyruvic acid and the D-Glucuronic acid are negatively charged, making xanthan gum a polyanion. After the fermentation process the anionic part of xanthan gum forms bonds with cations, thus forming a salt. The counter-ions that occur most frequently are natrium, calcium and potassium ions which stem from the fermentation broth [17].

4.5.3 Use of xanthan gum

Xanthan gum has diverse effects on the food products. On the one hand it increases a product's viscosity and therefore is used as a thickener. On the other hand it can suppress texture changes, holds ingredients in place and is often utilized as an emulsifier and stabilizer [19]. Due to all these capabilities, xanthan gum is often used in the food industry as a food additive and is known as E415. It often appears in finished products such as salad dressings, soups, ice creams [20].

Xanthan gum can also be spotted on the ingredients list of beauty products. It thickens these products, still allowing them to flow smoothly out of their packaging. Another favourable property is that xanthan gum suspends solid particles in liquids [19].

In molecular gastronomy xanthan gum is often used to thicken liquids. The change in consistency allows the cooks to form the substance as desired. This technique is called thickening [19].

4.6 Objective of the matura project

The aim of this project is to develop a vegan fried egg from scratch using molecular gastronomy techniques without relying on an existing recipe.

All experiments were based solely on some basic knowledge that was acquired before starting the experiments is was describe above. It was important to select the molecular gastronomy technique that is most suitable for the creation of each part of the egg.

For the egg yolk, the reverse spherification technique was selected. This technique is the most suitable because it allows to create a very realistic looking sphere that resembles an egg yolk: as the outer layer pops, the liquid inside flows out.

For the egg white, the thickening technique was selected. This technique requires a thickener. Xanthan gum can thicken a liquid making it easier to shape it into a preferable form. Once the liquid is thick enough, the focus lies on shaping a realistic looking egg white.

In the end both parts, the egg yolk and the egg white, were combined to form the desired final product: the vegan fried egg.

As part of the project the following two hypotheses were established and tested throughout the experiments:

- Hypothesis 1: the longer the sphere is left in the alginate solution, the thicker the gel layer will become.
- Hypothesis 2: adding more calcium lactate to the calcium solution increases the sphere’s ability to withstand pressure.

5 Experiments

All experiments were performed in the house kitchen using available kitchen tools. With every new experiment and the its result new knowledge was acquired that was later used to adjust the experiments and obtain the best possible result.

It needs to be considered that some experiments might not have been very accurate due to the fact that general kitchen tools were used.

5.1 Importance of the correct concentrations

5.1.1 Materials

- Calcium lactate (7 g)
- Sodium alginate (4 g)
- Lemon juice (200 mL)
- Tap water (1000 mL)
- 1 big bowl (2.7 L)
- 1 small bowl (0.5 L)
- 2 tablespoons
- Kitchen scale Mio Star cuisine plus

5.1.2 Method 1

In the first step an alginate solution was prepared by weighting 1 g of sodium alginate and mixing it with tap water in a large bowl. Then 4 g of calcium lactate were weighted and mixed with the lemon juice in a small bowl. Afterwards, a tablespoon was used to slowly drop the calcium solution into the alginate solution.

5.1.3 Results 1

When the lemon juice containing calcium was added to the alginate solution, nothing happened. It did not gel or show any signs of changing its texture. The calcium solution just sank to the bottom of the big bowl.

5.1.4 Method 2

The approach had to be adjusted to achieve a better result. More calcium lactate(3g) was added to the solution, as it was thought that this might help the calcium solution to gel. However, the calcium solution still did not gel. Consequently another approach was applied. This time more sodium alginate (3g) was added to see, if this would change the situation.

5.1.5 Results 2

As a result the calcium solution started to gel, but still was not thick enough. It was only a cohesive clump, when taken out of the water (Figure 5).

Figure 5: The calcium solution started to gel

5.1.6 Discussion

At first, the alginate solution did not contain enough alginate. Instead of adding 0.5% (of the water weight) alginate only 0.1% was added in the first part of the experiment. As a result, the concentration of the alginate solution was not correct that is why nothing happened, when the calcium solution was dropped into the alginate solution. After additional 3 g of alginate were added in the second part of the experiment, the concentration of the alginate solution equaled 0.4 % of the water weight. It was still not the required concentration of 0.5 %, but it was more than in the first phase of the experiment. That is why the lemon juice was slowly starting to gel. However, it was only a cohesive clump, when taken out of the alginate solution because the concentration of the solution was still not quite right yet.

This experiment highlighted the importance of the correct concentrations in both, the alginate and calcium, solutions because otherwise no sphere will be formed. In order for the concentrations to be precise the substances have to be weighted precisely as well. With an ordinary kitchen scale precise measurements cannot be achieved. Therefore, in the next experiments a professional scale was used.

5.2 Does calcium lactate leave a bitter aftertaste ?

For reverse spherification usually calcium lactate is used instead of calcium chloride because it should not leave a bitter aftertaste in flavored liquid. The goal of this experiment was to prove that calcium lactate would not affect the taste of the sphere. This information was required to plan further experiments.

5.2.1 Materials

- Calcium lactate 2 g
- Sodium alginate 1 g
- Tap water for calcium solution 100 g
- Tap water for sodium alginate 200 g
- 1 big bowl (2.7 L)
- 1 small bowl (0.5 L)
- Tablespoons
- Scale Mettler Toledo B2002-S
- Hand mixer Braun

5.2.2 Method

Sodium alginate and calcium lactate were each mixed with water in different bowls. A hand mixer was used to help the powder dissolve a little bit faster in the water and to create a smoother solution. The calcium mixture was clear as the calcium was dissolved. However, the sodium mixture still seemed a little dull, so it was set aside to clear up. Afterwards a bowl with tap water was prepared to rinse the spheres after taking them out of the alginate solution. The container with the calcium solution was standing on the left, the alginate solution in the middle and the water to rinse the spheres on the right (Figure 6). This particular set up was used in all the experiments to always keep an overview over the solutions. After setting up the experiment, it was time to drop some of the calcium mixture into the alginate mixture to create spheres.

Figure 6: Setup the experiment

In the end a taste test of the received product was conducted to find out whether a bitter aftertaste could be detected.

5.2.3 Results

During the process of making spheres the sodium alginate mixture started to jellify on its own. The gel was stirred and slowly started to turn liquid again. Some of the calcium mixture was dropped into the alginate solution, now that it was liquid again. This time the spherification partially worked, however not spheres were obtained, but jelly clumps. A liquid inside and a solid outside layer was wanted, however the jelly clumps were also solid on the inside.

After conducting the taste test, no bitter aftertaste be detected. The spheres tasted just like the tap water that was used for the calcium solution.

5.2.4 Discussion

The alginate solution turned into gel by itself because tap water was used for it. As explained in the introduction (see 4.3) , alginate and calcium are like a two-part glue. They start interacting as soon as they get in touch with each other. The tap water t used to create the alginate solution, contained calcium. Once alginate was mixed with tap water to create the alginate solution, calcium in the tap water and alginate got in touch and started to create a hydrogel. The alginate solution was very thick and this made it impossible to create spheres. Therefore distilled water was used for future experiments. It does not contain calcium or any other sorts of minerals ,therefore, prevents the alginate solution from jelling prematurely.

The taste test was a success: the sphere taste just like the tap water that was used for the calcium solution and no bitter aftertaste was detected. As calcium lactate does not leave a bitter aftertaste, any liquid can be used in future experiments, without its taste being altered.

5.3 Mango juice instead of water for the calcium solution

For this experiment the tap water, which was used for the calcium solution, was replaced with mango juice. Mango juice has an orange tone and is therefore better visible in the alginate solution than water. Additionally, it is important for spherification that the calcium solution is thick enough to penetrate the viscous alginate solution. As water has a low viscosity, it was important to replace it with a liquid, that would be able to penetrate the alginate solution and hold its shape [13]. Another reason why mango juice was chosen is that it is the same color as an egg yolk and can therefore create the perfect illusion, once formed into a sphere.

5.3.1 Material

- Mango juice 100 g
- Distilled water 200 g
- Calcium lactate 2 g
- Sodium alginate 1 g
- 2 small bowls (0.5 L)
- 1 food container (0.7 L)
- 1 Tablespoon
- 1 Ice cream spoon
- Distilled water to rinse the spheres
- Scale Mettler Toledo B2002-S
- Hand mixer Braun

Figure 7: Setup of the experiment

5.3.2 Method

The calcium solution and the sodium alginate solution were prepared as described in 5.2.2. After the solutions were prepared, they were set aside for a couple of hours to eliminate most of the air bubbles that formed during the mixing. Afterwards, the alginate solution was poured into a food container with a smaller basis to bring the surface of the alginate solution up and cover the whole sphere. It is important that the spheres are fully covered by the alginate solution, otherwise an uneven gel layer will be formed. The next step was to take a tablespoon full of the calcium solution and drop the calcium solution into the alginate solution.

5.3.3 Results

The calcium solution formed a sphere immediately as it touched the alginate solution. The sphere was left in the alginate solution for about 30 seconds. Afterwards it was carefully removed from the alginate solution and rinsed in distilled water to stop the spherification process. The outer gel layer of the sphere was very thin. The liquid inside started to flow out immediately once the sphere was punctured with a knife. For the first time since the start of the experiments a proper sphere was formed with a liquid inside and a solid outer gel layer (Figure 8).

As the sphere was still pretty small, a bigger ice cream spoon full of the calcium solution was used to make the next sphere. However the bigger spheres burst in the alginate solution while they were taken out (Figure 9)

Figure 8: The first proper sphere

Figure 9: The big sphere burst in the alginate solution

5.3.4 Discussion

As the juice was more viscous than the water used before, the calcium solution could penetrate the alginate solution much better. Additionally, the spheres could form better and hold their round shapes.

This time distilled water was used instead of tap water. As a result, the alginate did not gel by itself. It is important for reverse spherification that the calcium solution is denser than the alginate solution. If the calcium solution is not dense enough, it will remain on the surface of the alginate solution and will not be able to penetrate it; therefore, no spheres will be formed. Using distilled water, which does not contain calcium-ions, for the alginate solution resulted in the alginate solution staying liquid and not forming a gel. The required conditions were fulfilled; therefore, spheres could now be easily produced.

The bigger spheres burst while being taken out of the alginate solution because the liquid inside was too heavy for the thin outer layer. The pressure applied with the spoon while taking the spheres out must have been too strong.

5.4 Frozen reverse spherification

Frozen reverse spherification is a technique that has the advantage of creating spheres of a consistent size and perfectly round shape. To create a perfectly shaped sphere using a spoon is very difficult and takes a lot of practice. For an unexperienced person it is difficult to create spheres without them turning out ellipse-shaped. This is due to the fact that the calcium solution is liquid; and it is difficult to drop it into the alginate solution at once, as required to make a round sphere. this problem does not appear when frozen reverse spherification is used. The frozen calcium solution, often resembling a hemisphere, is dropped into the alginate solution as one whole piece. The edges of the hemisphere start to melt and interacting with the alginate in the alginate solution.

The only minus of frozen reverse spherification is that the hemispheres need to stay in the alginate solution a little longer than usual because they need to melt for the gel layer to form. It was concluded that frozen reverse spherification is the perfect technique for beginners, as it does not require as much practice as the normal reverse spherification techniques [13].

5.4.1 Material

- Mango juice 100 g
- Distilled water 200 g
- Calcium lactate 2 g
- Sodium alginate 1 g
- 1 small bowl (0.5 L)
- 1 food container (0.5 L)
- Tablespoons
- Scale Mettler Toledo B2002-S
- Hand mixer Braun
- Distilled water
  to rinse the spheres
- Silicone form

Figure 10 : Set up of the experiment

5.4.2 Method

After preparing the solutions as described in 5.3.2, the calcium solution was poured into a silicone form and put into the freezer for 3 hours. When the time was up, the frozen spheres were taken out and put into the alginate solution for 5 minutes.

5.4.3 Results

Once the frozen spheres touched the alginate solution, an outer gel layer started to form. The sphere was continuing to melt, forming a thicker layer. However, when the sphere was taken out of the solution, it burst again (Figure 11) . Also it was still frozen inside (Figure 12).

Figure 12 : The sphere burst in the alginate solution

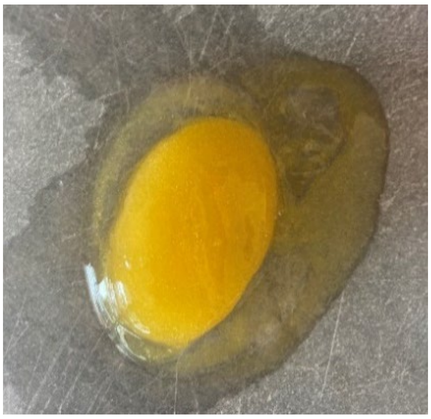


Figure 11 : The sphere was frozen on the inside

5.4.4 Discussion

While the sphere was taken out of the alginate solution, it burst very quickly revealing its frozen middle. This meant that the sphere did not have time to melt properly before being popped. The other observation was made that the alginate layer was too thin for this size of the sphere. It was required to establish a good ratio between the size of the sphere and the thickness of its gel layer, so the sphere would be more robust and not burst so easily. The size of the sphere could be reduced easily by using a smaller silicone form to freeze the calcium solution. However, it was not quite clear yet how to increase the thickness of the gel layer. It was assumed that the gel layer was not thick enough because the sphere did not spend enough time in the alginate solution. Therefore, the hypothesis 1 “the longer the sphere is left in the alginate solution, the thicker the gel layer will become” was established. This hypothesis was tested in the next experiment.

5.5 Proving hypothesis 1

5.5.1 The idea behind the hypothesis

Once alginate and calcium interact, they start forming coordinative bonds, which then create a three-dimensional structure. Keeping this in mind, it was assumed that the longer the sphere is kept in the alginate solution, the more coordinative bonds will be formed and as a result, the outer gel layer would become thicker.

5.5.2 Designing a method to prove the hypothesis

The gel layer of the sphere is generally very thin to be measured with an ordinary ruler. A different approach was required to decipher the thickness of the gel layer.

If one needs to find out the height (h), respectively, the thickness, of an object, and the width (w), length (l) and volume (V) of this object are known, the formula for volume could be used to calculate h (Formula A):

$$V = w \cdot l \cdot h$$

⬇

$$h = \frac{V}{w \cdot l}$$

As the volume of the gel layer is unknown in this experiment, this formula cannot be used as such. The density of the alginate gel was thought to help in this case. The volume of an object can also be calculated using the density and mass of this object and can therefore be replaced in the formula above.

Formula B to calculate the volume using the density (ρ) of an object and its mass (m):

$$V = \frac{m}{\rho}$$

The density of the alginate gel is a constant and can be derived through research on the internet. By weighting the gel layer of the sphere on a scale, the mass of the gel layer can measured. Replacing the volume in Formula A with Formula B results in following final formula:

$$h = \frac{m}{w \cdot l \cdot \rho}$$

In this particular experiment sodium alginate was used. Consequently the density of the sodium alginate gel had to be researched. The density amounts to 0.8755 g/cm^3 [21]. The variables mass (m), weight (w) and length (l) could only be defined by conducting an experiment.

5.5.3 Experiment

For this experiment a smaller silicone form was used. The big spheres produced in the last experiment (see 5.4) were difficult to handle and burst at the slightest contact. In addition, the big spheres did not resemble an egg yolk at all. This problem was expected to be resolved with the smaller silicon form, as the spheres should turn out smaller and rounder.

5.5.3.1 Material

See the list in 5.4.1
Additions:

- Smaller silicone form
- Triangle ruler
- Victorinox knife

5.5.3.2 Method

After the frozen calcium solution was taken out of the freezer, the first hemisphere was put into the alginate solution for 6 min and the second - for 30 min. This big time interval was chosen on purpose, to have a more distinct and tangible result.

Each sphere was removed from the alginate solution in its time and rinsed. Both spheres were separately examined. With the help of a knife the spheres were cut and the liquid flowed out of them, so that only the gel layer was left. After all the liquid was gone, the gel layer that was on the top of the sphere was positioned on the gel layer that was at the bottom of the sphere,. These two layers had to be unfolded because the thickness of only one gel layer had to be calculated. After the gel layer were unfolded, a segment was cut out.

This segment had to have strait sides, so it would be easy to measure them. A square was cut out from the gel layer of the sphere that spent 6 min in the alginate solution. This square's sides measured 2 cm. A rectangle was cut out of the gel layer of the sphere that spent 30 min in the alginate solution. Its width measured 1.6 cm and its length - 2.4 cm.

After the measuring process, both segments were weighted on a scale. The square weighted 0.3 g and the rectangle - 0.69 g. At this point in the experiment the width, length and mass of the segments were measured. As the density was already researched before (see 5.5.2), all the values were know fixed.

The only thing left to do was to insert them into the formula (defined in chapter 5.5.2) to calculate the height, respectively the thickness (h), of the two gel layers.

5.5.3.3 Results

As soon as the spheres were taken out of the alginate solution, it was already visible with the naked eye that the gel layer was thicker after spending 30 min in the alginate solution, compared to 6 min. Once the liquid flowed out of the outer gel layer, it was quickly noticeable that after only 6 min in the alginate solution the gel layer was extremely thin, which made it almost impossible to see with the naked eye. In contrary, the thickness of the gel layer that was building up in the alginate solution for 30 min could be spotted easily.

The observed results were supported by the calculations. The thickness of the gel layer of the sphere that spent 6 min in the alginate solution amounted to 0.85 mm. The thickness of the sphere's gel layer that spend 30 min in the alginate solution amounted to 2.1 mm. These results showed, that the thickness of the two gel layers differed in 1.25 mm, which is a very significant difference in comparison to the thickness of each gel layer.

5.5.3.4 Discussion

The results prove that the longer a sphere is left in the alginate solution the thicker its gel layer becomes. The concept of permeability explains the steadily thickening gel layer. The gel layer's pore sizes range from 5-200 nm [5]. This means that alginate molecules are not able to diffuse through the gel layer because they are too big. However, the diameter of calcium-ions measures about 0.446 nm [22] making it possible for them to diffuse from the inside of the sphere to the outside [13]. A gel layer outside of the sphere is formed, as the calcium ions diffuse from the inside of the sphere to the outside. New calcium ions that get in touch with the alginate in the alginate solution form new three-dimensional structures resulting in a thicker gel layer. Immediately after the removal of the spheres out of the alginate solution the jellification process stops, as there is no alginate available anymore to form a gel [13].

It is important to mention that this experiment had a high probability for inaccuracies in the measured values. The first possible inaccuracy could occur during the measuring of the cut-out gel layer segments, since it was very difficult to cut the thin gel layer with a knife. The sides of the segments came out oblique and sometimes corners of the segments where cut off. Despite several attempts, it was impossible to cut out a small but perfect rectangle or square out of the gel layer using a kitchen knife. All these difficulties led to the measurements of the sides being inaccurate, which in turn could have led to an imprecise calculation of the final thickness of each gel layer.

The second possible inaccuracy might have occurred during the weighting of the cut-out segments. After taking the spheres out of the alginate solution and rinsing them, the gel layer was still very wet. This remaining water could not have been dried with a paper towel due to the risk of damaging the gel layer. Consequently, some excess water was weighted along with the cut-out segments that probably resulting in an inaccurate mass values.

For this reason it is important to assess how significantly these inaccuracies may have impacted the final result. The objective of the experiment was to find out whether the thickness of the gel layer would vary depending on the time the sphere spent in the alginate solution; not the exact measures and mass of the gel. Therefore, the inaccuracies did not make a huge difference and were not considered material for the outcome. One gel layer was significantly thicker than the other. Slightly imprecise measurements could not change that. In addition, the calculated results were in line with the observations.

5.6 Implementing the results

The experiment in 5.5.3 confirmed that using a smaller silicone form was leading to production of a smaller and rounder spheres. In addition, after hypothesis 1 was proven, it was decided to prolong the time for a sphere to spend in the alginate solution. The time the spheres spent in the alginate solution was increased from 5 to 6 min. This rather small increase was selected as the gel layer should get thicker, but not too thick as this would result in an unpleasant eating experience.

In addition, prolonging the time of reaction would allow the middle of the spheres to melt properly avoiding the negative result described in 5.4 .

5.6.1 Material

Figure 13: Setup of the experiment

See the list in 5.4.1
Additional Material:

- Smaller silicone form

5.6.2 Method

For this experiment the same approach was used as in 5.4. with two amendments discussed in 5.6:

- A new silicone form for smaller spheres was used
- The time a sphere spent in the alginate solution was increased to 6min

5.6.3 Results

With the smaller silicone form the spheres turned out to be the perfect size and very much resembled an egg yolk (Figure 14). The outer gel layer was thick enough to resist the pressure that was created while taking the sphere out of the solution and putting it on a plate. Additionally, the sphere was no longer frozen inside after spending 6 min in the alginate solution.

Figure 14 : The sphere resembled an egg yolk

5.6.4 Discussion

In this experiment the perfect sphere was produced for the first time: it was round, looked like an egg and was liquid inside. Based on this result it was concluded that 6 minutes was the right period of time for the frozen sphere to spend in the alginate solution for the satisfying outcome .

The egg yolk of a sufficient quality was created. It ultimately meant that the reverse spherification was finally mastered.

5.7 Proving hypothesis 2

As the last step to complete the experiments concerning the egg yolk, the hypothesis 2 had to be proved.

Hypothesis 2: adding more calcium lactate to the calcium solution increases the sphere’s ability to withstand pressure.

5.7.1 The idea behind the hypothesis

As soon as calcium touches alginate, they start interacting. The simplified version of this interaction could be described as calcium connecting two alginate chains by filling the space between them. Based on this simplified image an assumption was made which stated that the more calcium was present in the calcium solution, the more “spaces” between the alginate chains would be filled, once the two reactants started to interact. The outcome would be a more firmer outer gel layer. Consequently the spheres containing more calcium were assumed to be able to withstand more pressure without bursting.

5.7.2 Designing a method to prove the hypothesis

Pressure is defined as the force applied on a certain area:

$$P = \frac{F}{A}$$

To find out which sphere is able to withstand more pressure the force (F), with which an object is pressing down on the spheres, and the area (A), on which the pressure is applied, have to be figured out.

In this particular experiment the spheres were identical. Additionally, the same object was used to apply pressure on both spheres. This meant that the area (A) was a constant throughout the experiment. The only changing value was the force applied on the spheres. In this experiment the acting force was the weight applied on the spheres. The weight is directly proportional to the mass of the object and therefore it could be assessed with the help of a scale: the higher the number on the scale ascended, the more weight was applied. In the end, it was concluded that applying more weight on the spheres corresponds to applying more pressure on the spheres.

5.7.3 Materials

- Mango juice 50 g
- Calcium lactate 1 solution: 1 g
- Calcium lactate 2 solution: 2 g
- Measuring cylinder 10 mL
- Potato masher
- 1 small bowl (0.5 L)
- 1 big bowl (2.7 L)
- 1 food container (0.5 L)
- Tablespoons
- Plate
- Small silicone form
- Scale Mettler Toledo B2002-S
- Hand mixer Braun
- Distilled water to rinse the spheres

5.7.4 Method

Figure 15 : Potato masher is used to press down on the sphere

At first the calcium solution with 50 g of mango juice and 1 g of calcium lactate was prepared using a hand mixer. Then a measuring cylinder was used to pour exactly 17 mL into the silicone form. This was the perfect amount of calcium solution for the spheres to be not too big, but also not too small. Afterwards the same procedure was used to create a calcium solution containing 2 g of calcium, which was then also measured and poured into the silicone form. While the spheres were resting in the freezer, the alginate solution was created as described in 5.2.2. After the spheres were taken out of the freezer, they were put into the alginate solution for them to form an outside gel layer. When the spheres were ready, the first one containing less calcium was put on a plate that was standing on a scale. Using the zero button, the display of the scale was reset to 0.00 g. Afterwards a potato masher was used to press down on the sphere until it burst (Figure 15). This whole process was repeated with the sphere containing 2 g of calcium.

After the first experiment was conducted, the exact same procedure was repeated once again, to ensure that the results were not a coincidence. Both experiments were filmed as a slow-motion video, so it would be afterwards easy to verify how much weight was applied when the spheres burst.

5.7.5 Results

In the first experiment the sphere containing 1 g of calcium burst when 99.20 g were displayed. The second sphere containing 2 g of calcium burst when 94.88 g were presented on the display of the scale, meaning that this sphere was able to withstand less pressure.

A similar result was received in the second attempt. The sphere containing less calcium burst when 109.6 g were presented on the scale and the sphere containing more calcium when 102. 86 g were applied.

5.7.6 Discussion

This experiment showed that the sphere containing more calcium burst while less weight was applied. This means that the hypothesis 2 was proven wrong.

A possible explanation for these results could be, the stiffness of the alginate G units while they are coordinated with calcium-ions. When alginate is dissolved in water, its chains are not bound to each other, so no fixed structure is present. As soon as alginate interacts with calcium, the structure changes drastically. The G units are now coordinated with the calcium-ions and form a rigid three-dimensional structure. In this new structure the G units lose their flexibility. On the contrary of what was thought in the beginning, the more calcium is present, the more G units are bound and the less flexible the alginate gel layer becomes. When pressure is applied to the spheres, a sphere containing less calcium has a more flexible gel layer, can stretch out and consequently withstand more pressure. The gel layer of the sphere containing more calcium is robust and consequently bursts quicker.

All of the experiments concerning the egg yolk were completed. At this stage it was time to move to the second part of the project: the creation of the egg white.

5.8 Creating the egg white using xanthan gum

5.8.1 Materials

- Coconut milk 300 mL
- Xanthan gum Betty Bossi 8 g
- Teaspoon
- Measuring cup
- 1 big bowl (2.7 L)
- Hand mixer Braun

Figure 16 : Setup of the experiment

5.8.2 Method 1

The coconut milk that was chosen for this experiment because it is white and consequently resembles a real egg white, was measured and poured into a bowl. Afterwards the first portion of xanthan gum was slowly sprinkled into the coconut milk. Then these two ingredients were mixed together using a spoon. However, it was quickly realized that the xanthan gum was not dissolving, when mixed with a spoon. Therefore, a hand mixer was used to mix the liquid. After the first small portion of xanthan gum was dissolved in the milk, more and more xanthan gum was added, while the liquid was continuously mixed . This process was repeated until all the required quantity of the ingredients was mixed together.

5.8.3 Results 1

The coconut milk started to thicken quite fast after the first amount of xanthan gum was added. It was not liquid anymore and was turning viscous. The texture of the milk was now similar to slime (Figure 17). It was time to form the thickened white substance into an egg white of a fried egg. Once the substance was formed into an egg white, the resemblance of the vegan egg white to a real one was quite shocking (Figure 18).

Nevertheless, the created egg white was still not perfect, as the consistency of the milk was not quite satisfactory: it was not as smooth as the egg white of a real egg yet. The substance still had small chunks in it, which prevented a perfect resemblance with an egg.

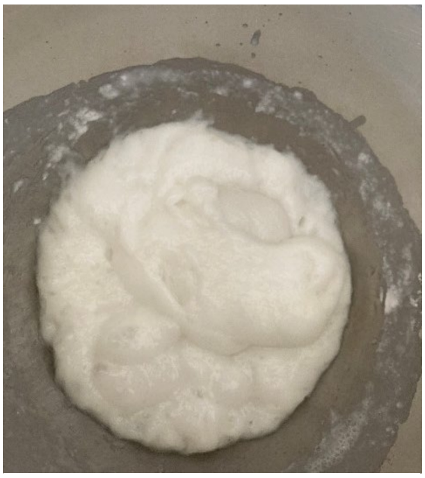


Figure 18: The coconut milk after xanthan gum was added

Figure 17: The vegan egg white resembles a real egg white

5.8.4 Discussion

The coconut milk turned out to be a bit chunky because too much xanthan gum was added too quickly. Therefore the moment when the resulting substance was still smooth, but already thick enough, was missed. The desired outcome was a substance that was thick enough to form an egg white, but would still look as smooth and real. To improve the outcome the experiment was conducted again.

5.9 Using less xanthan gum

5.9.1 Materials

See the list in 5.7.1

Additional material:

- 1 egg white (as a reference)
- 1 Pan
- 1 tablespoon of oil

5.9.2 Method 2

When the experiment was conducted for the second time to improve the egg white, the same approach was applied, yet less xanthan gum was used. This time the xanthan gum was added in smaller portions. Additionally, each new portion was added only after the previous portion was completely dissolved and showed its effect. Using this approach it could be assured that not too much xanthan gum was added. In the end, the egg white prepared in this experiment was compared to a real fried egg white.

5.9.3 Results 2

The second time the egg white turned out smoother than in 5.7.3. There were no chunks in the thickened milk and the surface was slick. Approximately 5 g of xanthan gum was used to achieve this desired result.

After comparing the produced vegan egg white to a real one, it could be concluded that they were extremely similar (Figure 19). The only remaining small difference between these two egg whites was the color: the real fried egg, white had a yellowish tone while the vegan egg white was white.

Figure 19: The vegan egg white compared to a real egg white

5.9.4 Discussion

In this experiment the xanthan gum was added in smaller portions and after longer time intervals. Using this method it was possible to verify if the milk was thick enough before adding the next portion of xanthan gum. This made it possible to capture the right moment to stop adding more xanthan gum and achieve the desired outcome.

5.10 Creating the vegan fried egg

Both techniques, the production of the egg yolk and of the egg white, were now mastered. The only that was left to do, was to combine these two parts to create the final product – a vegan fried egg. To make the final experiment more exciting it was decided to add different food colors to the some of the egg parts.

5.10.1 Materials

Figure 20: Setup of the experiment

- Calcium lactate 2 g
- Mango juice 100 g
- Alginate1.65 g
- Distilled water 330 g
- Food colors (red, black, purple)
- Scale Mettler Toledo B2002-S
- Hand mixer Braun
- 1 big bowl (2.7 L)
- 4 small bowl (0.5 L)
- 1 food container (0.7 L)
- teaspoons
- approx. 5 g Betty Bossi xanthan gum from a 8 g package
- Distilled water to rinse spheres
- Coconut milk 300 mL

5.10.2 Method

The spheres were prepared using the method described in 5.6.2, except this time food color was added to the calcium solution before freezing it. One sphere was left in the original orange color, as it should represent a realistic egg yolk. After the spheres were prepared, they were put into a freezer for about 3 hours. Then the egg white was prepared using the method described in 5.8.2. After the coconut milk was thick enough, it was divided into 4 different bowls. Three parts of the egg white were colored differently. One part of the egg white was left white as it was needed for the realistic looking fried egg. After 3 hours had passed, the spheres were taken out of the freezer an put into the alginate solution. In the end, the different colored spheres were assigned to the different colored egg whites. Care was taken not to assign parts of the same color to each other.

5.10.3 Result

After all egg yolks were properly assigned to their corresponding egg whites, 4 colorful fried eggs (Figure 22) and one realistic looking egg were (Figure 21) created.

Figure 21: A realistic looking vegan fried egg

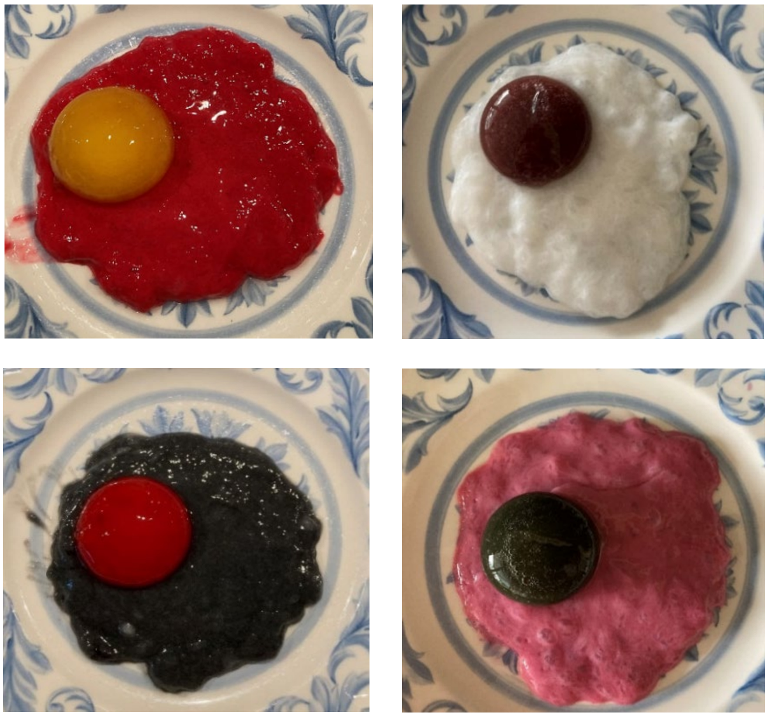


Figure 22: The colorful vegan fried eggs

Something strange started to happen after some spheres were already done. The alginate solution was partially transforming into a gel by itself, although distilled water was used for the solution.

5.10.4 Discussion

The alginate solution started to gel because small drops of the calcium solution got in touch with it unintentionally. During the step of making spheres, some of them burst while they were being taken out of the alginate solution. The whole content of the sphere, respectively the calcium solution, was now floating in the alginate solution. Calcium and alginate started to interact as soon as they got in touch with each other. Although it was noticed and the drops of the calcium solution, that accidentally got into alginate solution were removed, it was done not fast enough. Consequently, calcium spread in the alginate solution and these two reactants formed a gel.

6 Conclusion

After completing all experiments, some important aspects were concluded and were applied in the final production of the vegan fried egg.

In molecular gastronomy, in particular for the reverse spherification technique, the concentration of the solutions is very important. If the required concentration is not met, jellification will not occur at all. This mistake was made in the very first experiment and never repeated again.

The second important discovery was that the flavored liquid has to have a certain viscosity, otherwise it will not be able to penetrate the dense alginate solution and, consequently, no spheres will be formed. This discovery was made during the 5.2 experiment. For the next experiments water for the calcium solution was replaced by mango juice.

The standard reverse spherification is an advanced technique and needs a lot of practice till the perfectly shaped sphere can be created. That is why the frozen reverse spherification technique was chosen in 5.4 and from then on used for all the experiments. It is more suitable for beginners, as it is easier to produce perfectly shaped spheres than with the standard reverse spherification.

During the process of testing the first hypothesis the fourth important conclusion was made: the longer a sphere spends in the alginate solution the thicker its gel layer gets. This is due to the permeability of the alginate gel. The calcium ions can diffuse from the inside to the outside, interact with alginate and form a thicker gel layer. So, if the spheres burst at the slightest contact, the solution is simple: the time the spheres spend in the alginate solution has to be increased, for the gel layer becoming thicker and the spheres – easier to handle.

Through the experiment 5.7 the second hypothesis was proven wrong. The sphere containing more calcium burst quicker than the sphere containing less calcium. Therefore, if a flavored liquid already contains calcium, it has to be considered that adding additional calcium might result in a more sensitive sphere.

The most important final conclusion of the project is that even a beginner can practice molecular gastronomy working in a house kitchen without special equipment and still achieve great results with just a little practicing, but lots of patience and curiosity.

7 Table of Figures

Cover picture:

https://www.cookinglight.com/recipes/frizzled-sunny-side-up-eggs

https://www.gastrosenses.com/blog/mango-spheres/

Figure 1: The two monomers of alginat [4] 7

Figure 2: Structure of the three different blocks [4] 8

Figure 3: The structure of alginate gel; O-atoms that are coordinated with the calcium-ion are marked red [4, 11] 10

Figure 4: The structure of the anionic part of xanthan gum [18] 14

Figure 5: The calcium solution started to gel 17

Figure 6: Setup the experiment 19

Figure 7: Setup of the experiment 21

Figure 8: The first proper sphere 22

Figure 9: The big sphere burst in the alginate solution 22

Figure 10 : Set up of the experiment 23

Figure 11 : The sphere burst in the alginate solution 24

Figure 12 : The sphere was frozen on the inside 24

Figure 13: Setup of the experiment 30

Figure 14 : The sphere resembled an egg yolk 30

Figure 15 : Potato masher is used to press down on the sphere 33

Figure 16 : Setup of the experiment 34

Figure 17: The coconut milk after xanthan gum was added 35

Figure 18: The vegan egg white resembles a real egg white 35

Figure 19: The vegan egg white compared to a real egg white 37

Figure 20: Setup of the experiment 38

Figure 21: A realistic looking vegan fried egg 39

Figure 22: The colorful vegan fried eggs 39

8 BIBLIOGRAPHY

[1] H. This, „molecular gastronomy“. 22. Juni 2018. [Online]. Verfügbar unter: https://www.britannica.com/topic/molecular-gastronomy

[2] MasterClass, „A Guide to Molecular Gastronomy: 8 Molecular Gastronomy Methods“. 11. August 2021. [Online]. Verfügbar unter: https://www.masterclass.com/articles/molecular-gastronomy-guide

[3] D. Mooney und K. Y. Lee, „Alginate: properties and biomedical applications“. 1. Januar 2013. [Online]. Verfügbar unter: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3223967/#R4

[4] A. Marburger, „Alginate und Carrageenane – Eigenschaften, Gewinnung und Anwendungen in Schule und Hochschule“. 18. September 2003. [Online]. Verfügbar unter: https://archiv.ub.uni-marburg.de/diss/z2004/0110/pdf/dam.pdf

[5] R. Abka-khajouei, L. Tounsi, und N. Shahabi, „Structures, Properties and Applications of Alginates“. 29. Mai 2022. [Online]. Verfügbar unter: file:///C:/Users/polie/Downloads/marinedrugs-20-00364-v2.pdf

[6] U. Wuthier, *Erste Schritte in Chemie*. 2018.

[7] R. Vasliauskas, „Sodium Alginate and applications: a review“. 18. August 2020. [Online]. Verfügbar unter: https://www.elveflow.com/microfluidic-reviews/droplet-digital-microfluidics/sodium-alginate-and-applications-a-review/

[8] modernist pantry, „Sodium Alginate“. [Online]. Verfügbar unter: https://modernistpantry.com/products/sodium-alginate.html

[9] Colgate Global Scientific Communications, „What Is An Alginate Impression“. 2. Januar 2023. [Online]. Verfügbar unter: https://www.colgate.com/en-us/oral-health/dental-visits/what-is-an-alginate-impression#

[10] L. L. Liu, D. Li, und Y. Xia, „Egg-Box Structure in Cobalt Alginate: A New Approach to Multifunctional Hierarchical Mesoporous N-Doped Carbon Nanofibers for Efficient Catalysis and Energy Storage“. 26. August 2015. [Online]. Verfügbar unter: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4827465/

[11] R. Chokshi, „Alginates: The right chemistry for pharmaceutical applications“. 5. November 2015. [Online]. Verfügbar unter: https://ipecamericas.org/sites/default/files/EF15April29_5_RinaChokshi_FMC.pdf

[12] food crumbles, „Molecular gastronomy“. [Online]. Verfügbar unter: https://foodcrumbles.com/molecular-gastronomy-spherification/

[13] Dr. D. J. Sen, „Cross linking of calcium ion in alginate produce spherification in molecular gastronomy by pseudoplastic flow“. 7. Februar 2021. [Online]. Verfügbar unter: https://wjpsonline.com/index.php/wjps/article/view/cross-linking-calcium-ion-alginate-produce-spherification/379

[14] E. Dessipri, „XANTHAN GUM Chemical and Technical Assessment (CTA)“. 2016. [Online]. Verfügbar unter: https://www.fao.org/3/br568e/br568e.pdf

[15] Lee enterprises consulting, „Aerobic Fermentation Processing“. 26. Juli 2020. [Online]. Verfügbar unter: https://lee-enterprises.com/aerobic-fermentation-processing/

[16] J. G. Vicente, „Xanthomonas campestris pv. campestris (cause of black rot of crucifers) in the genomic era is still a worldwide threat to brassica crops“. 11. Oktober 2012. [Online]. Verfügbar unter: https://bsppjournals.onlinelibrary.wiley.com/doi/10.1111/j.1364-3703.2012.00833.x

[17] D. F. S. Petri, „Xanthan gum: A versatile biopolymer for biomedical and technological applications“. 16. Februar 2015. [Online]. Verfügbar unter: https://onlinelibrary.wiley.com/doi/10.1002/app.42035

[18] D. Gruyter, „Natural and synthetic polymers in fabric and home care applications“. 29. Juli 2017. [Online]. Verfügbar unter: https://www.degruyter.com/document/doi/10.1515/psr-2017-0021/html

[19] C. Pullen, „Xanthan Gum — Is This Food Additive Healthy or Harmful?“ 27. Mai 2017. [Online]. Verfügbar unter: https://www.healthline.com/nutrition/xanthan-gum

[20] info cons, „E415 – Xanthan Gum“. [Online]. Verfügbar unter: https://infocons.org/blog/2022/11/16/e415-xanthan-gum/

[21] K. Y. Lee, J. A. Rowley, P. Eiselt, D. J. Mooney, und E. M. Moy, „Controlling Mechanical and Swelling Properties of Alginate Hydrogels Independently by Cross-Linker Type and Cross-Linking Density“. 23. März 2000. [Online]. Verfügbar unter: https://pubs.acs.org/doi/10.1021/ma9921347

[22] Wuthier, Schilliger, und Graf, „Periodensystem der Elemente“. 2015.