

Development of a new resource-saving technology of rye-wheat bread on liquid rye sourdoughs using recycled bread

Olesya Savkina^{1,*}, Lina Kuznetsova¹, Olga Parakhina¹, Marina Lokachuk¹, Natalia Lavrenteva¹, and Elena Pavlovskaya¹

¹St. Petersburg branch State Research Institute of Baking Industry, Podbelskogo highway 7, 196608, St.Petersburg, Pushkin, Russian Federation

Abstract. Recycling of substandard bread, technological waste and bread from the distribution network is a promising way of waste management and raw materials saving. In order to optimize the old bread recycling process and to improve the quality of finished products, a new resource-saving technology for rye-wheat bread was developed. It was found that use under 25% of bread crumbs instead of flour was possible in a liquid sourdough with a moisture content of 70%. When old bread dosage increased from 50 to 100%, acid accumulation slowed down, the lifting force deteriorated, the viscosity increased, which may makes it difficult or impossible to pump the sourdough in industrial technological process. The liquid sourdough made with 25% of old bread had a better lifting capacity and contained more alcohol and volatile acids than the control. The quality of bread made using sourdough with 25% of old bread was comparable in quality to control bread made using traditional sourdough. Liquid rye sourdough with recycled old bread allowed the bread shelf life extension by slowing down the bread staling. No effect on mold rate was found when using recycled old bread in sourdough.

1 Introduction

Bread is a product that is produced and consumed almost in all countries over the world. The industrial bread production can be accompanied by significant losses due to technological defects, substandard bread, returns from the distribution network. The introduction of resource-saving technologies into the existing bakery enterprises can provide waste-free and environmentally friendly production. Therefore, the development of methods and technological solutions allowing reducing the loss of materials is an important task.

Old bread returned from the commercial network is not allowed to be processed at bakery enterprises in Russia, but it can be used as a substrate for producing different substances, such as lactic acid and hydrogen [1], ethanol [2, 3], succinic acid [4, 5], xanthan gum [6] and sugars [7].

Bread is a valuable material because it contains starch, protein, minerals, fiber, and vitamins. The starch is in a gelatinized state, which makes it more accessible for the action of enzymes [8]. In this regard, white bread waste as a substrate for the production of baker's yeast and for the cultivation of starter cultures was investigated [9, 10].

But in addition to old bread returned from the commercial network, defect and substandard bread may be formed due to problems in the technological process. Serious attention has been paid to the resource saving in the bakery industry, especially since the beginning of the last century, when industrialization began and the large

mechanized enterprises were built [11, 12]. But the old bread recycle methods are not effective enough today [12, 13].

In the Russian bread making industry defect bread and waste recycled in the enterprises by adding to the dough [11-14]. In accordance with the "Rules for the Organization and Conducting the Technological Process at the Bakery Enterprises" three semi-finished products used in dough making process can be made from old bread and waste: bread crumbs, crumbs (crackers) and soaked bread (special semi-finished product) [11-13]. Some of the processed bread can be sold in the retail network for the production of homemade kvass or as bread crumbs for culinary [13-14]

Bread hydrolysates obtained under the action of enzymes may be used in the dough [11]. It is recommended to use old bread and defect bread in sourdoughs. Studies show that the use of recycled bread in the dough has a positive effect on the quality of the bread and the delay in staling [12-16].

A number of disadvantages are possible if old bread is used. Newly made bread may possess smell of old stale bread. Rapid bread microbial spoilage possible when spoiled bread (moldy, limy or ropy) was used [12-16]. Besides soaked bread is an excellent medium for microbial spoilage pathogens. Therefore, soaked bread usage increases the risk of microbial contamination and moldy taste of bread [12].

The aim of this research was to develop a new resource-saving technology of liquid sourdough using recycled bread.

* Corresponding author: 1103savkina@mail.ru

2 Materials and methods

2.1 Sourdough preparation

25, 50, 75 and 100% of bread crumbs were used instead of flour (accounted in dry matter) in experimental sourdoughs. Nutrition mixture for control sourdough was made without the use of bread crumbs. Sourdough humidity was 70% [17]. The formulations for sourdoughs are given in Table 1.

Lactic acid bacteria (LAB) and yeasts strains were obtained from the St. Petersburg branch State Research Institute of Baking Industry. Four LAB strains (*L. brevis* 1, *L. plantarum* 30, *L. casei* 26, *L. fermentum* 34) and two yeasts strain (*S. cerevisiae* Y120 and *C. milleri*) were used [17].

Table 1. Sourdough formulations.

Ingredients, %	Control	Amount of bread crumbs in experimental sourdough, %			
		25	50	75	100
Rye flour	70.0	52.5	35.0	17.5	-
Bread crumbs	0	26.5	53.0	79.5	106.0
Water	134.0	125.0	116.0	107.0	98.0

2.2 Bread making procedure

The control breads were prepared in two varieties: 1. using sourdough without bread crumbs; 2. using sourdough without bread crumbs and bread crumbs were added in the dough in an amount equal to the content of crumbs in the experimental sourdough. The test bread was prepared using a liquid sourdough containing 25% bread crumbs instead of flour. The formulations for the rye-wheat breads are given in Table 2.

Breads were prepared by mixing flour, sourdough, salt, yeast, bread crumbs (control bread with bread crumbs in the dough) and water. Then the dough were shaped into 400g loaves, placed in aluminum pans and leavened at 30°C until the volume was increased. Breads were baked in oven at 210°C for 20 min.

Table 2. Rye-wheat bread formulations.

Ingredients, %	Control bread	Bread with bread crumbs in dough	Bread with bread crumbs in sourdough
Rye flour	40	35	40
Wheat flour	40	40	40
Sourdough	52	52	-
Sourdough bread crumbs	-	-	52
Old bread crumbs	-	6.3	-
Pressed yeast	0.5	0.5	0.5
Salt	1.4	1.4	1.4
Water	until dough humidity of 43%		

2.3 Nutrition mixture, sourdough and dough assessments

The sourdough rheological properties (dynamic viscosity) were investigated using a rotary viscometer (Reotest-2, Germany) at a shear rate of 0.9 s⁻¹ and temperature of 28–30 °C. Sourdough mass was 50 g. Viscosity was calculated using the formula given in the instructions for device (in Pa • s).

Nutrition mixtures for sourdoughs preparation (flour, water and bread crumbs in different proportion given in Table 1) were investigated. The sugar content in the sourdough nutrition mixtures was determined using Bertrand's method, which is based on the collection of copper oxide precipitate formed during the reduction of an alkaline copper solution in the presence of reducing sugars and analyzed by the manganometric method [18].

Sourdough, nutrition mixture and dough quality were evaluated next way: acidity was determined by titration, using a 0.1 n. solution of NaOH [19]. The lifting capacity was determined as time of floating of 10g dough balls in water at 32°C [19]. The increase in volume was evaluated as ratio between the final volume and the initial volume multiplied by 100%.

The content of volatile acids was determined by neutralizing the evaporated volatile acid using a 0.1 n. solution of NaOH [19]. The alcohol content was determined by using the iodometric method, which is based on the detection of sodium thiosulfate quantity spent in titration [19].

LAB and yeast amount in a sourdough and in nutrition mixture were evaluated using the method of microscopy and counting in a fixed colored preparation in 50 fields of view [20].

2.4 Bread assessment

Sensory (shape, surface, crumb color, porosity and texture, taste and smell) and physic-chemical characteristics were evaluated in baked bread.

2.4.1 Assessment of quality

Titrate acidity was determined by titration with 0.1 N solutions of NaOH [18]. Pore volume was evaluated as the ratio of crumb pore volume to the total bread volume, pore volume was determined as the difference between the volume of product and the volume of non-porous mass. Specific volume was evaluated as the ratio of bread volume and mass (100 g of bread). Crumb compressibility was determined on the automatic penetrometer Labor (Hungary). The crumbliness of the crumb was investigated in a 24 and 96 h of storage [18].

The volatile acids content was estimated by neutralizing the evaporated volatile acid using a 0.1 n. solution of NaOH. The alcohol content was determined by iodometric method based on sodium thiosulfate titration [18].

2.4.2 Sensory evaluation

10-member expert panel evaluated the bread organoleptic characteristics. Experts evaluated smell and taste, crumb texture, crust color and porosity. Each trait was evaluated on a scale from 1 to 5: 1– dislike extremely; 2 – dislike; 3 - slightly dislike; 4 – moderately; 5 – very good.

2.4.3 Microbial spoilage assessment

The impact of the old bread crumbs on mould and ropy disease of newly made bread was investigated. Sterile bread slices were contaminated by a pure culture of the mould *Penicillium chrysogenum*. Method described in details in previous study [13]. Bread after cooling was stored at 37°C and air humidity 80±5 °C before the appearance of ropy disease [19]. Ropy bread disease appearance was monitored in a 16 hours and every next 4 hours.

2.5 Statistical analysis

All experiments were carried out three times. Statistical analysis was conducted using Excel software. Comparison of the different factors influence was carried out using the method with significance tested at the 95% confidence level and differences among means were determined using the least significant difference and Duncan’s test of two-factor analysis of variance with one repetition (ANOVA). Results were given as mean ± standard deviation.

3 Results

The influence of the recycled bread crumbs quantity on liquid sourdough biotechnological indicators was investigated (Table 3).

Table 3. Influence of bread crumbs on sourdough biotechnological indicators.

Indicator s	Control	Amount of bread crumbs in experimental sourdough, %			
		25	50	75	100
Nutrient mixture for sourdough (flour/bread crumbs+ water)					
Acidity, degrees	2.3±0.2 ^a	3.3±0.2 ^b	4.4±0.2 ^c	4.8±0.3 ^d	5.6±0.3 ^f
Reducing sugar, %	3.7±0.2 ^a	6.3±0.3 ^b	6.5±0.4 ^b	6.5±0.4 ^b	3.7±0.2 ^c
Lactobacilli, 10 ⁷ cells·g ⁻¹	10.0±0.1 ^a	10.0±0.1 ^a	1.0±0.01 ^b	-	-
Sourdough after fermentation					
Acidity, degrees	9.3±0.2 ^a	9.8±0.2 ^b	11.3±0.2 ^c	10.0±0.3 ^b	8.4±0.2 ^d
Lifting capacity, min	24±1 ^a	17±1 ^b	32±2 ^c	39±3 ^d	52±3 ^f
Volume increasing, %	52±1 ^a	51±1 ^b	16±1 ^c	8 ±1 ^d	8±1 ^d
Volatile acids, %	23.9±1.3 ^a	30.5±2.0 ^b	28.8±1.2 ^c	29.2±1.2 ^c	28.7±1.0 ^c
Alcohol, % of dry weight	3.5±0.3 ^a	5.2±0.3 ^b	2.4±0.2 ^c	1.8±0.2 ^d	1.9±0.2 ^d
Lactobacilli, 10 ⁹ cells·g ⁻¹	2.2±0.2 ^a	1.9±0.2 ^a	0.9±0.1 ^b	0.8±0.1 ^b	0.5±0.2 ^c
Yeasts, 10 ⁸ cells·g ⁻¹	0.7±0.1 ^a	0.7±0.2 ^a	0.8±0.2 ^a	0.7±0.2 ^a	0.2±0.1 ^{ba}
a-f = Means ± SD within the same line with different lowercase superscript letters are significantly different (P ≤ 0.05)					

Since the composition and quality of the nutrient mixture greatly influences the sourdough biotechnological parameters, the content of reducing sugars, LAB and the acidity in nutrient mixtures used for the sourdough preparation were studied.

The initial acidity of the nutrition mixture for sourdough before fermentation increased along with an increase in the amount of bread crumbs. The content of reducing sugars, which are fermentable sugars and feeding for LAB and yeasts, was higher in a nutrition mixture made with 25-75% of bread crumbs. In a nutritional mixture made from 100% of bread crumbs, the amount of reducing sugars was the same as in the control.

It was found that in the nutrient mixtures prepared without bread crumbs and nutrient mixtures with 25% and 50% of bread crumbs, the content of LAB was 10 × 10⁸ cells· g⁻¹. With an increase of bread crumbs dosage up to 50%, the LAB amount in the nutrient mixture decreased in 10 times, and with a further increase up to 75% and 100%, LAB in the nutrient mixture were not detected at all.

With increasing in the bread crumbs dosage from 50 to 100%, biotechnological indicators deteriorated: acid accumulation slowed down, lifting force get worth (Table 3). Despite the fact that the content of LAB and yeast was the same in the control and in the sourdough

with 25% of bread crumbs, the sourdough with 25% of bread crumb had better lifting power and the content of alcohol and volatile acids in it was higher compared to the control.

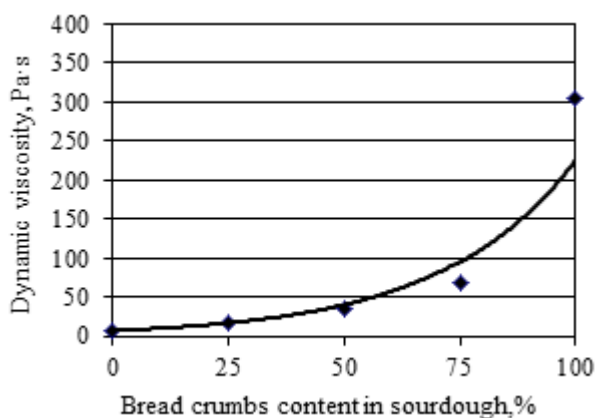


Fig. 1. Sourdough dynamic viscosity.

Sourdough viscosity was investigated. The viscosity increased when bread dosage increased, which may makes it difficult or impossible to transport and to dose the sourdough using pump (Fig. 1).

The data obtained showed that the optimal dosage was 25% of bread crumbs in sourdough.

The influence of liquid rye sourdough contained 25% of recycled bread crumbs on the new bread quality and its microbiological safety was investigated. It was found that the experimental bread samples in terms of physical, chemical and organoleptic characteristics were close to the control (Table 4, Fig. 2). Porosity, specific volume and compressibility were comparable in all samples. In bread made with sourdough containing 25% of bread crumbs was higher content of volatile acids and alcohol. This had a positive effect on its taste and smell (Fig. 2).

The crumbliness of the breads made with bread crumbs in sourdough was 2 times lower than that of the control samples.

The effect of the bread crumbs on the bread resistance to the microbial spoilage was established. When contaminated bread by *Penicillium chrysogenum*, the mould colonies hadn't gown on bread slices until total slice staling. No science if ropy disease was observed in all bread samples.

Table 4. Phisycο-chemical indicators of bread.

Indicators	Control	Made with bread crumbs in dough	Made with bread crumbs in sourdough
Acidity, degrees	8.0±0.2 ^a	7.6±0.2 ^b	7.8±0.3 ^b
Pore volume, %	68±2 ^a	66±2 ^a	67±2 ^a
Specific volume, cm ³ g ⁻¹	2.0±0.2 ^a	2.0±0.2 ^a	2.1±0.2 ^a
Quantity of alcohol, % of dried weight	0.88±0.05 ^a	0.87±0.05 ^a	0.96±0.04 ^b
Volatile acids, % of the total acidity	20.0±0.2 ^a	21.7±0.1 ^b	25.0±0.3 ^c
Compressibility in a 24 h, unite of device	20±2 ^a	21±2 ^a	21±3 ^a
Compressibility in a 96 h, unite of device	10±2 ^a	11±2 ^a	11±2 ^a
Crumbliness in a 24h, %	6.4±0.2 ^a	6.3±0.2 ^a	3.1±0.2 ^b
Crumbliness in a 96h, %	9.2±0.2 ^a	6.6±0.2 ^a	2.9±0.2 ^b

a-c = Means ± SD within the same line with different lowercase superscript letters are significantly different (P ≤ 0.05)

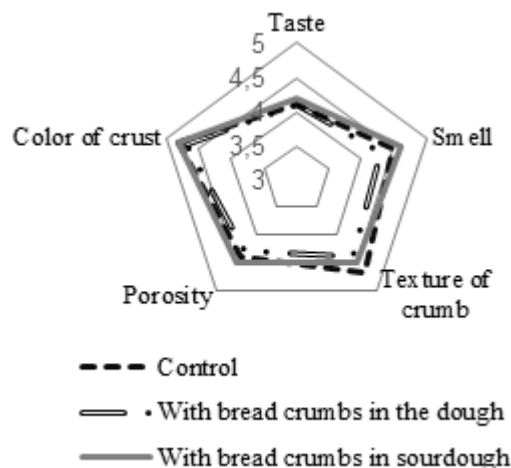


Fig. 2. Organoleptic characteristics of breads.

4 Discussions

New data on the influence of the nutritional mixture composition and the bread crumbs content on the liquid sourdough biotechnological parameters were obtained in these studies. At the present time, the data on influence of old bread on sourdough, dough and bread is limited in the scientific literature. The data obtained by us in this and in previous work [13] have shown that recycled bread has a different effect on various sourdough types possessing different humidity and microbial content.

The increasing in nutrient mixture acidity with old bread addition may be due to the high acidity of rye-wheat bread [8, 13]. But in the fermented sourdoughs containing 50-100% of bread crumbs the acidity decreased compared to the sourdoughs with 25% bread crumbs.

The data on the sugar content showed that the slowing of acid-forming activity with an increase in the bread crumb dosage was not associated with a sugar deficiency, since the content of reducing sugars in the sourdough with bread crumbs was higher than in the control (Table 3). The high content of reducing sugars in sourdough with bread is confirmed by other studies [13, 15, 16]. When the amount of old bread increased up to 75%, the content of reducing sugars increased too. In sourdough with 100% of old bread sugars content decreased and was comparable to the control. The data obtained for the liquid sourdough differ from the data obtained earlier for the dense rye sourdough. The dense sourdough contained more quantity of reducing sugars [13]. In addition, at 100% replacement of flour in with bread crumbs, more quantity of reducing sugars were found in dense sourdough than in the control. Obviously, this may be due to the difference in the moisture content of sourdough.

It was found that in the nutrient mixtures prepared without bread crumbs and with 25% and 50% of bread crumbs, the content of LAB was 10×10^8 cells \cdot g⁻¹. With an increase in the amount of bread crumbs up to 50%, the LAB amount in the nutrient mixture decreased in 10 times and with increase in the bread crumbs content up to 75% and 100%, LAB in the nutrient mixture were not detected. Consequently, the content of spontaneous fermenting microflora in the nutritional mixture with an increase in the dosage of bread crumbs was significantly reduced. The study of the microflora of the fermented liquid rye sourdough showed that replacing 25, 50, 75 and 100% of flour with bread crumbs also showed a decrease in the content of lactic acid bacteria. Thus, the decrease in the acidity of the experimental sourdough was possibly due to a decrease in the content of spontaneous microflora in the nutrient mixture introduced with flour and participating in the acid formation process along with starter microorganisms introduced during sourdough propagation [13, 18, 21].

Despite the slowing down of acid formation and a smaller amount of lactic acid bacteria in the sourdoughs made with 50-100% of bread crumbs, the content of volatile acids in it was higher. This may be due to the dominance of heterofermentative LABs, as well as to the fact that rye-wheat bread crumbs also contain a large amount of volatile acids [13, 19, 21].

The sourdoughs made with 50-100% of bread crumbs increased significantly less in volume. This may be due to the fact that the native proteins and carbohydrates of rye flour have been replaced by bread degraded ones. [8, 18]. Bread crumbs polymers were degraded during baking and have lost native properties. They differ from polymers of native flour [8, 21, 22]. Since the amount of yeast was comparable and the amount of fermentable sugars was higher in the sourdoughs with bread crumbs than in the control, the volume reduction was not associated with low fermentation activity [8, 19, 23]. The sourdough volume was lower because of native biopolymers degradation.

It is also of great importance to develop resource-saving technologies that would economic advantages for the manufacturer and would not require significant

changes in the baking technological process and new equipment. The success of the introduction of new technologies largely depends on the convenience of their application at already operating enterprises. Therefore, in our work, we tried to optimize and make available the bread recycling in successfully operating bakery enterprises. So, sourdough viscosity was evaluated, as it one of the important characteristics for liquid sourdough transporting. With an increase in the bread crumbs dosage more than 25%, the viscosity increased significantly, even with careful homogenization and grinding. It is also due to the change in bread biopolymers compared to native flour.

The lower crumbliness of the breads with bread crumbs have shown that the sourdough with bread crumbs allowed slowing down the staling of bread. This data confirmed data obtained by other researchers [14, 15]

Fermentation of bread crumbs in sourdough has a beneficial effect on the bread quality indicators. The content of alcohol and volatile acids in bread made with sourdough with 25% of bread crumbs (Table 2) was higher than in the control. This provided the improvement of the taste and smell of bread made with 25% of bread crumbs in sourdough. Comparison with the data obtained earlier showed that the sourdough type influenced the content of volatile acids [13].

The absence of mold and rosy-disease in infected bread indicated that bread recycling had not increased the risk of the bread microbial spoilage. This may be due to the antimicrobial activity of LAB [25, 26].

So the influence of bread crumbs in sourdough on the bread quality was shown. It is obvious that the bread crumb usage in the sourdough allowed increasing the amount of processed bread in comparison with the Russian norms. The use of bread crumbs in sourdough have not negatively affect the bread quality and have not increase the risk of microbial spoilage.

5 Conclusions

The data obtained showed that the amount of fermentable (reducing) sugars in the sourdoughs with bread crumbs was higher, and the yeast content was comparable to the control traditional sourdough. Thus, a decrease in the sourdough volume has not associated with deterioration in fermentation activity. It was due to the fact that native biopolymers (proteins and starch) were degraded in bread and could not retain gas bubbles.

It was found that an increase in the amount of bread crumb over 25% significantly increased the viscosity. This may make impossible transporting of sourdough by pumps in bread-making enterprises.

The sourdough containing 25% of bread crumbs had a higher acidity, higher content of volatile acids and alcohol than the control. The amount of lactic acid bacteria and yeast was comparable in both cultures. This is due to the fact that bread is a good nutrient mixture.

When the bread crumbs were fermented in sourdough, the crumbliness of the newly made bread was two times less during storage. This showed the

slowing of the staling process compared to bread based on traditional sourdough and bread made using bread crumbs in the dough.

Based on the results of the study, it is obviously that bread crumbs usage in the sourdough allows increasing the amount of recycled bread in comparison with the Russian norms.

References

1. A. Adessi, M. Venturi, F. Candelieri, V. Galli, L. Granchi, R. De Philippis, *Int. J. Hydrog. Energy*, **43** (20), 9569-9576 (2018)
2. S. Torabi, B. Satari, *Biomass Conversion and Biorefinery* (2020)
3. S. Haroon, A. Vinthan, L. Negron, S. Das, A. Berenjian, *Am. J. of Biochem. and Biotechnol.*, **12**, 102-109 (2016)
4. F. Koon, C. Cho, M. Ho, S.L. Carol, *Food Bioprod. Process.*, **92**, 282-290 (2014)
5. C.C.J. Leung, A.S.Y. Cheung, A. Y.-Z. Zhang, K.F. Lam, C.S.K. Lin, *Biochem. Eng. Journal.*, **65**, 10-15 (2012)
6. A.S. Demirci, I. Palabiyik, D. Apaydın, M. Mirik, T. Gumus, *LWT*, **101**, 40-47 (2019)
7. N. Thani, S.M.M. Kamal, F. Taip, A. Sulaiman, R. Omar, *Food and Bioproducts Processing*, **117**, 105-112 (2019)
8. S.P. Cauvain, L.S. Young, *Technology of Breadmaking*, second ed. (Springer, BakeTran, UK, 2007, 397)
9. O. Benabda, M. Kasmi, F. Kachouri, M. Hamdi, *Food Bioprod. Process*, **109**, 1-8 (2018) DOI: 10.1016/j.fbp.2018.02.007
10. M. Verni, A. Minisci, S. Convertino, L. Nionelli, C.G. Rizzello, *Frontiers in Microbiology* (2020)
11. A. Kosovan, *Rules for the organization and conduct of the technological process at the baking enterprises* (GOSNIIHP, Moscow, 1999)
12. L. Kuznetsova, O. Savkina, L. Usova, *Bread products*, **3** (2017)
13. O. Savkina, L. Kuznetsova, M. Lokachuk, O. Parakhina, E. Pavlovskaya, N. Lavrenteva, *E3S Web of Conferences*, **161**, 01082 (2020)
14. *Bread + Pastries and Confectionery* (Almanac, Hamburg, 2011)
15. M. Immonen, H. Ndegwa, Y. Wang, R. Coda, K. Katina, *International Journal of Food Microbiology* (2020)
16. M. Verni, A. Minisci, S. Convertino, L. Nionelli, C.G. Rizzello, *Front. Microbiology* (2020)
17. A. Kosovan, *The collection of modern technology of bakery products* (Moscow printing house, Moscow, 2008)
18. O. Savkina, L. Kuznetsova, M. Burykina, M. Kostyuchenko, O. Parakhina, *Agronomy Research*, **18** (3) (2020)
19. L. Puchkova, *Laboratory Workshop on Bakery Technology* (GIORD, Saint-Petersburg, 2004)
20. O. Afanasjeva, *Microbiology of bakery production* (Beresta, Saint-Peterburg, 2003)
21. M.G. Gänzle, *Food Microbiol.*, **37**, 2-10 (2014) DOI: 10.1016/j.fm.2013.04.007
22. A.S. Sivam, D. Sun-Waterhouse, S. Quek, C.O. Perera, *Journal of Food Science*, **75**, 8 (2010)
23. M. Schirmer, M. Jekle, T. Becker, *Procedia Food Science*, **1** (2011)
24. C. Kurtzman, J.W. Fell, T. Boekhout, *The Yeasts, A Taxonomic Study*, 5th edition (Elsevier, Amsterdam, 2011)
25. Y.I. Hassan, T. Zhou, L.B. Bullerman, *Food Science and Technology International*, **22** (1) (2015)
26. G. Zhang, J. Tu, F.A. Sadiq, W. Zhang, W. Wang, *Comprehensive Reviews in Food Science and Food Safety* (2019)