The Potential of Starch

–Different characteristics of modified wheat starches and their use in food processing

Stärkelsens potential – olika kategorier av modifiering av vetestärkelse och deras användningsområden i livsmedelsproduktion.

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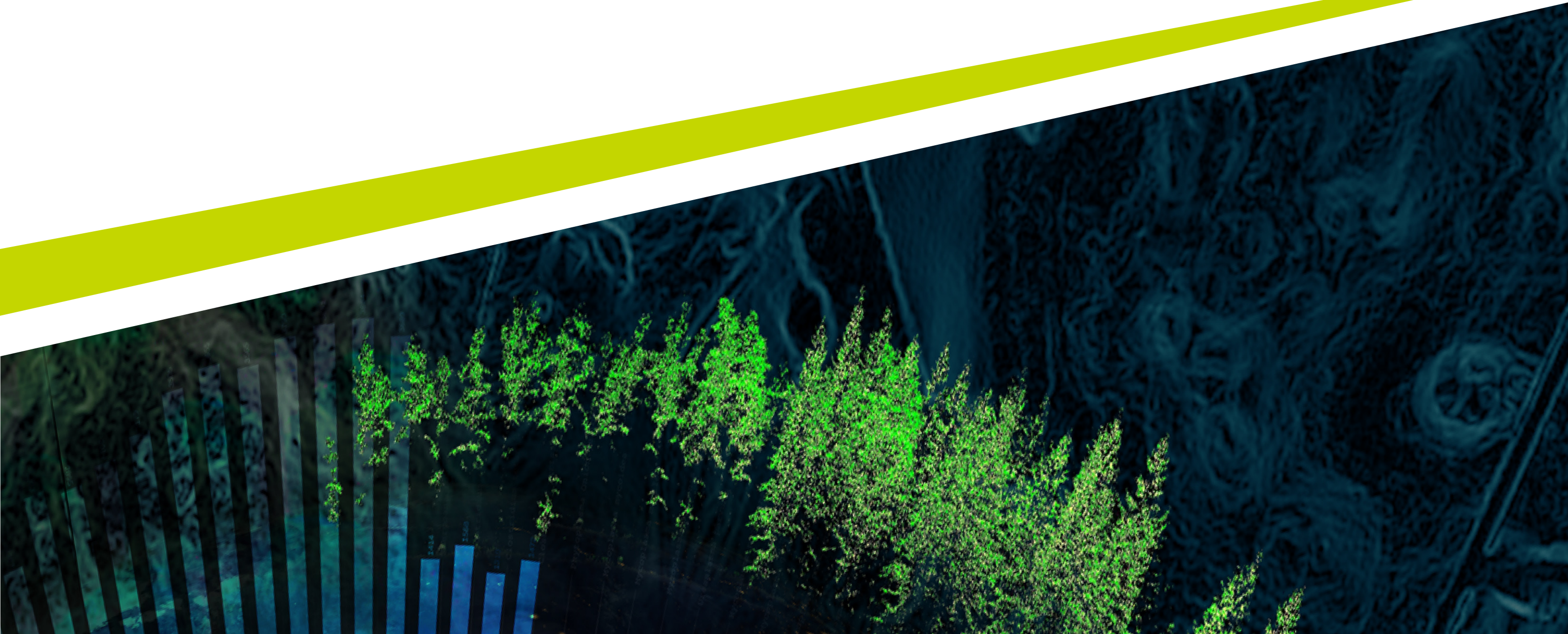

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Abstract

This is a study written as a part of the Agtech 2030-project, "*Increased value at the starch-and cereal protein market*", which is a collaboration between Lantmännen and the University of Linköping within the framework of the innovation platform Agtech 2030, hosted by Linköping university. This conceptual and literary based study concerns modification of wheat starch, one of many parts of the project from Agtech 2030. There are different methods of how to modify wheat starch with the emphasis in this paper on physical and chemical modifications. The study also gives examples of food applications of modified wheat starch. The result shows that the main difference between the two mentioned types of modifications are: (1) physical modifications change the starch on a granular level and does not require chemical agents. (2) Chemical modifications can change the molecular structure of the starch e.g. by substitution of hydroxyl groups on the glucose units of the starch molecules (amylose and amylopectin). (3) There are chemically modified starches that need to be classified as food agents, whereas physically modified starch in comparison can be labelled as an ingredient in food products.

Sammanfattning

Den här studien är en del av projektet, "*Ökat förädlingsvärde på stärkelse- och spannmålsproteinmarknaden"* tillhörande Agtech 2030, ett samarbete med Lantmännen och Linköpings Universitet. Detta arbete är en litteraturstudie om modifierad vetestärkelse, som är en del av många delar av projektet ur Agtech 2030. Det finns olika metoder för att modifiera vetestärkelse och i den här studien läggs det fokus på fysisk och kemisk modifiering. Studien belyser även exempel av hur modifierad vetestärkelse kan användas i olika livsmedel. Resultatet visar på att den huvudsakliga skillnaden på fysisk och kemisk modifiering är följande: (1) fysisk modifiering påverkar stärkelsegranulernas struktur och kräver inga kemiska tillsatser. (2) Kemisk modifiering kan ändra den molekylära strukturen av stärkelse t.ex. genom subsitution av hydroxylgrupper på glukosenheterna som bygger upp stärkelsemolekylerna (amylos och amylopektin). (3) Det finns kemiskt modifierade stärkelser som måste klassificeras som tillsatser, jämfört med fysiskt modifierad stärkelse som i livsmedel direkt kan betecknas som ingredienser.

Keywords: Wheat starch, physical modifications, chemical modifications, amylose, amylopectin, starch granules

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Abbreviations

DP	Degree of polymerization
DS	Degree of substitution
STPP	Sodium tripolyphosphate
SOP	Monosodium phosphate
STMP	Sodium trimetaphosphate
EPI	Epichlorohydrin
$POCl_3$	Phosphoryl chloride
OSA	Octenyl succinic anhydride
ATS	Amylomaltase-treated starch
HMT	Heat moisture treatment

1. Introduction

1.1. Project

This report is written as a part of the Agtech 2030-project, "*Increased value at the starch- and cereal protein market"* [1], (*Ökat förädlingsvärde på stärkelse- och spannmålsproteinmarknaden)* which is run in collaboration between Lantmännen and the University of Linköping within the framework of the innovation platform Agtech 2030, that is hosted by Linköping university. The "starch project" consists of many parts and one interesting component is to investigate the methods of how to modify wheat starch that this study concerns. Modification of starch is an example of why Swedish production of cereals and food products is important.

1.2. Wheat starch

There are approximately 30 000 varieties and 14 cultivated species of wheat in the world which can further be categorized into different types such as spring wheat and winter wheat, depending on the time of sowing (Wikipedia*,* 2020). Wheat is one of Sweden's top 10 agricultural commodities (*FAOSTAT, 2018*). In 2019, 2612 Swedish companies produced in total 1 399 900 tonnes winter wheat and 836 companies produced 214 000 tonnes of spring wheat in Sweden. In 2019 wheat represented 26 % of the total amount of cereals produced in Sweden (SCB, 2020). Wheat can be used for several foods, but it is most commonly used as flour intended for baking purposes. There are however many other uses for wheat. An interesting part of wheat is the starch, that can have several applications in the food industry. For example, starch can be used as thickening agents in soups or sauces. Starch also improves the crispness of certain snacks and fried products. Moreover, starch may serve as a substitute for fat where a lowered fat content is wanted such as in ice cream or salad dressing (Le-Bail *et al.* 2018). Furthermore, starch may also be applicable in the pharmaceutical industry where it has a role in the drug delivery

[1] Own translation

systems (Masina *et al.* 2017). Wheat starches can be isolated by separation from the rest of the kernel through different techniques that have been developed over the years. Two common separation methods of wheat starch are the hydrocyclone process and the high-pressure disintegration process. The hydrocyclone process is used to separate gluten from A and B-starch by in a series of steps including, the start where flour is mixed with water to a dough. After agglomeration of the gluten, the two types of starch (A and B) can be separated and washed. Further down during this process it is also possible to separate A and B – starch from each other. The other method, high-pressure disintegration process is a newer way to separate starch. In this method the wheat is mixed with water to a dough and then pressure is applied and homogenized. This can separate the starch from the gluten (Maningat *et al.* 2009).

Starches comprise approximately 70% of the grain in most cereals, whereas in wheat, starch makes up 75-80% of the kernel (Huber & BeMiller 2017) (Abbas *et al.* 2010). The dry weight of the wheat grains is around 75-80 % after threshing (Le-Bail *et al.* 2018). Starch consists of polysaccharide molecules that are built up of only one type of glucose units (D-glucopyranosyl units) linked with glycosidic bonds (Huber & BeMiller 2017; Abbas *et al.* 2010). Starch consists of two polysaccharides called amylopectin and amylose (Le-Bail *et al.* 2018). The chain length of the polysaccharides varies depending on the number of glucose units, which is termed "the degree of polymerization" (DP). Amylopectin has a general DP number of over 60 000 glucose units (Huber & BeMiller 2017), whereas amylose has a DP of 520-4400 (Hanashiro & Takeda 1998). Amylopectin and amylose differ in compositions and linkages of glucose units. Amylose is a linear molecule with glucose units linked together with α-D-(1→4) glycosidic bond. Amylopectin has a similar structure as amylose, but the main difference is branching. Amylopectin also consists of linear linked glucose units with a α-D-(1→4) glycosidic linkage, but with the exceptions of some glucose units linked with α-D-(1→6) glycosidic bonds forming a branched structure. At the branches, double helices of amylopectin can be formed (Singh *et al.* 2003). The ratio of amylopectin and amylose can differ depending on plant origin, with generally 70-80% amylopectin and 20-30% amylose (Schirmer *et al.* 2013). There are different types of starch depending on when it is synthesized and how big the granules are. There are three types of starch granules, the first is called A-type and have the biggest granules with lenticular formation, the second granule that is synthesized are smaller and called B-type with a spherical form and the last type is called the C-type that is very small. The A granules have a diameter of 14.1µm were the B granules that are smaller have a mean diameter 4.12µm (Maningat *et al.* 2009).

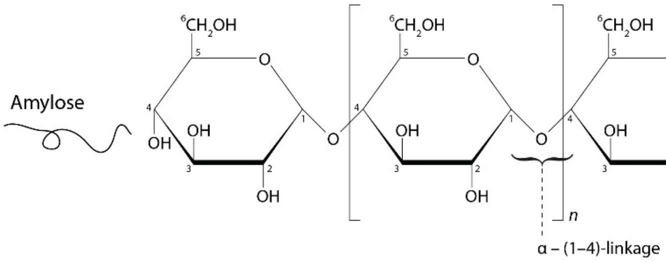

Figure 1. Amylose

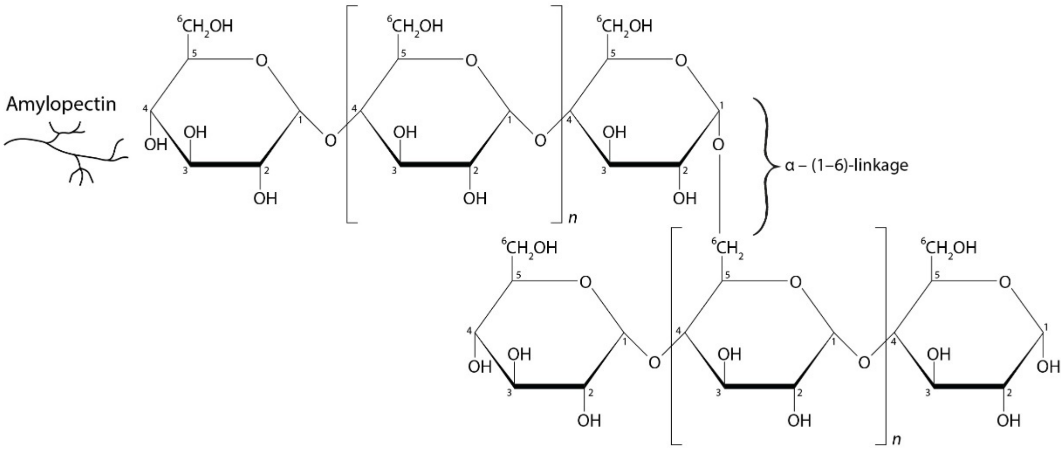

Figure 2. Amylopectin

Figure 1 and 2 are schematic representations of the how the difference in glycosidic linkages between the glucose units of amylose and amylopectin can affect the molecular structures.

1.3. Purpose

The purpose of this study is to, through a review of literature, describe different methods of how wheat starch can be modified physically and chemically, and what properties these modified starches will have depending on the choice of modification. One part of the interest of this study is to investigate different articles about modified wheat starches and what food applications they have been used in. This may give examples of food applications of modified wheat starch. Since wheat is a common crop in Sweden it is of interest to focus this study on modified wheat starch. Two questions are of interest in this study:

1. What physical and chemical methods can be used to modify starches and how are they performed in general and what are the differences between physical and chemical modifications?
2. In what food products have physically and chemically modified wheat starches been used and what type of modification was used according to the scientific literature?

2. Method

This study has been conducted by searching and reading literature within the field of starch in order to investigate which different methods of modifying starches there are, how these methods are performed, how they can change the properties of starches and what applications they can be used for. The search for articles has been divided into different groups of categories; (1) physical modifications, (2) chemical modifications, (3) wheat starch, (4) amylose and amylopectin and (5) food applications of wheat starches in order to answer the research questions of this study.

To find the articles, the following databases have been used: Google scholar, Scopus, Web of Science and Primo from SLU library. By only using the databases that are mentioned, there will be a limitation of the types of articles to be found and therefore the articles that have been used are from an academic literature and no practical literature from e.g. producers. The key words that have been used for finding articles have varied depending on the different categories. Some examples of the most common and important key words that have been used for this study are *Modified Starches, Wheat starch, Chemical modifications, Physical modifications, Cross-linking etc.* (Note, that these key words also were searched on using different suffix e.g. *Starch, Starches*). The choice of articles has been based on their relevance to the topic and on the number of citations.

In the category of food applications of modified wheat starches, the purpose of this search has been to find articles to give examples of applications. It was therefore more important to consider which modifications that were used than how many citations the article have. In the results they are listed as examples of food applications to show if there is a variety of ways that modified wheat starch can be used in different foodstuff and what method that have been used to modify the wheat starch and why this was a favourable choice of method.

3. Results

The chosen structure of this study has been inspired of the analytical aspects made of the research project Agtech 2030 "Starch project", that is together with Lantmännen. The discussion of analytical aspects has been presumed of different production categories and applications of starches in different industries. This study has been focused on the food industry. Another influence on this structure and the organisation of the different methods, has been from the literature of many articles and reviews that have been found during this study. Therefore, this section will present the following categories of methods.

First, the different modifications are divided into two main groups, the *Physical modifications* and the *Chemical modifications.* Under these topics the different types of physical – and chemical modifications will be described. The section on physical modification will discuss pregelatinization, cold-water-swelling and heat moisture treatment, of starches. Under the section on chemical modifications, oxidation and bleaching, esterification, etherification and cross-linking of starches will be described. This is to answer the first question of the purpose of this study which deals with different types of modifications and how they differ from one another. Secondly, there will be a section about examples of different articles of modified wheat starch and what food applications they have been used for. This will give a picture of what possibilities there are of using modified wheat starch in different food systems.

3.1. Physical modifications

Physical modifications can be classified as methods that do not use chemicals to produce a modified product. There are different varieties of methods and in this section, pregelatinized starch, cold-water-swelling starch and heat moisture treatment is going to be described. These types of modifications can in some cases indirectly have the same function as cooking the starch and can thereby be used, in instant food systems (BeMiller & Huber 2015).

The starch granules can also be disrupted by applying a mechanical force (Chiu & Solarek 2009). Since these starches are created by physical methods, they can be used directly in food systems without any risk of chemical agents in the food products. Therefore, they do not need to be classified as food agents (BeMiller 2018).

3.1.1. Pregelatinization modification of starch

Pregelatinized starch, can produce gels without any cooking, which is because of the state of the granules in these types of starches. They have already been cooked and can thereby be used and work as a gel in instant mixes. This is common, and it can be used in food products like puddings that the costumer can make by adding room temperature water at home (Huber & BeMiller 2017). There are different ways to make pregelatinized starch. One way is to use a drum drier during mixing of the starch with water to start gelatinization of the starch and by adding heat the starch gel will be dried, and thereafter milled to a powder. This pregelatinized starch can be used for example as thickeners in cold instant food products (Majzoobi *et al.* 2011). Since it is pre-cooked, there is no need of applied heat after this treatment. This is beneficial in food systems that cannot/should not be heated because of other reasons. They can work as mentioned in puddings as thickeners or applying texture of the food system (BeMiller 2018). Other alternatives are roll drying or spray drying (Chiu & Solarek 2009 s. 17).

3.1.2. Cold-water-swelling modification of starch

Cold-water-swelling modification is another type of physical modification where the granules still can swell since they are not disrupted during this process, unlike pregelatinization. This type of starch can be used in foodstuff were the product needs to keep the shape (Huber & BeMiller 2017). Cold-water-swelling modifications can be performed in different ways. The first two examples need an added pressure through a pressure reactor. The most common example is by using a solution of an organic solvent and water and the addition of heat. (Chiu & Solarek 2009; Dries *et al.* 2014; BeMiller 2018). According to Chiu *et al* (2009) one example is to use alcohol (e.g. ethanol) with a high percentage (between 70-80%) and to heat the starch solution to 157-177°C. Another option that is described is to use alkaline alcohols were an alcohol (e.g. ethanol) is mixed with water and in addition, a strong base is added. According to Chiu *et al* (2009) sodium or potassium hydroxide can be used as the base. In this method, it is not necessary to apply heat, instead a lower temperature around 20-40°C can be used. These types of modified starches can be useful in low calorie products (Chiu & Solarek 2009). The third method that is mentioned is to use aqueous polyols were 1,2-propanediol can be used at a high temperature of 145-155°C. This system can modify starches without an applied pressure. The last method that is described is spray drying, which is a method were a starch slurry first is sprayed from a nozzle spray dryer where steam is added to make the slurry gelatinized (Chiu & Solarek 2009). After the moisturizing and gelatinization , the gel is dried and can be made into a powder (BeMiller & Huber 2015). The cold-water-swelling modification of starches can be used in instant food systems but they can also, mixed with syrup, be used to make candy in form of gums or in muffins that contains berries that are going to stay on the top instead of sinking down in the dough (BeMiller 2018).

3.1.3. Heat moisture treatment

Another treatment of starches is heat moisture treatment (HMT) where the starch is moisturized and heated in between 84-140°C depending on the type of starch. The granules swell and can leak out amylose due to this treatment. In this method the main element is to use heat to modify the starch by the change of granular structure and molecular arrangement. Some of the properties of HMT described by BeMiller, (2018) are increased hot-paste viscosities and shear stabilities. Another interesting matter of this method that is discussed is that this treatment can give similar properties as some of the cross-linked chemically modified starches (presented in the next section). This means that it can give desired results in the food system without classify the modified starch as an additive but instead as an ingredient (BeMiller 2018).

3.2. Chemical modifications

One significant difference between chemical and physical modifications is that chemical modifications can change the structure of the D-glucopyranosyl units of the starch molecules. Compared to physical modifications that changes the structural arrangement of the granules, chemical modification allow for modifications on a molecular level (BeMiller & Huber 2015). It is easier to get a product with more tailored results and desired properties than a physical modification since there is a main change of the actual starch molecule.

Chemical modifications can be categorized into different groups. The categories depend on what different properties the modified starches will have in the end or what type of chemical agents that have been used. In a review regarding chemical modification techniques by Masina *et al* (2017), the methods are divided into monofunctional and bi-functional chemical reagents that are used for modification. Monofunctional reagents are examples where the hydroxyl groups of the glucose get substituted. This can make the starch molecules more chemically stable, but they will not react with each other. The monofunctional chemical reactions that are used to modify starches are categorized into different subgroups: oxidation, esterification, and etherification. Bi-functional reactions are for example the cross-linking method where the molecules are linked together by interactions between the hydroxyl groups (Masina *et al.* 2017). By cross-linking, the granules can be reinforced (Chiu & Solarek 2009).

3.2.1. Oxidation and bleaching

Oxidation of starch is a method where one derives carboxyl-, aldehyde- or keto-groups through oxidation of the hydroxyl groups at the glucose units (Mason 2009). There are different oxidizing reagents that can be used. Chen *et* al (2018) talk about periodate, chromic acid, permanganate, nitrogen dioxide, and sodium hypochlorite which are oxidizing reagents that can be used in this type of modification. For these reagents, carbonyl groups are created. They can further be oxidized to carboxyl groups. It is the number of carboxyl groups that decides if the method is called oxidation or bleaching. When there is a small number of carboxyl groups it is referred to as bleached starch (Chen *et al.* 2018), and for large numbers of carboxyl groups it is referred to as oxidized starch. The purpose of bleaching starches is to change the colours to lighter pigmentation (Mason 2009 s. 20). The results of an oxidized starch is a lower viscosity and lower retrogradation tendency (Chen *et al.* 2018), but they can also become more stable at lower temperatures and have a higher clarity (Masina *et al.* 2017). Other properties are products with longer shelf-life (Mason 2009 s. 20).

3.2.2. Esterification

Esterification gives properties like decreased gelatinization temperature and stability to retrogradation (Huber & BeMiller 2017). Other properties are chain repulsion of the starch molecules which results in a more soluble product. By the substitution, amylopectin and amylose chains cannot reinforce after retrogradation (Chen *et al.* 2018). Esterification can be done by many different methods, one common method is acetylation. The substitution to ester groups can be done at 1-3 of the hydroxyl groups of the glucose units. For acetylation, the degree of substitution (DS) gives the names low, medium or high DS starch and they can be produced by different chemical agents. Example of agents used for acetylation by Masina *et al* (2017) are acetic anhydride and sodium hydroxide. Another method is to use octenyl succinic anhydride (OSA). Starches modified with OSA is common in food systems were they act as emulsifiers (Chen *et al.* 2018).

3.2.3. Etherification

Etherification is also a method where the hydroxyl groups of the starch molecule are substituted. According to the review by Masina *et* al (2017) the hydroxyl groups can be substituted by carboxymethyl, hydroxypropyl, and/or hydroxyethyl groups. Examples of etherification reactions of native starch can be hydroxypropylation that will give a more stable starch (Masina *et al.* 2017). Propylene oxide can be used to react with the native starch and the finished products will have a lower gelatinization point and lower the retrogradation (Huber & BeMiller 2017; Fu *et al.* 2019).

3.2.4. Cross-linking

Cross-linked starches improve the stability of the starch by creating inter- or intramolecular bonds between starch molecules to create a meshwork. This can improve the stability to tolerate lower pH environments, increase the resistance to shear and create pastes with higher viscosity (Huber & BeMiller 2017). The chemical modification is performed by adding different chemicals that will interact with the hydroxyl groups to create these bonds. There are many alternatives of chemical agents that can be used and some of them are sodium trimetaphosphate (STMP), monosodium phosphate (SOP), sodium tripolyphosphate (STPP), epichlorohydrin (EPI) and phosphoryl chloride ($POCl_3$). They can be added at different concentrations and they give different results depending on what qualities that is wanted. STMP is very efficient at high temperatures when the starch is a little bit moisturized (Chen *et al.* 2018). $POCl_3$ is very common and used in an aqueous slurry with a high pH around 11 and presence of a neutral salt that could for example be NaCl or sulphate (Singh *et al.*; Chen *et al.* 2018). This can result in properties like increased pasting temperature or decrease in hot water solubility. EPI is another common chemical agent that give properties e.g. resistance to pH (Ačkar *et al*. 2010).

To investigate how the cross-linked method worked out it is important to measure the inter- and intramolecular bonds that have been created, but this can be difficult. Woo and Seib (1997) mention that the cross-linking methods can be evaluated by measuring the physical properties of the starch afterwards, for example the paste consistency (Woo & Seib 1997). Ačkar *et al* (2010) have been calculating degree of cross-linking. For example the degree of crosslinking can be measured by calculating the percental change in viscosity of the starch before and after modification (Ačkar *et al*. 2010).

3.2.5. Other modifications

There are other ways to modify starches than the chemical and physical modifications that are presented in this study. One example is the use of enzymes to modify starch. For example, one can use amylomaltase to break α-(1-4) glycosidic bonds between two glucose units. In the study by Kaur *et al.* (2012) they show that parts amylomaltase can transfer parts of amylose and connect it to amylopectin, creating a starch called amylomaltase-treated starch (ATS) (Kaur *et al.* 2012). This newer type of starch has properties as thermoreversible gelation. These properties make the ATS useful in low-fat yoghurts as fat replacers and can give a creaminess to the yoghurts (Alting *et al.* 2009).

Another category of modifications of starches is on a biotechnological or genetic way. In this way the starch can be modified directly in the synthetic pathway of starches in the plant. It is by affecting the enzymes that are a part of the starch synthetic pathway in the plant that can make changes in how they are built up. Some examples of modified starches is to increase the amylose content that can be used as thickeners in food systems (Kaur *et al.* 2012).

3.3. Classification of modified starches as food additives

According to the Regulation (EG) nr 1333/2008 (16 December 2008) on food additives, a modified starch that is made by chemical modifications is classified as a food additive. To be valid as a food additive, modified starch needs live up to the decided requirements. Two of these requirements are (1) that it should not be a health risk (2) and it needs to be favourable for the consumers in different ways. One of them is that it should increase the shelf-life of the product. *For full list, see – (EG) No. 1333/2008* (Council of the European Union, 2008).

3.4. Food applications of modified starch

In segment 3.5.1 and 3.5.2, examples of modified wheat starch (and other plant origins) are presented.

3.4.1. Examples of food applications of modified wheat starch

Radi *et al.*, (2009), Prepared a cross-linked wheat starch in two steps by first adding 1 M of hydrochloric acid (pH=0) to the starch slurry to make an acid treated starch. Secondly, they prepared an acid treated cross-linked wheat starch by using $POCl_3$ (pH=11) as one of the chemical agents to modify starch. The cross-linked wheat starch was then used to work as a replacement for fat in yoghurts. This modification and recipe can give a low-fat yoghurt with the same sensory properties as a high fat yogurt. (Radi *et al.* 2009).

Citrate starch is a resistant starch that can be created by modification of potato, corn, pea and wheat starches by esterification with citric acid. (Wepner *et al.* 1999).

Resistant starch is a type of starch that, among other properties, can function as a dietary fibre (Huber & BeMiller 2017). These modified starches were used for enrichment of dietary fibre in toast bread, wafers and pasta where some of the flour of the original recipe was replaced with the citrate starch from the different plant origins. The results from the pasta showed that when the modified citrate wheat starch was added, the resistant starch content was increased. The modified starch also resulted in a change of some sensorial properties, for example the taste, compared to regular pasta. These results show that citrate starch can be used to increase the content of dietary fibre in a food product without using wholegrain cereals that can affect the sensorial properties negatively (Wepner *et al.* 1999).

3.4.2. Food applications of modified starches from other plant origins

An example of modified starches from other plant origins are modified starches in a gluten-free dough made of potato, maize, pectin, and guar gum. The modified starch can be used to create a stronger gluten free dough. The chemically modified starches that were studied were acetylated distarch adipate (ADA) and hydroxypopyl distarch phosphate (HDP) that both were cross-linked, and high amylose corn starch (HACS). The results were a dough with slightly better applications, the gels turned out to be weak, but not enough compared to the effect of gluten (Witczak *et al*. 2012).

4. Discussion and conclusion

4.1. Analysis and discussion

The two research questions to answer were:

1. What physical and chemical methods can be used to modify starches and how are they performed in general and what are the differences between physical and chemical modifications?
2. In what food products have physically and chemically modified wheat starches been used and what type of modification was used according to the scientific literature?

Regarding the first one concerning modifications, there were a lot of articles in the literature that divided modifications into physical and chemical modifications. This turned out to be more different chemical ways to modify starches than physical modifications. The physical modifications in essence only "pre-cook" the starch by using heat, water and in some cases pressure. And that could be the reason of why there are a bigger variety of chemical modifications that can be used to modify starches. When looking for articles about physically modified wheat starch (or other plant origins) there were no articles found that used a physical method to modify starch and then use it in a food system. One reason for this could be that the keywords were not right, or that since physical modifications are classical methods, there could be articles about food applications of modified starch that are older than the articles that have been used for this study. An additional reason for this result could be the choice of only looking at scientific literature and not discussing food production by talking to factories and companies. There may be a lot of information to find here.

The second part of the first question concerned the difference between physical and chemical modifications of starches. As mentioned earlier, physical modifications affect the starch on a bigger scale, the granules. When they are moisturised and treated with heat they are swelling, and this can in some of the physical methods make the granules to break which creates an irreversible reaction. The main result of physically modified starches is that they quickly can absorb water. Chemical modifications, on the other hand, can modify starch on a smaller scale, where amylopectin and amylose can be changed on a molecular level e.g. by substitution that can prevent the amylose and amylopectin chains to realign with each other since there is a "new" bigger molecule that "take up to much space". This makes the starch more stable to retrogradation. The molecules can also be linked together as the cross-linked methods do which makes them more stable to tolerate more extreme environments as lower pH. Heat moisture treatment was interesting to read about since the method could yield properties of the starch similar to chemically cross-linked starches. For further studies it could be interesting to se if there are ways to develop this method or looking at other/new ways to physically modify starches that could have similar properties as the chemical modifications. This is interesting because one important difference between chemical and physical modification is that the chemically modified starches needs to be classified as food additives comparing to physical modifications that could be seen as an ingredient in the food system directly. This is one of the advantages with physical modifications compared to chemical modifications. However, since chemical modification can change the starch on a molecular level it can be more precise and tailor the starch to obtain properties that are wanted. Physical and chemical modifications are not the only two categories that can be used to modify starches. As mentioned under the headline "other modifications" starch can be modified by enzymes that can "cut and paste" parts of amylose and amylopectin to e.g. create the starch *amylomaltase-treated starch*. These starches have shown to be useful in low-fat yoghurts to add creaminess. The other category that can be used to modify starches is directly in the plant by genetic/biochemical modification that can affect the enzymes that are involved in the synthetic pathway of starches in the plant.

The second question was to investigate what types of modified wheat starches that can be used in different food systems by looking at the scientific literature. With the databases and keywords used, few articles with this structure and especially about wheat starch. Many articles on this topic seem to focus on other plant origins like potato starch or maize starch and most of the articles also focus on the actual methods that was used and was not further discussed of what food systems they could be applied in. It is possible that these types of experiments are done in the industry and their labs and thereby, there are not many articles published with this structure. Regarding the physical modifications, there were no relevant articles found in light of this study. The reason for this matter could be, as mentioned earlier, because of the information about physical modifications are not a new intervention. On the chemically modified wheat starches there were some articles. One of them was the article describing acid treated and cross-linked modified wheat starch to use as a replacement for fat in low-fat yogurts (Radi *et al.* 2009). It was used to try to give the same consistence as in regular yogurts but in low fat yogurts it could be hard to reach the same consistency. Another interesting article by Wepner *et al.* (1999) where modified wheat starch (resistant starch) was used to replace some of the flour to increase the content of dietary fibres in different food products as pasta and wafers. By using citrate starch, it can function as an enrichment with dietary fibres in the food system (Wepner *et al.* 1999).

4.2. Conclusion

The aim of this study was to describe different methods of how various type of starches can be modified and what properties these modified starches will have depending on the choice of modification in different food systems. To fulfil this aim, different methods of modifications of starch (mainly wheat) have been presented and some examples of food applications were modified starches can be used in. From the study, the following conclusions can be made:

- Two common categories of starch modification methods are physical and chemical modifications.
- The main difference between physical and chemical modification is how they affect the starch, on a granular or molecular level, and how they are made, with or without chemicals.
- Chemically modified starch needs to be classified as a food additive compared to physically modified starch that can be used directly as an ingredient.
- Chemical modification can change the starch molecule on a more detailed and tailored way compared to physical modification.
- One example of physical modifications "heat moisture treatment" can have similar properties as chemically cross-linked starch.

4.3. Some thoughts about the study and future studies on this topic

There is relatively large amount of literature on modified starches from other plant origins than wheat, and a practical study about different methods on applications of modified wheat starches could therefore have been interesting to see results from. Other suggestions could be the following: In other parts of the world, were other plant origins as sources of starch are common e.g. maize and potato starch, more articles are written about these plant origins. Another point of view could be that starch from other plant origins are easier to modify than wheat starch.

The literature contributing to this study has only been scientific articles and books from databases and that makes the span of different information smaller. If empirical information from industries e.g. interviews with producers of modified wheat starches and discussions with companies would have been done for this study, more examples of modified wheat starch and food applications.

This study has been focusing on the physical and chemical modifications of starches, there are only a few mentioned under the heading *Other modifications*. Genetic and biochemical modifications and modifications by enzymes are two interesting subjects to discuss and in particular how they could be used on a production level at a factory. However, it seems that the literature in this area is rather scarce regarding wheat as source for starch modification. Some information might be available in case of patents though. It would therefore be interesting to collect information about these types of modifications and compare the physicochemical properties with physical and chemical modifications.

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