

Industrial production of sourdoughs for the baking branch – An overview[☆]

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ABSTRACT

Sourdoughs are produced both in artisanal and industrial size. Sourdough manufacturers deliver the baking branch either with starters for production of in-house sourdoughs or with fully fermented sourdough products. In the latter case sourdough production is separated in time and space from the bread production. A big part of this convenience products are dried sourdoughs, which are mainly produced from rye and wheat flour, but also from other starch containing plants, like pseudocereals or legumes. The requirements regarding the raw materials used differ from that used for baking bread. The most applied drying techniques for sourdoughs are drum and spray-drying. Compared with other foods, sourdough and sourdough products have only a low risk regarding food safety due to $\text{pH} < 4.2$, however formation of biogenic amines or acrylamide has taken into account. More tools for sourdough authentication are needed but, before developing and validating methods, it would be necessary to include different sourdough products in a clear regulatory framework.

1. Introduction

In 2014 32 million tons of bread were produced within the 27 countries of EU (Bread Initiative, 2016). Bread consumption patterns differ widely within the EU, but most countries consume an average of 50 kg of bread per person per year (Bread Initiative, 2016). The European Bakery sector is composed by > 190,000 small and medium sized enterprises and 2.200 large companies employing > 2 million people. The market structure varies throughout Europe. According to the Bread-Initiative. Eu, a consortium consisting of five trade associations representing both craft and industrial companies in the cereal supply chain, in the United Kingdom the industrial sector representing 80% of bread production, it is 40% in Germany, 35% in France and 19% in Spain. In Germany, 73.5% of breads are produced with sourdough (Deutsches Brotinstitut e.V., 2016), which is used by both artisanal and industrial bakeries. Sourdough manufacturers deliver the baking branch either with starters for production of in-house sourdoughs or with fully fermented sourdough products. In the latter case sourdough production is separated in time and space from the bread production.

Sourdough is fermented by lactic acid bacteria or in combination with yeasts. Substrates are mainly wheat and rye flours mixed with water. Although other starch containing plants were always used for sourdough fermentation (Maurizio, 1919), their usage was negligible. With the growing demand for gluten-free bread, this alternative fermentation substrates gain new interest. Gluten-free bread and other leavened baked goods are consumed by people suffering from celiac

disease (0.3–1% of humans) and Non-celiac-gluten sensitivity (around 6%) (Scherf et al., 2016). Sourdoughs are an effective tool for improvement of gluten-free breads (Moroni et al., 2009). The aim of this review is to give an overview on commercial production of fresh and ready-to-use sourdoughs.

2. Industrial sourdoughs

Both artisanal and industrial bakers perform their own in-house sourdough fermentations. Consumers often expect a great variety of breads from one baker and within that, an authentic ingredient list, for example they expect that a spelt bread is produced without any wheat. Therefore a spelt sourdough is needed. Usually a bakery produces one or two sourdoughs by own fermentation, whereas special or rarely needed sourdoughs purchased as a ready-to-use product from sourdough manufacturers. Industries producing sourdough possess knowledge and experience to prevent mal-fermentations and generating antifungal compounds or exopolysaccharides during fermentation (Lacaze et al., 2007). In addition, sourdough industries provide bakery with dried sourdoughs as convenient ingredient in bakery pre-mixes. Overall the use of industrial sourdough products fermented prior the use in the bakery allows a greater variety in flavour and taste of the resulting breads.

There exist mainly two forms of industrial sourdough products on the market, which are used both by industrial and craft bakers: sourdoughs containing living microorganisms and “ready-to-use-

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sourdoughs”. Sourdoughs containing living microorganisms are used as a starter for baked goods production and sold in pasty or liquid form or as stiff or crumbly dough. Dried products in powder form are available too, thanks to gentle drying technologies such as spray, fluidized bed or freeze drying, which would keep microorganisms alive. “ready-to-use-sourdoughs” are fully fermented products wherein the microorganisms are usually inactivated after fermentation in order to obtain a shelf-stable product. Here fermentation is finished prior to use in bakery. They exist in powder, liquid or pasty forms. At the borderline between “living” and “ready to use” sourdoughs are also available. These may act as starter, but are usually applied as ready-to-use-product (Brandt, 2007; Brandt, 2014; Decock and Cappelle, 2015).

Sourdough fermentation at specialized industries is performed as in artisanal baking, except for the larger scale of fermentation. Final product quality is determined by the combination of the used raw material, the conditions of the process (temperature, dough hydration, amount of inoculum, fermentation time, etc.) and the fermenting microbiota. Both type I sourdoughs, which are characterized by relatively short fermentation times and leavening capacity, and type II sourdoughs which are fully fermented (Van Kerrebroeck et al., 2017) are applied. Additionally the inoculation of sourdoughs with bacteria propagated in laboratory media prior the application in sourdough is in use. Fig. 1 gives a schematic overview of the process and the various kinds of sourdough products. After fermentation, the sourdoughs are further processed depending on the intended use: starters for bakeries or ready-to-use-sourdough. In the latter case the microbes need to be inactivated or at least their activity has to be slowed down. Starters for bread production are not only available as sourdoughs, but also grown on culture media and after harvest enriched by centrifugation or filtering, as for example for baker's yeast.

2.1. Raw materials used

Sourdoughs are mainly based on wheat and rye flour. Beside whole grains flours, also milling fractions, such as bran or wheat germ, are

subjected for fermentation and deliver different taste and flavour compared to sourdoughs from refined flour. The main quality criterion for industrial sourdoughs is a constant total titratable acidity (tta) and therefore factors in the raw material affecting tta are important quality criteria. One factor is the concentration of phytate, which is usually correlated with the ash content of the flour (Fretzdorff and Brümmer, 1992). Phytate [*myo*-inositolhexakisphosphate] is the major storage form of phosphorus in the plant seed (Reae et al., 2004). During sourdough fermentation, phosphoric acid is released by endogenous cereal and bacterial phytase, which acts as buffer (Hammes et al., 2005). The resulting acid content of a sourdough depends from the available content of fermentable carbohydrates, therefore a high amyolytic activity of the raw materials is preferred. Success in breeding has led to a strong decrease in rye during the last decades (Brandt, 2015). A smaller particle size of wheat bran enhances the acidification rate (Coda et al., 2014a). Last, the enzymatic susceptibility of the flour, which is represented by the amount of damaged starch, is of importance (Struyf et al., 2017).

Favoured by the increasing demand for gluten-free sourdoughs, a lot of alternative flours are used for sourdough production: Pseudocereals, such as quinoa, amaranth, and buckwheat (Arendt and Moroni, 2013; Coda et al., 2014b), legumes such as chick pea, fava bean (Coda et al., 2017; Rizzello et al., 2015; Sozer et al., 2017), or starch containing vegetable species as chestnut (Rinaldi et al., 2017). Sorghum, millet, maize and rice are alternative flours conferring special taste (Alaunyte et al., 2012; Falade et al., 2014; Sekwati-Monang et al., 2012). Compared to wheat and rye processing, only a few bakeries produce gluten-free breads and therefore perform sourdough fermentations on artisanal or industrial scale. The quality criteria regarding the quality of the alternative flours used for production of sourdough are the same as mentioned before for rye and wheat processing. However, in contrast to wheat, rye or spelt the quality characteristics of alternative flours are not standardised and vary from batch to batch and not only from the year of harvest. For example, rice flour is usually milled from broken kernels bought from several places in the world. And the range of used

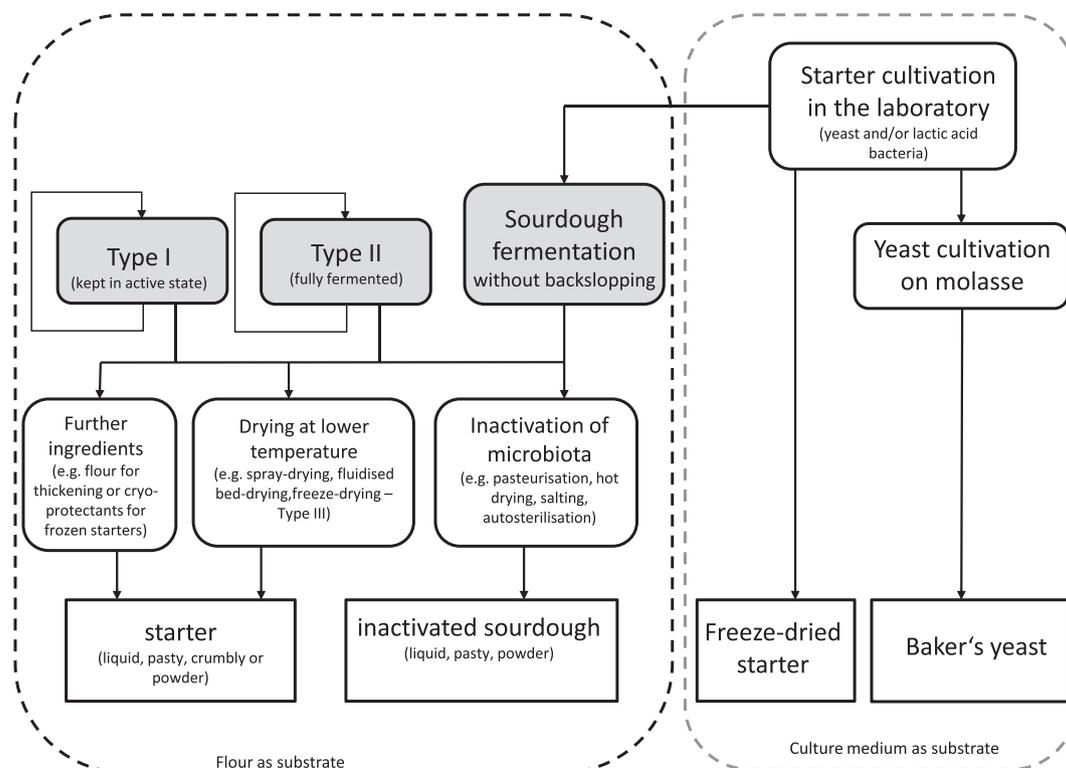


Fig. 1. Production schemes for fermented ingredients for baking purposes.

Table 1
Odor intensities (sensory profile) of gluten-free dried sourdoughs acc. ISO 13299:2016-09 (2016) on a scale from 0 to 3.

	Chick pea sourdough	Rice sourdough	Maize sourdough	Brown millet sourdough	Chestnut sourdough
Sour	1.3	1.2	2.0		1.5
Malty	1.5		1.9	1.3	1.6
Cereal (oat)		2.5		2.1	
Metallic		0.3			
Fatty		1.1		0.7	0.5
Dusty		1.5			
Roasty	1.9				
Mushroom	1.0				
Earth	0.9				
Marzipan				1.6	
Caramel	0.8		1.5	1.0	
Honey			1.5		
Smoky					2.2
Spicy					2.0
Peanut	2.1				
Meaty					2.1

Table 2
Concentrations of main flavour compounds of dried rice sourdough and the rice flour used for fermentation. Analysis was performed by AromaLAB GmbH, Planegg.

	Brown rice flour (µg/kg)	Brown rice sourdough (µg/kg)
1-Octen-3-on (mushroom)	6	65
Methional (cooked potatoe)	21	230
(E)-2-Nonenal (cardboard)	16	22
Phenylacetaldehyde (honey)	63	1300
2/3-Metylbutyric acid (cheesy-sweaty)	1700	820

flours is from whole-grain flours to by-products of food processing like residues from oil pressing (O'Shea et al., 2014). The main use of dried sourdoughs from alternative flours is the aroma and taste improvement of gluten-free baked goods. Table 1 shows the results of sensory profiling of different gluten-free dried sourdoughs (unpublished results). Because the odor widely differed, specific descriptors for odor were selected for each sourdough. Dried rice sourdough was further examined and its aroma compounds were compared with the concentrations in the used brown rice flour. Aroma compounds were isolated by SAFE (solvent assisted flavour evaporation distillation) according to Engel et al. (1999) and quantified by GC/MS with isotope-labelled standards (Anonymous, 2006). Compared to brown rice flour, most of the aroma compounds increased during fermentation and drying, except for 2/3-metyl-butanoic acid, which was reduced (Table 2). Characteristic aroma compounds are often already present in the raw material used for fermentation, but their concentrations are strongly affected by fermentation; thus a completely different sensorial profile is created (Czerny and Schieberle, 2002). Except for 1-octen-3on, all the compounds were also reported for wheat sourdough bread (Pétel et al., 2017).

2.2. Drying techniques

Spray and drum drying are among the most commonly drying techniques, followed by fluidized bed drying and freeze-drying.

For spray drying the liquid sourdough is atomized by a spray nozzle. While the droplets fall down, water evaporates, thanks to a hot air stream flowing in the dryer. Dried particles are then collected from the dryer. Due to evaporative cooling in the particles, the formation of Maillard products is limited.

In drum, or roller drying technology a horizontally mounted hollow

cylinder made of cast iron is steam-heated inside. The steam pressure applied defines the temperature on the outer surface of the drum. The liquid or pasty sourdough is applied as a thin layer on the surface, while the drum is rotating. Water and volatile compounds evaporate immediately and after a few seconds the sourdough (with a water content < 5%) is removed by a scraper (Tang et al., 2003). Application of the wet sourdough is often performed by one or more applicator rolls ensuring a thin product layer on the drum. During drying Maillard and other flavour reactions take place and malty and roasty-flavours are produced (Kirchhoff, 2000).

2.3. Microorganisms in use

Industrial production of sourdough products may be achieved by using sourdough from the previous batch (backslopping), which are used over decades (Lhomme et al., 2015; Müller et al., 2001; Vera et al., 2012), or from cultures propagated at small scale on laboratory media. For an industrial rye sourdough fermentation a stable persistence of *L. reuteri* over 10 years was demonstrated (Gänzle and Vogel, 2002; Zheng et al., 2015). There are only a few reports on the microbiota of industrial sourdough fermentations. In four of five French industrial organic bakeries the fermentations were dominated by *L. sanfranciscensis* (Michel et al., 2016) and in an Estonian industrial rye fermentation for bread production *L. helveticus*, *L. panis* and *L. Pontis* were predominant (Viïard et al., 2013). Another industrial French wheat sourdough was dominated by *L. panis*, *L. acetotolerans*, *L. amylolyticus* and *L. frumenti* (Vera et al., 2012). For a German industrial rye sourdough the dominating microbiota consisted of *L. amylovorus*, *L. reuteri*, and *L. pontis* (Müller et al., 2001). Beside this, back-slopped sourdoughs which consist usually of both homo- and heterofermentative lactobacilli, pure homofermentative lactobacilli are applied in batch processes for dried sourdoughs, as the yield of lactic acid is higher compared to a heterofermentative process where ethanol or acetic acid are produced, which are volatile during drying. As dried sourdoughs are used for flavour and taste enhancement of baked goods, this is the main selection criterion for the used lactobacilli. For dried sourdoughs containing living lactic acid bacteria the survival rate during drying is additionally of importance. Resistance to dehydration is species and strain dependent (Santivarangkna et al., 2007) and the dried sourdoughs need carefully selected packaging conditions (Peighambardoust et al., 2011).

3. Food safety aspects

As other food manufacturers, sourdough producers have to implement HACCP systems and therefore perform analysis to exclude any physical, chemical or biological risks possibly occurring during production. Physical risks, e.g. foreign bodies like broken glass, may be prevented by adopting measures such as sieves, magnets, metal or x-ray detection units and controls of broken glass. For risks of biological origin, which mainly means the occurrence or growth of pathogenic microorganisms, sourdough is a relatively safe food. Indeed, pH < 4.2 prevents the growth of pathogenic microorganisms; further baking inactivates any vegetative microbial form. Mycotoxins may contaminate sourdough, notwithstanding moulds do not grow under semi-anaerobic conditions. However they may be originated from contaminated flour. Mills are the main responsible actors in the food chain that may reduce mycotoxin contamination of flour by applying effective cleaning and sorting procedures. Indeed, moulds are mainly located in the outer layers of the grain. During sourdough fermentation mycotoxins may be degraded (Valle-Algarra et al., 2009; Vidal et al., 2014). When rye and spelt flours, intentionally contaminated with ergot alkaloids, were used in sourdough fermentation a small reduction of this mycotoxin was achieved. Moreover, the ergot alkaloids were strongly reduced during the subsequent drying of the sourdoughs (Brandt and Kniel, 2015). Yet, more research is needed in the field of sourdough biotechnology for reducing mycotoxin contamination.

Production of gluten-free sourdoughs needs special precautionary measures, because separate production rooms, carefully selected raw materials and intensive cleaning procedures have to be used. Although gluten proteins are partially hydrolysed during fermentation, a competitive ELISA has to be used to quantify gluten in gluten-free sourdough. This quantification method was validated on an intentionally contaminated quinoa sourdough (Köhler et al., 2013).

3.1. Acrylamide

Acrylamide (2-propenamide) is a process contaminant, which may be formed during Maillard reaction from asparagine and sugar-derived carbonyl compounds (Keramat et al., 2011). Acrylamide is regarded as potentially carcinogen (CONTAM, 2015) and the European Commission (Regulation 2017/2158) has defined benchmark levels and mitigation measures for the reduction of acrylamide in food. Bread has relatively low levels of acrylamide compared to other food, e.g. French fries, but, being a staple food it contributes to the total intake of acrylamide. No benchmark levels for acrylamide exist in dried sourdoughs, although, being a baking ingredient, the formation of acrylamide should be considered. Generally the acrylamide content of breads leavened with sourdough is lower than in breads fermented without sourdough (Forstova et al., 2014). One reason is the drop in pH, as it lowers the Maillard reaction rate by favouring protonation of the amine group of asparagine and therefore the formation of a Schiff base. However, chemical acidification is less effective in acrylamide reduction than biological acidification (Bartkiene et al., 2017), because in the latter sugars are consumed by microorganisms during fermentation. In baking, dried sourdoughs are used in low amounts (1–10% of flour) so they contribute only in small amounts to the acrylamide content of the final bread. The acrylamide content of dried sourdoughs was under the limit of detection (20 µg/kg) (unpublished results).

3.2. Microorganisms

Starters with a long history of safe use in food, such as, backslapped sourdoughs are regarded as traditional food and therefore need no qualified presumption of safety (QPS) status. Almost all microorganism used in the production of sourdoughs are in the QPS-list. Newly described species, which may be the result of refined identification methods today, can also be recognized as used for long time (Vogel et al., 2011). For lactic acid bacteria with a QPS status a restricted safety assessment of the used cultures is sufficient (Vogel et al., 2011), including the potential to form physiologically active biogenic amines or to harbour genes coding for transferable antibiotic resistance. Fermenting bacteria associated with food, with the possible exclusion of enterococci, do not pose a clinical problem (BIOHAZ, 2008), even if resistant to antibiotics. However they may act as a reservoir for transferable antibiotic resistance genes for pathogens and therefore bacteria with resistance to clinically relevant antibiotics should not be used. Biogenic amines are a group of mildly toxic compounds which can be formed in fermented food by decarboxylation of amino acids (Nout, 1994). Reports about intoxication by biogenic amines upon consumption of baked goods are rare. In a survey of 23 commercial breads in Spain, produced with or without sourdough, no biogenic amines were detected (Diana et al., 2014). In lupine (Bartkiene et al., 2011) and flaxseed sourdough (Bartkiene et al., 2014) formation of biogenic amines was observed, but far beyond the levels causing potential intoxication. When some selected strains were used, the concentration of biogenic amines in flaxseed sourdough was reduced (Bartkiene et al., 2014).

4. Regulatory aspects

Different expectations from consumers to bread sold as “sourdough bread” are encountered in the world. Whereas on one hand in some

countries it is expected that sourdough bread is leavened without baker's yeast, in some others it is legal to declare as “sourdough bread” even the product obtained without fermentation and using citric or lactic acid. The most detailed legal regulations regarding the use of sourdough are laid down in the specifications for breads registered with protected geographical indication (Regulation EU1151/2012). For “Pan de Alfacar” the sourdough has to be fermented in wooden bins or for “Pane di Matera” the sourdough has to be started with incorporation of fruits. Although sourdough is an intermediate product during bread production, it has found its way into legal framework in some countries like France, Austria or Germany long time ago and actually in Belgium, the Netherlands and Spain a regulatory framework for sourdough is in preparation. Sourdough is an intermediate product of bread production, having different meanings: (i) leavening agent for traditional bread production; (ii) souring method for rye bread production; (iii) microbologically active product used as starter; or (iv) the result of microbial fermentation, wherein microbes have been inactivated. Because of different meanings and array of sourdough preferences (e.g. low acid in southern Europe, high in the north, use as leavening agent or baking improver) the issue of a universally recognized declaration arises. Basing this declaration on a minimum acid content or a minimum/maximum fermentation time may exclude some used sourdough processes. To define a minimum value of cell density of lactic acid bacteria and/or yeasts would face the issue of detecting microorganisms in the final bread, given that during baking microbes are inactivated and DNA is degraded to a certain extent. Application of quantitative PCR in dried sourdough is able to give information about the use of sourdough, although not undoubtedly (Wieschebrock et al., 2011). Pontonio et al. (2017) developed a method, which clearly could distinguish between sourdough- or baker's yeast leavened bread. To prevent misleading of the consumer, more tools for sourdough authentication are needed but, before developing and validating methods, it would be necessary to include different sourdough products in a clear regulatory framework.

5. Conclusion

Industrial sourdoughs are produced in the same way as in artisanal baking. The specialization allows the sourdough manufacturers to deliver a broad range of products, which may be used for gluten-free baked goods and for wheat breads.

Conflicts of interests

The author is employed by Ernst Böcker GmbH & Co. KG, a sourdough producing company.

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