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Baking: Sourdough Bread

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A Mixture with Many Names

If a mixture of flour and water is left at ambient temperature for a prolonged period it transforms into a remarkably sour, aromatic, and gaseous mass of dough. This transformation, caused by endogenous and exogenous microflora, is a biochemical phenomenon known as fermentation. A variety of labels are given to this mixture: pre-ferment, levain, poolish, biga, barm, pâte fermentée, mother, chef, and sponge, but sourdough starter is one of the most common terms used. The specific label used is usually dependent upon the geographic location of production, the choice of production method, and the particular formulation used. The breadth of terms used can often confuse and bewilder many bakers. Nonetheless, while the label for the mixture may differ, the fundamental scientific principles behind its production and application do not.

Protecting the Heritage of Sourdough

The primary role of a sourdough starter is to aerate (leaven) a bread dough (Decock and Capelle 2005). Sourdough starter typically accounts for no more than 50% of the bread dough (Hansen and Schieberle 2005). The resulting breads are collectively known as sourdough bread. Rye or wheat flours are the most commonly used flours for sourdough production, although a variety of flours can be used, such as barley and sorghum (Mariotti et al. 2014; Sluková et al. 2016). Sourdough fermentation is considered to be one of the oldest food biotechnological processes for fermenting cereal foods (Gobbetti et al. 2008). Today, sourdough breads are common in a wide range of cuisines around the globe, in particular in Europe, the Middle East, North America, and the Mediterranean (Spicher 1999). In Italy alone, almost all of the approximately 200 traditional Italian breads today use sourdough starters in their production (Minervini et al. 2012). Traditional sourdough production is quite a labour-intensive and time-consuming process, considerably more so than the conventional ‘straight dough method’ that uses a commercial yeast to leaven bread. Baker’s Yeast (*Saccharomyces cerevisiae*) is the primary leavening agent used in the ‘straight dough method’ (Jayaram et al. 2013). This involves a relatively short bulk fermentation, usually lasting a couple of hours at 27 °C (McGee 2004). Due to the ubiquity of these yeast breads, the ‘culture’ and craft surrounding sourdough baking has been, for the most part, lost by many bakers. A select few specialists and enthusiast bakers are preserving the heritage of sourdough bread production (Catzeddu 2011).

Artisan over Convenience

In recent times, there has been a global upsurge in demand and consumer appreciation for the flavour and taste of authentic, artisan-style sourdough bread (Minervini et al. 2012). The nutritional, technological, and shelf life properties of sourdough bread have been found to be superior to those of yeast bread (Gobbetti et al. 2014). Moreover, their sensory properties set these breads apart. The deep sour taste, pronounced complex aromas and flavours, dense crumb, and thicker crust are just some of the distinctive sensory properties that a sourdough starter can bestow on a bread (Pétel et al. 2017). Research has shown that sourdough bread contains a broader range of volatile compounds, which contribute to bread flavour (especially in the bread crumb), in comparison to yeast bread (Decock and Cappelle 2005).

The baking process is an important baking step for the development of bread crust flavour, whereas complex microbial interactions during fermentation are responsible for the formation of the characteristic flavour of the bread crumb (Hansen and Schieberle 2005). A multitude of environmental and ecological factors govern the fermentation process: temperature, pH, redox potential, ionic strength, dough composition, dough yield, and microbial enzymatic reactions (Font de Valdez et al. 2010; Spicher 1999). Thus, a deeper understanding of the sourdough fermentation process can assist the baker in controlling the production of consistent-quality bread through a more straightforward process.
Sourdough Fermentation – It Is All About the Microbes

Traditional sourdough fermentation is a complex process. The microflora involved in the fermentation process are composed of stable associations of cultures of symbiotic Lactic Acid Bacteria (LAB) and wild yeasts (Gänzle and Ripari 2016). These are derived from natural contaminants present in the flour or as spores throughout the environment, and convert simple sugars, found in the flour, into carbon dioxide gas (CO₂), organic acids, and alcohols under anaerobic conditions (Gobbetti 1998).

Lactic Acid Bacteria

Lactic Acid Bacteria (LAB) are bacteria characterised by the production of lactic acid as the primary by-product of fermentation (Monedero et al. 2017). In addition to lactic acid, many LAB strains can produce carbon dioxide gas (CO₂) as a by-product, which contributes to leavening. There is immense diversity among the strains of LAB in a sourdough; approximately 50 different species of sourdough LAB have been isolated from traditional sourdough starters (De Vuyst and Neysens 2005). The majority of strains belong to the genus *Lactobacillus*, with *L. sanfranciscensis*, *L. brevis*, and *L. plantarum* among the key species of *Lactobacillus* (Gänzle et al. 2007). Growth temperature for *Lactobacillus* is in the range 2–53 °C; however, the optimum range is 30–40 °C (Hammes and Vogel 1995).

In mature sourdough starters, the ratio of LAB to yeast ranges from 10:1 to 100:1 (Minervini et al. 2012). The dominance of LAB is a result of their adaption to the unique environment. LAB possess several stress response mechanisms that are activated to enable the bacteria to overcome the hostile environment: acidity, oxidation, periods of starvation and dehydration, and extremes of temperature (De Angelis et al. 2001).

Broadly speaking, LAB fall into three general categories based on specialised carbohydrate fermentation pathways: (i) facultatively homofermentative, (ii) facultatively heterofermentative, and (iii) obligately heterofermentative. Facultatively homofermentative LAB almost exclusively degrade simple sugars into lactic acid (>85%) as a sole by-product of fermentation. On the other hand, heterofermentative types produce ethanol, acetic acid, and CO₂ in addition to lactic acid (<50%) as by-products of fermentation (Hansen and Schieberle 2005). The final category, obligately heterofermentative, differ from facultatively heterofermentative as they have the ability either to produce lactic acid solely or, depending on the sugars available, to produce ethanol and acetic acid in addition to lactic acid (Hammes and Vogel 1995).

Yeasts

Yeasts are single-celled facultative microbes (a type of fungi) capable of converting simple sugars into ethanol (alcohol) and CO₂ under anaerobic conditions (Jayaram et al. 2013). The primary role of yeast is to leaven the dough; however, they also play a role in flavour and aroma production. Researchers have isolated more than 20 different species of yeasts from sourdoughs (De Vuyst and Neyesens 2005). The most representative species belong to the genera *Saccharomyces* and *Candida*, with the species being *S. exigus*, *C. humilis*, and *C. krusei* (Corsetti and Settanni 2007).

Sourdough Fermentation Process

In wheat and rye flours, the primary fermentable carbohydrates (maltose, sucrose, glucose, and fructose) are within starch granules. Starch accounts for approximately 60–70% of the carbohydrates in wheat and rye flours (Gänzle and Ripari 2016). LAB predominantly metabolise maltose and fructose (Corsetti and Settanni 2007). Yeasts, on the other hand, mainly metabolise glucose, fructose, and sucrose. Before they can digest these sugars, endogenous flour enzymes, such as amylase, break the starch (and polysaccharides) down into simple sugars (Brandt 2007) (Figure 10.1).

<table>
<thead>
<tr>
<th>TABLE 10.1</th>
<th>Examples of Common Species of <em>Lactobacillus</em> Strains Associated with Sourdough Fermentation</th>
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<tr>
<td>Facultatively Homofermentative</td>
<td>Facultatively Heterofermentative</td>
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<tr>
<td><em>L. acidophilus</em></td>
<td><em>L. plantarum</em></td>
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<td><em>L. amylovorus</em></td>
<td><em>L. pentosus</em></td>
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<td><em>L. farcininis</em></td>
<td><em>L. alimentarius</em></td>
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<td><em>L. mindensis</em></td>
<td><em>L. paralimentarius</em></td>
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<td><em>L. crispatus</em></td>
<td><em>L. casei</em></td>
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<tr>
<td><em>L. johnsonii</em></td>
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<td><em>L. amylolyticus</em></td>
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Following this, the microbes degrade simple sugars into pyruvic acid through a process known as glycolysis (Pétel et al. 2017). Several salient compounds are subsequently generated from pyruvic acid through one of two fermentation processes characterised by different general metabolic paths: lactic acid fermentation and alcohol fermentation (Figure 10.1). During lactic acid fermentation, the enzymes secreted by the LAB reduce pyruvic acid into lactic acid. In contrast, similarly to the brewing of beer, alcoholic fermentation involves conversion of pyruvic acid into ethanol by the action of yeast. Alcoholic fermentation by yeast directly produces a number of key flavour compounds (Hansen and Hansen 1994).

### Traditional Sourdough Fermentation with a Touch of Back-Slopping

The underlying function of traditional sourdough fermentation is the continuity of the established microflora. This is achieved through the consecutive re-inoculation of a new batch of sourdough with a portion of a previously fully fermented batch of starter (10–40% w/w), known as an inoculum (De Vuyst and Neysens 2005). The inoculum is mixed into an initial basic dough of flour and water, which is then incubated at 20–30 °C (Nionelli et al. 2014). Continuous propagation is maintained and optimised through a cyclic enrichment process known as back-slopping (Figure 10.2). This entails the scheduled refreshment of nutrients into the dough through the addition of raw materials: fresh flour and water (typically 5–25% w/w) (Figure 10.2).

The fermentation times for the microbes differ. LAB require over 12 hours, under optimum conditions, to produce sufficient quantities of flavour compounds. Yeasts, on the other hand, only require a few hours to produce adequate amounts of flavour compounds (Hansen and Schieberle 2005; Chavan and Chavan, 2011). Depending on the microflora present at the beginning of the process and the desired qualities of the final product, each refreshment step takes place every 8–24 hours (Pontonio et al. 2015) and is repeated between 5 and 10 times in total (Böcker et al. 1995; Hammes and Gänzle 1998).

Back-slopping introduces the required nutrients for the development of the microbiota and flavour-contributing molecules for the sourdough (Ercolini et al. 2013). In this way, starter microflora can be continuously maintained over several decades or even longer (Vogel et al. 2011). One commercial example of this is the renowned Boudin Bakery in San Francisco, USA; the starter culture used in each loaf of bread at Boudin Bakery is said to be the
Stability of the Ecosystem

The main characteristic of a mature sourdough starter is that facultatively and obligately heterofermentative LAB dominate over homofermentative LAB (Vander Meulen et al. 2007). The common facultative heterofermentative strains include L. fermentum, L. brevis, and L. plantarum (Corsetti 2012; Mariotti et al. 2014; Minervini et al. 2015). Of obligately heterofermentative LAB, L. sanfranciscensis is the prevalent strain, and an important microbe, which is found in over 75% of sourdoughs (Gänzle and Ripari 2016). Heterofermentative LAB are actually called the ‘aromatic’ microflora (De Cock and Cappelle 2005). These microbes produce considerable levels of acetic acid, which is important for pleasant, mild, sour flavour development (Hansen and Schieberle 2005; Kaseleht et al. 2011). Furthermore, acetic acid-tolerant yeast species, mainly S. cerevisiae and C. humilis, thrive in these acid conditions (Lacumin et al. 2009; Valmori et al. 2010; Minervini et al. 2015). In addition, these yeast strains are also known to provide a considerable contribution to the flavour profile of the final bread (Makhoul et al. 2015).

The initial dough encompasses microbiota endogenous to the raw material itself. These include several strains of yeast (Candida, Pichia, Rhodotorula, Saccharomyces, and Torulaspora), filamentous fungi (Alternaria, Cladosporium, Fusarium, Aspergillus, and Penicillium), bacteria (Glucobacter, Micrococcaceae, Enterobacteriaceae, and Pseudomonas), and diverse LAB (Enterococcus, Lactococcus, Lactobacillus, Leuconostoc, Pediococcus, and Streptococcus) (Siewmann et al. 2018). The decline of these microbes and the prevalence of favourable microbes is not immediate. The dough is ever-evolving throughout the fermentation process; it can take up to one week for microbiota to evolve toward a stabilised, mature, and active sourdough (De Vuyst et al. 2014). Temperature, time, acidity, and the addition of nutrients (back-slops) are key interdependent fermentation parameters (Van der Meulen et al. 2007).

Temperature affects the acetic acid-to-lactic acid ratio in the dough. Higher temperatures (30–37 °C) tend to lead to the dominance of L. fermentum (Gänzle et al. 1998). High fermentation temperature generally results in high acidity, caused by enhanced LAB metabolism, which is detrimental to yeast metabolism (Vranckens et al. 2011). Low to moderate temperatures (<30 °C) facilitate heterofermentative LAB species thriving in sourdough; with longer fermentation times, they produce a favourable mixture of lactic acid, acetic acid, and/or ethanol (De Vuyst et al. 2014). As time and the number of back-slops increase, the pH of the dough decreases. During the early days of fermentation and back-slopping, the addition of nutrients enables the production of organic acid, resulting in a decrease in pH to 5.0–6.2. At this stage, lactic acid fermentation begins, hindering the growth of microbes that are sensitive to acidity (De Vuyst and Neyesens 2005; Ercolini et al. 2013). Between 5 and 10 days of fermentation, with four or more back-slops completed, a gradual decrease in pH to approximately 4.0 is achieved. This results in a well-adapted LAB and yeast community being established (Brandt 2007; Ripari et al. 2016).

Bringing the Dough Together

The heritage, art, and skill involved in the production of high-quality sourdough bread are undeniable. Attention to detail, experience, and passion for sourdough production are vital qualities of the artisan baker; however, these cannot solely account for consistent, high-quality bread. Controlling the fermentation process, through back-slopping, provides favourable conditions in the sourdough for the development of a coveted microflora profile. Therefore, it is a firm understanding of the fundamental scientific principles behind the metabolic activity of the sourdough microorganisms that is the most significant knowledge a baker can possess.

REFERENCES


