Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 01, Page 9-28

http://www.jmaterenvironsci.com

A Review of Spontaneous Sourdough as a Functional Ingredient for Improving the Sensory and Nutritional Quality of Wheat Bread

I. EL Houssni [1*], A. Zahidi [3], K. Khedid [2], R. Hassikou [1]

[1] *Department of Biology, Laboratory of Botany, Mycology and Environment, Faculty of Sciences, Mohammed V University, Rabat, Morocco*

[2] *Department of Microbiology, National Institute of Health, Rabat, Morocco.*

[3] *Department of Drug Sciences, Laboratory of Medicinal Chemistry, Faculty of Medicine and Pharmacy, Mohammed V University, Rabat, Morocco.*

**Corresponding author, Email address: imaneelhoussni@gmail.com*

Received 06 Sept 2021,
Revised 30 Dec 2021,
Accepted 03 Jan 2022

Keywords
- ✓ Wheat bread,
- ✓ Sourdough,
- ✓ Lactic acid bacteria,
- ✓ Yeasts,
- ✓ Quality characteristics.

imaneelhoussni@gmail.com
Phone : +212 6 17 55 17 96

Abstract

Background : Currently, the increase in the nutritional value of food constitutes a major challenge in global nutrition, which is mainly aimed at preventing malnutrition and related diseases. Among the foods that are subject to this challenge, wheat bread, the traditional staple food of many populations worldwide, is often denigrated because of its low nutritional value due to the poor manufacturing practices that use baker's yeast. **Methods :** Research was conducted on a wide range of databases (MEDLINE via PubMed, SpringerLink, Scopus, and Science Direct), over the period from **1970** to **2020**, using the keywords : Wheat bread, sourdough, Lactic acid bacteria, yeasts, quality characteristics, nutritional value. **Results :** All reviewed publications proposed the use of sourdough during bread-making as an alternative to baker's yeast. Its effectiveness has been proven through its capacity to improve the nutritional composition of wheat bread, which remains capable to satisfy the daily nutritional requirements in macronutrients and micronutrients, along with its sensory characteristics in terms of taste, flavor, volume, texture, and shelf life. Interestingly, the consumption of sourdough bread as a staple food prevents diabetes, gluten intolerance, and mineral deficiency, which are major global public health problems. **Conclusion :** The use of sourdough in the bread production industry may become a future innovative technology, considering the changes in the human diet, caused by the increase in the production of processed foods, rapid urbanization, and changing lifestyles.

1. Introduction

Globally, in developing countries, the diets are mainly plant-based with a limited amount of animal source foods, including cereal products. Among them, wheat bread which is the most consumed product for centuries [1-2]. Nutritionally, its consumption is recommended due to the high nutritional value of wheat, which constitutes an important source of principal micronutrients and macronutrients for billions of people. It is rich in starch, dietary fiber, proteins, minerals, and vitamins [3-4].

Worldwide, commercially produced bread is leavened with baker's yeast mainly dominated by the yeast strain *Saccharomyces cerevisiae* [5-6-7]. The use of baker's yeast, under optimal processing conditions, leads to the production of smooth and uniform dough, and well aerated and tasty bread because of the production of CO_2 and alcohols during fermentation [5-8-9]. Whereas the CO_2 confers volume and lightness to the bread, and the alcohols (which evaporate during baking) make it tastier [9]. Thus, confirming the technological performance of yeast fermentation in baking applications.

Unfortunately, despite the important gustatory, rheological, and organoleptic profile of baker's yeast bread, nutritionally, its consumption remains inadvisable because of its harmful effects on health. Between many effects, we find the intolerance to gluten, which is an indigestible protein predominantly found in wheat. While it is essential for the elasticity during kneading, and the leavening during fermentation, its ingestion remains intolerable because it provokes an abnormal immune response that induces an excessive production of antibodies against gluten, which creates an inflammatory response in the intestinal villi, that alters the intestinal assimilation of nutrients [10-11- 12-13]. Furthermore, the consumption of bread with baker's yeast increases the blood glycemia level due to the rapid digestion of its starch content, which leads to the development of diabetes [14-15- 16]. Without forgetting the prejudicial effect of chemicals added during industrial bread-making to enhance the flavor and speed up the manufacturing process of bread.

For these reasons, health experts have been interested in the nutritional adequacy of wheat bread in a plant-based diet. Accordingly, numerous studies is carried out by referring to a traditional fermentation process, which remains effective up to the present day, in order to produce bread, which fulfills nutritional requirements of consumers for optimal health along with improved sensory features.

This article highlights the evidence on the reliability of this technology through a selective literature search using electronic databases from 1970 to 2020. A further objective is to discuss the particular challenges in this field and to make recommendations to encourage the use of this technology.

2. Material and Methods

The search for literature and experimental data involved a variety of electronic databases: MEDLINE via PubMed, SpringerLink, Scopus, and Science Direct. The review used the search terms: *Wheat contaminants*, *sourdough types*, *sourdough microbiota*, *sourdough fermentation*, *sourdough microbiota effects*, *baker's yeast*, *bread sourdough*, *baker's yeast bread*, *sourdough and starch digestibility*, *sourdough and gluten degradation*, *sourdough and phytic acid reduction*. They were searched in sources from 1970 to 2020. This involved all articles written with a focus on the microbial biodiversity of sourdough and its effect in improving the sensory and nutritional quality of wheat bread. There was no language restriction for documentary searches. All data were extracted, fully read, and validated by the first author. 197 articles were identified; 150 of them were retained, of which 84 % concerned full text and 16 % were abstract data. This article was written by the first author and validated by the second, the third and the fourth authors.

3. Results and Discussion

Wheat grains are a significant human foodstuff worldwide [17]. They constitute a staple food in most parts of the world. Their consumption warrants an important role in a healthy diet as it reduces the risk of developing diet-related disorders such as obesity and cardiovascular diseases [18]. Its health benefits can be ascribed mostly to its nutritional composition rich in starch along with fiber, also containing an important amount of proteins, minerals, and vitamins [19]. They not only meet the nutritional and metabolic needs of humans, but also provide a good substrate for microbial growth [20-21-22]. Natural contaminants of wheat grains belong to the group of eukaryotic (moulds and yeasts) and prokaryotic (bacteria) organisms, which are mostly concentrated in the outer layers [23]. Their biodiversity and concentration depend on grain quality, storage conditions, and mill's process [24]. They are associated with the environment in which grains are grown. They may come from air, dust, soil, water, insects, rodents, birds, animals, humans, storage and shipping containers, and handling and processing equipment [25-26]. The microbial contamination of wheat can be affected by many environmental factors, especially climatic conditions such as temperature and rainfall, physical damage due to insects or mould attacks, and application of insecticides and fungicides [23- 27-26].

Microorganisms of wheat grains might follow the different phases of flour production and can be found in products made with flour, such as Sourdough. It consists of an acidic sharp-tasting mixture of flour and water obtained after fermentation using a microbial ecosystem, consisting mostly of lactic acid bacteria which synergistically co-existing with yeast, and originating is either from native wheat grains microbiota, or a starter culture [28-29-30-31-32].

Based on the kind of technology applied in their preparation, as used in artisan and industrial processes, sourdough has been classified into three types [20-21-23-33]. Type I sourdoughs involve in its preparation, traditional techniques, implying three-phase evolution of the growing microbial communities toward a stable ripe active sourdough. This type of sourdough is performed at ambient temperature (20 - 30 °C), and is based on backslopping which ensures its daily and continuous refreshment by leading to the prevalence of strains that are most adapted to the ecosystem of this type of sourdough originating from the flour which acts as the only non-sterile component [34-35]. In contrary to type I sourdoughs, type II sourdoughs develop in one step under temperatures that exceed 30 °C, in a very acidic environment at a pH < 3.5, for long periods of up to 5 days [20-36-37-38]. Those sourdoughs are used mostly in industrial processes using adapted culture starter to the flour- water mixture to start fermentation. Type III sourdoughs involve in its preparation a mixed process that manifests through the initiation with a LAB starter culture, followed by traditional backslopping, and as the last step, the evaporation of subsequent water leading to dried preparation [39-22-40]. They are considered as the dried form of type II sourdoughs [22]. Numerous drying techniques have been used, commonly, spray-drying and drum-drying. However, the use of these techniques provokes a loss of volatile flavor compounds during the evaporation of water. Thus, to keep more complete flavor properties of the sourdough bread produced, some researchers recommend the conservation of this type of sourdough in liquid form and its stabilization by pasteurization or by cooling [41].

As discussed above, wheat flour is not microbiologically sterile, neither is it heat treated before use. When the flour is mixed with water, LAB and yeasts become more and more adapted to the environmental conditions of sourdough and start to grow, reaching numbers above those of the adventitious microbiota, generally between 10^4 and 10^7 CFU/g [20-21-42]. As reported, the higher number is counted for the LAB ($> 10^8$ CFU / g) compared to yeasts ($< 10^7$ CFU / g) (22). Besides, the yeasts and LAB are often associated with sourdough, whereas the yeasts / LAB ratio is generally 1:100 [43-44]. This could indicate a high competition and a lack of non-competitive association between yeast species.

As specified, the LAB species are the most frequently observed bacteria in sourdough. They mostly belong to the genus *Lactobacillus* [45]. The number of *Lactobacillus* species identified has shown a considerable variety. It can reach up to more than 60 different species of LAB [20-46-47].

A large variety of *Lactobacillus* species belonging to the class of homofermentative and heterofermentative species has been isolated from Sourdough. An updated overview of the LAB species most commonly found in fermented sourdough is compiled in Table 1. Undesirable bacteria such as *Staphylococcus aureus* and *Bacillus cereus*, as well as other bacteria, may be present in minor concentrations [20]. Based on the numerous studies which have been performed on the identification of the main species of LAB isolated from sourdough, some authors revealed that the two most prevalent species were *Lactobacillus sanfranciscensis* (present in 47 % of the sourdoughs), *Lactobacillus plantarum* (44 %). These were followed by the *Lactobacillus brevis* (22 %), *Lactobacillus reuteri*, (19 %), *Lactobacillus alimentarius* (18 %), *Lactobacillus rossiae* and *Lactobacillus delbrueckii* (10 %) [48]. Besides to these species, other researchers identified *Lactobacillus fermentum*, *Lactobacillus paralimentarius*, and *Lactobacillus amylovorus* as the most common species isolated from sourdough [22-49-50]. On the other hand, it is postulated that the prevalence of *Lb. sanfranciscensis* in many sourdoughs indicates a dispersal-limited development of the sourdough LAB communities [48]. In a comparative study, 15 Lactobacilli species have been shown to occur both in sourdough and in human and animal intestines, they include *Lactobacillus reuteri*, *Lactobacillus acidophilus*, and *Lactobacillus plantarum* [36].

The biodiversity of LAB sourdough is suggested to be significantly dependent on the types of sourdough. Accordingly, *Lactobacillus brevis*, *Lactobacillus plantarum*, *Lactobacillus paralimentarius*, *Lactobacillus rossiae*, and *Lactobacillus sanfranciscensis* are the most dominating bacteria in sourdough fermentation processes that are characterized by low incubation temperatures and continuous backslopping (traditional sourdoughs, type I sourdoughs) [33-51-52]. In sourdough type II, which is characterized by higher temperatures, longer fermentation times, and higher water contents, *Lactobacillus amylovorus*, *Lactobacillus fermentum*, *Lactobacillus pontis*, and *Lactobacillus reuteri*, are the most dominating bacteria in this type of fermentation [33-53-49]. Furthermore, sourdoughs type III are known to be colonized mainly by LAB that is resistant to drying, e.g. *Lactobacillus brevis*, *Pediococcus pentosaceus*, and *Lb. plantarum* [20].

Several species of yeast are also found in sourdough (Table 2). *Saccharomyces cerevisiae*, *Candida humilis*, *Pichia kudriavzevii*, *Kazachstania exigua*, *Torulaspora delbrueckii*, *Candida colliculosa*, and *Wickerhamomyces anomalus* are the most frequently encountered in sourdough [54]. However, *Saccharomyces cerevisiae* has been reported to be the main yeast species in the sourdough ecosystem [55-56]. In contrast, in other separate studies, *Pichia anomala* and *W. anomalus* are abundantly found as compared to *S. cerevisiae* [57-22]. In sourdough, *Saccharomyces cerevisiae* is different from baker's yeast because its Crabtree is negative (insensitivity to glucose) [58]. The evidence from the literature indicates that acidity, water content, and sugars affect significantly the growth and abundance of the yeast population [59].

The microbial species coexisting in sourdough often interact among them through nutritional or trophic relationships [27-20-23-25]. These interactions result in the creation of non-competitive associations of different species of LAB on the use of all four flour carbohydrates (Maltose, Sucrose, Fructose, and Glucose), which constitutes an indispensable source of energy for their development and multiplication. A prominent example includes the stable association between *Lb. sanfranciscensis* and *Lb. plantarum*, where the first preferentially utilizes maltose and is generally unable to ferment fructose, while the second preferentially ferments glucose and fructose with maltose metabolism being subject to carbon catabolite repression [27-60]. The lack of competition for carbohydrates seems to be one of the prerequisites for the stability of LAB/yeast associations during fermentation [27].

Table 1 : Species of lactic acid bacteria isolated from sourdough

Species	Obligate heterofermentative	Facultative heterofermentative	Obligate homofermentative	References
Lactobacillus zymae	x	-	-	[41-132-133]
Lactobacillus acidifaninae	x	-	-	[132]
Lactobacillus hammesii	x	-	-	[134]
Lactobacillus buchneri	x	-	-	[20-36-135]
Lactobacillus namurensis	x	-	-	[136]
Lactobacillus spicheri	x	-	-	[133]
Lactobacillus fructivorans	x	-	-	[137-138]
Lactobacillus sanfranciscensis	x	-	-	[137-138-139-140]
Lactobacillus brevis	x	-	-	[132-137-139-138]
Lactobacillus amylovorus	-	-	x	[133-137-138-139]
Lactobacillus delbrueckii	-	-	x	[133-135-137-138-139]
Lactobacillus acidophilus	-	-	x	[133-135-137-138-139]
Lactobacillus johnsonii	-	-	x	[133-135-139]
Lactobacillus paralimentarius	x	x	-	[133-139-141]
Lactobacillus mindensis	x	-	-	[142]
Lactobacillus plantarum	-	x	-	[21-133-137-138-139]
Lactobacillus alimentarius	-	x	-	[133-137-138-139]
Lactobacillus farciminis	-	-	x	[39-133-135-137-138-139]
Lactobacillus casei	-	x	-	[133-137-138]
Lactobacillus fermentum	x	-	-	[133-137-138]
Lactobacillus reuteri	x	-	-	[133-137-138]
Lactobacillus pontis	x	-	-	[133-137-138]
Lactobacillus rossiae	x	-	-	[137-139-144]
Lactobacillus panis	x	-	-	[137-138-139-145]

Lactobacillus frumenti	x	-	-	[139-146]
Lactobacillus siliginis	x	-	-	[41-133]
Pediococcus pentasaceus	-	x	-	[20-139]
Weissella confusa	x	-	-	[135-137-138]
Weissella cibaria	x	-	-	[135-137-138]
Leuconostoc Lc. citreum	x	-	-	[137-138]
Leuconostoc mesenteroïdes	x	-	-	[137-138]
Lactobacillus hilgardii	x	-	-	[41-133]
Lactobacillus rhamnosus	-	x	-	[137-138]
Lactobacillus pentosus	-	x	-	[41-133]
Lactobacillus mindensis	-	-	x	[20-41-133]

Table 2 : Species of yeasts isolated from sourdough

Species	References
Saccharomyces cerevisiae	[47-137-139-147-148-149-150]
Kazachstania exigua	[137-139]
Candida humilis	[137-139]
Pichia kudriavzevii	[137-139]
Torulaspora delbrueckii	[137-139-149]
Wikerhamomyces anomalus	[137-139]
Candida krusei	[47-150]
Torulaspora holmii	[47-61-147-148-149]
Pichia saitoi	[47]
Candida stellata	[61-147]
Saccharomyces exiguus	[147-150]
Streptomyces inusitatus	[147]
Candida guillermondii	[148]
Hansenula anomala	[149]

For instance, the absence of competition between *Lb. Sanfranciscensis* and *S. exiguus* for maltose is fundamental for the stability of this association, knowing that *S. exiguus* preferentially uses glucose or sucrose, this association is also essential to reduce the competition and enhance the growth of both species [61-62]. The competitive interactions of microbial species in sourdough influence their production of lactic and acetic acids. An example of the association between *Lb. sanfranciscensis* and *S. cerevisiae* were optimal for producing acetic acid [63]. But the addition of *Torulopsis holmii* was found to improve dough acidification by *Lb. sanfranciscensis* and *S. cerevisiae* enhanced acid production by *Lb. sanfranciscensis* and *Lb. Plantarum*. The production of lactic and acetic acids decreased due to the faster consumption of maltose and, especially, of glucose by *S. cerevisiae* when associated with *Lb. Sanfranciscensis* [64-65].

During the last few years, the use of sourdough in the bread-making process has greatly increased, leading to an increase in the demand for bread sourdough consumption, due to its powerful organoleptic, nutritional, rheological, and healthy properties, as compared to bread made with baker's yeast. Table 3 summarizes the characteristics of sourdough bread versus baker's yeast.

The application of sourdough on bread-making make several documented effects, including the improvement of dough acidification, which participates in the optimization of its sensory and rheological properties. Consequently, it enhances the quality, taste, and flavor of wheat bread [66-67- 68]. In a comparative study evaluating the effect of acidification by the addition of sourdough and biological and chemical acidifiers on volume, some researchers confirmed the effectiveness of sourdough acidification in improving rheological properties and reported that the volume of bread was increased when the biological acidifiers were added, while the chemical acidifiers did not influence on bread volume [69]. In contrast, other researchers reported that the higher acidity could negatively affect the bread quality, it could induce an unpleasant flavor, and reduce the volume of bread, as well as diminish the crumb softness [70]. Generally, the acidity development depends on the sourdough microbial biodiversity [71]. For example, the association of *Lactobacillus brevis*, *Lactobacillus plantarum* and *Saccharomyces cerevisiae* is identified as being responsible for the high acidity of the dough during fermentation [72]. In most cases, the sourdoughs produced by heterofermentative LAB (*Lb. brevis)* displayed the lowest pH compared to sourdoughs produced by homofermentative LAB (*Lb. Plantarum)* [73-74]. In this regard, the decrease of pH is attributed to acetic and lactic acid production [75-76]. This production of acids affects the gluten network. For this purpose, acetic acid makes the gluten network harder, while lactic acid generates a more elastic gluten network, and therefore to obtain a better and more aromatic flavor and textural properties of bread [77-78]. In addition to the influence of sourdough microbiota, the fermentation conditions at particular fermentation times considerably affect the acidity level of dough, where the pH value declined with a longer fermentation time [79-80]. Several authors have widely discussed the effect of the mixture of sourdough and baker's yeast on the acidification degree [81]. It has been reported that this combination developed an acidity higher than the baker's yeast and sourdough individually [72- 81-82]. This finding may be due to the synergistic phenomenon that occurs between the metabolic reactions of the microbiota of this mixture, where the lactic acid bacteria increase the metabolic activity of baker's yeast [83].

Another more interesting effect concerns the volume of dough and bread. The inclusion of sourdough has been reported to either improve [72-84-85-86-87] or decrease the volume of bread [88]. The positive influence of sourdough on volume depends mostly on the microbial strains utilized. It has been reported that the microbial association of *Lb. plantarum*, *Lb. brevis*, and *S. cereviciae* in sourdough is responsible for the increase in the volume developed during breadmaking, knowing that the association of *Lb. plantarum* and *Lb. brevis* had no effect as reported in the study of some researchers [89]. This is because heterofermentative lactic acid bacteria increase the metabolic activity of *S. cerevisiae* producing considerable amounts of CO_2 during fermentation, and thus increasing the volume of bread [83]. On the other hand, other researchers suggested that the accumulation of water-soluble pentosanes might increase the volume due to the modification of water distribution [82]. One more example of properties that have been improved once sourdough is added is texture. It constitutes one of the determining characteristics of bread quality, which is critical to consumer acceptance of baked products. Bread hardening is mainly attributed to the recrystallization of amylopectin. It has been proposed that moisture diffusion between crumb and crust as well as the starch-gluten interactions contribute significantly to the increase in bread hardness [90]. It has been observed that the bread sourdough exhibits a slower rate of hardening during storage compared to bread made with baker's yeast [68-66]. Numerous studies have explained the softening effect of sourdough treatment by the fact that exo-polysaccharides produced by sourdough LAB have the potential to improve bread texture [66].

Table 3 : Characteristics of sourdough bread versus baker's yeast bread [131]

Characteristics	Sourdough bread	Baker's yeast bread
pH	3.8 – 4.6	5.3 – 5.8
Lactic acid	0.4 – 0.8 %	0.005 – 0.04 %
Acetic acid	0.1 – 0.4 %	0.005 – 0.04 %
Bread volume	0.22 – 0.30 %	≤ 0.20
Flavour	Complex aroma and flavour Staling	
Staling	Slow	Rapid
Shelf life	Good protection against microbial contaminations	High sensibility to bacteria and mould spoilage
Some nutritional aspects	Optimal phytase activity and hydrolysis of phytic acid responsible for ion (Ca^{2+} , Fe^{2+} , Mg^{2+} etc.) binding Free amino acid concentration increase Decrease of glycemic index	Low phytase activity, decalcifying effect Free amino acid concentration similar to that of flour

Regarding the shelf life, several studies highlighted that the addition of sourdough has a positive effect on extending the shelf life of bread [91-92-93-94-95-96]. Its restriction is considerably related to the metabolic activities of the microorganisms contaminating the bread. However, the production of various types of antimicrobial compounds by LAB and yeasts of sourdough extend the shelf life of bread. It involves lactic acid, benzoic acid, hydrogen peroxide, propionic, and acetic acid [97-98-99- 100]. Likewise, the 4-hydroxyphenyllactic and phenyllactic acids, which are identified in the metabolic products of *Lb. plantarum* has shown a potential antifungal activity [101-102-103]. Moreover, the Reuterin, which is synthesized by *Lb. reuteri*, have also shown a powerful antifungal and antibacterial activity [104]. The usefulness of fatty acids as inhibitors of the development of bread contaminants has been stated through the identification of coriolic acid, which is a hydroxy- fatty acid derived from peroxides [105]. Although it is well known since ancient times, nowadays there is an increasing trend in consumer demands for foods with high nutritional values and with specific physiological functions of health relevance. The sourdough bread represents the ideal food for this category of consumer. Several nutritional effects resulting from the use of sourdough are cited in the literature. In this review, we discussed its influence on wheat gluten degradation, wheat starch digestibility, and wheat phytic acid reduction.

Sourdough fermentation constitutes an innovative practice that solves the nutritional problem of gluten intolerance in populations who depend on wheat as a staple foodstuff. It is well known that wheat gluten represents one of the nutritional components that are prejudicial to health, especially for people with celiac disease [106]. Numerous studies have been carried out to find a pharmacological treatment for this disorder, and the only solution now is to adopt a gluten-free diet [107- 108]. The attempts made to reduce wheat gluten content adversely affect the sensory qualities of the gluten-free bread [109-110]. However, the use of sourdough has been reported to be effective in degrading gluten during bread making, while improving the texture and delaying staling of bread produced [110-111-112-113]. Its consumption has been shown in clinical tests to be tolerable by gluten-intolerant patients [114]. The mechanism involved implies the improvement of the enzymatic activity of microbial or native wheat proteolyzes of gluten, favored by the lowering of pH caused by the metabolism of sourdough microbiota especially *Lactobacilli* [115-116-117].

Another advantage of sourdough addition consists of slowing starch digestibility in wheat flour-based products such as bread. Interestingly, the slowing down of starch digestibility constitutes a major nutritional problem, particularly in populations on a diet based on wheat bread with baker's yeast, because its starch content is rapidly digested and absorbed, leading to hyperglycemia in people with diabetes [14-15-16]. However, the use of sourdough delays the digestion of starch, because the organic acids produced during fermentation reduce the postprandial glycemic response in human blood. For instance, acetic acid reduces gastric emptying, while lactic acid induces interactions between starch and gluten, thereby reducing starch availability [118-119-120-121].

The use of sourdough as a fermentation agent during bread making has been stated to be effective in reducing the phytic acid content [122-123]. Knowing that its presence interferes with the absorption of minerals via the complexation mechanism with divalent minerals (Zn^{2+} ; Ca^{2+} ; Mg^{2+} ; Fe^{2+}), leading to the formation of phytates, and thus disrupting their homeostasis in the human body, hence the emergence of mineral deficiencies [124-125-126]. The authors explain this mechanism by the action of exogenous phytases produced by sourdough microbiota, including lactic acid bacteria and yeasts [127-128-129]. In contrast to these studies, the analysis of the flour and the sourdough mixture highlighted the predominance of the wheat endogenous phytase activity over sourdough microorganism phytase activity [122-123]. In this case, the lowering of pH because of acid production due to the fermentative metabolism of sourdough microflora is fundamental in providing favorable conditions for endogenous wheat phytase [41-129-130]. From these few studies, it is obvious that the acidity conditions created by the addition of sourdough also favor the action of the sourdough microorganism phytases, hence the significant improvement effect of the bioavailability of sourdough bread minerals.

Finally, the use of sourdough in baking constitutes an innovative technology to prevent the pandemic of so-called societal diseases. It is a functional ingredient that improves digestive symptoms by reducing the gluten content in bread for people with celiac disease. It decreases the digestibility of starch and therefore prevents diabetes and hyperglycemia in diabetics. Thus, it provides to the bread a better degradation of phytic acid, while improving the contribution in mineral content, and hence decreasing the prevalence of mineral deficiencies [151,152]. Consequently, sourdough bread allows us to receive all the benefits of wheat cereal. Without forgetting its effect on the improvement of the sensory quality of bread, which is the main objective of many consumers.

4. Recommendations

- ✓ The preparation of sourdough fermentation initiated by a starter culture of optimally selected lactic acid bacteria can be useful for industrial application to obtain higher quality bakery products.
- ✓ There is a need for an appropriate method to preserve the microbial composition and performance of sourdough during its preparation after consecutive refreshments.
- ✓ It is important that health professionals, consumers and other interested stakeholder groups are aware of the negative effects that sourdough microbiota may cause on the biodiversity and metabolic functions of certain intestinal microbial species.
- ✓ It would be interesting to consider a study to elucidate the relationships among the microbial activity of sourdough and sensory properties of bread along with the types of metabolites involved to explain the improving effect of the addition of sourdough.
- ✓ It is recommended that a study of dough rheological behaviour is required to obtain quality results and to develop reference models.
- ✓ When gluten is degraded in sourdough fermentation, it may affect the quality of bread. It is therefore important to select a microbiota, which only degrades the specific allergy-causing fragments of gluten to sustain the bread quality.

5. Conclusion

Over the last few decades, the human diet has undergone a remarkable evolution in response to the increasing demand for healthier foods. Sourdough technology could be useful for the production of healthy and tasty food. It helps to improve dough properties and bread texture and flavor, delays the staling process, and protects the bread from mould and bacterial spoilage. Moreover, it is useful in the production of bread with slow starch digestibility and hence low glycemic responses, low content of phytic acid ensuring a high bioavailability of minerals, and reduced content of gluten tolerable by gluten-intolerant people. Besides, the use of sourdough can also be extended to other bakery and pastry products to improve efficiency and increase customer satisfaction, and thus significantly affecting economic profitability.

References

[1] S.P. Cauvain, "How much more bread research do we need", *Getreide-technologie,* 58 (2004) 508-521.

[2] I. Jenson, "Bread and baker's yeast", *Microbiology of Fermented Foods,* (1998) 172-198.

[3] B.L. O'Dell, A.R. De Borland, S.R. Koirtyohann, "Distribution of phytate and nutritionally important elements among morphological components of cereal grains", *Journal of Agricultural Food Chemistry*, 20 (1972) 718-720.

[4] K. Kulp, J.G. Ponte Jr., "Handbook of Cereal Science and Technology", Marcel Dekker INC, ISBN : 9780824782948 (2000).

[5] G.H. Fleet, "Yeasts in foods and beverages: impact on product quality and safety", *Current Opinion in Biotechnology,* 18 (2007) 170–175.

[6] Y. Linko, P. Javanainen, S. Linko, "Biotechnology of bread baking", *Trends in food Science and Technology,* 8 (1997) 339–344.

[7] M. Newberry, N. Phan-Thien, O. Larroque, R. Tanner, N. Larsen, "Dynamic and elongation rheology of yeasted bread doughs", *Cereal Chemistry,* 79 (2002) 874–879.

[8] V. Giannou, V. Kessoglou, C. Tzia, "Quality and safety characteristics of 511 bread made from frozen dough", *Trends in Food Science and Technology,* 14 (2003) 99–108.

[9] N. Struyf, E. Van der Maelen, S. Hemdane, J. Verspreet, K.J. Verstrepen, C.M. Courtin, "Bread Dough and Baker's Yeast : An Uplifting Synergy", *Comprehensive Reviews in Food Science and Food Safety,* 16 (2017) 850–867.

[10] M. Garcia-Molina, M. Gimenez, S. Sanchez-Leon, F. Barro, "Gluten Free Wheat : Are We There ? ", *Nutrients,* 11 (2019) 487.

[11] J.A. Tye-Din, H.J. Galipeau, D. Agardh, "Celiac Disease : A Review of Current Concepts in Pathogenesis, Prevention, and Novel Therapies", *Frontiers in Pediatrics,* 6 (2018).

[12] N. Sharma, S. Bhatia, V. Chunduri, S. Kaur, S. Sharma, P. Kapoor, et al, "Pathogenesis of Celiac Disease and Other Gluten Related Disorders in Wheat and Strategies for Mitigating Them", *Frontiers in Nutrition*, 7 (2020).

[13] D. El Khoury, S. Balfour-Ducharme, I.J. Joye, "A Review on the Gluten-Free Diet : Technological and Nutritional Challenges", *Nutrients*, 10 (2018) 1410.

[14] E.E.J.G. Aller, I. Abete, A. Astrup, J.A. Martinez, M.A. Baak, "Starches, Sugars and Obesity", *Nutrients,* 3 (2011) 341–369.

[15] C.O. Eleazu, "The concept of low glycemic index and glycemic load foods as panacea for type 2 diabetes mellitus; prospects, challenges and solutions", *African Health Sciences,* 16 (2016) 468.

[16] A.W. Barclay, P. Petocz, J. McMillan-Price, V.M. Flood, T. Prvan, P. Mitchell, J.C. BrandMiller, "Glycemic index, glycemic load, and chronic disease risk – a meta-analysis of observational studies", *American Journal of Clinical Nutrition*, 87 (2008) 627–637.

[17] L. Marquart, J.L. Slavin, R.G. Fulcher, "Whole-Grain Foods in Health and Disease", Cereals and Grains Assn, ISBN : 9781891127298 (2002).

[18] J.L. Slavin, D. Jacobs, L. Marquart, K. Wiemer, "The role of whole grains in disease prevention", *Journal of the American Dietetic Association,* 101 (2001) 780–785.

[19] J. Slavin, "Whole grains and human health", *Nutrition Research Reviews,* 17 (2004) 99.

[20] L. De Vuyst, P. Neysens, "Biodiversity of sourdough lactic acid bacteria", *Trends in Food Science and Technology*, 16 (2005) 43–56.

[21] L. De Vuyst, M. Vancanneyt, "Biodiversity and identification of sourdough lactic acid

bacteria", *Food Microbiology,* 24 (2007) 120–127.

[22] L. De Vuyst, S. Van Kerrebroeck, H. Harth, G. Huys, H.-M. Daniel, S. Weckx, "Microbial ecology of sourdough fermentations : Diverse or uniform ?", *Food Microbiology,* 37 (2014) 11– 29.

[23] A. Corsetti, L. Settanni, "Lactobacilli in sourdough fermentation", *Food Research International,* 40 (2007) 539-558.

[24] L.K. Berghofer, A.D. Hocking, D. Miskelly, E. Jansson, "Microbiology of wheat and flour milling in Australia", *International Journal of Food Microbiology,* 85 (2003) 137-149.

[25] S.A. Vogelmann, M. Seitter, U. Singer, M.J. Brandt, C. Hertel, "Adaptability of lactic acid bacteria and yeasts to sourdoughs prepared from cereals, pseudocereals and cassava and use of competitive strains as starters", *International Journal of Food Microbiology,* 130 (2009) 205–212.

[26] A. Corsetti, L. Settanni, C. Chaves Lopez, G.E. Felis, M. Mastrangelo, G. Suzzi, "A taxonomic survey of lactic acid bacteria isolated from wheat (Triticum durum) kernels and non-conventional flours", *Systematic and Applied Microbiology,* 30 (2007) 561 - 571.

[27] M. Gobbetti, "The sourdough microflora: interactions of lactic acid bacteria and yeasts", *Trends in Food Science and Technology,* 9 (1998) 267–274.

[28] L. De Vuyst, H. Harth, S. Van Kerrebroeck, F. Leroy, "Yeast diversity of sourdoughs and associated metabolic properties and functionalities", *International Journal of Food Microbiology,* 239 (2016) 26–34.

[29] M. Gobbetti, F. Minervini, E. Pontonio, R. Di Cagno, M. De Angelis, «Drivers for the establishment and composition of the sourdough lactic acid bacteria biota", *International Journal of Food Microbiology,* 239 (2006) 3–18.

[30] F. Minervini, R. Di Cagno, A. Lattanzi, M. De Angelis, L. Antonielli, G. Cardinali, et al., "Lactic acid bacterium and yeast microbiotas of 19 sourdoughs used for traditional/typical Italian breads: Interactions between ingredients and microbial species diversity", *Applied and Environmental Microbiology,* 78 (2012) 1251-1264.

[31] R.J. Tamani, K.K.T. Goh, C.G. Brennan, "Physico-chemical properties of sourdough bread production using selected Lactobacilli starter cultures", *Journal of Food Quality,* 36 (2013) 245– 252.

[32] O. Simsek, A.C. Hilmi, S. Tulumoğlu, "Isolating lactic starter cultures with antimicrobial activity for sourdough processes", *Food Control,* 17 (2004) 263–270.

[33] L. De Vuyst, G. Vrancken, F. Ravyts, T. Rimaux, S. Weckx, «Biodiversity, ecological determinants, and metabolic exploitation of sourdough microbiota", *Food Microbiology,* 26 (2009) 666–675.

[34] R. Van der Meulen, I. Scheirlinck, A. Van Schoor, G. Huys, M. Vancanneyt, P. Vandamme, L. De Vuyst, "Population dynamics and metabolite target analysis of lactic acid bacteria during laboratory fermentations of wheat and spelt sourdoughs", *Applied and Environmental Microbiology,* 73 (2007) 4741-4750.

[35] S. Weckx, R. Van der Meulen, D. Maes, I. Scheirlinck, G. Huys, P. Vandamme, L. De Vuyst, "Lactic acid bacteria community dynamics and metabolite production of rye sourdough fermentations share characteristics of wheat and spelt sourdough fermentations", *Food Microbiology,* 27 (2010) 1000-1008.

[36] W.P. Hammes, M.G. Ganzle, (1998). "Microbiology of fermented foods", Springer, ISBN : 9781461379904 (1998).

[37] C.B. Meroth, J. Walter, C. Hertel, M.J. Brandt, W.P. Hammes, "Monitoring the Bacterial

Population Dynamics in Sourdough Fermentation Processes by Using PCRDenaturing Gradient Gel Electrophoresis", *Applied and Environmental Microbiology,* 69 (2003) 475–482
[38] P. Decock, S. Cappelle, "Bread technology and sourdough technology", *Trends in Food Science & Technology,* 16 (2005) 113–120.
[39] S. Siragusa, R. Di Cagno, D. Ercolini, F. Minervini, M. Gobbetti, M. De Angelis, «Taxonomic structure and monitoring of the dominant population of lactic acid bacteria during wheat flour sourdough type I propagation using Lactobacillus sanfranciscensis starters". *Applied and Environmental Microbiology,* 75 (2009) 1099-1109.
[40] M. Gaggiano, R. Dicagno, M. Deangelis, P. Arnault, P. Tossut, P. Fox, M. Gobbetti, "Defined multi-species semi-liquid ready-to-use sourdough starter", *Food Microbiology,* 24 (2007) 15–24.
[41] R.S. Chavan, S.R. Chavan, "Sourdough Technology - A Traditional Way for Wholesome Foods : A Review", *Comprehensive Reviews in Food Science and Food Safety,* 10 (2011) 169– 182.
[42] G. Spicher, H. Stephan, "Handbuch Sauerteig : Biologie, Biochemie, Technologie", Behr's Verlag, ISBN : 9783860225127 (1999).
[43] M. Gobbetti, A. Corsetti, J. Rossi, F. La Rosa, S.D. Vincenzi, "Identification and clustering of lactic acid bacteria and yeasts from wheat sourdoughs of central Italy", *Italian Journal of Food Science,* 1 (1994) 85–94.
[44] G. Ottogalli, A. Galli, R. Foschino, "Italian bakery products obtained with sourdough: characterization of the typical microflora", *Advances in Food Science,* 18 (1996) 131–144.
[45] A. Alfonzo, G. Ventimiglia, O. Corona, R. Di Gerlando, R. Gaglio, N. Francesca, et al, "Diversity and technological potential of lactic acid bacteria of wheat flours", *Food Microbiology,* 36 (2013) 343–354.
[46] W.P. Hammes, M.J. Brandt, K.L. Francis, M. Rosenheim, F.H. Seitter, S. Vogelmann, "Microbial ecology of cereal fermentations", *Trends in Food Science and Technology,* 16 (2005) 4-11.
[47] G. Spicher, W. Nierle, "Die Mikroflora des Sauerteiges", *Z Lebensm Unters Forch*, 178 (1978) 389-392.
[48] S. Van Kerrebroeck, D. Maes, L. De Vuyst, "Sourdoughs as a function of their species diversity and process conditions, a meta-analysis", *Trends in Food Science & Technology,* 68 (2017) 152–159.
[49] F. Minervini, M. De Angelis, R. Di Cagno, M. Gobbetti, "Ecological parameters influencing microbial diversity and stability of traditional sourdough", *International Journal of Food Microbiology,* 171 (2014) 136–146.
[50] M. Gobbetti, M.G. Ganzle, Handbook of sourdough biotechnology, Springer, ISBN : 9781461754250 (2013).
[51] X. Liu, M. Zhou, C. Jiaxin, Y. Luo, F. Ye, S. Jiao, et al, "Bacterial diversity in traditional sourdough from different regions in China", *LWT,* 96 (2018) 251–259.
[52] L. Kline, T.F. Sugihara, "Microorganisms of the San Francisco sour dough bread process. II. Isolation and characterization of undescribed bacterial species responsible for the souring activity", *Applied Microbiology,* 21 (1971) 459–465.
[53] A. Hansen, P. Schieberle, "Generation of aroma compounds during sourdough fermentation : Applied and fundamental aspects", *Trends in Food Science & Technology,* 16 (2005) 85-94
[54] G. Huys, H-M. Daniel, L. De Vuyst, "Taxonomy and Biodiversity of Sourdough Yeasts and Lactic Acid Bacteria", *Handbook on Sourdough Biotechnology,* (2012) 105–154.

[55] H. Gul, S. Ozcelik, O. Sagdıc, M. Certel, “Sourdough bread production with lactobacilli and S. cerevisiae isolated from sourdoughs”, *Process Biochemistry,* 40 (2005) 691–697.
[56] C. Lacroix, “Protective cultures, antimicrobial metabolites and bacteriophages for food and beverage biopreservation”, Woodhead Publishing, ISBN : 9780857090522 (2011).
[57] H.A. Sakandar, K. Usman, M. Imran, “Isolation and characterization of gluten-degrading Enterococcus mundtii and Wickerhamomyces anomalus, potential prebiotic strains from indigenously fermented sourdough (Khamir)”, *LWT,* 91 (2018) 271–277.
[58] J. Tulha, J. Carvalho, R. Armada, F. Faria-Oliveira, C. Lucas, C. Pais, et al, “Yeast, the Man’s Best Friend”, *Scientific, Health and Social Aspects of the Food Industry,* (2012).
[59] C.M. Rosell, J. Bajerska, A.F. El Sheikha, “Bread and its fortification : Nutrition and health benefits”, CRC Press/Taylor & Francis Group, ISBN : 9781498701563 (2015).
[60] A. Corsetti, P. Lavermicocca, M. Morea, F. Baruzzi, N. Tosti, M. Gobbetti, “Phenotypic and molecular identification and clustering of lactic acid bacteria and yeasts from wheat (species Triticum durum and Triticum aestivum) sourdoughs of Southern Italy”, *International Journal of Food Microbiology,* 64 (2001) 95–104.
[61] A. Galli, L. Franzetti, M.G. Fortina, “Isolation and Identification of Sourdough Microflora' in Microbiol – Aliments”, *Nutrition*, 6 (1988) 345–351.
[62] E. Nistal, A. Caminero, S. Vivas, J.M. Ruiz de Morales, L.E. Saenz de Miera, L.B. Rodriguez Aparicio, J. Casqueiro, “Differences in faecal bacteria populations and faecal bacteria metabolism in healthy adults and celiac disease patients”, *Biochimie.* 94 (2012) 1724–1729.
[63] A. Vollmar, F. Meuser, “Influence of Starter Cultures Consisting of Lactic Acid Bacteria and Yeast on the Performance of a Continuous Sourdough Fermenter”, *Cereal Chemistry,* 69 (1992) 20-27.
[64] G. Spicher, E. Rabe, R. Sommer, H. Stephan, “The Microflora of Sourdough. XIV. Communication : About the Behaviour of Homofermentative Sourdough Bacteria and Yeasts in Mixed Culture”, *Zeitschrift fur Lebensmittel Untersuchung und Forschung,* 173 (1981) 291-296.
[65] G. Spicher, E. Rabe, R. Sommer, H. Stephan, “Communication : on the Behaviour of Heterofermentative Sourdough Bacteria and Yeasts in Mixed Culture”, *Zeitschrift fur Lebensmittel Untersuchung und Forschung,* 174 (1982) 222-227.
[66] E.K. Arendt, L.A.M. Ryan, F. Dal Bello, “Impact of sourdough on the texture of bread”, *Food Microbiology,* 24 (2007) 165-174.
[67] J.M. Brummer, K. Lorenz, “European developments in wheat sourdoughs”, *Cereal Foods World,* 36 (1991) 310-314.
[68] K. Katina, R.L. Heinio, K. Autio, K. Poutanen, “Optimization of sourdough process for improved sensory profile and texture of wheat bread”, *LWT – Food Science Technology,* 39 (2006) 1189-1202.
[69] D.K. Komlenić, Ž. Ugarčić-Hardi, M. Jukić, M. Planinić, A. Bucić-Kojić, I. Strelec, “Wheat dough rheology and bread quality effected by Lactobacillus brevis preferment, dry sourdough and lactic acid addition”, *International Journal of Food Science & Technology,* 45 (2010) 1417-1425.
[70] S. Kaditzky, R.F. Vogel, “Optimization of exopolysaccharide yield in sourdoughs fermented by lactobacilli [J]”, *European Food Research and Technology,* 228 (2008) 291-299.
[71] C.I. Clarke, T.J. Schober, E. Angst, E.K. Arendt, “Use of response surface methodology to investigate the effects of processing conditions on sourdough wheat bread quality”, *European Food Research and Technology,* 217 (2003) 23-33.

[72] M.B. Habibi Najafi, A. Pourfarzad, H. Zahedi, Z. Ahmadian-Kouchaksaraie, M.H. Haddad Khodaparast, "Development of sourdough fermented date seed for improving the quality and shelf life of flat bread : study with univariate and multivariate analyses", *Journal of Food Science and Technology,* 53 (2015) 209–220.
[73] H. Hadaegh, S.M. Seyyedain Ardabili, M. Tajabadi Ebrahimi, M. Chamani, R. Azizi Nezhad, "The Impact of Different Lactic Acid Bacteria Sourdoughs on the Quality Characteristics of Toast Bread", *Journal of Food Quality,* 2017 (2017) 1–11.
[74] H. Robert, V. Gabriel, D. Lefebvre, P. Rabier, Y. Vayssier, C. Fontagne-Faucher, "Study of the behaviour of Lactobacillus plantarum and Leuconostoc starters during a complete wheat sourdough breadmaking process", *LWT - Food Science and Technology,* 39 (2006) 256-265.
[75] M. Korakli, M. Pavlovic, M. Ganzle, G. Rudi, F. Vogel, "Exopolysaccharide and kestose production by Lactobacillus sanfranciscensis LTH2590", *Applied and Environmental Microbiology,* 69 (2003) 2073-2079.
[76] O. Pepe, G. Blaiotta, M. Anastasio, G. Moschetti, D. Ercolini, F. Villani, "Technological and molecular diversity of Lactobacillus plantarum strains isolated from naturally fermented sourdoughs [J]", *Systematic and Applied Microbiology,* 27 (2004) 443-453.
[77] D. Koceva, V. Slaanac, M. Juki, "Influence of Acidification on Dough Rheological Properties", *Rheology,* (2012).
[78] C.C. Lee, S.J. Mulvaney, "Dynamic viscoelastic and tensile properties of gluten and glutenin gels of common wheats of different strength", *Journal of Agricultural and Food Chemistry.* 51 (2003) 2317-2327.
[79] K.S. Aplevicz, P.J. Ogliari, E.S. Sant'Anna, "Influence of fermentation time on characteristics of sourdough bread", *Brazilian Journal of Pharmaceutical Sciences,* 49 (2013) 234-239.
[80] A. Abedfar, A. Sadeghi, "Response surface methodology for investigating the effects of sourdough fermentation conditions on Iranian cup bread properties", *Heliyon*, 5 (2019) e02608.
[81] S. Paramithiotis, S. Gioulatos, E. Tsakalidou, G. Kalantzopoulos, "Interactions between *Saccharomyces cerevisiae* and lactic acid bacteria in sourdough", *Process Biochemistry,* 41 (2006) 2429–2433.
[82] A. Corsetti, M. Gobbetti, F. Balestrieri, F. Paoletti, L. Russi, J. Rossi, "Sourdough lactic acid bacteria effects on bread firmness and staling", *Journal of Food Science,* 63 (1998) 347 - 351.
[83] M. Gobbetti, A. Corsetti, J. Rossi, "Interaction between lactic acid bacteria and yeasts in sourdough using a rheofermentometer", *World Journal of Microbiology and Biotechnology,* 11 (1995) 625 - 630.
[84] P. Crowley, T.J. Schober, C.I. Clarke, E.K. Arendt, "The effect of storage time on textural and crumb grain characteristics of sourdough wheat bread", *European Food Research and Technology,* 214 (2002) 489 - 496.
[85] A. Corsetti, M. Gobbetti, B. De Marco, F. Balestrieri, F. Paoletti, L. Russi, J. Rossi, "Combined effect of sourdough lactic acid bacteria and additives bread firmness and staling", *Journal of Agricultural and Food Chemistry,* 48 (2000) 3044–3051.
[86] M. Gobbetti, M.S. Simonetti, A. Corsetti, F. Santinelli, J. Rossi, P. Damiani, "Volatile compound and organic acid productions by mixed wheat sour dough starters : influence of fermentation parameters and dynamics during baking", *Food Microbiology*, 12 (1995) 497–507.
[87] M.A. Martinez-Anaya, B. Pitarch, P. Bayarri, C. Benedito de Barber, "Microflora of the sourdoughs of wheat flour bread. X. Interactions between yeasts and lactic acid bacteria in

wheat doughs and their effects on bread's quality", *Cereal Chemistry*, 67 (1990) 85–91.
[88] B. Barber, C. Ortola, S. Barber, F. Fernandez, "Storage of packaged white bread", *Zeitschrift fur Lebensmittel Untersuchung und Forschung*, 194 (1992) 442-449.
[89] C. Collar, C. Benedito, M.A. De Barber, "Martinezanaya, Microbial sourdoughs influence acidification properties and breadmaking potential of wheat dough", *Journal of Food Science*, 59 (1994) 629-633.
[90] R.E. Hebeda, H.F. Zobel, "Baked goods freshness : technology, evaluation, and inhibition of staling ", CRC Press, ISBN : 9780824793487 (1996).
[91] C.I. Clarke, T.J. Schober, E. Angst, E.K. Arendt, "Use of response surface methodology to investigate the effects of processing conditions on sourdough wheat bread quality", *European Food Research and Technology*, 217 (2003) 23–33.
[92] D. Chen, J. Wang, F. Jia, C. Zhang, "Effects of Sourdough Addition on the Quality and Shelf Life of Chinese Steamed Bread", *Grain & Oil Science and Technology*, 1 (2018) 85-90.
[93] E. Armero, C. Collar, "Antistaling additives, flour type and sourdough process effects on functionality of wheat doughs", *Journal of Food Science*, 61 (1996) 299–303.
[94] H. Gul, S. Ozcelik, O. Sagdic, M. Certel, "Sourdough bread production with lactobacilli and S. cerevisiae isolated from sour-doughs", *Process Biochemistry*, 40 (2005) 691.
[95] K. Katina, M. Salmenkallio-Marttila, R. Partanen, P. Forssell, K. Autio, "Effects of sourdough and enzymes on staling of high-fibre wheat bread", *LWT – Food Science and Technology*, 39 (2006) 479–491.
[96] E. Torrieri, O. Pepe, V. Ventorino, P. Masi, S. Cavella, "Effect of sourdough at different concentrations on quality and shelf life of bread", *LWT-Food Science and Technology*, 56 (2014) 508–516.
[97] W. Messens, L. De Vuyst, "Inhibitory substances produced by Lactobacilli isolated from sourdoughs – a review", *International Journal of Food Microbiology*, 72 (2002) 31–43.
[98] J. Schnurer, J. Magnusson, "Antifungal lactic acid bacteria as biopreservatives", *Trends in Food Science and Technology*, 16 (2005) 70–78.
[99] M.K. Magnusson, A. Arvola, U.K.K. Hursti, L. Aberg, P.O. Sjoden, "Choice of organic foods is related to perceived consequences for human health and to environmentally friendly behavior", *Appetite*, 40 (2003) 109–117.
[100] J. Schnurer, J. Magnusson, "Antifungal lactic acid bacteria as biopreservatives", *Trends in Food Science and Technology*, 16 (2005) 70–78.
[101] F. Dal Bello, C.I. Clarke, L.A.M. Ryan, H. Ulmer, T.J. Schober, K. Strom, et al, "Improvement of ¨ the quality and shelf life of wheat bread by fermentation with the antifungal strain Lactobacillus plantarum FST 1.7", *Journal of Cereal Science*, 45 (2007) 309–318.
[102] P.F. Lavermicocca, A. Valerio, S. Evidente, A. Lazzaroni, A. Corsetti, M. Gobbetti, "Purification and characterization of novel antifungal compounds from sourdough the Lactobacillus plantarum 21B", *Applied and Environmental Microbiology*, 66 (2000) 4084–4090.
[103] L.A.M. Ryan, F.D. Bello, M. Czerny, P. Koehler, E.K. Arendt, "Quantification of phenyllactic acid in wheat sourdough using high resolution gas chromatography-mass spectrometry", *Journal of Agricultural and Food Chemistry*, 57 (2009) 1060 – 1064.
[104] M.G. Ganzle, "Reutericyclin: biological activity, mode of action, and potential applications", *Applied Microbiological and Biotechnology*, 64 (2004) 326–332.
[105] M. Czerny, P. Schieberle, "Important aroma compounds in freshly ground wholemeal and white wheat flour – identification and quantitative changes during sourdough fermentation",

Journal of Agricultural and Food Chemistry, 50 (2002) 6835–6840.
[106] J.S. Fraser, "Pathogenesis of coeliac disease: Implications for treatment", *World Journal of Gastroenterology*, 7 (2001) 772.
[107] D. El Khoury, S. Balfour-Ducharme, I.J. Joye, "A Review on the Gluten-Free Diet : Technological and Nutritional Challenges", *Nutrients*, 10 (2018) 1410.
[108] C. Ciacci, P. Ciclitira, M. Hadjivassiliou, K. Kaukinen, J.F. Ludvigsson, N. McGough, et al, "The gluten-free diet and its current application in coeliac disease and dermatitis herpetiformis", *United European Gastroenterology Journal*, 3 (2014) 121–135.
[109] A. Houben, A. Hochstotter, T. Becker, "Possibilities to increase the quality in gluten-free bread production: an overview", *European Food Research and Technology*, 235 (2012) 195–208.
[110] E. Zannini, E. Pontonio, D.M. Waters, E.K. Arendt, "Applications of microbial fermentations for production of gluten-free products and perspectives", *Applied Microbiology and Biotechnology*, 93 (2011) 473–485.
[111] M. Moore, B. Juga, T. Schober, E. Arendt, "Effect of lactic acid bacteria on properties of gluten-free sourdoughs, batters, and quality and ultrastructure of gluten-free bread", *Cereal Chemistry*, 84 (2006) 357–364.
[112] D. Bender, V. Fraberger, P. Szepasvári, S. D'Amico, S. Tömösközi, et al, "Effects of selected lactobacilli on the functional properties and stability of gluten-free sourdough bread", *European Food Research and Technology*, 244 (2018) 1037–1046.
[113] M. Moore, F. Dal Bello, E. Arendt, "Sourdough fermented by Lactobacillus plantarum FST 1.7 improves the quality and shelf life of gluten-free bread", *European Food Research and Technology*, 226 (2008) 1309–1316.
[114] R. Di Cagno, M. De Angelis, S. Auricchio, L. Greco, C. Clarke, M. De Vincenzi, et al, "Sourdough bread made from wheat and nontoxic flours and started with selected lactobacilli is tolerated in celiac sprue patients", *Applied and Environmental Microbiology*, 70 (2004) 1088- 1096.
[115] M. De Angelis, R. Coda, M. Silano, F. Minervini, C. Rizzello, R. Di Cagno, et al, "Fermentation by selected sourdough lactic acid bacteria to decrease coeliac intolerance to rye flour", *Journal of Cereal Science*, 43 (2006) 301–314.
[116] R. Di Gagno, C. Rizzello, M. De Angelis, A. Cassone, G. Giuliani, A. Benedusi, et al, "Use of selected sourdough strains of Lactobacillus for removing gluten and enhancing the nutritional properties of gluten-free bread", *Journal of Food Protection*, 71 (2008) 1491–1495.
[117] C. Rizzello, M. De Angelis, R. Di Cagno, A. Camarca, M. Silano, I. Losito, et al, "Highly efficient gluten degradation by lactobacilli and fungal proteases during food processing : new perspectives for celiac disease", *Applied and Environmental Microbiology*, 73 (2007) 4499–4507.
[118] I. Bjorck, H. Liljeberg Elmstahl, "The glycaemic index: Importance of dietary fibre and other food properties", *Proceedings of the Nutrition Society*, 62 (2003) 201-206.
[119] A. Fardet, F. Leenhardt, D. Lioger, A. Scalbert, C. Remesy, "Parameters controlling the glycaemic response to breads", *Nutritional Research Reviews*, 19 (2006) 18–25.
[120] M. De Angelis, R. Coda, M. Silano, F. Minervini, C. Rizzello, R. Di Cagno, et al, "Fermentation by selected sourdough lactic acid bacteria to decrease coeliac intolerance to rye flour", *Journal of Cereal Science*, 43 (2006) 301–314.
[121] M. Maioli, G. Pes, M. Sanna, S. Cherchi, M. Dettori, E. Manca, G. Farris, "Sourdough-

leavened bread improves postprandial glucose and insulin plasma levels in subjects with impaired glucose tolerance", *Acta Diabetologica*, 45 (2008) 91–96.
[122] K. Poutanen, L. Flander, K. Katina, "Sourdough and cereal fermentation in a nutritional perspective", Food Microbiology, 26 (2009) 693–699.
[123] V. Preedy, R. Watson, V. Patel, "Flour and Breads and Their Fortification in Health and Disease Prevention ", Academic Press, ISBN : 9780123808875 (2011).
[124] P. Bora, "Anti-nutritional factors in foods and their effects", Journal of Academia and Industrial Research, 3 (2014) 285–290.
[125] F. Grases, R.M. Prieto, A. Costa-Bauza, "Clinical aspects of natural and added phosphorus in foods", Springer, ISBN : 9781493965663 (2017).
[126] V. Kumar, A.K. Sinha, H.P.S. Makkar, K. Becker, "Dietary roles of phytate and phytase in human nutrition : A review", Food Chemistry, 120 (2010) 945–959.
[127] K. Shirai, S. Revah-Moiseev, M. Garcia-Garibay, V. Marshall, "Ability of some strains of lactic acid bacteria to degrade phytic acid", Letters in Applied Microbiology, 19 (1994) 366–369.
[128] H. Lopez, A. Ouvry, E. Bervas, C. Guy, A. Messager, C. Demigne, C. Remesy, "Strains of lactic acid bacteria isolated from sourdoughs degrade phytic acid and improve calcium and magnesium solubility from whole wheat flours", Journal Agricultural and Food Chemistry, 48 (2000) 2281–2285.
[129] A. Reale, U. Konietzny, R. Coppola, E. Sorrentino, R. Greiner, "The importance of lactic acid bacteria for phytate degradation during cereal dough fermentation", Journal of Agricultural and Food Chemistry, 55 (2007) 2993-2997.
[130] F. Leenhardt, M.-A. Levrat-Verny, E. Chanliaud, C. Remesy, "Moderate decrease of pH by sourdough fermentation is sufficient to reduce phytate content of whole wheat flour through endogenous phytase activity", Journal of Agricultural and Food Chemistry, 53 (2005) 98–102.
[131] A. Corsetti, "Technology of Sourdough Fermentation and Sourdough Applications", Handbook on Sourdough Biotechnology, (2012) 85–103.
[132] M. Vancanneyt, P. Neysens, M. De Wachter, K. Engelbeen, C. Snauwaert, I. Cleenwerck, et al, "Lactobacillus acidifarinae sp. nov., from wheat sourdoughs", International Journal of Systematic Evolutionary Microbiology, 55 (2005) 615-620.
[133] H.A. Sakandar, R. Hussain, S. Kubow, F.A. Sadiq, W. Huang, M. Imran, "Sourdough bread : A contemporary cereal fermented product", Journal of Food Processing and Preservation, (2019) e13883.
[134] R. Valcheva, M. Korakli, B. Onno, H. Prévost, I. Ivanova, A.M. Ehrmann, et al, "Lactobacillus hammesii sp. nov., isolated from French sourdough", *International Journal of Systematic Evolutionary Microbiology*, 55 (2005) 763-767.
[135] R.F. Vogel, R. Knorr, M.R.A. Muller, U. Steudel, M.G. Ganzle, M.A. Ehrmann, "Non-dairy lactic fermentations : the cereal world", *Antonie van Leeuwenhoek*, 76 (1999) 403–411.
[136] I. Scheirlink, R. Van der Meulen, A. Van Schoor, I. Cleenwerk, G. Huys, P. Vandamme, L.D. Vuyst, M. Vancanneyt, "Lactobacillus namurensis sp. nov., isolated from a traditional Belgian sourdough", *International Journal of Systematic Evolutionary Microbiology*, 57 (2007) 223-227.
[137] V. Preedy, R. Watson, V. Patel, "Flour and Breads and Their Fortification in Health and Disease Prevention", Academic Press, ISBN : 9780123808875 (2011).
[138] D. Aune, N. Keum, E. Giovannucci, L.T. Fadnes, P. Boffetta, et al, "Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality :

systematic review and dose-response meta-analysis of prospective studies", *BMJ*, 353 (2016) i2716.
[139] K. Papadimitriou, G. Zoumpopoulou, M. Georgalaki, V. Alexandraki, M. Kazou, R. Anastasiou, E. Tsakalidou, " Sourdough Bread ", *Innovations in Traditional Foods*, (2019) 127– 158.
[140] N. Weiss, U. Schillinger, "Lactobacillus sanfrancisco sp. nov., nom. Rev.", *Systematic and Applied Microbiology*, 4 (1984) 507-511.
[141] Y. Cai, H. Okada, H. Mori, Y. Benno, T. Nakase, "Lactobacillus paralimentarius sp. nov., isolated from sourdough", *International Journal of Systematic Bacteriology,* 49 (1999) 1451-1455.
[142] M.A. Ehrmann, R.F. Vogel, "Molecular taxonomy and genetics of sourdough lactic acid bacteria", *Trends in Food Science and Technology,* 16 (2005) 31-42.
[143] R.F. Vogel, G. Bocker, P. Stolz, M. Ehrmann, D. Fanta, W. Ludwig, et al, "Identification of lactobacilli from sourdough and description of Lactobacillus pontis sp. Nov.", *International Journal of Systematic Bacteriology,* 44 (1994) 223-229.
[144] A. Corsetti, L. Settanni, D. Van Sinderen, G.E. Felis, F. Dellaglio, M. Gobbetti, "Lactobacillus rossiae sp. nov., isolated from wheat sourdough", *International Journal of Systematic and Evolutionary Microbiology,* 56 (2005) 587-591.
[145] B.G. Wiese, W. Strohmar, F.A. Rainey, H. Diekmann, "Lactobacillus panis sp. Nov., from sourdough with a long fermentation period", *International Journal of Systematic Bacteriology,* 46 (1996) 449-453.
[146] M.R.A. Miiller, M.A. Ehrmann, R.F. Vogel, "Lactobacillus frumenti sp. nov., a new lactic acid bacterium isolated from rye-bran fermentations with a long fermentation period", *International Journal of Systematic and Evolutionary Microbiology,* 50 (2000) 2127-2133.
[147] T.F. Sugihara, L. Kline, L.B. Mc Cready, "Nature of the San Francisco Sour Dough French Bread Process. II", Microbiological aspects. *Baker's Digest,* 44 (1970) 51-56.
[148] S. Barber, R. Baguena, "Microflora of the Sourdough of Wheat Flour Bread. XI. Changes during Fermentation in the Microflora of Sour Doughs Prepared by a Multi-stage Process and of Bread Doughs", *Revista de Agroquimica y Tecnologia de Alimentos.* 29 (1989) 478-491.
[149] M. Infantes, C. Tourner, "Etude de la Flore Levure de Levains Naturels de Panification Provenant de Differentes Regions Francaises", *Sciences des Aliments,* 12 (1992) 271-287.
[150] M. Gobbetti A. Corsetti J. Rossi, "The sourdough microflora. Interactions between lactic acid bacteria and yeasts: metabolism of amino acids", *World Journal of Microbiology and Biotechnology,* 10 (1994) 275–279.
[151] S. Ma, Z. Wang, X. Guo, F. Wang, J. Huang, B. Sun, X. Wang, Sourdough improves the quality of whole-wheat flour products: Mechanisms and challenges—A review, *Food Chemistry,* 360 (2021) 130038, https://doi.org/10.1016/j.foodchem.2021.130038
[152] M. Ebrahimi, S. M. Ali Noori, A. Sadeghi, O. emir Coban, J. Zanganeh, S. M. Ghodsmofidi, Z. Malvandi, M. Raeisi, Application of cereal-bran sourdoughs to enhance technological functionality of white wheat bread supplemented with pumpkin (Cucurbita pepo) puree, LWT, (2022) 113079, https://doi.org/10.1016/j.lwt.2022.113079

(2022) ; http://www.jmaterenvironsci.com