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Review

Starch and modified starch in bread making: A review

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Starch is an important source of energy in human nutrition. It is also widely used as a processing aid in several food and non-food industries. Starch in wheat flour contributes to the development of optimal bread crumb and crust texture. It is also responsible for physical deterioration of bread quality through staling. Starch is mainly extracted from starch-rich plants such as cereals, root and tuber crops and legume seeds. It can be modified using chemical, physical or enzymatic techniques to obtain modified starch. Traditional plant breeding or genetic modification can also be used to produce starches with modified functionalities. Modified starches are essential food processing aids because of their enhanced functional properties. The aim of this paper is to review the role of starch in bread making and subsequently elucidate the influence of modified starch on the quality of wheat bread.

Key words: Bread, modified starch, starch, wheat.

INTRODUCTION

Bread is an important source of energy in the human diet because of its high content of readily digestible starch (40 g/100 g) (Mckevith, 2004). Bread is an unstable, elastic, solid foam, the solid part of which contains a continuous phase composed in part of an elastic network of cross-linked gluten molecules and in part of leached starch polymer molecules; and a discontinuous phase of entrapped, gelatinized, swollen, deformed starch granules (Gray and Bemiller, 2003). It is made from four principle ingredients: wheat flour, water, salt and yeast. In modern production processes, other ingredients and additives such as fat, sugar, emulsifiers and enzymes must be added to ensure uniformity in quality and increase product diversity. These essential and non-essential ingredients used in bread making are first mixed into viscoelastic dough which is then fermented in two or several stages before being baked. Starch is the most abundant fraction of milled wheat flour. The amount of starch (and sugars) in wheat flour increases from about 64% (dry-basis) in flour of 100% extraction rate to 71% (dry-basis) in flour of 70% extraction rate (Delcour and Hoseney, 2009). The contribution of starch to bread making is related to its water absorption property during dough development; gelatinization and pasting behavior during baking; and crystallization and retro gradation behavior on cooling and storage. The impact of starch on bread making is also influenced by other flour components, especially protein, which, although present in a relatively smaller

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quantity (12-14%, dry-basis), plays an important functional role in the development of the characteristic bread texture (Lagrain et al., 2013; Goesaert et al., 2005). The other important dry-matter constituents of wheat flour are the non-starch polysaccharides, lipids and ash (Goesaert et al., 2005; Delcour and Hoseney, 2009).

Starch structure and composition

Starch is the major source of stored energy in plants. Cereal grains, legume seeds and root and tuber crops are the principle sources of starch for human nutrition. Starch is a macronutrient in several foods and supplies 50 to 80% of the calories consumed by most of the world's population (Bertolini, 2010; Copeland et al., 2009). Starch is metabolized in the human body to sugars, which are an important source of energy, and which enables the body to perform several functions. Starch also serves as an important ingredient in several food products and as a processing aid in several non-food industries (Bertolini, 2010; Bemiller and Whistler, 2009). Starch is synthesized in the plastid of plant cells through a series of complex biosynthetic pathways controlled by several enzymes (Jobling, 2004). It is deposited as water insoluble semi-crystalline granules in the storage tissues of plants such as grains, roots and tubers (Copeland et al., 2009). Each starch granule is composed of two homo-polysaccharide fractions (amylose and amylopectin), which make up 98-99% of the dry-weight of the granule (Tester et al., 2004; Copeland et al., 2009). The amylose fraction makes up 20 to 30% of the starch granule while the amylopectin fraction makes up 70 to 80% (Belitz et al., 2009; Liu, 2005; Jobling, 2004). Starch granules also contain small amounts (0.5 to 2% w/w) of non-starch polysaccharides, lipids, proteins and ash (Liu, 2005; Copeland et al., 2009).

The amylose fraction of starch is an essentially linear polymer that is made up of about 99% α-(1→4) linked D-glucopyranose molecules and less than 0.5% α-(1→6) branches (Copeland et al., 2009). The degree of polymerization of amylose ranges from 1,000-10,000 glucose units, which corresponds to a molecular weight of 10^5-10^6 (Copeland et al., 2009). By contrast, the amylopectin fraction is a highly branched polymer consisting of about 95% α-(1→4) linked D-glucopyranose molecules and 5% α-(1→6) branches (Copeland et al., 2009). The degree of polymerization of amylopectin exceeds 10^6 glucose units, which corresponds to a molecular weight of about 10^8 (Copeland et al., 2009). In addition to amylose and amylopectin, some starch granules also contain molecules with characteristics (such as chain length of linear molecules, branch chain length and density of branching points) that lie between those of amylose and amylopectin (Liu, 2005). Starch granules differ in shape, size, size distribution and crystallinity depending on the botanical source. Starch granules may be lenticular, polyhedral, spherical, oval, elliptical or kidney-shaped, and range in size from 2 to 150 µm (Belitz et al., 2009; Liu, 2005; Tester et al., 2004). Starch granules are simple or compound in nature with concentric or eccentric layers of varying density (Belitz et al., 2009). Some granules have bimodal size distribution whereas others have unimodal size distribution (Delcour and Hoseney, 2009; Tester et al., 2004; Copeland et al., 2009). Starch granules exist individually or clustered as compound granules (Copeland et al., 2009; Delcour and Hoseney, 2009). About 70% of the mass of a starch granule is amorphous and 30% crystalline (Belitz et al., 2009). The semi-crystalline character of starch granules indicates a high degree of orientation of glucan molecules, which is attributed to double helical structures formed by the outer branches of amylopectin polymers. Amylose, amylopectin branching points and the amylopectin molecules in a disordered conformation make up the amorphous portion of starch granules (Eliasson et al., 2013; Copeland et al., 2009).The major sources of industrial starch are maize (corn), cassava (tapioca), wheat and potato. These crops account for more than 99% of world starch production (Bertolini, 2010). United States of America is the major producer of maize starch; Europe is the major producer of wheat and potato starch; whereas cassava starch is mainly produced in Asia (Jobling, 2004).

Native starch has limited industrial applications because of its high hot-paste viscosity; poor thermal, shear and acid stability; and high susceptibility to retrogradation and syneresis (Huber and Bemiller, 2010; Bertolini, 2010; Singh et al., 2007). However, when starch is modified, it serves as a useful polymer material in several food and non-food industries. Starch modification changes several physicochemical features of the amylose and amylopectin polymers: the positive characteristics are enhanced whereas the undesirable qualities are suppressed (Ashogbon and Akintayo, 2014; Kaur et al., 2012; Huber and Bemiller, 2010). Starch can be modified using physical, chemical, enzymatic or genetic methods (Kaur et al., 2012; Huber and Bemiller, 2010; Tharanathan, 2005) in order to enhance its positive functional attributes that can be used in food and non-food processing industries. Modified starch is used in the food industry to texturize and thicken foods, maintain gel strength and clarity, make edible food coatings, retard retro gradation, stabilize emulsions, improve freeze-thaw stability, substitute fat, encapsulate aroma compounds and increase the resistant starch content (Belitz et al., 2009; Bertolini, 2010). Modified starch is also an important raw material in several non-food industries, such as paper, adhesive, agricultural, cosmetic, medical, pharmaceutical, oil, plastics and textile industries (Bertolini, 2010; Bemiller and Whistler, 2009). Starch hydrolysis products (i.e. glucose syrups, high fructose syrups, syrup solids, maltodextrins and fructose) are used in confectionery and beverage industry and can be subjected to microbial fermentation to yield organic acids, alcohols, ketones, polyols, amino acids, nucleotides, biopolymers, lipids, proteins, vitamins, antibiotics and hormones (Bertolini, 2010; Bemiller and Whistler, 2009).

Starch in bread making

The unique dough-forming and bread making property of wheat flour is attributed to the storage protein fraction known as gluten, which is formed when wheat flour is hydrated and subjected to mechanical shear (Goesaert et al., 2005). The three dimensional gluten network is responsible for retention of carbon dioxide formed during fermentation, temporary binding of water required to gelatinize starch and formation of the typical foam structure of bread (Lagrain et al., 2013; Goesaert et al., 2005). Gluten functionality in bread making is enhanced by interaction with other wheat flour components, especially starch. Starch constitutes 70 to 85% of wheat flour (Goesaert et al., 2005; Slavin et al., 2001) and is, after gluten, the second most important fraction in wheat flour for bread making. When starch granules in wheat flour are hydrated, they absorb up to 50% of their dry weight of water and swell slightly and reversibly (Goesaert et al., 2005). The interaction of starch and gluten in dough creates a stable network that can retain fermentation gas in the dough structure and prevent collapse of bread during baking and cooling (Delcour and Hoseney, 2009; Ahlborn et al., 2005; Hoseney and Rogers, 1990). Wheat flour destined for bread making usually has a small amount of damaged starch (about 8%) (Goesaert et al., 2005), which is vital to the development of bread with good quality characteristics. Damaged starch in wheat flour increases the water absorption capacity of the flour and is hydrolyzed by α-amylase into maltose, which is used as a fermentable sugar by yeast (Delcour and Hoseney, 2009). However, too much damaged starch (> 10%) is not desirable in wheat flour because it causes formation of sticky dough, which is difficult to handle and gives bread with an adhesive crumb (Sluimer, 2005).

When dough is heated, starch granules absorb water, swell, gelatinize and lose their semi -crystalline nature. The linear amylose polymers leach out of the granules leaving amylopectin-enriched granules. Starch gelatinization in the crumb causes formation of a porous crumb structure whereas the higher temperature at the dough surface results in crust formation (Eliasson et al., 2013; Primo-Martin et al., 2007). Starch swelling and loss of granular structure is restricted by the limited amount of water in dough and competition between starch and non-starch polysaccharides for the available water in the dough (Gray and Bemiller, 2003). The net effect is that only a small amount of amylose is leached in the intergranular phase where it forms inclusion complexes with polar lipids, which are endogenously present in wheat starch or which may have been added as a baking ingredient (Goesaert et al., 2005). Moisture gradient in the bread, the temperature profile and added ingredients, such as sugar, are the most important factors that affect starch gelatinization and swelling in dough (Hoseney and Rogers, 1990; Varriano-Marston et al., 1980). Starch granules in the exterior portions of the bread are less swollen, and thus less gelatinized, than those in the centermost portions because the higher temperatures on the crust surface accelerate loss of moisture by evaporation and thus limit the extent of gelatinization (Varriano-Marston et al., 1980). The different molecular organizations of starch in the crumb and crust can be evaluated using X-ray diffraction patterns. Starch crystallinity is higher in the crust than in the crumb. The X-ray pattern of starch granules in the crust is predominantly an A pattern superimposed with a V pattern (fat-amylose complex) whereas crystallinity in the crumb is mainly characterized by the fat-amylose complex (Varriano-Marston et al., 1980). Freshly baked bread has a soft and resilient crumb that is attributed to crystallization of amylose (Goesaert et al., 2005; Hug-Iten et al., 2003). Long term storage of bread leads to loss of flavour, deterioration of crumb quality and development of a tough leathery crust (Delcour and Hoseney, 2009; Gray and Bemiller, 2003), which are collectively referred to as staling. Amylopectin recrystallization (i.e. retrogradation) plays a major role in bread firming after the initial cooling process (Eliasson et al., 2013; Bosmans et al., 2013; Goesaert et al., 2009a; Goesaert et al., 2008; Ribotta and Le Bail, 2007; Hug-Iten et al., 2003). However, it is important to note that the mechanism of staling is a complex phenomenon that is also influenced by several other physico-chemical reactions, such moisture migration from the crumb to the crust (Bosmans et al., 2013; Purhagen et al., 2011; Ribotta and Le Bail, 2007) and gluten-starch interactions (Goesaert et al., 2008). Microbial amylases or malt enzymes are regularly added to wheat flour to optimize the amylase activity of the flour (i.e. standardize the flour) and retard bread staling (Goesaert et al., 2005). Amylase degrades damaged starch particles in the dough and thus increases the maltose content, which promotes yeast activity during fermentation. The increased levels of maltose also promotes the formation of Maillard reaction products, which intensify bread flavor and give the crust its characteristic smell and dark brown colour. Furthermore, amylase decreases the molecular weight of starch polymers and causes the formation of maltodextrins, which contribute to increased crumb softness, improved crumb resilience and decreased staling rate (Goesaert et al., 2009a; Hug-Iten et al., 2003; Rojas et al., 2001). The reduction in molecular weight of starch polymers contribute to the antifirming effect by weakening the amylopectin networks and increasing amylose mobility, crystallization and network formation (Goesaert et al., 2009b; Hug-Iten et al., 2003). Maltodextrins act as antifirming agents by hindering the association of crystallizable helices and / or by their plasticizing action, which reduce amylopectin chain mobility (Goesaert et al., 2009b).

Chemically modified starch in bread making

Chemically modified starch is obtained when starch is treated with chemical reagents to introduce new chemical substituent groups, effect molecular scission, or promote molecular oxidation or molecular re arrangement (Huber and Bemiller, 2010). Starch is a suitable material for chemical modification because of the numerous hydroxyl groups in its constituent polymers. The reaction of chemicals with starch takes place at the hydroxyl groups on carbon 2, 3 and 6 of the anhydroglucose units to give converted (depolymerized), dextrinized, cross-linked, stabilized (substituted), oxidized, cationized or graft copolymerized starch (Singh et al., 2007; Huber and Bemiller, 2010; Tharanathan, 2005). Due to concerns on consumer safety and technological reasons, not all types of substituted starches are suitable for application in food processing. The types of chemically modified starches that are useful in food processing are the converted, dextrinized, cross-linked, stabilized and oxidized starches (Huber and Bemiller, 2010).

Bread made from wheat flour that is partially substituted with esterified (acetylated) or etherified (hydroxypropylated) starch shows increased crumb adhesiveness and a more open crumb structure but no improvement in specific volume (Miyazaki et al., 2008; Miyazaki et al., 2005; Goesaert et al., 2008). However, when vital gluten is added to wheat flours containing hydroxypropylated or acetylated tapioca starch, the bread is softer than that containing the same amount of native tapioca starch or wheat flour alone (Miyazaki et al., 2005a, b). Among the various esterified and etherified starches studied by Miyazaki et al. (2005a) and Miyazaki et al (2008), it is only hydroxypropylated starch that was able to decrease the staling rate of bread. Octenyl succinic anhydride starch (OSA starch) is an esterified starch with surface active properties (Eliasson et al., 2013; Sweedman et al., 2013; Dokić et al., 2008). The glucose subunits within the starch molecule are hydrophilic and soluble in aqueous solution, whereas the n-octenyl succinate chains are hydrophobic and lipophilic (Sweedman et al., 2013). These starch granules have high effective surfaces, which induce high density of non-covalent bonds between the system components and thereby increase dough rigidity (Hadnadev et al., 2013). Breads treated with OSA starches show improved specific volumes, crumb whiteness and softness (Hadnadev et al., 2014).

Partial substitution of wheat flour with cross-linked starch increases crumb dryness and firmness but does not improve the specific volume or decrease the staling rate (Goesaert et al., 2008; Miyazaki et al., 2008; Miyazaki et al., 2005a; Hung and Morita, 2005; Hung and Morita, 2004). Hung and Morita (2004) found that cross-linked corn starch (5-10%) was able to increase the specific volume of bread and decrease crumb firmness when vital gluten was added to the formulation. Yeo and Seib (2009) found that partial substitution of wheat flour with cross-linked wheat starch (30%) and supplemented with vital gluten increases the specific volume of bread but decreases crumb firmness. Furthermore, Yeo and Seib (2009) noted changes in the nutritional quality of the bread in the form of increased contents of total dietary fibre, slowly digestible fibre and resistant starch.

Genetically modified starch in bread making

Native starch granules contain 70-80% amylopectin and 20-30% amylose and small amounts (0.5-2% w/w) of non-starch polysaccharides, lipids, proteins and ash (Belitz et al., 2009; Copeland et al., 2009; Liu, 2005). Traditional plant breeding techniques or genetic modification can be used to produce novel starches with modified functionalities (Davis et al., 2003). High amylose starch (starch with up to 70% amylose content), waxy starch (99-100% amylopectin content) or starch with modified amylopectin structure, phosphate content or granule size and number have been produced by genetic modification (Kaur et al., 2012; Jobling, 2004). Starch modification in planta changes the physicochemical properties, thermal characteristics and granule structure of starch and consequently its functionality during processing (Abdel-Aal et al., 2002). High-amylose wheat flour and waxy wheat flours are, on their own, unsuitable for bread making. Waxy wheat flour decreases bread volume and gives a glutinous and weak crumb with large gas cells (Park and Baik, 2007; Morita et al., 2002). Sahlstrom et al. (2006) found that waxy wheat flour has no significant effect on the volume of hearth bread, but it decreases the form ratio, weight and overall appearance of the bread and causes development of a crumb with a more open pore structure. High amylose wheat flour gives bread with low specific volume and crumb with small gas cells (Morita et al., 2002). The only positive attribute of bread made from waxy wheat flour is that it stales at a slower rate than bread made from standard wheat flour or high-amylose wheat flour (Morita et al., 2002). This is because the absence of amylose in waxy starch decreases the tendency of gelatinized material to gel (Jobling, 2004). Bread made from whole waxy wheat flour has low specific volume, bitter taste and dark brown colour (Hung et al., 2007). The additional deterioration in quality characteristics of bread made from whole waxy wheat flour, in comparison to that made from refined waxy wheat flour, is due to the high fibre and ash contents in the whole waxy wheat flour rather than the high amylopectin content. Similarly to bread made from refined waxy wheat flour, bread made from whole waxy wheat flour stales at a slower rate than bread made from standard wheat flour (Hung et al., 2007). Bread made from standard wheat flour contains small amounts of resistant starch (Sajilata et al., 2006). The amount of resistant starch in baked bread can be increased further by adjusting the processing conditions or using processing aids such as sour dough acids (Liljeberg et al., 1996) or by partial substitution of wheat flour with high amylose starch (Hung et al., 2005; Hoebler et al., 1999; Liljeberg et al., 1996; Eerlingen et al., 1994). On storage, the resistant starch content in bread increases further due to amylopectin retrogradation (Miyazaki et al., 2005b; Eerlingen et al., 1994). Partial replacement of wheat flour with high amylose starch or flour in bread making is of nutritional importance because waxy starch is able to resist digestion in the intestine and hence decreases the glycaemic index of bread (Hoebler et al., 1999). The nature of the substitute high amylose flour and the level of substitution impart different effects on bread quality. Miyazaki et al. (2005b) showed that substitution of wheat flour with 10% or 30% high amylose wheat flour does not affect loaf volume or appearance of the bread crumb but 50% substitution decreases loaf volume and gives bread crumb with inferior appearance. By contrast, Eerlingen et al. (1994) found that substitution of wheat flour with a relatively low amount (20%) of high amylose corn starch decreased bread volume.

Partial substitution of wheat flour with waxy flours or starches from different botanical sources decreases bread volume (Hung et al., 2007; Bhattacharya et al., 2002; Hibi, 2001) and crumb firmness (Bhattacharya et al., 2002; Purna et al., 2011; Purhagen et al., 2011). The results obtained with staling rate are less conclusive. Bhattacharya et al. (2002) and Hayakawa et al. (2004) showed that substitution of wheat flour with waxy durum wheat flour (10-30%) or waxy wheat flour (less than 20%), respectively, decreases the staling rate of bread. By contrast, Purna et al. (2011) found that substitution of wheat flour with hard waxy wheat flour (15-45%) does not decrease the staling rate of bread. High levels of waxy wheat flour (more than 20%) damages the crumb texture and causes post-bake shrinkage (Purna et al., 2011; Hayakawa et al., 2004). The negative effects of waxy flours on bread quality can be mitigated by supplementing wheat flour with vital gluten. Lee et al. (2001) showed that bread made from wheat flour, waxy wheat starch (25 or 50%) and vital gluten had a higher volume and softer and porous crumb structure than bread baked from blends of regular wheat starch (24% amylose) and vital gluten. Although amylopectin recrystallization is a major cause of crumb firming in stored bread (Eliasson et al., 2013; Bosmans et al., 2013; Goesaert et al., 2009a; Goesaert et al., 2008; Ribotta and Le Bail, 2007), partial substitution of wheat flour with waxy flours decreases crumb firmness because the low amylose content in the bread gives it a lower than normal post-bake crumb firmness (Purna et al., 2011). The increased water absorption capacity of waxy flour and modified water distribution also contribute to increased crumb softness of bread containing waxy flour (Eliasson et al., 2013; Purna et al., 2011; Purhagen et al., 2011; Hung et al., 2007).

Physically modified starch in bread making

Physically modified starches are considered to be natural materials with high safety because they are produced without the use of chemicals or biological agents (Ashogbon and Akintayo, 2014; Kaur et al., 2012). Physically modified starch can be obtained by heat treatment or mechanical shearing and include pre-gelatinized starch, granular cold water soluble starch, mechanically sheared starch, annealed starch, heat-moisture treated starch and dry-heated starch (Kaur et al., 2012; Huber and Bemiller, 2010). Novel methods that can be used to synthesize physically modified starch include osmotic pressure treatment, deep freezing, instantaneous controlled pressure drop, pulsed electric field, corona electrical discharges, superheat treatment, iterated syneresis, radiation, sonication, photo-oxidation and exposure to ultra violet or polarized light (Kaur et al., 2012; Tharanathan, 2005).

Partial substitution of wheat flour with extruded wheat flour (Martínez et al., 2013) or pregelatinized wheat starch (Miller et al., 2008) increases the damaged starch content of the flour leading to increased water absorption and gas production during fermentation. To ensure that adequate bread characteristics are maintained, only small amounts (less than 5%) of damaged flour should be used to replace the wheat flour (Martínez et al., 2013; Miller et al., 2008). Partial substitution of wheat flour with heat-moisture treated maize starch (modification conditions are not clearly defined) decreases the specific volume and crumb softness of bread (Miyazaki and Morita, 2005). The heat-moisture treated starch is unable to improve the quality of bread due to the inability of the modified starch to effectively interact with gluten (Miyazaki and Morita, 2005). Bread made from wheat flour that has been partially substituted with high pressure-treated oat, millet or sorghum flours has higher crumb firmness, lower crumb cohesiveness and specific volume than bread made from standard wheat flour (Angioloni and Collar, 2012).

Enzymatically modified starch in bread making

Enzymatic modification of starch during bread making takes place in situ. Native wheat flour is rich in β-amylase, which is largely inactive, and which is susceptible to heat inactivation before starch gelatinizes. By contrast, wheat is low in α-amylase activity although this enzyme is essential for the development of desirable bread properties such as high volume, low staling rate and soft crumb texture (Delcour and Hoseney, 2009). Thus, wheat flour is normally supplemented with malt or fungal α-amylase to improve its bread making properties. α-Amylase improves bread volume by catalyzing the breakdown of damaged starch to maltose, which the yeast utilizes to produce carbon dioxide. The antistaling action of amylases is due to the formation of dextrins of a particular size and / or modification of the starch structure to give it different retrogradation properties (Delcour and Hoseney, 2009). There are several other novel kinds of enzymatically modified starch (Kaur et al., 2012) that could be useful in bread making. For instance, glycogen-branching enzymes or cyclomaltodextrinase can be used to synthesize starches with limited retrogradation ability (Kim et al., 2008; Auh et al., 2006), which could be used to decrease the staling rate of bread.

Dual-modified starch in bread making

A single type of modification is usually insufficient to impart all the desired properties to starch intended for a specific application. Although many commercial starch products are made with more than two types of modification (Huber and Bemiller, 2010), most of the published studies in bread making have investigated the impact of dual-modified starches (i.e. modified starches made with only two types of modification such as physical/chemical, chemical/chemical or chemical/ enzymatic methods). Hibi (2001) showed that substitution of wheat flour with retrograded waxy corn starch (5%) increases specific volume and decreases staling rate, whereas Eerlingen et al. (1994) found that extruded retrograded waxy corn starch (20%) decreases bread volume and crumb firmness and increases resistant starch content in bread. Bread made from wheat flour that has been substituted with 5-15% cross-linked waxy corn starch, with or without vital gluten, has a higher specific volume and stales at a slower rate than the control (Hung and Morita, 2004; 2005). Bread made from wheat flour and cross-linked waxy barley starch stales faster and shows a higher enthalpy change in melting of crystalline region of starch than control bread containing normal wheat starch (Inagaki and Seib, 1992) or bread formulated with waxy barley starch (Toufeili et al., 1999).

As already discussed earlier, non-physically modified OSA starch granules are able to increase dough rigidity because of the high density of non-covalent bonds between the system components. By contrast, pre-gelatinized or hydrolyzed OSA starch granules possess weakened or destroyed crystalline structures which create fewer bonds with the system components and thus decrease dough rigidity (Hadnadev et al., 2013). Nonetheless, the differences in dough quality are not reflected in the bread quality, except for crust color. Breads treated with non-physically modified OSA starches or dual-modified OSA starches show increased specific volumes, crumb whiteness and softness as compared to breads prepared from normal wheat flours (Hadnadev et al,. 2014). Crusts of breads treated with dual-modified OSA starches are darker than for those treated with non-physically modified OSA starch (Hadnadev et al., 2014).

CONCLUSION

Starch is an important source of energy in human nutrition. The major sources of starch for human nutrition are cereals, root and tuber crops, and legumes. Wheat is the most widely used cereal for bread making because of the chemical nature of its storage protein fraction, which form viscoelastic dough when hydrated. After protein, starch is the second most functionally important fraction in wheat flour for bread making. Starch contributes to the formation of optimal dough; is responsible for setting of the crumb during baking; and contributes to the physical deterioration of bread quality through staling. Attempts have been made to improve the baking quality of wheat flour through the addition of chemically, physically, genetically or enzymatically modified starches. Improvement in the quality of bread has been achieved in some instances and appears to be dependent on the nature of the modified starch, botanical origin of the starch, dosage used, and presence or absence of dough improving agents such as vital gluten.

Conflict of interests

The author declares that there is no conflict of interests regarding the publication of this paper.

REFERENCES

Abdel-Aal ESM, Hucl P, Chibbar RN, Han HL, Demeke T (2002). Physicochemical and structural characteristics of flours and starches from waxy and nonwaxy wheats. Cereal Chem. 79:58-64.

Ahlborn GJ, Pike OA, Hendrix SB, Hess WM, Huber CS (2005). Sensory, mechanical and microscopic evaluation of staling in low-protein and gluten-free breads. Cereal Chem. 82:328-335.

Angioloni A, Collar C (2012). Effects of pressure treatment of hydrated oat, finger millet and sorghum flours on the quality and nutritional properties of composite wheat breads. J. Cereal Sci. 56:713-719.

Ashogbon AO, Akintayo ET (2014). Recent trend in the physical and chemical modification of starches from different botanical sources: A review. Starch/Stärke 66:41-57.

Auh JH, Chae HY, Kim YR, Shim KH, Yoo SH, Park KH (2006). Modification of rice starch by selective degradation of amylose using alkalophilic *Bacillus cyclomaltodextrinase* J Agric. Food Chem. 54:2314-2319.

Belitz HD, Grosch W, Schieberle P (2009). Food Chemistry. Springer-Verlag, Berlin.

Bemiller, Whistler (2009). Starch. Chemistry and Technology. Academic Press, New York.

Bertolini AC (2010). Trends in starch applications. In: Bertolini AC (ed) Starches: Characterization, Properties and Applications. CRC Press, Florida. pp. 1-20.

Bhattacharya M, Erazo-Castrejón S, Doehlert DC, McMullen MS (2002). Staling of bread as affected by waxy wheat flour blends. Cereal Chem. 79:178-182.

Bosmans GM, Lagrain B, Ooms N, Fierens E, Delcour JA (2013). Biopolymer interactions, water dynamics and bread crumb firming. J. Agric. Food Chem. 61:4646-4654.

Copeland L, Blazek J, Salman H, Tang MC (2009). Form and functionality of starch. Food Hydrocol. 23:1527-1534.

Davis JP, Supatcharee N, Khandelwal RL, Chibbar RN (2003). Synthesis of novel starches in planta: opportunities and challenges. Starch/Stärke 55:107-120.

Delcour JA, Hoseney RC (2009). Principles of Cereal Science and Technology. AACC Int. Inc. Minnesota.

Dokić P, Dokić L, Dapcevic T, Krstonosic V (2008). Colloid characteristics and emulsifying properties of OSA starches. Progr. Colloid Polym. Sci. 135:48-56.

Eerlingen RC, Van Haesendonck IP, De Paepe G, Delcour JA (1994). Enzyme resistant starch. III. The quality of straight dough bread containing varying levels of enzyme resistant starch. Cereal Chem. 71:165-170.

Eliasson AC, Bergenståhl B, Nilsson L, Sjöö M (2013). From molecules to products: some aspects of structure-function relationships in cereal starches. Cereal Chem. 9:326-334.

Goesaert H, Brijs K, Veraverbeke WS, Courtin CM, Gebruers K, Delcour JA (2005). Wheat flour constituents: how they impact bread quality, and how to impact their functionality. Trends Food Sci. Technol. 16:12-30.

Goesaert H, Leman P, Buttebier A, Delcour JA (2009a). Antifirming effects of starch degrading enzymes in bread crumb. J Agric Food Chem. 57:2346-2355.

Goesaert H, Leman P, Delcour JA (2008). Model approach to starch functionality in bread making. J Agric. Food Chem. 56:6423-6431.

Goesaert H, Slade L, Levine H, Delcour JA (2009b). Amylases and bread firming – an integrated review. J Cereal Sci. 50:345-352.

Gray JA, BeMiller JN (2003). Bread staling: molecular basis and control. Compr. Rev. Food Sci. 2:1-20.

Hadnadev TRD, Dokić LP, Hadnadev MS, Pojić MM, Torbica AM (2014). Rheological and breadmaking properties of wheat flours supplemented with octenyl succinic anhydride-modified waxy maize starches. Food Bioprocess Technol. 7:235-247.

Hadnadev TD, Pajic-Lijakovic I, Hadnadev M, Mastilovic J, Torbica A, Bugarski B (2013). Influence of starch sodium octenyl succinate on rheological behaviour of wheat flour dough systems. Food Hydrocol. 33:376-383.

Hayakawa K, Tanaka K, Nakamura T, Endo S, Hoshino T (2004). End use quality of waxy wheat flour in various grain based foods. Cereal Chem. 81:666-672.

Hibi Y (2001). Effect of retrograded waxy corn starch on bread staling Starch/Stärke 53:227-234.

Hoebler A, Karinthi H, Chiron M, nChamp M, Barry JL (1999). Bioavailability of starch in bread rich in amylose: metabolic responses in healthy subjects and starch structure. Euro. J. Clin. Nutr. 53:360-366.

Hoseney RC, Rogers DE (1999). The formation and properties of wheat flour doughs. Crit. Rev. Food Sci. 29:73-93.

Huber KC, BeMiller JN (2010). Modified starch: Chemistry and properties. In: Bertolini AC (ed) Starches: Characterization, Properties and Applications. CRC Press, Florida, pp.145-203.

Hug-Iten S, Escher F, Conde-Petit B, (2003). Staling of bread: role of amylose and amylopectin and influence of starch-degrading enzymes. Cereal Chem. 80:654-661.

Hung PV, Maeda T, Morita N (2007). Dough and bread qualities of flours with whole waxy wheat flour substitution. Food Res. Int. 40:273-279.

Hung PV, Morita N (2004). Dough properties and bread quality of flours supplemented with cross-linked corn starches. Food Res. Int. 37:461-467.

Hung PV, Morita N (2005). Thermal and rheological properties of dough and bread as affected by various cross-linked cornstarch substitutions. Starch / Staerke 57:540-546.

Hung PV, Yamamori M, Morita N (2005). Formation of enzyme-resistant starch in bread as affected by high-amylose wheat flour substitutions. Cereal Chem. 82:690-694.

Inagaki T, Seib PA (1992). Firming of bread crumb with cross-linked waxy barley starch substituted for wheat starch. Cereal Chem. 69:321-325.

Jobling S (2004). Improving starch for food and industrial applications. Curr. Opin. Plant Biol. 7:210-218.

Kaur B, Ariffin F, Bhat R, Karim AA (2012). Progress in starch modification in the last decade Food Hydrocolloid. 26:398-404.

Kim EJ, Ryu SI, Bae HA, Huong NT, Lee SB (2008). Biochemical characterization of a glycogen branching enzyme from *Streptococcus mutans*: enzymatic modification of starch. Food Chem. 110:979-984.

Lagrain B, Wilderjans E, Glorieux C, Delcour JA (2013). Role of gluten and starch in crumb structure and texture of fresh and stored straight-dough bread. Inside Food Symposium, 9-12 April, Leuven, Belgium.

Lee M-R, Swanson BG, Baik B-K (2001). Influence of amylose content on properties of wheat starch and breadmaking qualities of starch and gluten blends. Cereal Chem. 78:701-706.

Liljeberg H, Akerberg A, Bjorck I (1996). Resistant starch formation in bread as influenced by choice of ingredients or baking conditions. Food Chem. 56:389-394.

Liu Q (2005). Understanding starches and their role in foods. In: Cui SW (ed) Food Carbohydrates: Chemistry, Physical Properties and Applications. CRC Press, Florida, Pp.309-355.

Martínez M, Oliete B, Gómez M (2013). Effect of the addition of extruded wheat flours on dough rheology and bread quality. J. Cereal Sci. 57:424-429.

Mckevith B (2004). Nutritional aspects of cereals. British Nutrition Foundation. Nutr. Bull. 29:111-142.

Miller RA, Maningat CC, Hoseney RC (2008). Modified wheat starches increase bread yield. Cereal Chem. 85:713-715.

Miyazaki M, Maeda T, Morita N (2005a). Gelatinization properties and bread quality of flours substituted with hydroxypropylated, acetylated and phosphorylated cross-linked tapioca starches. J Appl. Glycosci. 52:345-350.

Miyazaki M, Maeda T, Morita N (2005b). Starch retrogradation and firming of bread substituted with hydroxypropylated, acetylated and phosphorylated cross-linked tapioca starches for wheat flour. Cereal Chem. 82:639-644.

Miyazaki M, Morita N (2005). Effect of heat-moisture treated maize starch on the properties of dough and bread. Food Res. Int. 38:369-376.

Miyazaki M, Maeda T, Morita N (2008). Bread quality of frozen dough substituted with modified tapioca starches. Eur. Food Res. Technol. 227:503-509.

Morita N, Maeda T, Miyazaki M, Yamamori M, Miura H, Ohtsuka I (2002). Dough and baking properties of high-amylose and waxy wheat flours. Cereal Chem. 79:491-495.

Park S, Baik B-K (2007). Characteristics of French bread baked from wheat flours of reduced starch amylose content. Cereal Chem. 84:437-442.

Primo-Martin C, van Nieuwenhuijzen NH, Hamer RJ, van Vliet T (2007). Crystallinity changes in wheat starch during the breadmaking process: Starch crystallinity in the bread crust. J Cereal Sci. 45:219-226.

Purhagen JK, Sjöö ME, Eliasson A-C (2011). The use of normal and heat-treated barley flour and waxy barley starch as anti-staling

agents in laboratory and industrial baking processes. J. Food Eng. 104:414-421.
Purna SKG, Miller RA, Seib PA, Graybosch RA, Shi Y-C (2011). Volume, texture, and molecular mechanism behind the collapse of bread made with different levels of hard waxy wheat flours. J. Cereal Sci. 54:37-43.
Ribotta PD, Le Bail A (2007). Thermo-physical assessment of bread during staling. LWT - Food Sci. Technol. 40:879-884.
Rojas JA, Rosell CM, de Barber CB (2001). Role of maltodextrins in the staling of starch gels. Eur. Food Res. Technol. 212:364-368.
Sahlstrom S, Bævre AB, Graybosch R (2006). Impact of waxy, partial waxy, and wildtype wheat starch fraction properties on hearth bread characteristics. Cereal Chem. 83:647-654.
Sajilata MG, Singal RS, Kullkarni PR (2006). Resistant starch – a review. Comp. Rev. Food Sci. Food Saf. 5:1-17
Singh J, Kaur L, McCarthy OJ (2007). Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications – A review. Food Hydrocolloid. 21:1-22.
Slavin JL, Jacobs D, Marquart L (2001). Grain processing and nutrition. Crit. Rev. Biotechnol. 21(1):49-66.
Sluimer P (2005). Principles of Breadmaking. Functionality of Raw Materials and Process Steps. AACC Int. Inc., Minnesota.
Sweedman MC, Tizzotti MJ, Schäfer C, Gilbert RG (2013). Structure and physicochemical properties of octenyl succinic anhydride modified starches: a review. Carbohydr. Polym. 92(1):905–920.
Tester RF, Karkalas J, Qi X (2004). Starch – composition, fine structure and architecture. J Cereal Sci. 39:151-165.
Tharanathan RN (2005). Starch – value addition by modification. Crit. Rev. Food Sci. 45:371-384.
Toufeili I, Habbal Y, Shadarevian S, Olabi A (1999). Substitution of wheat starch with non-wheat starches and cross-linked waxy barley starch affects sensory properties and staling of Arabic bread. J. Sci. Food Agric. 79:1855-1860.
Varriano-Marston E, Ke V, Huang G, Ponte Jr. J (1980). Comparison of methods to determine starch gelatinization in bakery foods. Cereal Chem. 57:242-248.
Yeo LL, Seib PA (2009). White pan bread and sugar-snap cookies containing wheat starch phosphate, a cross-linked resistant starch. Cereal Chem. 86:210-220.