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Dietary fibre and phenolic compounds in broccoli *(Brassica oleracea* Italica group*)* and kale *(Brassica oleracea* Sabellica group*)*

- A literature study about the potential uses of side streams

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Titel på svenska

Kostfibrer och fenoliska ämnen i broccoli *(Brassica olercea Italica gruppen)* och grönkål *(Brassica oleracea Sabellica-gruppen) – en litteraturstudie över användningspotentialen hos sidoströmmarna.*

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Abstract

This introductory paper reviews potential uses of side streams obtained from the production of broccoli and kale. Here, it becomes clear that of these two products, large quantities are available, which are not consumed today although these side streams have properties making them of interest for future food consumption. Material left as unharvested side streams on field are normally not included in the definitions of food waste or food loss. Such materials are also less well studied as compared to other food waste/losses, contributing to difficulties to approximate the total amount of this underutilised resource.

In fact, the major part of the biomass in the broccoli and kale production is not ending up as edible produce for the consumers, but instead as waste or side streams. Thus, the potential is considerable for use of this biomass to extract functional ingredients or as a raw material source for production of health beneficial food products. Both broccoli and kale have been shown to have high levels of bioactive compounds, e.g. phenolic compounds, and dietary fibre, which makes them interesting for the production of functional food or novel food products. However, the distinctive taste of broccoli and kale is an issue, restricting addition to food products to a low percentage, to secure that the undesirable taste is successfully masked. Another challenge is the impact on the texture that the vegetable powder made from these side streams might have on the product.

Generally, intake of dietary fibre and bioactive compounds are positive for human health, contributing with e.g. effects of lowering the risk of developing certain cancer forms. The present introductory paper presents a short overview of the development of the definition of dietary fibre, as well as some information related to their chemical composition and health effects. Similar information is given for the different groups of phenolic compounds. This literature study indicates clear opportunities for using broccoli and kale in the production of health beneficial food, even though more studies are needed to fully evaluate the most efficient and consumer acceptable use.

Sammanfattning

Denna introduktionsuppsats presenterar den potentiella användningen av sidoströmmar från produktionen av broccoli och grönkål. Det står klart att stora kvantiteter av dessa grödor är tillgängliga, kvantiteter som idag inte konsumeras men som har egenskaper som gör dem intressanta för en framtida matkonsumtion. Material som lämnas som oskördade sidoströmmar på fältet räknas normalt inte in i definitionerna av matsvinn och matavfall. Detta material är även mindre välstuderat jämfört med andra typer av matsvinn och matavfall, vilket bidrar till svårigheter att uppskatta den totala mängden av denna underutnyttjade resurs.

Faktum är att den största delen av biomassan i broccoli- och grönkålsproduktion inte kommer att användas som ätbara produkter som når konsumenterna, utan kommer istället att bli svinn eller sidoströmmar. Därmed finns det en betydande potential för denna biomassa att användas för att extrahera funktionella ingredienser eller som råmaterial för att producera hälsofrämjande livsmedel. Både broccoli och grönkål har visats innehålla höga halter av bioaktiva ämnen, exempelvis fenoliska ämnen och kostfibrer, vilket gör dem intressanta för produktion av funktionella livsmedel eller nya livsmedelsprodukter. Dock kan den distinkta smaken av broccoli och grönkål vara ett hinder, vilket kan begränsa tillsatsen till låga procenthalter såvida inte den oönskade smaken är framgångsrikt maskerad. En annan utmaning är den påverkan på konsistens som ett grönsakspulver från dessa sidoströmmar kan ha på produkten.

Generellt är ett intag av kostfibrer och bioaktiva ämnen positiva för hälsan och bidrar med effekter som att minska risken för att utveckla vissa cancerformer. Denna introduktionsuppsats ger en överblick av utvecklingen av definitionen av kostfibrer samt information relaterad till kostfibrers kemiska uppbyggnad och effekt på hälsan. Liknande information presenteras för de olika grupperna av fenoliska ämnen.

Denna litteraturstudie visar på att finns möjligheter att använda broccoli och grönkål i produktionen av hälsofrämjande livsmedel, även om fler studier är nödvändiga för att till fullo kunna utvärdera det mest effektiva och konsumentaccepterade användningsområdet.

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Abbreviations

Table 1: Abbreviations used in this introductory paper and their corresponding meaning

Abbreviation	Meaning
DF	Dietary Fibre
SDF	Soluble Dietary Fibre
IDF	Insoluble Dietary Fibre
TDF	Total Dietary Fibre
NSP	Non-Starch Polysaccharides
SCFA	Short-Chained Fatty Acids

1 Background

A diet rich in fruits and vegetables is well known to lower the risk of the development of certain forms of cancers (Oyebode *et al.*, 2014), specifically in the gastrointestinal tract (Bradbury *et al.*, 2014; Kim & Je, 2016). Also, such a diet decreases the risk of developing other chronic diseases, such as diabetes and heart diseases (Liu, 2013). Lastly, a diet rich in vegetables might lower the osteoclast activity (cells that breaks down the bone tissue as opposed to osteoblasts that build up bone tissue), thereby reducing the loss of bone mass (Tomofuji *et al.*, 2012). The positive effects of fruits and vegetables consumption have been attributed to the high content of bioactive compounds, including antioxidants in these types of food (Liu, 2013). Bioactive compounds in fruit and vegetables can be defined as essential and non-essential compounds in food products that have an effect on human health (Biesalski *et al.*, 2009). Certain groups of bioactive compounds have been suggested to affect the vascular health positively, by interacting with cellular activities or by the contribution to scavenging of free radicals or other reactive oxygen species (Wang *et al.*, 2011; Liu, 2013). However, intake of dietary supplements, in terms of vitamin C and vitamin E did not significantly reduce the risk of cardiovascular diseases or cancer (Lee *et al.*, 2005; Cook *et al.*, 2007; Lin *et al.*, 2009). Thus, replacing consumption of fruits and vegetables with the intake of supplements might not be a solution, possibly because individual bioactive compounds may need to be combined with other compounds, for a synergistic effect, or be combined with other constituents of food such as dietary fibre, for a positive outcome.

Additional to a high content of bioactive compounds, fruits and vegetables are known to contain high amounts of dietary fibre, which have been suggested to contribute beneficially to the levels of cholesterol in the blood (Surampudi *et al.*, 2016). Also, dietary fibre has an impact on the rate of gastric emptying, thereby contributing to a feeling of longer lasting satiation after a meal (Mackie *et al.*, 2016). Furthermore, dietary fibre promotes the peristaltic movement of the intestines, and hence lowering the transit time and reducing the risk for constipation (Wrick *et al.*, 1983). Finally, dietary fibre is beneficial for the gut microbiota, which has a crucial role in colonic health, human metabolism and immune system (Paturi *et al.*, 2010; Desai *et al.*, 2016). However, all the mentioned health benefits may not be attributed to the fibres per se, but some can be the result of a by-product (consisting of short chained fatty acids (SCFA)) excreted from the gut bacteria using the fibres in their metabolism (den Besten *et al.*, 2013). Another feature is that dietary fibre can also protect nutritional or health beneficial compounds, such as antioxidants, from digestive enzymes, so that they can be transported to the colon and be beneficial for the gut microbiota (Quirós-Sauceda *et al.*, 2014).

During the production of vegetables and fruits, waste is generated, due to the fact that some parts of the plants or parts of the produced crop does not end up as human food (Parfitt *et al.*, 2010). Some examples are the stalks and leaves in maize production (Lv *et al.*, 2017) and the stems and leaves in cauliflower and globe artichoke (Femenia *et al.*, 1998). In fact, approximately 60 per cent of the produced biomass is wasted in certain types of vegetable production (Strid *et al.*, 2014). This inefficient use of produced biomass contributes to a great loss of freshwater, fertiliser (Kummu *et al.*, 2012), nutrients (Spiker *et al.*, 2017) and calories (Kummu *et al.*, 2012; Spiker *et al.*, 2017) and also to an inefficient use of agricultural land (Kummu *et al.*, 2012). To alleviate poverty, malnutrition and hunger for the increasing world population, estimated to reach nine billion in 2050 (Parfitt *et al.*, 2010), global food waste should be decreased. The food production is calculated to have to reach a level of 60 per cent higher than the levels of 2005-2007 in order to feed the population of 2050 (Alexandratos & Bruinsma, 2012).

Today, it is estimated that approximately 1/3 of the edible parts of food produced globally becomes waste somewhere during the food supply chain (Gustavsson *et al.*, 2011). In this calculation, the biomass left on the field is not included. An example of a food supply chain (FSC), as well as examples on food waste in each step, can be found in the work of Parfitt et al (2010) and are summarised in .

Table 2.

Table 2: Food supply chain. Stages in the food supply chain with examples of food waste characteristics during the stage (Parfitt *et al.*, 2010).

Stage	Examples, food waste characteristics
Harvesting	Edible crops left in the field, ploughed into soil, damaged by pests, wrong time for harvest, damaged during harvest, not reaching required standard of quality, size or shape.
Transportation	Spoiling, bruising, transportation not optimal
Storage	Drying out, contamination, pests, disease
Processing (cleaning, de-hulling, pounding, grinding, packaging, milling)	Processing losses (peeling, slicing)
Packaging (weighing, labelling, sealing)	Inappropriate packaging, spillage, damage by pests
Distribution	Damage during transport, poor handling, poor storage
Consumer	Poor storage and preparation in homes, discarded prematurely

Of the amount of food waste in the FSC, approximately 10 per cent are estimated to be lost during harvesting (including mechanical damage and spilling during harvest and sorting after harvest, but not produce left unharvested on the field) and 25 per cent are estimated to be lost during processing and packaging (including spilling and degrading during processing, peeling, slicing and boiling and insufficient handling, storage and transportation) (Gustavsson *et al.*, 2011). The amount that are not harvested are usually not included in the food loss calculations, with some exceptions, e.g. in the work of Strid *et al* (2014) and Hartikainen *et al* (2017). As an example, of the not harvested material in vegetable production, an average of 57 % were found to have the possibility to be used as human food (Johnson *et al.*, 2018).

One way to reduce the amount of waste in food production is to adopt a circular perspective. Circular bioeconomy is a concept in which the amount of waste is minimised and the value of products, materials and resources is maintained as long and as high as possible (European Commission, 2015). Examples of how this concept can be used in practice may be to upgrade the waste or side streams for production of added value products such as biofuel (Dahiya *et al.*, 2018), animal feed (Hu *et al.*, 2011; Yi *et al.*, 2015) or novel food products (Femenia *et al.*, 1997; Collar *et al.*, 2009). The most efficient solution for minimising the negative impact of food waste on the environment would be to make novel food products from the food waste, instead of using it for composting, incineration, anaerobic digestion (e.g. to make biofuel) and business as usual (Oldfield *et al.*, 2016).

In this introductory paper, an overview of the field of research regarding dietary fibre and phenolic compounds will be presented, as well as a short historical overview of the evolution of the term “dietary fibre”, the role of phenolic compounds and dietary fibre in health and lastly there will be a presentation of broccoli and kale as crops, including historical information and specific scientific findings. Some of the most common methods used for analysis of dietary fibre and phenolic compounds will be described and some examples of future uses of side streams tin order to reduce the waste will be presented.

2 Fibre

2.1 A definition of dietary fibre

The health benefits of a regular intake of dietary fibre have been known since several decades (Hipsley, 1953; Burkitt *et al.*, 1972). Despite this, there has historically been some problems to define the concept of dietary fibre, both in research and to the consumers. The definition of dietary fibre has been debated since the 1970s (Phillips & Cui, 2011). Furthermore, the definition of dietary fibre differs among countries, making comparisons of studies difficult.

The term ”*dietary fibre*” was first coined by Hipsley (1953) in an article about the relation between diet with high levels of fibre during pregnancy and the decreased occurrence of pregnancy toxaemia (today called eclampsia). In this definition, lignin, cellulose and the hemicelluloses were defined as dietary fibre. Later on, it was suggested that dietary fibre should be defined as ”*the skeletal remains of plant cells that are resistant to digestion by enzymes of man*” (Trowell, 1972), and that it were these dietary fibre that contributed with health benefits. A few years later, the definition was developed into *”[dietary fibre consist of] the remnant of edible plant cell polysaccharides lignin and associated substances resistant to digestion by the alimentary enzymes of humans*” (Trowell, 1974). Here, the substances that were discussed were structural polysaccharides, lignin, unavailable lipids (waxes associated with fibre) and unavailable nitrogen, and their possible inclusion into the dietary fibre concept (Trowell, 1974).

These first definitions only contained the chemical aspects of the compounds collectively called dietary fibre, together with information about which of the compound that should be included in the concept. In the beginning of the 21th century the health promoting aspects were incorporated into the concept. One example of this incorporation is the definition from The American Association for Cereal Chemists (AACC), stating; ”*[d]ietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation*.”(AACC, 2001). Another definition was stressing that only substances that are naturally occurring in plants should be included into the dietary fibre concept: "*Dietary fiber consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants. Added fiber consists of isolated, non-digestible carbohydrates that have beneficial physiological effects in humans. Total fiber is the sum of Dietary Fiber and Added Fiber*" (Food and Nutrition Board, 2001). This later definition resulted in a clearer labelling of content in food.

Only a few years later a more international agreed definition for dietary fibre was presented. After several years of discussion, the Codex Alimentarius (founded in 1963 by FAO and WHO in order to promote the work with international food standards) was able to agree about a new, international definition for dietary fibre. This new definition was as follows:" *Dietary fibre means carbohydrate polymers with a degree of polymerisation (DP) not lower than 3, which are neither digested nor absorbed in the small intestine. A degree of polymerisation not lower than 3 is intended to exclude mono- and disaccharides. It is not intended to reflect the average DP of a mixture. Dietary fibre consists of one or more of: Edible carbohydrate polymers naturally occurring in the food as consumed, carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means, synthetic carbohydrate polymers. Dietary fibre generally has properties such as:*

• *Decrease intestinal transit time and increase stools bulk*
• *Fermentable by colonic microflora*
• *Reduce blood total and/or LDL cholesterol levels*
•*Reduce post-prandial blood glucose and /or insulin levels.*"

(Codex Alimentarius, 2008).

In addition to carbohydrates, dietary fibre also includes the phenolic compound lignin, if it is intrinsic to the plant based food (Codex Alimentarius, 2017).

To summarise; the definition of dietary fibre has taken turns into the different areas of chemical and physiological aspects during the last 60 years. With the Codex definition, a great step was taken in order to streamline the work with dietary fibre, even if some debate is still present as to which compounds that should be included in the context of dietary fibre (Dai & Chau, 2017).

2.2 Constituents of dietary fibre

Cellulose

Cellulose is the most abundant plant polysaccharide on Earth (Vermerris & Nicholson, 2006; Horwath, 2015), being formed as a linear polymer by β-glucose connected by 1,4-bonds, which means that the glucose units are bound between carbon 1 in the first glucose molecule and carbon 4 in the second glucose molecule, (Figure 1) (Schweizer & Edwards, 1992).
Cellulose molecules can be 1000-4000 units (Figure 1) long in the parenchyma cell walls being the bulk of undefined tissue in plants (MacDougall & Selvendran, 2001). A total of 20-30 per cent of the dry weight in the parenchyma cell wall consists of cellulose (MacDougall & Selvendran, 2001). However, cellulose molecules may contain up to 12 000 units in the plant cell secondary walls (MacDougall & Selvendran, 2001), or even up to 15 000 units (Gibson, 2012).

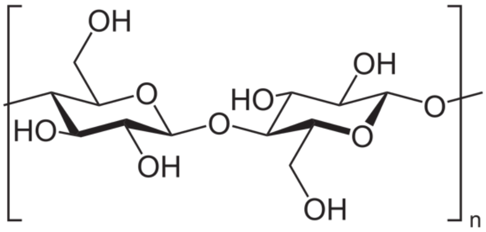

Figure 1. Chemical structure of 1-4-linked β-glucose with, which build up cellulose.

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Pectin (or pectic substances)

Pectin, or also called pectic substances (Voragen *et al.*, 2009), is a group of complex polysaccharides (Ridley *et al.*, 2001). The structure is composed of a linear chain of 1,4-linked α-D-galacturonic acid units (Figure 2), usually with neutral sugars such as L-rhamnose, D-galactose and L-arabinose in the side chains. Pectic substances can often be found in the middle lamellae in plant cell walls, where they form complexes with cellulose (so called insoluble protopectin), which during the ripening leads to the formation of pectin (Fernandez, 2001). Pectic substances can act as stabiliser for the primary cell wall by acting as an embedment for the cellulose network (Taiz *et al.*, 2015).

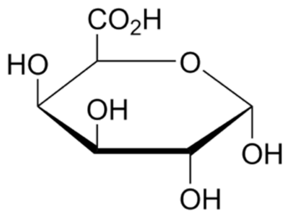

Figure 2: Galacturonic acid, one of the constituents of pectic substances.

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Pectic substances can be divided into three major pectic polysaccharides (Ridley *et al.*, 2001; Taiz *et al.*, 2015):

1. homogalacturonan (HG); a linear chain of 1,4-linked alpha-D-galacturonic acid residues (Taiz *et al.*, 2015). This type of pectin is the main part found in plants and has the most impact on the properties of pectin (Voragen *et al.*, 2009).
2. rhamnogalacturonan I (RH I); with a backbone of alternating rhamnose and galacturonic acid residues with side chains of neutral pectic polysaccharides, e.g. arabinans, galactans and arabinogalactans (Taiz *et al.*, 2015).
3. rhamnogalacturonan II (RG II); with the same backbone as HG, but with side chains of several different sugars in a complicated pattern of linkages (Taiz *et al.*, 2015).

Due to the different structures in the groups of pectic compounds, pectin can be used for different purposes, e.g. a thickening and stabilising agent in food products such as jam and dairy products (Voragen *et al.*, 2009), as a gelling agent (Voragen *et al.*, 2009; Christiaens *et al.*, 2015) or as emulsifier (Fernandez, 2001; Christiaens *et al.*, 2015).

Hemicellulose

Hemicelluloses is a heterogenous group of polysaccharides composed of a range of different polysaccharides such as glucomannan, xylan, xyloglucan, glucuronoxylan, arabinoxylan and glucuronoarabinoxylan, with a backbone of 1–4-linked glucose, mannose or xylose residues (Figure 3) (Scheller & Ulvskov, 2010). Traditionally, hemicelluloses were defined as the remaining polysaccharides when the cellulose and the pectin were removed (Scheller & Ulvskov, 2010). The traditional way of defining hemicelluloses it today not seen as scientifically correct, and therefore the composition of the constituents is instead applied to define the polysaccharide type (Scheller & Ulvskov, 2010). Hemicelluloses can presently be defined as "cell-wall polysaccharides that are insoluble in water but can be extracted with aqueous alkali and hydrolysed into its component monosaccharides with diluted sulphuric acid" (Schädel *et al.*, 2010)

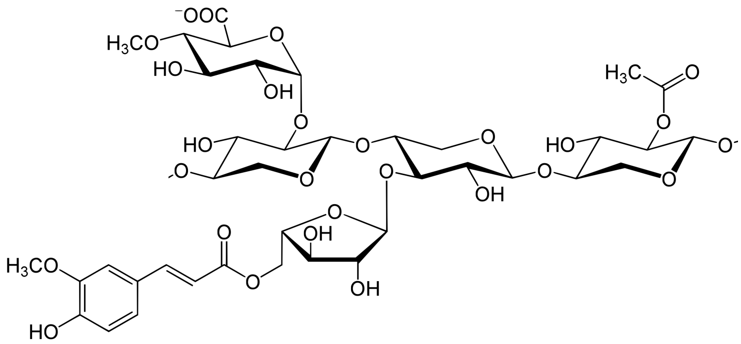

Figure 3. Chemical structure of glucuronoarabinoxylan, a member of the hemicelluloses.

By Yikrazuul - Own work by uploader; ISBN 978-1600219047 S. 19, Public Domain, https://commons.wikimedia.org/w/index.php?curid=7141633

Lignins

The phenolic polymer lignin, although not a carbohydrate, is still included in the definition of dietary fibre. Lignin were included in the first definition of dietary fibre by Trowell (1974), and are included in the current definition if lignin is intrinsic in the plant material (Codex Alimentarius, 2017).
Lignin provides structural support to plant secondary cell wall (Vermerris & Nicholson, 2006). It has a complex and variable structure first described by

Adler (1977) (Figure 4). Lignin has high molecular weight (MacDougall & Selvendran, 2001) and high levels of branching (Mongeau & Brooks, 2001). Due to its complex structure the polymer is often referred to as the plural form lignins instead. The main constituents in lignin are cinnamyl alcohols coniferyl alcohol, sinapyl alcohol and p-coumaryl alcohol (MacDougall & Selvendran, 2001; Vermerris & Nicholson, 2006), with the relative levels of these cinnamyl alcohols as one of the important difference between the different lignin structures (Theander & Åman, 1979).
In general, lignin can represent 15-25 % of the biomass in plants (Vinardell & Mitjans, 2017). There is an increasing amount of research done about lignins health beneficial properties, e.g. in the area of preventing diabetes and obesity (Vinardell & Mitjans, 2017).

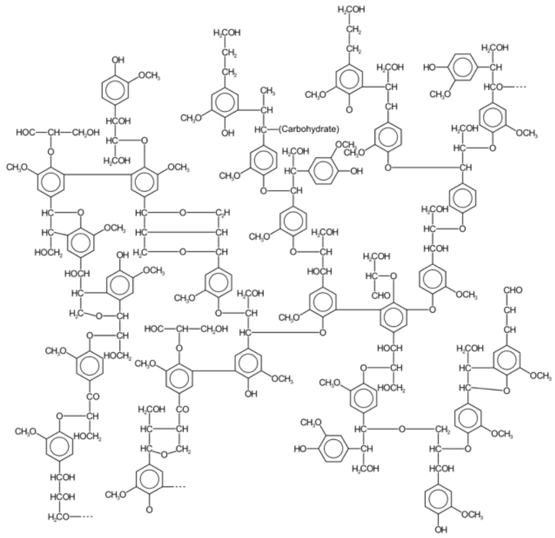

Figure 4. One example of the chemical structure of lignin, as first described by Adler (1977).

By real name: Karol Głąbpl.wiki: Karol007commons: Karol007e-mail: kamikaze007@ tlen.pl - own work from: Glazer, A. W., and Nikaido, H. (1995). Microbial Biotechnology: fundamentals of applied microbiology. San Francisco: W. H. Freeman, p. 340. ISBN

Oligosaccharides

Oligosaccharides are smaller sized polysaccharides compared to cellulose, pectic substances and hemicellulose, and are defined as carbohydrates with 2-20 monomeric sugar units (Roberfroid & Slavin, 2001). Examples of oligosaccharides are oligofructose and inulin (Figure 5). Oligosaccharides are not digested by the enzymes in the upper gastrointestinal tract and have a low caloric value, and have hence recently gotten more focus as a sweetener

and fat replacement in foods (Coussement & Franck, 2001). When the oligosaccharides reach the colon, they are metabolised by the bacteria into for instance short chained fatty acids (SCFA) (den Besten *et al.*, 2013), with health benefits that are explained below in Section 2.4.2.
Oligosaccharides, such as inulin are especially common in the crops Jerusalem artichokes and chicory, with chicory as the main industrial crop for commercialised inulin extraction (Coussement & Franck, 2001; Franck, 2002).

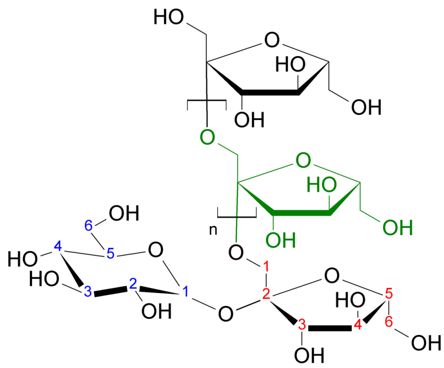

Figure 5: Chemical structure of the oligosaccharide inulin. Image from Florian Fisch [Public domain] https://commons.wikimedia.org/wiki/File:Inulin_strukturformel.png

Gums and mucilage

There is some confusion about the two terms gums and mucilage, with the two terms sometimes used indistinctly. Both are classified as soluble dietary fibre (see definition in section 2.4.1.) From a botanical point of view, the two different substances originate from different parts of the plant and have different functions. Gums are excreted as a response to mechanical injury and are supposed to heal the injured area and are highly soluble in water (Jones & Smith, 1949; Cano-Barrita & León-Martínez, 2016). Mucilage swells in water but is not completely soluble in water (Jones & Smith, 1949; Choudhary & Pawar, 2014), does not form gels as pectin and is mainly produced in the seed coats or at the surface of the root (Cano-Barrita & León-Martínez, 2016).
Gums are polysaccharides, mainly heteroglycans with branched structures, which contribute to a desirable texture in processed food products by acting as gelling, thickening or emulsifying agents (Saha *et al.*, 2017; Salarbashi & Tafaghodi, 2018). Significant portions of the gums are derived from plant cell walls, e.g. pectins, alginates, guar gum and carrageenan (MacDougall &

Selvendran, 2001). Gums used in food are also called “hydrocolloids” due to their affinity for water (Vaclavik & Christian, 2014). Hydrocolloids often include pectins (Saha & Bhattacharya, 2010), leading to some confusion about pectin being a separate group or a constituent of gums.
Mucilage comes from the seed coat, or spermoderm, especially from species in the plant genus *Plantago* (MacDougall & Selvendran, 2001) or from flax seed, quince and lucerne (Jones & Smith, 1949) The mucilage consists mainly of pectic substances and hemicelluloses (Kreitschitz & Gorb, 2017) and has been suggested to be described as a specialised pectin-rich secondary cell wall, even though the composition is distinct from more typical secondary cell walls with cellulose (Haughn & Western, 2012). The major neutral sugars in mucilage are D-xylose, L-rhamnose and L-arabinose (MacDougall & Selvendran, 2001; Kaur *et al.*, 2018). Mucilage has important physiological effects in both the small and the large intestines and is only partially degraded by the colonic bacteria (MacDougall & Selvendran, 2001). It can be used as a laxative, facilitating the bowel movements and can contribute to a lowering of blood cholesterol levels (Surampudi *et al.*, 2016).

2.3 Occurrence of dietary fibre

Dietary fibre consists mainly of cellulose, hemicellulose, pectins, lignins, gums and mucilage, and most of these are constituents of the plant cell wall (Figure 6). Thus, the composition of dietary fibre in plant-based food depends on the composition of plant cell wall in the food. Significant impact has been shown from plant species and the specific part of the plant used, the stage of maturity of the plant and the post-harvest modifications of the food items on cell wall composition of the plant food products (Schäfer *et al.*, 2017). In the living plant, the cell wall have numerous functions; it provides strength to the plant cell, it affects the transportation of larger size compounds in and out of the cell, influences the growth of the cell and affects the interactions with herbivores (Brett & Waldron, 1996; Taiz *et al.*, 2015). For the plant as whole, the cell wall with its content of dietary fibre provides a structural support against gravity and environmental forces and also make water transport possible in tall plants (Brett & Waldron, 1996; Taiz *et al.*, 2015). Therefore, tougher and more dietary fibre rich structures are found in plant parts with needs to withstand higher forces or harsher conditions, such as the stem (Evans *et al.*, 2003), and hulls seeds (Chen *et al.*, 2012; Barros *et al.*, 2015). The levels of dietary fibre are specifically high in the thick, often lignified secondary cell wall with high levels of lignin and cellulose (Evans *et al.*, 2003; Barros *et al.*, 2015). Furthermore, the dietary fibre of the secondary cell wall are also structurally different from those of the primary cell wall (MacDougall & Selvendran, 2001; Taiz *et al.*, 2015). The primary cell wall is usually thin, with high amounts of pectins and lower amounts of cellulose and hemicellulose (Taiz *et al.*, 2015). The secondary cell wall is normally formed in the plant when the cell have stopped growing in size (Taiz *et al.*, 2015) The best studied secondary cell walls are from highly lignified cells that become dead cells when they have reached maturity, e.g. xylem vessels and fibres in woody tissues (Taiz *et al.*, 2015).

Vegetables that are eaten by humans consist mainly of fast growing, immature tissues, in which the secondary cell wall will not develop or has not developed to a significant level of lignification which would have made the tissues tougher (Brett & Waldron, 1996).

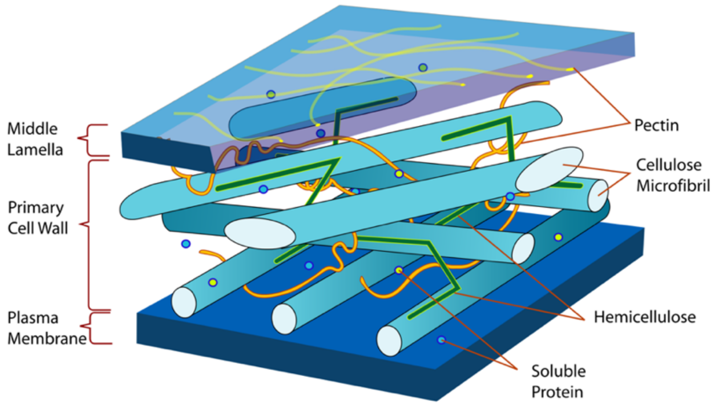

Figure 6: Model of the cell wall of a plant cell. Pectin, cellulose, soluble proteins and hemicellulose build up a matrix.

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2.4 Chemistry and effects on human health

2.4.1 Physiochemical properties of dietary fibre

The dietary fibre components can be divided into groups according to various criteria, e.g. by monosaccharide composition, specific attached sugars, level of branching, origin or chemical properties (Bemiller, 2001). Most commonly dietary fibre is subdivided into two major groups; one with polymers that are soluble in water, soluble dietary fibre (SDF), and a second one with polymers that are insoluble in water, insoluble dietary fibre (IDF). Most plant foods contain a combination of soluble and insoluble fibre (Hassan *et al.*, 2011). The SDF contains mainly pectins, gums and mucilage, while the IDF contains primarily cellulose, hemicellulose and lignin. For food processing or other industrial uses, the properties of the dietary fibre as a food ingredient are important. This, e.g. the water retention capacity (WRC), defined as the amount of water retained by a known weight of fibre, is an important character (Robertson *et al.*, 2000), as is oil-holding capacity (OHC) defined as the amount of oil retained by the fibres after mixing, incubation with oil and thereafter centrifugation (Elleuch *et al.*, 2011) and swelling capacity (SWC), the change in volume of the dry sample after hydration in distilled water overnight (Zhang *et al.*, 2011).

2.4.2 Impact on health

The food intake is influencing transit time as well as bulk and consistency of the stool. A large proportion of refined foods (e.g. white flour) with low amounts of fibre has been found to result in small firm stools passing slowly, which was also correlated to several diseases in industrial societies. Thus, intake of more fibre rich food was reported as beneficial for the health (Burkitt *et al.*, 1972). Specifically, the SDF have been reported as contributing with health benefits to humans, e.g. by lowering the total cholesterol in the blood (Mandimika *et al.*, 2012; Surampudi *et al.*, 2016). Content of SDF has been shown to affect the serum cholesterol levels and inflammations factors in the blood (Ning *et al.*, 2014). The content of SDF also impacts the rate of gastric emptying which leads to longer feeling of satiation after a meal (Mackie *et al.*, 2016). The IDF is promoting the peristaltic movement of the intestines and hence lowering the transit time (Wrick *et al.*, 1983) and is beneficial for the human gut microbiota (Paturi *et al.*, 2010; Desai *et al.*, 2016). Processing of dietary fibre has shown a negative correlation with transit time and volume of the stool, explained by the loss of structure in the dietary fibre while processed (Monro *et al.*, 2016). Bacteria strain in the microbiota are differently affected by the dietary fibre content (Yang *et al.*, 2014). Thus, the gut microbiota can be readily affected by changes in the diet (Li *et al.*, 2009).

However, some of these positive health effect reported from intake of dietary fibre may originate from other sources than from the fibres per se. A by-product, e.g. short chained fatty acids (SCFA), excreted from the gut bacteria as they use the fibres in their metabolism, have been reported as one such source (den Besten *et al.*, 2013; Sawicki *et al.*, 2017). These short chained fatty acids have been found to lower the risk of depression (Miki *et al.*, 2016), regulate the uptake of lipids to have an impact on the cholesterol metabolism (den Besten *et al.*, 2013), and improve the immune system (Corrêa-Oliveira *et al.*, 2016). Thus, a diet rich in dietary fibres is an objective to strive for.

2.5 Analytical methods for dietary fibres

When analysing dietary fibre, there is no available procedure to be utilised for all types of foodstuffs or diets (Southgate, 1978). Instead, the method that enables the most accurate measurement for the characterisations of dietary fibre should be chosen (Southgate, 1978). The method to be used depends on the aspects of the dietary fibre that are of relevance for the study. An analytical methodology that is often applied is to measure the total amount of dietary fibre, divided into the amount of SDF and IDF (Asp *et al.*, 1983; Prosky *et al.*, 1988; McCleary *et al.*, 2012). Another commonly applied method is to measure the sugar constituents that are the building blocks of dietary fibre (Englyst *et al.*, 1994; Theander *et al.*, 1995) after removing starch, and later calculate the amount of non-starch polysaccharides and Klason lignin (Theander *et al.*, 1995). Klason lignin is defined as the sample insoluble constituent remaining after hydrolysis in sulfuric acid (Technical Association of the Pulp and Paper Industry, 2006). Furthermore, methods have been developed mimicking the environment of the human gastrointestinal tract in order to evaluate which part of the fibre are not

digested in this environment (Asp *et al.*, 1983). Lack of digestion in the human gastrointestinal tract is a major definition of the dietary fibre and the latter methods are building on this knowledge. The first such method used an 16-hour incubation for enzymatic digestion of carbohydrates and proteins in the food sample, and thereafter the obtained dietary fibre was divided into SDF and IDF. The composition of the fibre subgroups could be further analysed chromatographically (Asp *et al.*, 1983). The mentioned method was later improved by McCleary *et al* (2015), with an incubation time more resembling the digestion time in the human gastrointestinal tract of 4 hours. The method of McCleary *et al* was also adapted for including e.g. resistant starch and oligosaccharides according to the new definition of dietary fibre from Codex (Codex Alimentarius, 2008). Using another approach, Englyst (1994) measured dietary fibre as the non-starch polysaccharides (NSP). First the starches are removed enzymatically and thereafter NSP are hydrolysed with acid to their constituent sugars. The constituent sugars are thereafter analysed with LC, HPLC or spectrophotometry (Englyst *et al.*, 1994).
Whichever method that is chosen for the determination of the content of dietary fibre, it is important to understand the presence of other substances and also what is recovered in the chosen method of analysis (Englyst *et al.*, 2013).

3 Phenolic compounds

3.1 A definition of phenolic compounds

Phenolic compounds are defined as ” *substances possessing an aromatic ring bearing one or more hydroxyl group including their functional derivatives*” (Figure 7) (Shahidi & Naczk, 2004). A variety of phenolic compounds and their derivatives exist, e.g. flavonoids, simple phenols, stilbenes, tannins, lignans and lignins. Various classification systems are present for the phenolic compounds, although the number of carbons is the most widely used today (Vermerris & Nicholson, 2006). The most common phenolic compounds in the genus Brassica are the phenolic acids (hydroxybenzoic acid and hydroxycinnamic acid derivatives) and flavonoids (Figure 8). An overview of the different groups can be seen in Figure 9.
The phenolic compounds shows various functions in plants, e.g. they acts as antifeedants and anti-pathogens (protects against pathogens such as virus, bacteria and fungus), contributes to pigmentations of plants, functions as

antibiotics (protects against bacteria), natural pesticides (protects against pests such as insects, rodents, fungi and other plants), attractants for pollinators, protective agents (e.g. for UV light), make the cell walls impermeable for gas and water and gives physical stability in the plant (Shahidi & Naczk, 2004). Phenolic compounds are normally weak acids and are ubiquitous present in plants, where they usually are present as esters or glycosides rather than as free compounds (Vermerris & Nicholson, 2006).

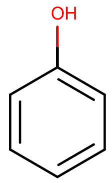

Figure 7. The defining structure of phenolic compounds; an aromatic ring with one or more hydroxyl group directly attached.

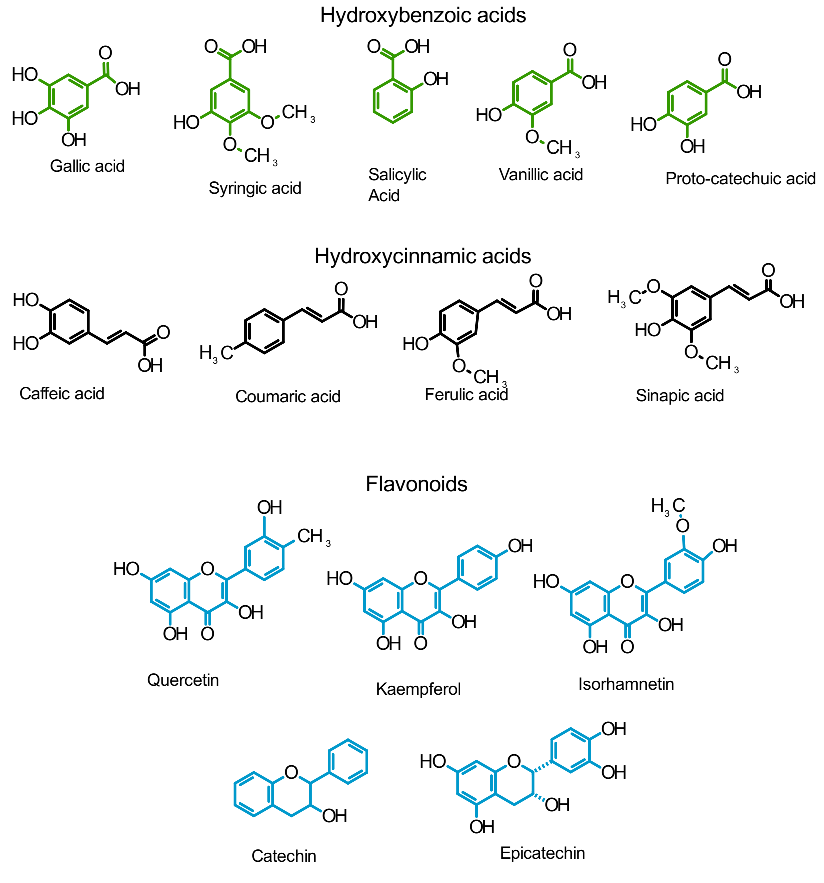

Figure 8 Examples of the most common phenolic compounds in Brassica.

Inspired from (Kumar, 2017)

3.2 Constituents of phenolic compounds

More than 8000 different types of phenolic compounds have been identified in plant material (Shen *et al.*, 2017), and of these hundreds have been characterised in plant based food (Manach *et al.*, 2004; Cartea *et al.*, 2011). Despite the wide range of phenolic compounds present being defined from their number and configuration of carbons in the molecule (Vermerris & Nicholson, 2006), the majority of phenolic compounds in plants can be divided into the two major groups in plants, phenolic acids and flavonoids, which are presented below.

3.2.1 Phenolic acids

Approximately 30 % of the phenolic compounds in plant-based food are defined as phenolic acids. However, the concentration and composition of the phenolic acids depend on location and year of the production of the plant, cultivar used and also of the harvesting and processing techniques applied in food production (Martinez *et al.*, 2017). The phenolic acids can be divided into two major subclasses: hydroxybenzoic acids and hydroxycinnamic acids.

The subclass of hydroxybenzoic acids includes substances such as gallic acid, vanillic acid, protocatechuic acid and salicylic acid. The main structure of the hydroxybenzoic acids is a benzene ring with up to four hydroxyl groups attached (Vermerris & Nicholson, 2006) (Figure 8).

In the subclass of hydroxycinnamic acids substances like caffeic acid, chlorogenic acid, coumaric acid and ferulic acid can be found. The main structure is one benzene ring with a carbon chain of three carbon attached, in addition to the hydroxyl groups (Vermerris & Nicholson, 2006) (Figure 8).

3.2.2 Flavonoids

Flavonoids are even more common than phenolic acids in plant based food, contributing approximately 60 % of the phenolic compounds (Martinez *et al.*, 2017). Flavonoids have a structure of C_6-C_3-C_6, which means that they have two benzene rings connected by a three-carbon chain (Vermerris & Nicholson, 2006). The group can be further divided into subgroups (e.g. chalcones, aurones and flavonols) depending on the arrangement of the carbon chain, and thereafter the subgroups are divided into additional groups based on compounds composition (Vermerris & Nicholson, 2006).
In Brassica, the main flavonoids are the flavonols kaempferol, quercetin and isorhamnetin (Schmidt *et al.*, 2010a; b; Cartea *et al.*, 2011) (Figure 8).

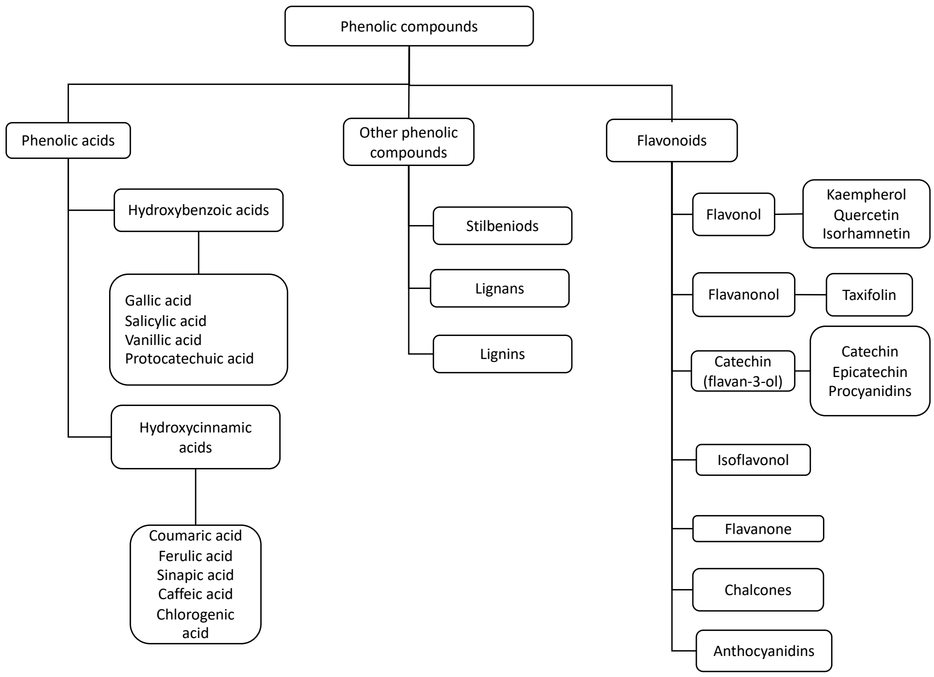

Figure 9: Hierarchy of some of the most common phenolic compounds.

3.3 Occurrence and function of phenolic compounds

Generally, high levels of phenolic compounds are found in plants and not least in green leafy vegetables (Sakakibara *et al.*, 2003; Lin & Harnly, 2010; Kumar, 2017). Also, phenolic compounds, especially the group of compounds named lignins, can make up approximately 30 per cent of the secondary cell wall in plants (Scheller & Ulvskov, 2010). Furthermore phenolic compounds are in general found in higher concentrations in plant parts that are exposed to solar radiation, temperature fluctuations or other types of environmental stress (Zietz *et al.*, 2010; Groenbaek *et al.*, 2016). One reason for phenolic compounds being present in high quantities in plants at stressed conditions may be due to their capacity to act as antioxidants. Antioxidant are known to scavenge reactive oxygen species (ROS), including free radicals and hence lower the risk for oxidative stress damages. One commonly used definition of an antioxidant is "*any substance, present in comparable low concentrations, that delays, prevents, or removes oxidative damage to a target molecule*" (Halliwell & Gutteridge, 2015a), and examples of antioxidants are carotenoids, phenolic compounds and some vitamins (Shi & Noguchi, 2001; Halliwell & Gutteridge, 2015a)

Reactive oxygen species (ROS) include free radicals of oxygen as well as other reactive molecules such as hydrogen peroxide (H_2O_2). Free radicals are defined as "*any species* [atoms, molecules, ion etc] *capable of independent existence that contains one or more unpaired electrons*" (Halliwell & Gutteridge, 2015c), and can for this reason react efficiently with other molecules, for example the DNA molecule and give rise to mutations (Sardina *et al.*, 2012). ROS are produced during the cells' normal metabolism (Sardina *et al.*, 2012) but may also be formed due to abiotic (radiation, temperature and moisture) and biotic (herbivores) factors (Suzuki *et al.*, 2014). However, ROS normally only constitute a problem to the cells if their concentrations becomes immensely high and exceed the capacity of the antioxidant defence in the cells which control the levels (Halliwell & Gutteridge, 2015b). Under these conditions, the cell might experience oxidative stress, which is a situation when the concentration of ROS is enhanced, which will disturb the cellular metabolism and its regulation and hence risk to damage cellular constituents (Lushchak, 2011).

3.4 Chemistry and effects on human health

The phenolic compounds can be divided into two separate groups according to their solubility; extractable polyphenols (EPP), soluble in aqueous-organic solvent, and non-extractable polyphenols (NEPP), insoluble in aqueous-organic solvent (Pérez-Jiménez *et al.*, 2014). During food intake, the NEPP are known to reach the human colon almost intact due to the fact that they are not released from the food by the human digestive system (mastication, acid pH in stomach or action of digestive enzymes) (Pérez-Jiménez *et al.*, 2014).

Epidemiological studies have shown that diets with high levels of phenolic compounds can improve the vascular health (Wang *et al.*, 2011), lower the risk of cardiovascular diseases (Manach *et al.*, 2005; Williamson, 2017), lower the risk of developing certain forms of cancers (Kyle *et al.*, 2010), lower the mortality in cancer (Ivey *et al.*, 2015) and lower the risk of chronic inflammations (Williamson, 2017; Kasprzak *et al.*, 2018). The bioavailability of phenolic compounds is dependent on other macromolecules in the food matrix (Scheepens *et al.*, 2010), for example proteins (Jakobek, 2015; Foegeding *et al.*, 2017) and dietary fibre (Quirós-Sauceda *et al.*, 2014; Phan *et al.*, 2015; Gonzalez-Aguilar *et al.*, 2017).

In addition, the composition of the gut microbiota, fermenting the phenolic compounds and their associated substances, influences the amount of absorbable metabolites that are beneficial to the human metabolism (Selma *et al.*, 2009; Pérez-Jiménez *et al.*, 2014; Martinez *et al.*, 2017).

3.5 Analytical methods for phenolic compounds

The analyses of phenolic compounds are a challenge due to the fact that the group consists of over 8000 different compounds, with different characteristics. Therefore, measurement of the total antioxidant activity, e.g. with the Folin-Ciocalteu phenol reagent which measures the reducing capacity of a sample can be used as a rough estimate of total phenolic content in a sample. The methods works on the principle that there is an electron transfer between the reagent, molybdotungstate, and the phenolic compounds (Prior *et al.*, 2005; Sánchez-Rangel *et al.*, 2013), which gives a change of colour at the wavelength of 765 nm. The total phenolic content measured by Folin-Ciocalteu was shown to have a good correlation with the sum of the individual polyphenols from HPLC according to one study of Kaulmann et al (2014), though other reducing substances might interfere (Sánchez-Rangel *et al.*, 2013). Another method to analyse the content of phenolic compounds is to use HPLC, an analysis that can be performed also after hydrolysis with acid or alkaline conditions (Guo *et al.*, 2001; Lin & Harnly, 2007; Olsen *et al.*, 2009; Kumar, 2017).

4 Antioxidant dietary fibre

Recently, studies have suggested to group antioxidants and dietary fibre into one joint group, i.e. as antioxidant dietary fibre (Sánchez-Rangel *et al.*, 2013), due to the interactions between these two groups of compounds (Le Bourvellec & Renard, 2012). Dietary phenolic compounds bind spontaneously and rapidly to cellulose, hemicellulose, lignin and pectins (Phan *et al.*, 2015), which can affect the release of phenolic compounds from the food inside the gastrointestinal tract (Padayachee *et al.*, 2017). The dietary fibre entraps and protects the phenolic compounds from digestive enzymes while they are transported through the intestines, resulting in that the phenolic compounds reach the microbiota mainly intact (Perez-Jimenez *et al.*, 2009; Palafox-Carlos *et al.*, 2011). Therefore, antioxidant dietary fibre (ADF) has been defined as dietary fibre rich material that contains antioxidant phenolic compounds in high amounts associated to the fibre matrix (Saura-Calixto, 1998).

5 Broccoli and kale

5.1 Introduction to broccoli and kale

Broccoli (earlier *Brassica oleracea italica*, now denoted *Brassica oleracea* Italica group) and kale (earlier *Brassica oleracea acephala*, now denoted *Brassica oleracea* Sabellica group) are both members of the Brassicaceae family, and the Brassica genus. There is no clear record of starting time for cultivation of Brassica vegetables (Gray, 1982), partly because the distinction of broccoli and cauliflower is not clear early in history. Broccoli originated most likely in the eastern Mediterranean area, even if the exact location and time is not known (Maggioni, 2015). One of the first literature records mentioning broccoli is from Britain around 1774, using the terms ”sprout cauliflower” and ”Italian asparagus” to describe broccoli (Gray, 1982). Also, some records from medieval times might be about broccoli and kale, although the vegetables mentioned may also be close relatives (Gray, 1989; Maggioni, 2015).

In Sweden, the broccoli production occupied 362 hectares (1 hectare = 10 000 m^2) in 2016 (Persson, 2017). This is a slight reduction in areal from 2015, when 375 hectares broccoli were cultivated in Sweden. However, the acreage of broccoli cultivation has increased in total during later years, from 2008 the cultivated acreage has increased by 67 % (Persson, 2017). As a comparison, the production of kale has increased from 49 hectare 2014 to 89 hectare in 2017 (Persson, 2018), with no data collected before the year 2014.

5.2 Broccoli

As a whole, consumption of broccoli has been suggested to result in health benefits due to the content of nutrients and bioactive compounds such as glucosinolates, phenolic compounds, minerals, vitamin C, vitamin K and folic acid (Vasanthi *et al.*, 2009; Ares *et al.*, 2013; Liu *et al.*, 2018). Depending on the cultivar, location of the field and the season of harvest, the content of sugar (glucose, fructose, sucrose) varies considerably in the stems, leaves and florets of broccoli (Bhandari & Kwak, 2015a). As to the different parts of the broccoli, the florets were found to have higher levels of glucosinolates and free sugars compared to the leaves and stem, and with the highest levels of phenolic compounds in the leaves and the stem richest in vitamin C (Bhandari & Kwak, 2014, 2015b) and sodium (Liu *et al.*, 2018), with moderate levels of sugars (Bhandari & Kwak, 2015a). The leaves are also rich in vitamin E and K, magnesium and calcium (Liu *et al.*, 2018).
Leaves and stems of broccoli are not used for food purpose to the same extent as the florets, although these side streams of broccoli are often as nutritional as the florets. Stems and leaves have been found richer in sugars than the florets, and had higher levels of sugar in the autumn season as compared with the levels in the spring season (Bhandari & Kwak, 2014, 2015b). Furthermore, the stem were found to have lowest cultivar dependent variations in content of phytonutrients as compared to other parts of the broccoli and also when comparing autumn and spring season (Bhandari & Kwak, 2014). Broccoli have differences in sugar composition that are organ-specific (stem and florets) (Houben *et al.*, 2011). Due to the high nutritional content of broccoli stems and leaves, novel uses for these parts would be valuable. However, the stem in broccoli can be perceived as tough due to the thickened vascular cell walls, which might cause problems with consumer acceptability (Muller *et al.*, 2003). Due to the physiological functions of stems, the majority of broccoli stem cell wall polymers are not water soluble (33 % of the dry weight) compared to soluble polymers (3 % of the dry weight) (Schäfer *et al.*, 2017). The content of lignin is in most cases low in broccoli (Muller *et al.*, 2003), while the levels of pectin and hemicellulose are higher (Houben *et al.*, 2011). In general, the broccoli plant has a water content of 81-86 % (Liu *et al.*, 2018).

There is a lack of studies about the exact volume of non-harvested biomass on the broccoli field, though measurements have been done in greenhouses. Approximately 45-50 % of the edible parts of broccoli has been theoretically estimated to become waste during processing, and approximately 70 % of the total weight of broccoli becomes waste on the field (Campas-Baypoli *et al.*, 2009), due to the lack consumer market for the stem and leaves of the plant. The division of the broccoli plant can be seen in Figure 10. In a greenhouse experiment, approximately 90 % of the above ground biomass was determined as waste, which included stems, leaves and too small inflorescences (Dominguez-Perles *et al.*, 2010). Thus, it is clear from the above description that substantial amounts of valuable side streams are available from broccoli cultivation, which is possible to be valorised into nutritional food or novel food products.

Figure 10: A broccoli plant divided into florets, stem (with roots) and leaves

5.3 Kale

The name kale is used for a variety of large leafy specimens of *Brassica oleracea* (Hahn *et al.*, 2016) (Figure 11). In this introductory paper, the denomination kale or curly kale is used for the specimens in the *Brassica oleracea* Sabellica *group.* Leafy kales are considered as the first cultivated brassicas (Maggioni, 2015), although the exact cultivars have been difficult to identify. Some historical document suggests that leafy brassicas were used for human consumption and as animal feed in ancient Greece and Rome (Maggioni, 2015).

Figure 11: A kale plant ready for first harvest (left) and a kale plant with central stem exposed (right)

Kale is a good source for bioactive compounds such as vitamin C, carotenoids including some that have pro-vitamin A activity, phenolic compounds, and glucosinolates (Becerra-Moreno *et al.*, 2014; Kaulmann *et al.*, 2014). The concentration of these compounds can be affected by e.g. environmental factors. Frost exposure improved the phytochemical content and sensory properties even further in the edible parts of the kale plant (Steindal *et al.*, 2015; Groenbaek *et al.*, 2016). As the plant matures, the levels of vitamin C and phenolic compounds increase (Korus, 2011). Levels of soluble sugars and vitamin C decrease with longer exposure to cold or cold storage and also with delayed harvest (Hagen *et al.*, 2009). However, despite a decrease in the level of vitamin C with the mentioned treatments, the levels are still high (Hagen *et al.*, 2009).

The antioxidant capacity in kale is affected by the soil type (Łata, 2014), as well as the geographic location of the fields (Ferioli *et al.*, 2013). The composition of flavonoids in kale is dependent on genotypic and climatic factors, such as temperature and solar radiation during the cultivation time, and higher concentration of flavonoids is found in older cultivars (so called heirloom cultivars) as compared to newer ones (Schmidt *et al.*, 2010a; Zietz *et al.*, 2010; Neugart *et al.*, 2012). Also the time of season is impacting the mineral content in kale, with higher levels early in the season, although variation between cultivars has been reported (Rosa & Heaney, 1996). The tough central stem of curly kale (Figure 12 and Figure 13) is composed of mainly lignified secondary xylem, with high levels of pectins (Wilson *et al.*, 1988), and low levels of lignin (Evans *et al.*, 2003)

Figure 12: Longitudinal section of kale stem. To the left is the topmost part of the stem and to the right is the lower part of the stem.

*Figure 13. Transverse section of the lower part of the stem in kale (*B. olearacea *Sabellica* group). *Notice the thick lignified layer.*

6 Side streams and food loss

6.1 Side streams

Side streams is a term for the materials of products being produced in a production line, but not being the major target product in this line. In agricultural and horticultural production, quite a range of side streams are existing, e.g. the straw from wheat production (where wheat kernels for food production are the target, while the straw often have other uses), the pomace after juice or oil production, and the leaves and parts of stems of the broccoli plant. Even though the side streams are not the target food product, they may still have a potential to be valorised into useful products. A few examples of how the side streams can be used are shown below:

- Fibre supplements in biscuits, cereal bars or snacks, e.g. cauliflower upper stem, artichoke bracts/petals and chicory leaves (Ferreira *et al.*, 2015) and soybean hulls (Yang *et al.*, 2014).
- Food additives, e.g. core of maize stalks (Lv *et al.*, 2017), lower part of the asparagus spear (Fuentes-Alventosa *et al.*, 2009), cabbage outer leaves (Tanongkankit *et al.*, 2012) and pomace after juice production (Ferreira *et al.*, 2015).
- Animal feed, e.g. pomace from juice production (Nawirska & Kwasniewska, 2005), broccoli stems and leaves (Hu *et al.*, 2011), broccoli by-products (Yi *et al.*, 2015) and broccoli florets (Mustafa & Baurhoo, 2016).

For dietary fibre material aimed at being used as food additives, there are some characteristics that are desirable (Larrauri, 1999). Such specific characteristics include being insipid in taste, colour and odour, have a good shelf life, have the expected physiological effects, be reasonable in price and be compatible with food processing (Larrauri, 1999). Most dietary fibre material do not meet all these criteria, meaning that depending on the product and its requirement certain criteria need to be fulfilled. Consumers' of today often have high expectations on food; it should not only be tasty, but also contribute to health benefits (Ridderheim & Kairos Future, 2015). Addition of dietary fibres from side streams from field crop production may contribute beneficially to the gut microbiota, and thereby meet consumers' expectations of healthy food.

6.2 Food waste and food loss

In order to have a useful discussion about the amount of food that, for some reason, could be eaten but is not, defining food waste and food loss is necessary. Both the term food waste and food loss are used in the literature, although sometimes inconsistently defined, making comparisons and life-cycle assessments insecure. However, the edible but non-harvested parts in vegetable production is usually not included in the food loss definitions, with some exceptions such as Strid *et al* (2014) and Hartikainen *et al* (2017). These edible but non-harvested parts include parts with cosmetic damages and overproduction (de Hooge *et al.*, 2018) and parts with no available food market. The following section discusses some of the different definitions in the literature.

6.2.1 Some examples of definitions of food waste and food loss.

In a well cited report from FAO (Gustavsson *et al.*, 2011) the distinction between *food waste* (the decrease of edible food at the end of the food chain, mainly retail and consumers) and *food loss* (the decrease in edible food throughout the food supply chain that leads to human consumption, essentially at production, post-harvest and processing) is stated (Figure 14).

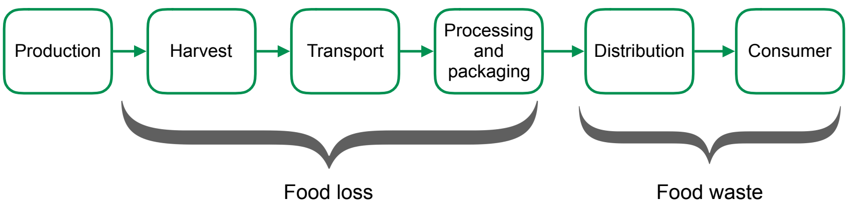

Figure 14 Difference between food loss and food waste.

According to Gustavsson et al. (2011)

Gustavsson et al. (2011) also stresses that the food waste is influenced by retailer's and consumer's behaviour and expectations on the products.
A more detailed explanation can be found in Buzby et al (2014) were they describe food loss as "*food available post harvest for human consumption but that are not consumed for any reason".* In the same article, food waste is defined as a component of food loss, being edible items that are not consumed, e.g. by being discarded in the retail phase or food discarded on the plate by consumers (Buzby *et al.*, 2014). Thus, food loss could be the result of changes in the product after storage or cooking, e.g. parts of the products that are cut away prior to cooking, shrinkage due to moisture loss in a sub-optimal storage or loss from pests and mould (Buzby *et al.*, 2014). Thereby, the two above mentioned studies results in a similar definition of food waste (Gustavsson *et al.*, 2011; Buzby *et al.*, 2014).
A recent study has used the difference between the total amount of food produced and the amount of food employed in any kind of productive use, either as food or as non-food (e.g. as fodder for animals) as a short and informative definition of food waste (Bellemare *et al.*, 2017). However, other studies have suggested abandoning the concept of food waste and instead use a grouped definition of food loss (Quested & Johnson, 2009) as described below:

1. **Avoidable losses**. This group is referring to the food and drinks that are thrown away because they are no longer wanted as food, e.g. because they have exceeded their "eat before"-date. The products were at some point edible but have deteriorated.
2. **Possible avoidable losses**. In contrast to the group before, this group contains the parts that are eaten by some people but are left by other (e.g. apple peels and core), or parts that could be eaten when processed in some way (e.g. skins of potato or pumpkin) or foods that are selected due to specific criteria (size or shape).
3. **Unavoidable losses.** The remaining group consists of the waste from food and drink preparation that are normally not edible (e.g. banana peel, tea leaves, coffee ground and slaughter waste). Also included are the losses at harvest, and during storage, transportation and processing that could not be avoided with best available techniques and reasonable costs.

As the examples above show, there are several ways to define and classify the amount of produced food material that are not eaten. For convenience the term “food loss” will be used henceforth in this text to describe the produced, but for some reason not eaten human food.

6.2.2 Example: Broccoli side streams in baked goods

Broccoli for human food consists of harvested broccoli florets and the upper part of the stem, i.e. the topmost part of the plant, that is cut off and after harvest is brought by the distribution chain to reach the consumers as a vegetable product. The lower part of the stem and the leaves, which make up over 50 per cent of the total weight of the plant, are normally not harvested, but left in the field. These side streams can instead be used as an ingredient e.g. in baked goods.

Previous studies have shown steam blanching prior to slicing and vacuum drying at 80 °C as a possibly recommended process suitable for the production of functional dietary fibre powder from the otherwise discarded parts of white cabbage (Tanongkankit *et al.*, 2012, 2015). Similar methods could have good effect on broccoli side streams. However, a previous investigation has also shown the less processed dietary fibre being more beneficial for the gut microbiota than fibre with higher degree of processing (Monro *et al.*, 2016). Broccoli stems could be used in baking, either by drying, milling and adding it as a powder, or by grating it raw. However, the lower parts of the stem are quite fibrous and broccoli have a strong taste, which may thereby affect the taste and sensory qualities of the products (Femenia *et al.*, 1998). While adding the broccoli side streams as an ingredient, it is vital to understand the requirements of the final product with its nutritional benefits in order to select the most optimal processing method for the broccoli powder.

If broccoli powder is to be used as an ingredient, the powder could be prepared through different methods for blanching, drying, and milling which in turn may affect the nutritional content of the ingredient (Tanongkankit *et al.*, 2012). With the use of ultrafine grinding (with a particle size of 100-1000 nm), fractions of smaller dietary fibre can be obtained (Zhu *et al.*, 2010). This ultrafine powder resulted in a higher content of soluble fibre, and a reduction in hydration properties (WHC, WRC and swelling capacity) and antioxidant capacity as compared to powder from commercial milling. The small particle size of the ultrafine powder allowed it to penetrate into the structure of foods, resulting in a high dispersibility and solubility of the powder in the food systems. The particles of the ultrafine powder were are also easier absorbed due to their greater surface area and will thereby be more readily digested by enzymes and microbiota in the gut (Zhu *et al.*, 2010). An ideal broccoli powder should be useable as a food ingredient, have a good nutritional value, and be safe from human pathogens.

When baking bread with sourdough or baker's yeast it is important to make a dough with a great network of gluten threads, which results in an elastic dough with good rheological properties (Mis *et al.*, 2017). Broccoli powder added to the dough would contribute with valuable minerals for the yeast and bacteria in the dough, and the soluble dietary fibre could increase the water holding capacity, leading to a better dough (Arufe *et al.*, 2017; Han *et al.*, 2017). Since dough with added dietary fibre takes longer time to develop (Mis *et al.*, 2017), it could be an idea to add broccoli powder in sourdough bread, since it has a longer development time and hence the dough could have the opportunity to benefit from the fibre in matter of structural and nutritional properties (Gobbetti *et al.*, 2014). Adding broccoli powder in sourdough could also make bioactive compounds more available for human absorption, since the steps of fermentation, acidification, proteolysis and activation of enzymes (steps that are missing when baking with bakers' yeast) may affect the matrix in which these compounds are bound (Gobbetti *et al.*, 2014). There is a need to develop fibre-rich gluten free alternatives, since many of the gluten free products that are on the markets today lack vital nutrients and components such as dietary fibre, vitamins and minerals (Han *et al.*, 2017). When it comes to gluten free cakes, which often have a problem of low nutritional value, an additive of broccoli leaf powder of 2 % had a good impact on the content of protein, minerals and phenolic compounds without affecting the sensory qualities (Drabińska *et al.*, 2018).

To conclude, there are opportunities for using broccoli side streams in e.g. bread and cakes, with increasing nutritional value as a result. The problem is the risk of drawbacks in texture and taste and how to efficiently prepare the side streams into a useable ingredient.

7 Conclusions

Generally, this paper identifies the large quantities of produce that could be consumed as human food but currently are not. Two major definitions, food waste and food loss, are used to characterise food items possible to eat but not eaten. Basically, the material left unharvested in the field is not included in any of these definitions and is also less studied, making approximations of the total amount of this underutilised resource difficult.

The major part of the biomass in the broccoli and kale production is not ending up as vegetables for the human consumption but is instead considered as waste or side streams. Thus, the potential is obvious to utilise this inexpensive biomass for extraction of functional ingredients or as a raw material for making health beneficial food products. However, clear challenges currently restrict the use of these side streams. Such challenges include the distinctive taste, allowing only low percentages of addition in food products, and the negative textural impact vegetable powder might have on a product. Broccoli and kale are both known to contain high levels of bioactive compounds, e.g. phenolic compounds, as well as dietary fibre, of relevance for functional food or novel food products. Therefore, the potential to increase the content of minerals, vitamins and dietary fibre in gluten-free cakes by the use of powder from broccoli leaves have been evaluated with promising results in earlier studies.

As for the definition of dietary fibre, there is a history of disagreement, that now has come to an international agreement. A range of methods is currently available, some being defined as international standards, of which the analyses of the total amount of dietary fibre and for identification of the different constituents.

The phenolic compounds correspond to over 8000 identified substances. Many of these substances are known to have a beneficial effect on human health by reducing the risk of developing certain forms of cancer, cardiovascular diseases and chronic inflammations.

Antioxidant dietary fibre is a novel terminology implemented due to the fact that phenolic compounds and dietary fibre are often found either solely together or in combination with other substances in complexes. Thereby, the dietary fibre contributes to a transportation of the intact phenolic compounds to the intestines, where the bacterial flora uses the dietary fibre and phenolic compounds in its metabolism. During this metabolism, the bacteria are producing e.g. short chained fatty acids (SFCA), which are beneficial for the human health.

Throughout this literature study, the focus has been on the potential use of the side streams from broccoli and kale production. To conclude, a wide array of opportunities is existing while searching for novel uses of broccoli and kale side streams within the production of health beneficial food. However, substantial and additional studies are needed to fully evaluate the most efficient and consumer acceptable use of these side streams.

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