BENEFICIAL EFFECTS AND FUNCTIONAL ASPECTS OF SOURDOUGH TECHNOLOGY

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Abstract - Sourdough is a mixture of flour and water that is fermented with lactic acid bacteria and yeasts. Actually, the use of the sourdough process for the production of sourdough bread has a long tradition but in recent years, traditional sourdough breads have again started to attract consumers as a result of improved organoleptic properties, pronounced flavor, prolonged shelf life and natural production without the use of any additives. These improved properties are results of the some biochemical changes occur during sourdough fermentation.

Index Terms - Fermentation, Nutrition, Sourdough, Lactic Acid Bacteria

I. INTRODUCTION

Sourdough is a mixture of flour (mainly wheat or rye) and water that is fermented with lactic acid bacteria (LAB) and yeasts [1-2-3]. Sourdough fermentation is a traditional process for the production of wheat and rye breads. At present, it is also used for the production of other bread types with different flours and for the manufacture of various cereal-based products. The use of sourdough technology improves the quality of cereal products characterized by flavor, nutritional value, texture and shelf life [4]. In addition, it confers a natural image to the product from a consumer perspective [5]. The typical characteristic of sourdough mainly relies on the metabolic activities of its active microflora, basically represented by LAB and yeasts. As a result of the metabolic activities of LAB and yeasts, biochemical changes occur during sourdough fermentation and the quality of the dough and bread are affected [6]. Various components in flours (carbohydrates, nitrogen sources, minerals, lipids and free fatty acids and enzyme activity) and process parameters of the dough (temperature, dough yield, O_2, fermentation time, and number of sourdough propagation steps) influence the microflora of sourdough and the propeties of the leavened product, as during fermentation, the action of microbial and indigenous enzymes causes the biochemical changes in the components of the flour [7-8]. The rate and extent of these changes greatly influence the properties of the sourdough and the quality of the resulting baked product [4]. The microflora involved in fermented foods contribute to the improvement of the organoleptic properties, the shelf life of the final products and their nutritional profile [9], due to the metabolic activity of the microorganisms which is governed by the interaction with the grain constituents. LAB produce lactic and acetic acids and the pH is typically decreased below pH 5.0. Acidification contributes to the activation of certain enzymes such as proteases, amylases, hemicellulases and phytases. It has been reported that acidification, production of microbial metabolites and activity of enzymes affect components of flour and dough technology via different mechanisms [10]. This review summarizes the beneficial effects and functional aspects of sourdough technology on the nutritional, organoleptic and technological quality of doughs and breads.

II. ORGANIC ACID PRODUCTION

During sourdough fermentation, LAB produce lactic and acetic acids and pH is typically reduced to below 5.0. Organic acid production enhances flavor, improves texture and also inhibits pathogenic and spoilage organisms as a result of the low pH levels and inhibitory effect of some organic acids [11]. During the sourdough process, lactic acid and in particular acetic acid exert inhibitory effect [12]. The inhibitory effect of organic acids are related to impacting cell homeostatic systems since, the decreasing pH acidifies the cell and then the cell consumes a great amount of energy to maintain intracellular pH homeostasis [13-14-15]. Organic acids dissociate depending on their dissociation constants (pKa), temperature and certain other factors, and produce protons. However, the cytoplasmic membrane is impermeable to protons. On the other hand, organic acids are mainly lipophilic and undissociated molecules of organic acids easily enter through the cell membrane. In the cell, a higher internal pH than pKa causes organic acids to dissociate when entering the cytoplasm, which decreases the intracellular pH by releasing the proton. Protons acidify the cytoplasm and cells try to overcome this problem by pumping out the protons to the external environment. The cell uses the main part of its energy content to remove newly formed protons, which results in slower growth kinetics [14-16]. At very low pH levels (4.5 or below), it is difficult to remove all the protons from the cell and it cannot retain its internal pH. Bacteria maintain internal pH near neutrality to prevent denaturation of structural proteins, enzymes, nucleic acids and phospholipids. Organic acids can

also affect membrane permeability. A low pH and high proton concentration in the cell denature proteins, reduces the membrane proton gradient, neutralize the proton-motive force. The exposure of cellular compounds to protons can affect the ionic bonds of macromolecules and structure. A low pH may damage cellular macromolecules in the cell wall, cell membrane, metabolic enzymes, protein synthesis and genetic material [13].

Furthermore, formed acetic acid is of major importance for the development of flavor and contributes to the aroma of bread dough. Therefore, the content of lactic and acetic acids in sourdoughs is very important for the taste and flavor of sourdough bread [17]. The molar ratio between lactic and acetic acid is defined as the fermentation quotient (FQ) and the FQ should be around 4 in sourdoughs to obtain a balanced bread taste [12]; with the optimum considered to be in the range of 2.0-2.7 [7]. Regarding rye sourdough bread, the optimal FQ was reported to be in the range of 1.5-4.0 [18].

A drop of pH causes some modifications by enhancing the performance of certain enzymes, such as amylases, proteases, hemicellulases and phytases. Differences in pH and enzyme activity affect the nutritional quality of the structure-forming components; i.e., protein, starch, lipid, dietary fibre, vitamins, minerals, sterols and phenolics, via different mechanisms [10-19]. In rye sourdoughs, acidification is also important as the acidification of rye doughs improves the physical properties of the dough by making them more elastic and extensible and confers the acid flavor notes so characteristic of rye breads [20].

III. ANTIBACTERIAL AND ANTIFUNGAL ACTIVITIES

During sourdough fermentation, the rapid consumption of fermentable carbohydrates by LAB and the formation of lactic acid, accompanied by a reduction of the pH, have an inhibitory effect on other microorganisms. Besides lowering the pH, a wide range of antimicrobial compounds, for example, diacetyl, hydrogen peroxide, acetic acid and other short chain fatty acids, are synthesised by LAB and some of them effectively inhibite pathogen bacteria and fungi [21].

Reference [22] screened 335 LAB strains isolated from sourdoughs and 18 isolates that belonged to three different Lactobacillus (Lb.) species, Lb. sakei (formerly Lb. bavaricus), Lb. curvatus and Lb. plantarum showed antimicrobial activity indicated by a proteinaceous compound. Lactobacilli isolated from wheat sourdoughs belonging to the species Lb. sanfranciscensis, Lb. brevis, Lb. fructivorans, Lb. fermentum, Lb. plantarum, Lb. farciminis, Lb. acidophilus, Lb. alimentarius and Lb. hilgardii strains showed the largest spectrum of inhibition among the strains [23-24].

Inhibitory activity of certain antimicrobial compounds produced under bread-making conditions can be changed under different sourdough bread production conditions [25]. A total of 437 Lactobacillus strains isolated from sourdoughs were screened for their antimicrobial compound production against different indicator strains. Some LAB strains produced an inhibition zone against one or more indicators. It was reported that a bacteriocin-like inhibitory substance was produced by Lb. pentosus which was also active under sourdough conditions [26]. In another study, in situ bacteriocinogenic activity of Lactococcus (Lc.) lactis was reported [27]. Prevention of visual rope generation caused by Bacillus (B.) subtilis and B. licheniformis in sourdoughs at low pH values was reported [28] [29]. However, higher pH values were not effective in preventing rope since bacteriocins produced by Lactobacillus strains have optimal activities at pH 3.0-4.0 [30-31-32]. Reference [33] reported the antimold activity of some Lactobacillus spp. Among the species, Lb. sanfranciscensis had the largest spectrum and inhibited molds related to bread spoilage such as Fusarium, Penicillium, Aspergillus and Monilia. Caproic acid and also acetic, formic, propionic, butyric and n-valeric acids were responsible for the antimold activity. Another study investigated the antifungal activity of several sourdough LAB and Lb. plantarum strain showed a very broad spectrum of activity and inhibited many fungal species the most commonly isolated from contaminated baked goods belonging to Eurotium, Penicillium, Endomyces, Aspergillus, Monilia and Fusarium [34].

IV. PHYTASE ACTIVITY

Whole meal cereals are good sources of minerals but the bioavailability of minerals may be limited due to the presence of phytate, the salt form of phytic acid. Phytic acid (myoinositol hexakisphosphate) is a compound found in most cereal grains, legumes and nuts and it strongly binds minerals like iron and zinc [35-36]. By forming insoluble complexes with dietary cations, it impairs mineral absorption in humans [10-12]. The low pH values associated with sourdough fermentation lead to the solubilisation of the phytic acid complex as a result of the phytase activity of grain raw materials, LAB and yeasts; therefore, mineral bioavailability is increased [8] as phytase activity is accelerated in the acidic environment of sourdough fermentation [37]. Acid production and lowering the pH is the major mechanism for LAB to improve mineral bioavailability [10]. A wide variation in phytase activity has been detected in some yeasts and LAB isolated from sourdoughs [38-39-40].

V. PROTEASE ACTIVITY

Proteolytic enzymes, proteases, are grouped into proteinases and peptidases. Proteinases catalyse protein degradation into smaller peptide fractions and peptidases hydrolyze specific peptide bonds or completely breakdown peptides to amino acids [19]. In sourdough production, acidification causes increased gluten solubility and endogenous cereal proteinase activity. Gluten proteins, fractions of gliadins (50-60%) and glutenins (40-50%), show different structure and functionality. The viscoelastic gluten network during the preparation of doughs allow the entrapment of CO_2 released during fermentation and result in breads with a light, porous crumb structure. [41-42]. Primary proteolysis, the break down of proteins to peptides, is mainly attributable to flour endogenous proteinases in wheat and rye sourdoughs [43-44-45]. Besides primary proteolysis by cereal proteases, strain-specific proteolytic activity of LAB also contributes to proteolysis. The degradation of wheat and rye proteins is very important for bread flavor, volume and texture. The partial hydrolysis of glutenins during sourdough fermentation results in disruption of the gluten network and increases the solubility of gluten proteins [19]. The increasing solubility of gluten proteins promotes swelling and increased water uptake [46]. Besides gluten, the partial acid hydrolysis of starch also leads to increased water binding capacity. Degradation of gluten protein structures in sourdoughs affects the viscoelastic properties of the final dough depending on the extent of the protein degradation. The rheological consequence of gluten degradation is the reduction of elasticity and firmness of the sourdough and subsequent bread dough. A weaker gluten network increases the expansion of dough, but also decreases gas retention. Therefore, the acidity level of sourdough and subsequent bread dough must be carefully controlled to attain increased volume [6]. It is generally observed that a limited degree of proteolysis during sourdough fermentation is beneficial and improves the bread flavor without adverse effects on texture and volume [19-44].

The gluten proteins of wheat and secalins of rye belong to prolamins, which are responsible for coeliac disease (gluten-sensitive enteropathy), a chronic gastrointestinal tract disorder where the ingestion of gluten from wheat, rye and barley and their crossbred varieties, leads to damage of the small intestinal mucosa by an autoimmune mechanism in genetically susceptible individuals [47-48]. The current treatment for coeliac disease is a life-long gluten-free diet. However, controlled proteolysis in wheat and rye sourdoughs may be used as a tool to reduce gluten levels to such an extent that the products can be tolerated by coeliac patients [49-50].

Proteolytic degradation during fermentation provides the substrates for microbial growth and conversion of amino acids to flavor precursor compounds [44] and antifungal metabolites [34]. The hydrolysis of peptides (secondary proteolysis) by sourdough lactobacilli leads to the accumulation of aminoacids in the dough in a strain dependent manner. On the other hand, yeasts decrease amino acids levels in dough [19]. As a result, both the sourdough yeasts and LAB may facilitate the flavor formation, either directly via metabolizing amino acids to flavor compounds or indirectly by transforming them into secondary compounds that can serve as new precursors for further conversions [51]. Different strains of LAB exhibit proteolytic activity during sourdough fermentation. Among LAB, Lb. sanfranciscensis has been shown to be particularly capable of degrading proteins or peptides, and proteinase, dipeptidase and aminopeptidase are the main enzymes that characterize the proteolytic system of this bacterium [52-53]. Some other studies reported proteolytic activities of Lb. brevis subsp. lindneri, Lb. farciminis, Lb. casei, Lb. plantarum and Pediococcus (Pd.) pentosaceus [54] [55] [56] [57].

VI. EXOPOLYSACCHARIDE PRODUCTION

Microbial exopolysaccharides (EPS), long chain sugar polymers, are metabolites produced by bacteria, microalgae and to a lesser extent, fungi [58-59]. Extracellular polysaccharides are secreted into the extracellular environment in the form of slime or associated with the cell surface in the form of capsules. Many food-grade microorganisms produce EPS especially LAB, Propionibacteria and Bifidobacteria [60-61-62]. Some LAB species are a good source of EPS which are also recognized for their contribution to the texture, mouth feel, taste perception and stability of the final food product [63-64]. Most of the EPS-producing LAB strains studied were isolated from dairy products but it is known that some LAB species produce EPS and links between specific metabolic activities of sourdough cultures [65]. EPS production from sucrose by sourdough origining LAB such as Lb. sanfranciscensis, Lb. frumenti, Lb. pontis, Lb. reuteri, Lb. panis, Lb. plantarum, Pd. pentosaceus, Weissella (W.) confusa and W. cibaria were previously reported [66] [67] [68] [69] [70].

VII. ACRYLAMIDE REDUCTION

Acrylamide, a thermal processing contaminant, is generated in carbohydrate and asparagine rich foods that has been processed at high temperatures [71]. Bread is an important source of dietary acrylamide exposure due to its relatively high consumption rate besides acrylamide levels in bread crust [72] [73]. Fermentation in breads reduces acrylamide content due to a consumption of the limiting precursor asparagine by yeast [74]. It was reported that acrylamide content could be reduced by using LAB excreting lower amylolytic activity and higher

proteolytic activity. [75]. Some researchers have linked LAB strains belong to species Lb. casei-casei, Lb rhamnosus, Lb. plantarum, Lb. paracasei, Lb. sanfranciscensis, Lb. reuteri, Lb. sakei , Pd. acidilactici and Pd. pentosaceus to acrylamide reduction in bakery products [75-76] [77-78]. The phenomonia for acrylamide reduction can be strain dependent due to limiting factor of the reactants or decreased pH. On the other hand, sourdough fermentation with suitable Lactobacillus strains can be used as an innovative technology to reduce the acrylamide content of breads.

VIII. STARCH DIGESTIBILITY

Dietary carbohydrate represents a major source of plasma glucose and an increase in the amount of rapidly digestible carbohydrate in the diet increases blood glucose levels (GI). The level of starch digestibility is generally characterized by the rate and duration of the glyceamic response [79] and the GI is an important indicator of starch digestibility. The use of sourdough fermentation technology, especially in low pH levels, leads to a significant reduction in the glyceamic response (GI about 50) in comparison with usual yeast leavened white bread (white-wheat flour; GI 100) [80-81-82-83-84] [85]. The effect of the sourdough process on the starch digestibility can be related to the formation of organic acids. In addition, the chemical acidification in sourdough fermentation can affect starch gelatinisation and promote the formation of resistant starch that is less digestible [81-86].

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