Impact of sourdough on the texture of bread

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Abstract

Sourdough has been used since ancient times and its ability to improve the quality and increase the shelf-life of bread has been widely described. During sourdough fermentation, lactic acid bacteria (LAB) produce a number of metabolites which have been shown to have a positive effect on the texture and staling of bread, e.g. organic acids, exopolysaccharides (EPS) and/or enzymes. EPS produced by LAB have the potential to replace more expensive hydrocolloids used as bread improvers. Organic acids affect the protein and starch fractions of flour. Additionally, the drop in pH associated with acid production causes an increase in the proteases and amylases activity of the flour, thus leading to a reduction in staling. While improving the textural qualities of bread, sourdough fermentation also results in increased mineral bioavailability and reduced phytate content. In this review we will be discussing the effect of sourdough on wheat and rye bread as well as the potential of sourdough to improve the quality of gluten-free bread.

Keywords: Sourdough bread texture; Sourdough lactic acid bacteria; Exopolysaccharides; Phytate content

1. Introduction

The use of the sourdough process as a form of leavening is one of the oldest biotechnological processes in food production (Röcken and Voysey, 1995). Its main function is to leaven the dough to produce a more gaseous dough piece and as such a more aerated bread. In recent years the traditional sourdough bread production has enjoyed renewed success with the ever increasing demand by the consumer for more natural, tasty and healthy foods (Brummer and Lorenz, 1991). Early dough fermentation would probably have relied on a mixture of natural yeasts and lactic acid bacteria (LAB) (Oura et al., 1982; Williams and Pullen, 1998). The underlying functionality of such an adventitious microbial population is that dough formed by the addition of water to ground cereals will be fermented by the micro-organisms naturally present to become a sourdough characterized by acid taste, aroma and increased volume due to gas formation (Hammes and Ganzle, 1998). In addition to the yeasts naturally present on the cereal grains, brewers' yeast was often added to enhance the fermentation process (Oura et al., 1982; Röcken and Voysey, 1995; Williams and Pullen, 1998). Variations in the process parameters including temperature, dough yield as well as the amount and composition of starter cultures determine the quality and handling properties of sourdough (Barber et al., 1992). In wheat breads, sourdough is mainly used to improve flavour (Hansen and Hansen, 1996), however the addition of sourdough also has a major effect on the dough and the final bread structure. The utilisation of baker's yeast has not eliminated the use of sourdoughs in rye breadmaking, where a reduction in pH is necessary to achieve suitability for baking (Oura et al., 1982; Hammes and Ganzle, 1998; Salovaara, 1998). There is considerable consensus with regard to the positive effects of sourdough addition for bread production, including improvements in bread volume and crumb structure (Corsetti et al., 2000; Clarke et al., 2002; Crowley et al., 2002), flavour (Thiele et al., 2002), nutritional values (see Fig. 1; Liljeberg and Björck, 1994; Liljeberg et al., 1995) and shelf-life (Corsetti et al., 1998b; Lavermicocca et al., 2000, 2003; Dal Bello et al., 2006).

2. Understanding the technological functionality of sourdough application

Despite its long tradition and the well-documented positive effects conferred on bread products by its use,

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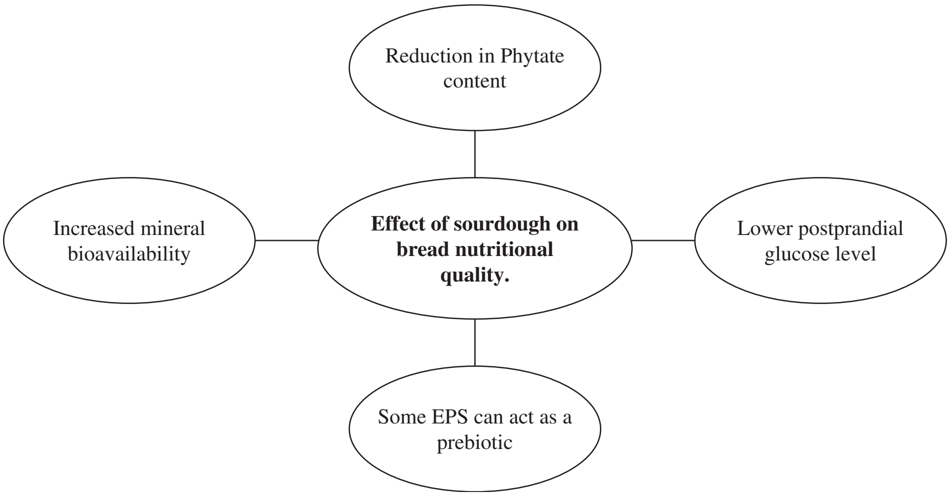

Fig. 1. Effects of sourdough on the nutritional quality of bread.

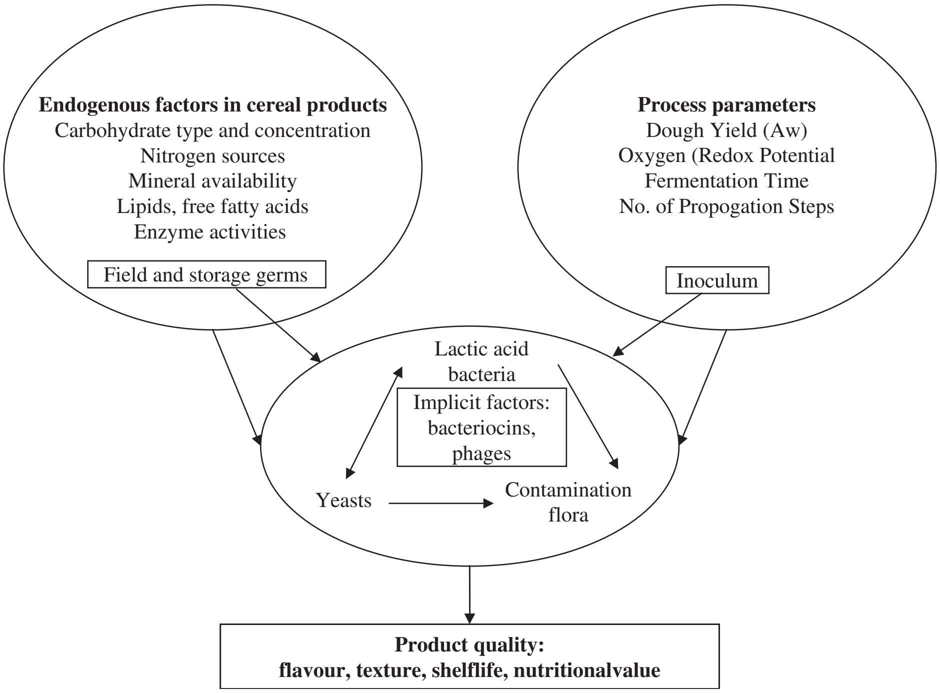

Fig. 2. Factors affecting growth and metabolic conditions of the sourdough microbiota and the quality of sourdough bread (from Hammes and Ganzle, 1998).

various details about sourdough technology have not yet been fully understood. This remains the case not only with regard to sourdough microbial ecology and physiology, despite much progress in this respect (Gobbetti, 1998; Hammes and Ganzle, 1998; Brandt, 2001), but also in relation to the influence of sourdough on the structure of dough and bread. Mechanisms at work in sourdough and its application are complex and numerous (Fig. 2). A variety of flour characteristics and process parameters contribute to exercising very particular effects on the metabolic activity of the sourdough microflora. During fermentation, biochemical changes occur in the carbohydrate and protein components of the flour due to the action of microbial and indigenous enzymes. The rate and extent of these changes greatly influence the properties of the sourdough and ultimately the quality of the final baked product. A number of hypothesis have been put forward that can help to explain the effects of sourdough on dough and bread quality including those that are related to the direct impact of pH on dough structure, those corresponding to the effect of acid on cereal enzymes and indeed those that are related to the effect of the micro-organisms alone.

3. Ecology of sourdough

As the texture parameters of the finished bread are determined by the microbial acidification and rate of substrate breakdown, it is important to characterize the micro-organisms responsible for those activities. The microbial ecology of the sourdough fermentation is determined by ecological factors (Hammes and Ganzle, 1998; Vogel et al., 1996). Endogenous factors are determined by the chemical and microbial composition of the dough, whereas exogenous factors are determined mainly by temperature and redox potential. In practice, strong effects are exerted by process parameters such as dough yield, addition of salt, amount and composition of the starter, number of propagation steps and fermentation time (De Vuyst and Neysens, 2005). The impact of these parameters during continuous propagation of sourdough causes the selection of a characteristic microbiota. In mature sourdoughs LAB range from 1×10^9 to 3×10^9 cfu per gram sourdough, and yeasts from 1×10^6 to 5×10^7 cfu per gram sourdough (Hammes et al., 2005). Microbiological studies have revealed that more than 50 species of LAB, mostly species of the genus *Lactobacillus*, and more than 25 species of yeasts, especially of the genera *Saccharomyces* and *Candida* (Brandt, 2001; Ottogalli et al., 1996), occur in sourdough. The most commonly isolated LAB and yeasts from Type I and II sourdoughs (Gänzle, 2005) are presented in Table 1. Specifically, the species *Lactobacillus plantarum*, *Lactobacillus sanfranciscensis*, *Lactobacillus pontis* and *Lactobacillus panis* are recognized as key organisms in sourdoughs (Vogel et al., 1999; Gänzle, 2005). As shown by Gül et al. (2005), individual strains and combination thereof strongly affect the final bread texture. Differences have been reported in parameters such as specific volume as well as crumb and crust hardness (Gül et al., 2005). Thus, because of the variation in acidification properties and metabolism among different LAB, the ecological composition of each sourdough specifically influences the quality of the bread. The deliberate exploitation of desirable metabolic activities in LAB is enabled by the demonstration of the contribution of individual metabolic traits on bread quality and will ultimately enable the selection of the most suitable starter culture to be used in baking applications (Ehrmann and Vogel, 2005).

3.1. *Primary effects of acidification*

The pH of a ripe sourdough varies with the nature of the process and starter culture used but for wheat sourdoughs it ranges from 3.5 to 4.3 (Collar et al., 1994a; Wehrle and Arendt, 1998; Thiele et al., 2002). The nature of the flour, in particular its ash content, has a considerable effect on acidification characteristics (Collar et al., 1994b). Depending on the rate of addition, therefore, the pH of the bread dough will also vary. Given a typical application rate of approximately 20%, dough pH values ranging from 4.7 to 5.4 have been reported (Collar et al., 1994a). The acidification of the sourdough and the partial acidification of the bread dough will impact on structure-forming components like gluten, starch and arabinoxylans. The swelling of gluten in acid is a well-known effect (Zeleny,

Table 1
LAB and yeast species composition of Type I and Type II sourdoughs (from Brandt and Gänzle, 2005)

LAB		Yeasts	
Type I	Type II	Type I	Type II
Dominant			
L. sanfranciscensis	*L. pontis*	*C. humilis*	—
	L. panis		
Commonly isolated			
L. alimentarius	*L. acidophilus*	*S. exiguous*	*S. cerevisiae*
L. brevis	*L. crispatus*	*S. cerevisiae*	*I. orientalis*
L. fructivorans	*L. delbrueckii*	*I. orientalis*	
L. paralimentarius	*L. fermentum*		
L. pentosus	*L. reuteri*		
L. plantarum			
L. pontis			
L. spicheri			
Lc. mesenteroides			
W. confusa			
Other species detected			
L. hammesii	*L. amylovorus*	*Torulaspora delbrueckii*	*C. glabrata*
L. mindensis	*L. frumenti*	*C. boidinii*	
L. nantensis	*L. johnsonii*	*Debaromyces hansenii*	
L. rossii	*L. mucosae*	*Dekkera bruxellensis*	
Pediococcus spp.	*L. paracasei*	*Galactomyces geotrichum*	
W. cibaria	*L. rhamnosus*	*Torulaspora pretoriensis*	

C. = *Candida*; L. = *Lactobacillus*; Lc. = *Leuconostoc*; S. = *Saccharomyces*; W. = *Weissella*.

1947; Axford et al., 1979) and mild acid hydrolysis of starch in sourdough systems has also been hypothesized (Barber et al., 1992). Acids strongly influence the mixing behaviour of doughs whereby doughs with lower pH values require a slightly shorter mixing time and have less stability than normal doughs (Hoseney, 1994). The direct influence of organic acids on the rheological properties of dough has been examined intensely using both empirical (Tsen, 1966; Tanaka et al., 1967; Maher Galal et al., 1978; Wehrle et al., 1997) and fundamental techniques (Wehrle et al., 1997).

In the past, several studies directly focused on the influence of organic acids and sodium chloride on the rheological properties measured using the farinograph (Tanaka et al., 1967; Maher Galal et al., 1978; Wehrle et al., 1997) and extensiograph (Tsen, 1966; Tanaka et al., 1967). The farinograph is commonly used to provide empirical information regarding the mixing properties of doughs (Spies, 1990). The water absorption of flour, as determined using the farinograph, is an important factor influencing the handling properties and machinability of dough and is related to the quality of the finished baked product (Catterall, 1998). Studies of wheat dough using the farinograph showed that water uptake or consistency was increased by adding organic acids in the absence of salt (Tanaka et al., 1967; Maher Galal et al., 1978). It was also reported that the addition of organic acids substantially decreased mixing time and weakened the dough (Maher Galal et al., 1978; Wehrle et al., 1997). Maher Galal et al. (1978) put forward the hypothesis that, in an acidic environment there is a sizeable positive net charge and proteins solubility is increased. The increased intramolecular electrostatic repulsion leads to an unfolding of the gluten proteins and an increased exposure of hydrophobic groups but the presence of strong intermolecular electrostatic repulsive forces prevent the formation of new bonds. The net effect of these events is a weakening of the structure and thus a softening effect. Such a hypothesis is further supported by Takeda et al. (2001) who reported an increased solubility of the constituent gluten proteins at acidic pH values. This disentanglement of the gluten protein network upon the addition of acid is in keeping with the results obtained from empirical measurement of dough properties using the extensograph, which show that the addition of acid, in the presence of salt, results in doughs with increased resistance and decreased extensibility (Tsen, 1966; Tanaka et al., 1967). An explanation of the dough response during this test, given in terms of the entangled protein network model, is that when a piece of dough is subjected to elongation, it will tear when the network between the two entangled regions reaches its full extension, thus the more entangled the network the higher its resistance to deformation (Masi et al., 2001). Fundamental rheological studies on chemically acidified doughs have also been performed by Wehrle et al. (1997). The authors reported that, under optimal mixing conditions, the addition of acids leads to doughs with lower phase angle values, and thus a more elastic behaviour. A fundamental rheological evaluation of the effect of acid and salt on model gluten systems was also indicative of an increase in both the softness and elasticity of gluten in the presence of acid (Schober et al., 2003).

3.2. *Secondary effects of acidification*

Further to the direct impact of low pH on dough characteristics, secondary effects of acidification and fermentation time include changes in the activity of cereal or bacterial enzymes associated. Kawamura and Yonezawa (1982) described wheat flour proteases that have optimal activity around pH 4. In addition, Bleukx et al. (1997) detected proteolytic enzymes with acidic pH optima in vital wheat gluten. In the same vein, Thiele et al. (2002) found a greater increase in the concentration of particular amino acids in an acidified relative to a non-acidified dough system during a 50-h fermentation period. These authors concluded that the most important factors governing the levels of amino acids in wheat dough is dough pH, fermentation time and the consumption of amino acids by the fermentative microbiota.

4. Changes in the cereal protein fraction during sourdough fermentation

From a rheological point of view it is well established that as fermentation progresses there is a change in nature of the elements contributing to dough structure such as the decrease in the viscosity described for a gluten solution (Kawamura and Yonezawa, 1982). The protein fraction of wheat and rye flours is of crucial importance for bread quality. Proteolysis provides precursor compounds for the formation of aroma volatiles during baking as well as substrates for microbial conversion of amino acids to flavour precursor compounds (Schieberle, 1996; Thiele et al., 2002). The gluten proteins in wheat flour determine dough rheology, gas retention and bread volume (Weegels et al., 1996). Using empirical techniques to measure the rheology of fermented doughs, Di Cagno et al. (2002) found a decrease in resistance to extension and an increase in both extensibility and degree of softening. Further to the impact of sourdough on the structure and rheology of the constituent gluten proteins making up the framework of the dough, its effect on gas formation must also be considered in view of the fact that gas formation by microorganisms is necessary in order to obtain leavened bread. In the case of sourdough breads, carbon dioxide is produced by both LAB and yeast and the contribution of each group to the overall gas volume differs with the type of starter culture and the dough technology applied (Hammes and Ganzle, 1998).

Acidification due to growth of LAB also alters the gluten network. At pH below 4.0 there is a sizable positive net charge and the increased electrostatic repulsion enhances protein solubility and effectively prevents the formation of new bonds (Clarke et al., 2004; Schober et al., 2003). The reduction of intermolecular and intramolecular disulfide bonds solubilizes gluten proteins and potentially allows greater access by proteolytic enzymes allowing for more efficient proteolysis (Thiele et al., 2002). Some of the consequences of proteolysis include an improvement in bread flavour. The accumulation of amino acids during sourdough fermentation enhances the formation of flavour volatiles during baking. Another consequence of proteolysis is a change in dough rheology and bread texture. The acidification of wheat sourdough results in a large reduction of elasticity and firmness of the dough (Clarke et al., 2004). Model studies to determine the direct effect of lactate and NaCl on gluten properties highlighted the strong influence of low pH on the elasticity and firmness of wheat gluten (Schober et al., 2003). The gliadin macropolymer (GMP) is a major determinant of the volume and texture of wheat breads in a straight dough process, however, despite the GMP depolymerization during sourdough fermentation, most studies report larger loaf volumes when sourdough fermented wheat breads are compared to straight dough process (Corsetti et al., 1998a).

5. Application of exopolysaccharides (EPS) produced by sourdough LAB

The addition of plant polysaccharides is a common practice in the production of bread to improve textural properties and shelf-life of bread. Recently, the suitability of EPS produced by sourdough LAB to replace plant polysaccharides has been investigated. Two classes of EPS from LAB can be distinguished: extracellularly synthesized homopolysaccharides (HoPS) and heteropolysaccharides (HePS) with (ir)regularly repeating units that are synthesized from intracellular sugar nucleotide precursors. Studies of the application of EPS-forming starter cultures have primarily focused on HePS from lactobacilli in dairy fermentations. HePS are produced in small amounts usually below $0.5\,\mathrm{g\,l^{-1}}$ (De Vuyst and Degeest, 1999; Laws and Marshall, 2001). HoPS are composed of only one type of monosaccharide and are synthesized by extracellular glucan—and fructosyltransferases using sucrose as the glycosyl donor (Monchois et al., 1999). A preliminary assessment of the performance in baking applications of reuteran, dextran and levan from lactobacilli has been recently discussed (Brandt et al., 2003). The fructan from *L. sanfranciscensis* has been found to positively affect dough rheology and bread texture (Brandt, 2001; Korakli et al., 2000). Interestingly, EPS produced in situ have been found to be more effective than externally added. Additionally, the metabolic activity of LAB during sourdough fermentation also results in other metabolites including mannitol, glucose and acetate, which can improve bread quality (Korakli et al., 2003). Polymers produced from lactobacilli thus may be expected to beneficially affect a number of technological properties of bread, including water absorption of the dough, dough machinability, increased loaf volume and retarded bread staling (Tieking and Ganzle, 2005). These studies provide evidence that EPS produced by sourdough LAB have the potential to improve dough rheology and bread texture and show that EPS produced by LAB may be used to replace or reduce more expensive hydrocolloids used to improve bread texture. Moreover, some of the EPS produced by LAB have prebiotic properties (Gibson and Roberfroid, 1995). In particular, the levan produced by *L. sanfranciscensis* LTH2590 is metabolized by bifidobacteria (Korakli et al., 2003) and selectively stimulated the growth of bifidobacteria during cultivation of human faecal microflorae in vitro (Dal Bello et al., 2001).

6. Synergistic activity of sourdough and dough additives

Further to reliance on the integral components of dough, there is an increasing trend for the use of additives in the baking industry to achieve optimum functionality in terms of dough handling properties and bread quality attributes including shelf-life (Rosell et al., 2001). The interaction between sourdough and a number of additives such as exogenous enzymes and non-starch polysaccharides has been recently evaluated (Corsetti et al., 2000; Di Cagno et al., 2003). Corsetti et al. (2000) have determined the contribution made by the addition of α-amylase, protease, pentosans and pentosanases to the rate of staling observed in sourdough breads prepared using strains of *Saccharomyces cerevisiae*, *L. sanfranciscensis* and *L. plantarum*. These authors reported that the positive effect seen for the sourdough bread was further enhanced by the addition of α-amylase. In breads where pentosans alone or a mixture of pentosans, endoxylanase and a strain of *Lactobacillus hilgardii* were added, an even greater delay in bread firming and staling was observed. The authors concluded that the combined use of LAB and pentosans may be a fundamental prerequisite in the retardation of breadcrumb firmness. Di Cagno et al. (2003) studied the interactions between sourdough LAB and exogenous enzymes in order to optimize acidification, acetic acid production and textural properties of sourdough during the fermentation process. The enzymes used were those typically applied to improve dough functionality, i.e. glucose-oxidase, lipase, endo-xylanase, α-amylase or protease. The authors found that, of the 11 species of LAB used, only three were positively influenced by the addition of enzymes with regards to the rate and extent of acidification. The use of enzymes in the context of sourdough may be difficult given that the acidic environment may interfere with their activity. It was reported however that, in some cases, the combined use of sourdough and enzymes could reduce the risk of dough weakening and the loss of gas retention properties (Di Cagno et al., 2003).

7. Bread texture and staling

The textural properties of a food have been described as "that group of physical characteristics that are sensed by the feeling of touch, are related to the deformation, disintegration, and flow of the food under the application of a force and are measured objectively by functions of force, time and distance" (Bourne, 1982). This is however an extremely restrictive meaning in relation to those properties that can be felt in the mouth or the hand and excludes physical characteristics such as temperature, optical and electrical properties (Bourne, 1982). Another way to view texture is that texture is a sensory characteristic, thus it is only the human being which can perceive, describe and quantify it. Texture is generally regarded as a multi-parameter attribute (Szczesniak, 1987).

Bakery products have a very short shelf-life and their quality is dependant on the period of time between baking and consumption. During storage, a decrease in bread freshness parallel to an increase in crumb hardness produces a loss of consumer acceptance known as staling (Hebeda et al., 1990). Staling has been defined as 'a term which indicates decreasing consumer acceptance of bakery products caused by changes in crumb other than those resulting from the action of spoilage organisms' (Bechtel et al., 1953). Changes during staling occur in both the crumb and the crust of the bread (D'Appolonia and Morad, 1981). Changes which occur in the texture of the crumb are: the crumb becomes harder, tougher, as well as more crumbly and opaque. Although a complex series of events occur during staling including changes in the crystallinity of the starch during storage, bread staling is mainly associated with the firming of the crumb (Pateras, 1998; Gray and Bemiller, 2003). Crust staling is generally caused by moisture migration from the crumb to the crust (Lin and Lineback, 1990) resulting in a soft, leathery texture and is generally less objectionable than crumb staling (Newbold, 1976).

Bread crumb is a complicated viscoelastic, foam material. Due to this complexity the mechanism of bread staling is not fully understood and despite extensive study, bread staling has not been eliminated and remains responsible for huge economic losses (Gray and Bemiller, 2003). Starch is the main component of bread and its gelatinization induces major changes during the baking of bread. The swollen granules and partially solubilized starch act as essential structural elements of bread (Keetels et al., 1996). On cooling and aging of bread, rearrangements in the starch fraction lead to a series of changes including gelatinization and crystallization. This transformation is called starch retrogradation and is thought to be responsible for the staling effect in the bread system (Zobel and Kulp, 1996). Starch is composed of amylose and amylopectin with both these components playing different roles in the staling of bread. Amylose is thought to retrograde directly after backing whereas amylopectin retrogrades in a constant manner over 5 days. Every et al. (1998) have reported that starch–starch and starch–protein interactions are of equal importance in bread staling. However, due to the fact bread is comprised of about 85% starch, it would be reasonable to assume that starch–starch interactions play a more critical role in bread texture. Characteristics of bread crumb that have been used to determine the staling rate are changes in the taste, aroma, hardness, opacity, crumbliness, starch crystallinity, absorptive capacity, susceptibility to alpha amylase and soluble starch content, however no one method will completely measure or describe the degree of staling noticed by the consumer (Sidhu et al., 1996).

7.1. *Effect of sourdough on bread staling*

The application of LAB in the form of sourdough has been reported to have positive effects on bread staling. One such effect is an improvement in loaf specific volume, which is associated with a reduction in the rate of staling (Axford et al., 1968; Maleki et al., 1980) as has been demonstrated by a reduction in crumb softness for sourdough breads during storage (Corsetti et al., 2000; Crowley et al., 2002). A decrease in the staling rate as measured by differential scanning calorimetry has also been reported for breads containing sourdough (Barber et al., 1992; Corsetti et al., 1998a, 2000). It has been noted, however, that the anti-staling effect found for sourdough is dependant from the particular strain performing the fermentation, and that this effect involves dynamics other than those associated with the degree of acidification. Starch molecules can be affected by enzymes produced by LAB, causing a variation in the retrogradation properties of the starch. This in turn slows the rate of staling. Additionally, proteolysis of gluten subunits has also been proposed (Corsetti et al., 1998a). Addition of excess concentrations of proteolytic enzymes is detrimental to the bread quality, however Van Eijk and Hille (1996) reported that the addition of an optimum amount of protease increases the shelf-life of bread. Additionally, proteases aid in the liberation of water associated with the protein network thus allowing for an increased alpha amylase activity (Schwimmer, 1981). In conclusion, the acidic conditions and proteases associated with sourdough play a role in reducing the staling rate of bread.

8. Rye sourdough

The introduction of baker's yeast has not eliminated the use of sourdoughs in rye breadmaking, where a reduction in pH is necessary to achieve suitability for baking (Oura et al., 1982; Hammes and Ganzle, 1998; Salovaara, 1998). The baking properties of rye and wheat flours differ in so far as rye flours contain high levels of pentosans. In rye doughs the proteins play a lesser role in the structure forming process than in wheat doughs, because the pentosans inhibit the formation of the gluten network (Cauvain, 1998). Solubility and swelling properties of pentosans increase at the low pH values characteristic of sourdoughs (Hammes and Ganzle, 1998). Additionally, acidic conditions partially inactivate the enzymic, particularly amylase, activity in rye flour (Seibel and Brümmer, 1991). This is an important aspect, as the starch in rye gelatinises at the relatively low temperature of 55–70 °C, which coincides with the temperature range for maximum α-amylase activity (Cauvain, 1998). In the presence of rye flour of poor quality, the amylase activity is so high that the crumb can become completely hydrolysed. An excessive amount of α-amylase in rye flour produces not only a sticky crumb, but, at higher levels, it produces a very open grain and a reduction in loaf volume (Hammes and Ganzle, 1998). The acidification also exerts positive effects on the structure of starch granules, leading to an increased water-binding capacity (Hammes and Ganzle, 1998). Acidification of rye doughs improves their physical properties by making them more elastic and extensible and confers the acid flavour notes characteristic of rye breads.

9. Wheat sourdough

Whereas sourdough is an essential ingredient for ensuring baking properties of doughs containing more than 20% of rye flour, its addition to wheat doughs remains optional (Röcken, 1996). There is however a vast array of traditional products that rely on the use of sourdough fermentation in order to yield baked goods with particular characteristics. The use of LAB and yeasts in the form of sourdough is well established in Italy (Corsetti et al., 2001), Germany (Seibel and Brümmer, 1991), Spain (Barber and Báguena, 1989) and France (Infantes and Tourneur, 1991). Some examples of sourdough baked goods include the well-known Italian products associated with Christmas, Panettone, which originated in Milan (Sugihara, 1977) and Pandoro originally from Verona (Zorzanello and Sugihara, 1982) or their counterpart, Colomba, which is traditionally associated with Easter (Sugihara, 1977). San Francisco sourdough French breads (Kline et al., 1970) and soda crackers (Sugihara, 1985) are two further examples of wheat products that rely on the process of souring. Several reports have also stated that the incorporation of LAB in the form of sourdough notably delays wheat bread staling (Crowley et al., 2002; Clarke et al., 2004). The use of sourdough in wheat breads has gained popularity in recent times as a means to improve the quality and flavour of wheat breads (Brummer and Lorenz, 1991; Corsetti et al., 2000; Thiele et al., 2002). However, there is much disparity in the results concerning the effect of sourdough on the final wheat product and the use of sourdough has been shown to either decrease (Armero and Collar, 1996) or increase (Crowley et al., 2002; Hansen and Hansen, 1996) final bread quality.

10. Gluten-free sourdough

Coeliac disease (CD) is a chronic enteropathy caused by the intake of gluten proteins from widely prevalent food sources, such as wheat, rye, barley and possibly oats. The condition is exacerbated by the ethanol soluble storage proteins or prolamins from wheat, rye, barley and possibly oats. The ingestion of gluten induces an inflammatory response resulting in the destruction of the villous structure of the small intestine (Shan et al., 2002). CD results in malabsorption secondary to small intestinal villous atrophy (Fasano, 2005). Currently the only effective treatment for CD is the strict lifelong renunciation of gluten-containing foods (Fasano and Catassi, 2001; Feighery, 1999).

The majority of the gluten-free bakery products on the market are of very poor quality, particularly when compared to their wheat counterparts (Arendt et al., 2002). This is mainly due to the unique properties of gluten, and the absence of a protein network in gluten-free products. Furthermore, in view of the fact that gluten-free breads do not contain gluten, and are mainly starch based, the onset of staling is more rapid than in gluten-containing breads (Moore et al., 2004). Currently different approaches are under investigation to produce breads that can be tolerated by CD patients. One approach involves the use of non-toxic flours and the application of sourdough to improve the quality of gluten-free bread (Moore, 2005). Recently, the effects of addition of sourdough produced using a mixture of non-toxic brown rice flours, corn starch, buckwheat and soya flour to a gluten-free bread recipe were investigated (Moore, 2005). The authors evaluated over a 5-day storage period the influence of sourdoughs made from different strains of LAB on the textural quality of gluten-free bread. The sourdough-containing breads were compared to a non-acidified control and a chemically acidified control. Changes in dough structure could not only be detected by small deformation viscoelastic measurements but also by confocal laser-scanning microscopy (Fig. 3). A significant difference in phase angle was observed between sourdough and non-fermented batter. This result showed that the fermentation causes an increase in elasticity over the initial 24 h of fermentation. The protein fraction of the gluten-free sourdough was degraded overtime (Fig. 3). This process was, and however far less obvious in a gluten-free system than with gluten isolated from wheat-based sourdough (Fig. 3). When the sourdoughs were incorporated at a 20% level into the gluten-free batter no significant differences were observed in the structure (Fig. 3), which is not the case in wheat dough containing 20% sourdough (Fig. 3). The authors concluded that, with the application of sourdough, the onset of staling was delayed, thus indicating that addition of sourdough to a gluten-free recipe can improve the quality of the resulting bread.

Recently a new approach has been investigated based on sourdough fermentation to degrade toxic epitopes of wheat flour (Di Cagno et al., 2004, 2005). This approach requires the virtually complete hydrolysis of gliadins. However, this extend of protein hydrolysis compromises the technological functionality of wheat flour, and thus for product formulation the fermented sourdough has to be applied in combination with unfermented non-toxic flours. Two types of bread containing ca. 2.5% of wheat sourdough and unfermented oat, buckwheat and millet flours were

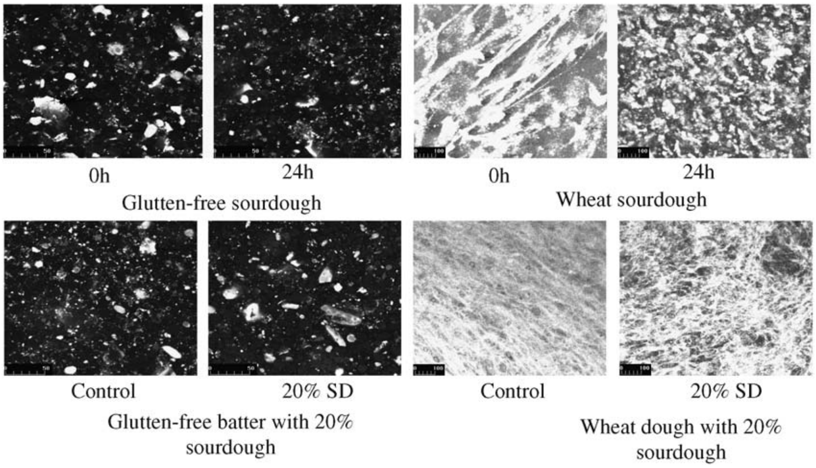

Fig. 3. Confocal microscopy showing wheat and gluten free dough as well as sourdough (from Moore et al., 2004).

manufactured with baker's yeast or sourdough lactobacilli and used for in vivo double blind acute challenge on CD patients (Di Cagno et al., 2004). Thirteen out of the 17 patients showed a marked alteration of the intestinal permeability after ingestion of baker's yeast bread, but after consuming sourdough bread the intestinal permeability of these patients did not differed from the baseline values. Same finding were obtained by using the commercial probiotic bacteria VSL♯3 as starters for wheat sourdough fermentation (De Angelis et al., 2005), showing that proteolysis due to selected LAB can in fact degrade the gliadin fraction of wheat flour allowing fermented wheat flour to potentially be used as a base for future gluten-free recipes. However even if this approach may not be directly applicable for the industrial production of gluten-free bread, the results collected so far strongly indicate that selected LAB can be used to degrade any potential contaminant present in gluten-free flours.

11. Conclusions

Sourdough has been used since ancient times and its ability to improve the quality and increase the shelf-life of bread has been widely described. There exist a myriad of microbial, technological and processing dimensions that must be considered in order to produce cereal products of optimum quality. Significant advances have been made in understanding the contributions made by the presence of acids, the fermentation period and the role played by cereal and bacterial enzymes in terms of sourdough and bread characteristics. Recently, sourdough has been successfully applied for the improvement of the qualities of gluten-free bread. Moreover, proteolytic activities of LAB show great potential in the reduction of gluten contamination in gluten-free recipes. In conclusion, the studies presented in this review indicate that sourdough addition has positive effects on the technological, nutritional as well as functional properties of bread.

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