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PHYSICO-CHEMICAL, RHEOLOGICAL AND TECHNOLOGICAL CHARACTERIZATION OF SOME MIXTURES OF WHEAT, OAT, BARLEY AND MILLET FLOURS

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The aim of the research was to evaluate the addition effect of various whole flours, such as fibers sources, to wheat flour, on the physico-chemical and technological properties of dough. In this regard, a dark wheat flour and its mixtures with whole oat, barley and millet flours were analyzed (in proportions of 85:15 and 70:30). The changes of the following parameters have been analyzed: wet gluten, gluten index, protein content, ash content, pH, falling number, as well as farinographic and alveographic parameters of dough. The results showed that the addition of whole oat, barley and millet flours significantly changed the physico-chemical and technological properties of dough, compared to dark wheat flour ($p<0.05$). The results are important in guiding the bakery industry for using new types of fiber-enriched flours.

Keywords: alveographic parameters, barley, β-glucans, farinographic parameters, millet, mixtures of flours, oat, physico-chemical parameters, wheat

Introduction

The potential for using in bakery industry various assortments of cereals flours, (other than wheat, such as oat, barley, millet etc.) or coming from pseudo-cereals (eg. buckwheat) was limited, because of the lack of gluten and the higher fiber amounts of some sources. The addition of oat, barley or millet flours in the recipes of various bakery products was described as having negative effects on dough rheology and on the main sensory parameters of bakery products (Litwinek *et al.*, 2013; Bojňanská *et al.*, 2013). Consequently, the diversification of bakery products had been seriously moderated by the use of these flours in small quantities, and therefore their functional potential was not used at its true value.

Cereals such as wheat, millet and barley were part of the basic diet of ancient populations in a vast geographical areas (Middle East, North Africa and Europe), but gradually the wheat gained a significant importance and the other cereals were used especially in animal feed (Tannahill, 1988; Newman and Newman, 2006).

Whole oat flour has a significant higher amount of mineral substances (+20%), lipids (about 6.2 times higher) and total fibers (+ 86%), compared to whole wheat flour (Manolache *et al.*, 2013). The protein content of the two assortments of flours is similar and the amount of starch in whole oat flour is on average about 10 g/100 g d.m. lower than for wheat flour (Šramková *et al.*, 2009). From the point of view of the fibers nature, the whole wheat flour contains a higher amount of cellulose and about 4 times less β-glucans (Grausgruber *et al.*, 2004; Usman *et al.*, 2010).

Barley is an important source of polyglucides, which represent about 80% of the kernel weight, being one of the most important sources of β-glucans (Blažeková, 2015; Szczodrak, 1992; Granfeldt, 1994). Researches conducted by Czuchajowska *et al.* (1998) established that the chemical composition of whole barley kernels was variable, in terms of protein content, respectively between 12.5% for barley with high content of amylose (HA barley) and 15.5% for waxy barley (W barley) (Granfeldt, 1994). The mineral content ranges from 2.11% to nonwaxy bareley and 3.0% to high amylose barley. Free lipid content is more homogeneously distributed among different types of barley: about 2.6% for nonwaxy and waxy barley, respectively 2.16% for barley with high amylose content. The starch content varies relatively moderately, between 65.2% (HA barley) and 67.6% (NW barley) and the total β-glucans between 5.5% (HA-barley) and 6.6% (W-barley) (Czuchajowska *et al.*, 1992; Czuchajowska *et al.*, 1998).

Although millet has been an important culture in the past, for the people of southern and eastern Europe, the interest in eating it has fallen. Millet remains today an important source of nutrients in the diet of Asian people (Saleh *et al.*, 2013). The chemical composition of millet is variable, depending on the cultivar. The common millet contains about 12.5% proteins, 3.5% lipids, 3.1% mineral substances, 5.2% fibers and 63.8% starch (Hulse *et al.*, 1980; U. S. National Research Council/National Academy of Sciences, 1982).

The use of composite flours, from wheat flour and other cereals or pseudo-cereals, has a major research interest due to: the challenges linked to population growth, the competition between food market and energy market because the contribution of biofuels from cereals increases, the interest in obtaining functional food, the combining of local (such as millet in some countries in Africa) and imported resources (wheat), in order to reduce the cost of bread making (Gomez *et al.*, 1992).

The rheological properties of dough made of composite flours, even if the main component is wheat flour, are very variable and sometimes raise significant issues in their technological capitalization (Hüttner *et al.*, 2010). These technological issues are related to the extra amount of fibers, with which whole flours from various cereals or pseudo-cereals participate in dough preparation. Fibers can cause mechanical damage to gluten films or may affect the water distribution in dough (Litwinek *et al.*, 2013, Choi *et al.*, 2012). Water retention in fibers can cause the incomplete hydration of gluten proteins and the formation of short-chain gluten networks, with altered elastic properties (Popa *et al.*, 2015, Tamba-Berehoiu, 2015, Stear, 1990). On the other hand, flours from other cereals do not form gluten, which is why their addition significantly contributes to the decrease of the dough gluten content, compared to a dough made exclusively from wheat.

Therefore, rheological parameters such as: dough stability, extensibility and alveographic mechanical work are affected (Rojas *et al.*, 1999; Popa and Tamba-Berehoiu, 2016). The effects are visible on the quality and sensory parameters of the bakery products, parameters that are criteria of consumers' acceptability, namely: the decrease in bread volume, worsening of taste, color and flavor (Salehifar *et al.*, 2006; Bojňanská and Urminská, 2013; Pastuszka *et al.*, 2012).

The purpose of the paper and related research was to explore the potential of whole oat, barley and millet flours added to wheat flour, to obtain fiber rich bakery products, as sources of β-glucans. In this respect, we evaluated:

- the effect of the addition of oat, barley and millet flours to wheat flour, on the physico-chemical parameters of the flour mixtures (humidity, pH, wet gluten content, ash content, falling number);
- the effect of the addition of whole oat, barley and millet flours on the rheological parameters of the dough, by farinographic and alveographic analysis.

Materials and methods

The following assortments of flours were used to carry out the research: dark wheat flour from harvest 2016, with a natural high content of protein (no gluten added), produced by Farinsan SA; standardized whole oat flour, purchased from SC Cope SA Piatra Neamt, with the following characteristics: moisture (%) max. 10, ash content (%) max. 1.2, protein content (%) 10, fibres content (%) 4, carbohydrates content (%) 66, lipid content (%) 8, granulation characterized by an average particle size of less than 500 µ for 97% of the particles, the remaining 3% having dimensions between 500 and 1000 µm; whole barley flour from the stone mill (according to the producer, Solaris Plant S.R.L.); whole millet flour from the stone mill (according to the producer, Solaris Plant S.R.L.). Some of the physico-chemical characteristics of these flours are discussed in the "Results and discussions" chapter.

The experimental plan included the testing of wheat, oat, barley and millet flours, as well as the testing of different mixtures of these flours, according to Table 1. The testing was performed in three replicas (n=3), the results were statistically processed, taking into account the mean values as representative.

The statistical interpretation of the data was based on the analysis of the significant differences between means, using Student test. The abbreviations used in the text to express the significance of differences, based on the probability of transgression were: *significant $p<0.05$; **very significant $p<0.01$ and ***extremely significant $p<0.001$(Fišteš, 2014; Snedecor, 1966).

Table 1. The experimental scheme and the analysis methods

Variant No./Flour assortments	Wheat (%)	Oat (%)	Barley (%)	Millet (%)	Performed analyses
Control	100	0	0	0	Wheat flour and mixtures with other assortments of flours:
1	**85**	**15**	0	0	- moisture M% 130^0 C, thermobalance Precisa XM 60,
2	**70**	**30**	0	0	- protein P% and ash A% content (NIR method, INFRAMATIC 8600 Perten);
3	**85**	0	**15**	0	- pH (Serna-Saldivar method, 2012: extraction of 10 g of sample in 100 ml of distilled water for ½ hour. Measurement was performed with a pH-meter Testo 206 pH1);
4	**70**	0	**30**	0	- wet gluten content WG% and gluten index GI (ICC no. 155 method);
5	**85**	0	0	**15**	- falling number FN (ISO 3093); - farinogram (ISO 5530-1:2013); - alveogram (ISO 27971:2015)
6	**70**	0	0	**30**	Oat, barley and millet flour: - moisture; - pH.

Results and discussion

The results obtained from the physico-chemical analysis of wheat flour and of the mixtures of wheat, oat, barley and millet flours (n=3) are presented in Table 2.

Table 2. Physical and chemical quality parameters of wheat flour and flour mixtures

Parameter / Flour type	M(%)	pH	P(%)	A(%)	WG(%)	GI	FN(s)
Wheat	13.950 ± 0.050	6.54 ± 0.04	17.567 ±0.058	0.993 ± 0.030	42.400 ± 0.529	89.660 ± 2.081	421.667 ± 7.637
Oat	10.263 ± 0.032	6.32 ± 0.02	11.000 ±0.125	1.420 ±0.050	nd	nd	733.000 ± 6.083
Barley	10.200 ± 0.020	5.51 ± 0.02	10.700 ±0.100	1.000 ±0.025	nd	nd	388.667 ± 5.131
Millet	10.250 ± 0.026	6.48 ± 0.02	10.500 ±0.135	0.643 ±0.045	nd	nd	326.667 ± 5.773
Wheat-Oat (85:15)	13.833 ± 0.058	6.52 ± 0.02	17.166 ±0.153	1.016 ± 0.015	37.600 ± 0.100	86.667 ± 3.512	490.800 ± 8.000
Wheat-Oat (70:30)	13.567 ± 0.058	6.48 ± 0.01	16.400 ±0.200	1.080 ± 0.020	31.200 ± 0.100	92.000 ± 2.000	469.667 ± 3.512
Wheat-Barley (85:15)	13.367 ± 0.058	6.40 ± 0.010	17.100 ±0.200	0.953 ± 0.006	39.167 ± 0.058	90.000 ± 3.464	450.333 ± 5.033
Wheat-Barley (70:30)	13.200 ± 0.100	6.27 ± 0.01	16.867 ±0.231	0.960 ± 0.010	34.267 ± 0.252	88.000 ± 3.464	403.000 ± 11.000
Wheat-Millet (85:15)	13.733 ± 0.058	6.52 ± 0.01	16.800 ±0.200	0.973 ± 0.006	37.633 ± 0.351	85.333 ± 1.155	443.333 ± 7.638
Wheat-Millet (70:30)	13.500 ± 0.100	6.49 ± 0.01	15.667 ±0.416	0.923 ± 0.006	30.833 ± 0.802	92.333 ± 2.082	390.333 ± 4.509

nd – not determined

Flour moisture. Moisture parameter (%) was characterized by normal values for the wheat flour (13.95±0.05%). Whole oat, barley and millet flours had relatively low humidity values, probably due to the fact that they were obtained using a dry grinding technology (10.26% for oat flour, 10.20% for barley flour and 10.25% for millet flour).

Flour pH ranged from 5.51 for whole barley flour to 6.54 for wheat flour. With the exception of the wheat–millet flour mixture, where pH did not differ significantly (t=2.3), the pH of all tested flours was extremely significantly different (t=8.4*** for wheat–whole oat flour mixture up to t=53.94*** for whole barley–millet flour mixture).

Regardless of the addition level, the oat flour did not significantly changed the pH of flour mixtures when compared to wheat flour (t=0.77 ns for samples with 15% oat flour, and t=0.40 ns for samples with 30% oat flour).

The addition of whole barley flour extremely significant decreased the pH of flour mixtures in relation with wheat flour, in both studied variants (t=6.007*** for the 15% whole barley flour mixture and t=11.468*** for the 30% whole barley flour mixture).

The addition of whole millet flour did not significantly change the pH of flour mixtures, when compared to wheat flour, for none of the variants of the mixtures (t=0.685 for 15% millet flour and t=1.921 for 30% millet flour).

The native protein content of wheat flour was very high (17.567%). The protein content of whole flour of oat, barley and millet was extremely significantly lower than that of wheat flour, ranging from 11.0% in whole oat flour to 10.5% in millet flour. Oat flour had a significantly higher protein content than barley flour (+0.3%, t=3.246*) and very significantly higher than millet flour (+0.5%, t=4.707**). The protein content of barley and millet flours did not differ significantly (t=2.06 ns).

The mineral content (ash) differed extremly significantly ($p<0.001$) between the analyzed flours, being the highest in the case of oat flour (1.42%) and the lowest in the case of millet flour (0.64%). The only flours that did not differ significantly, concerning the ash, were wheat flour versus barley flour (0.993% vs. 1.000%, t=0.311). The content of mineral substances did not significantly change in the case of the addition of 15% oat, barley or millet flour into wheat flour. When 30% whole oat flour was added, the mineral content increased significantly from 0.993% to 1.08 (t=4.179*). When whole millet flour was added, the mineral content decreased significantly from 0.993% to 0.923% (t=3.963*). It was noted that the addition of whole barley flour did not significantly change the mineral content of the analyzed flours.

Wet gluten content decreased extremely significantly ($p<0.001$) in all flours mixtures, depending on the amount of oat, barley or millet flours added. The most significant decreases were recorded for samples enriched with millet and oat flours (-26.4% compared to wheat flour, for the mixture with 30% whole oat flour, respectively -27.3% for the mixture with the addition of 30% millet flour).

Gluten index. There were no significant differences between gluten index values of wheat flour when compared to the values of flour mixtures containing oat, barley and millet. There was only one exception, concerning the assortment 85% wheat–15% millet flours, when the gluten index significant decreased from 89.666 to 85.333 (t=3.155*).

Falling number. Falling number values differed extremely significantly between the three analyzed flour assortments. The highest value of the parameter was observed for whole oat flour (733 s), while the lowest value was recorded for millet flour (326.667 s). Wheat flour had a value of 421.667 s, very significantly higher than barley flour (388.667; t=6.212**).

Generally, the addition of 15% other flours to wheat flour had significantly increased the value of the falling number, when compared to the value of wheat flour. Thus, when 15% oat flour was added, the falling number value increased extremely significantly, by 68.33 s (t=10.701***), when 15% barley flour was added, the falling number value increased very significantly, by 28.66 s (t=5.428**) and when 15% millet flour was added, the falling number value increased significantly, by 21.66 s (t=3.473*). The results are unexpected because, with the exception of oat flour, the falling number values of other flours are significantly lower than wheat flour. When the quantity of oat, barley and millet flours added into wheat flour was increased to 30%, the falling number values significantly decreased, when compared to the values of 15% mixtures. The increase of the falling number in the wheat-whole oat flour mixture was due to the higher value of this parameter in the whole oat flour (733 s). The falling number is in relation with the characteristics of the oat starch, versus wheat starch, namely: higher gelatinization temperature (Wang and White, 1994; Doehlert *et al.*, 1997; Kaarlehto and Salovaara, 2000), lower amylase activity (Meredith and Jenkins, 1973), as well as a reduced availability for enzymes attack. Thus, for wheat–oat flour mixtures, the falling number significantly decreased from 490 to 469.667 s (t=- 4.031*), for wheat–barley flours mixture the falling number decreased extremely significantly from 450.333 s to 403 s (t=- 6.677***) and for wheat – millet flours mixture the decrease was also extremely significant from 443.333 s to 390.333 s (t=-10.350***). On the other hand, the significant decrease of the falling number, between the two wheat-whole oat flours mixtures (15% vs. 30%), was probably based on the increase of fibers and lipids, as the amount of whole oat flour was higher (knowing that both fibers and lipids are interfering with the hydration processes of the starch granules). It is also not negligible any effect on the particles size, since the average dimensions of the whole oat flour particles were higher than that of the wheat flour particles, knowing that the falling number is significantly influenced by the particles size.

The results obtained from the farinographic analysis of dough, made from wheat flour and from mixtures with oat, barley and millet flours, are presented in Table 3.

The *water absorbtion (WA)* of flour mixtures increased when compared to the WA of the wheat flour, except for the addition of millet flour, in which case the decrease of the WA was observed. The explanation is probably related to the fiber content of the flours, the fiber amount of millet flour being smaller than that of the oat and barley flours. The greatest increase of WA was observed when oat flour was added. Thus, when 15% of oat flour was added, the WA increased by 2.9% (t=13.294***) and when 30% of oat flour was added, the WA increased by 6.7% (t=30.158***). The addition of 15% barley flour did not significantly change the WA (t=0.399), but the addition of 30% barley flour resulted in an extremely significant increase of the WA by 3.17% (t=14.326***). The millet flour extremely significantly decreased dough WA, by 5.5% for the 15% mixture (t=-23.344***) and by 8.13% for the 30% mixture (t=-22.967***).

Table 3. Farinographic parameters for wheat flour and mixtures of flours dough

Parameter*/ Flour assortment	WA (%)	DT (min)	ST (min)	$DS_{10'}$ (UF)	$DS_{12'}$ (UF)
Wheat	65.166 ± 0.351	9.666 ± 0.764	10.833 ± 0.473	3.667 ± 2.309	68.000 ± 2.645
Wheat – Oat (85:15)	68.100 ± 0.100	8.467 ± 0.451	5.400 ±0.264	0 ± 0.000	83.000 ± 3.000
Wheat – Oat (70:30)	71.833 ± 0.153	8.300 ± 0.100	3.933 ±0.115	23.333 ± 6.506	90.667 ± 11.015
Wheat - Barley (85:15)	65.367 ± 0.115	6.167 ± 0.351	8.133 ±0.513	8.133 ± 0.513	25.000 ± 0.500
Wheat - Barley (70:30)	68.333 ± 0.153	5.833 ± 0.058	6.667 ±0.153	25.333 ± 4.509	70.333 ± 2.517
Wheat - Millet (85:15)	59.667 ± 0.208	5.500 ± 0.100	5.667 ±0.351	42.333 ± 6.658	81.667 ± 12.583
Wheat - Millet (70:30)	57.033 ± 0.503	5.167 ± 0.209	7.333 ±0.763	45.333 ± 4.509	94.000 ± 6.000

*WA-water absorbtion; DT–development time; ST–stability, DS10–dough softening degree at 10 minutes from begining of mixing; DS12–dough softening degree at 12 minutes from the end of development time.

Dough development time. The dough development time for the control flour (wheat flour) can be considered extremely high, probably due to the high amount of gluten, when the time required to incorporate all the flour components, into a homogeneous matrix, needs to be longer. As a general feature of the experiment, the development times of the flour mixtures were shorter compared to the control flour (-1.20, respectively -1.37 minutes for mixtures with the addition of whole oat flour; respectively -3.50 and -3.84 minutes for the mixtures with barley flour and -4.17 and -4.5 for the mixtures with millet flour.

Dough stability. The addition of cereal flours, others than wheat, resulted in a decrease in dough stability. The most significant decrease was observed when oat flour was added. Thus, when 15% oat flour was added, dough stability halved, the decrease being extremely significant (t=8.823***). When 30% oat flour was added, dough stability was about 64%, also extremely significantly lower (t=24.555***). When barley flour was added, the decrease of dough stability was smaller, although the differences when compared to the dough stability of wheat flour are significant (-15.7% for 15% barley flour mixture, t=7.208***; respectively -38% for 30% barley flour mixture, t=8.664***).

The addition of 15% millet flour, decreased extremely significantly (t=9.364***) the value of dough stability parameter, by about 47%. Interestingly, the addition of 30% millet flour resulted in a significant increase (t=3.458*) of dough stability value, when compared to the 15% mixture. It is possible that for this variant, the lower fibers content had a lower impact on dough stability. It is known that fibers, by their cellulosic nature, can cause mechanical damages to the gluten networks and implicitly to their ability to maintain dough stability (Webster, 2016).
When other assortments of flours were added, dough stability decrease was linear, as the amounts of flours of different cereals increased (extremely significantly for 15% and 30% oat mixture, t=-8.823***, respectively 24.55***; very significantly t=-4.743** for 30% barley flour mixture, insignificantly for 15% barley flour mixture).

Dough softening. Dough softening was evaluated on the basis of the two parameters provided by the farinographic analysis, carried out on Farinograph E Brabender: softening at 10 minutes, from the beginning of the kneading operation and softening measured at 12 minutes, after reaching the maximum farinographic curve (corresponding to the end of dough development phase).

The results showed that for softening measured at 10 minutes, were registered statistically significant increases for all analyzed mixtures, when compared to wheat flour, regardless of the used variant (15% or 30%). The highest increases, extremely significant, were observed when millet flour was added to wheat flour (42.333 UF for 15% mixture, t=9.503*** and 45.333 UF for 30% mixture, t=14.246***, compared to 3.667 UF for wheat flour). Very significant increases were recorded for 30% oat flour mixture (from 3.667 UF to 23.33 UF, t=4.938**; for 15% oat flour mixture, dough softening being 0). This value did not differ significantly from the corresponding value in wheat flour (t=2.751; p=0.0513) and can be explained by the different hydration duration of the oat fibers, relative to other dough components. This phenomenon can cause changes in the profile of the pharinographic curve, over the time interval at which this parameter is measured (10 minutes after the start of the kneading process). For 15% barley flour mixture, the value of 10 min. dough softening was significantly increased (t=3.27*), compared to wheat flour and for 30% barley flour mixture, dough softening increased very significantly t=7.408**. In the case of dough softening measured at 10 minutes, no significant differences were found between the tested variants (15% versus 30%) for none of the flours. In fact, the addition of other cereal flours to wheat flour, over the amount of 15%, did not influence the value of this parameter, neither in the case of oat flour, nor in the case of barley or millet flour.

In the case of dough softening measured at 12 minutes after the end of dough development, the results obtained were contradictory. Thus, when 15% oat flour was added, dough softening increased extremely significantly (from 68 UF to 83 UF, t=44.529***), while adding 30% oat flour caused a significant increase of dough softening at 90.667 UF (t=3.465*). When oat flour was added, the differences were not significant between 15% and 30% variants. In the case of millet flour, only 30% mixture determined a very significant increase of dough softening measured at 12 minutes (from 68 UF to 94 UF, t=6.868**). With the exception of barley flour, for which there are extremely significant differences between variants, regarding the effect on dough softening parameter (t=14.256***), for oat and millet flours, there are no significant differences between variants (15% vs. 30%). The differences between the evolution of two dough softening, measured at 10 and 12 minutes, are related to the length of the mechanical stress applied to the dough at the time of measurement. If, in the case of 10-minute softening, we talk about a mechanical stress applied for 10 minutes, in the case of 12-minute softening, we talk about a mechanical stress applied for 20-21 minutes (because the softening at 12 minutes is measured from the moment of the maximum peak of the pharinographic curve). Potential explanations for the increase of dough softening degree, with the addition of oat flour, could be: the larger amount of water initially introduced into the system, in relation to wheat flour, corroborated with the higher degree of gluten network deterioration, in the presence of fibers at kneading, etc. There are studies in the literature which suggest that the addition of oat flour causes a drop in dough water retention capacity (Oomah, 1983).

The results obtained from the alveographic analysis of dough, made of wheat flour and by oat, barley and millet flours mixtures, are shown in Table 4 (n=3).

Table 4. Alveographic parameters of wheat flour and mixtures of flours dough

Parameter*/ Flour assortment	**P (mm)**	**L (min)**	**W (10^{-4}J/g)**	**P/L**	**Ie (%)**
Wheat	46.667 ± 2.082	185.333 ± 10.016	155.000 ±5.000	0.250 ± 0.050	41.633 ±0.208
Wheat – Oat (85:15)	83.000 ± 3.000	71.333 ±3.214	171.000 ±8.544	1.173 ± 0.065	40.300 ±0.300
Wheat – Oat (70:30)	116.000 ± 5.291	33.000 ±3.000	155.000 ±5.000	3.520 ± 0.034	0 ±0.000
Wheat - Barley (85:15)	77.000 ± 3.000	88.000 ±2.000	193.667 ±3.511	0.877 ± 0.045	46.533 ±0.379
Wheat - Barley (70:30)	110. 333 ± 1.528	66.333 ±3.786	228.667 ±12.097	1.67 ± 0.113	44.533 ±0.252
Wheat - Millet (85:15)	49.333 ± 0.578	108.333 ±2.082	135.000 ±11.790	0.453 ± 0.045	44.900 ±0.010
Wheat - Millet (70:30)	51.667 ± 2.517	52.000 ±2.000	107.667 ±10.786	0.807 ± 0.060	42.633 ±0.321

*P-Resistance; L-Extensibility; ST-stability, W-Mechanical work; P/L-Resistance/Extensibility ratio; Ie-Elasticity index

It can be observed in Table 4 that wheat flour was characterized by a very high alveographic extensibility parameter (L=185.333 mm), respectively by a low resistance/extensibility ratio (P/L=0.250). From the bakery characteristics point of view, most of the quality parameters are outside the ideal variation limits specified by some literature sources: P [65–70 mm], L [130–150 mm], P/L [0.55–0.65], W>200 cm^2 (Banu et. al., 2000). It can be observed that the effect of the addition of fiber-rich flours is related to the decrease of dough extensibility and the increase of dough resistance, for all analyzed mixtures, when compared to the control flour.

Dough resistance. The strongest effect on the resistance parameter was registered for fiber–richest flours. Thus, when 15% of these flours were added, oat flour increased the value of dough resistance by 36 mm and barley flour by 30 mm; when 30% cereals flours were added, the dough resistance values were higher by 69 mm for oat flour and by 64 mm for barley flour. The effect of fiber–rich flours (barley, oat) on dough resistance was 10–14 times stronger than that of added millet flour. In the case of wheat-millet flour mixtures, dough resistance was insignificantly modified, when compared to control flour, both for 15% variant (+3 mm, t=2.137 ns) and for 30% variant (+6 mm, t=2.651 ns).

Extensibility of dough. The extensibility parameter had been affected in a similar way. The most prominent extensibility decrease effect was observed when added whole oat flour (-114 mm for the 15% addition and -152 mm for the 30% addition). The addition of barley flour reduced the extensibility of dough by 97 mm in the case of 15% variant and by 116 mm in the case of 30% variant. The addition of millet flour had initially a lower effect on dough extensibility, compared to other flours. Thus, the addition of 15% millet flour decreased the value of the parameter by 77 mm. However, the addition of 30% millet flour resulted in a decrease in extensibility, even higher than the one observed in the case of barley flour (-133 mm). The observed effects were probably due to the cumulative intervention of several factors: lowering of gluten content, modification of dough water mobility in the presence of fibers (by its unavailability for hydration of certain dough components, including gluten), mechanical actions of breaking the dough protein films, due also to fibers.

Mechanical work. It was noted that the most powerful growth effect was determined by the addition of barley flour ($+39x10^{-4}$ J/g, for the 15% variant, respectively $+74x10^{-4}$ J/g for the 30% variant). The addition of 15% whole oat flour, significantly increased the mechanical work value ($+16x10^{-4}$ J/g, t=2.800*), but the 30% addition did not significantly change the parameter (t = 0). The addition of millet flour decreased insignificantly the value of mechanical work in the 15% variant ($16x10^{-4}$ J/g, t=2.705 ns), and very significantly in the 30% variant ($47x10^{-4}$ J g, t=6.896**).

The *dough P/L ratio* (between resistance and extensibility) significantly ($p<0.05$) increased for all the cereal flours and analyzed variants, relative to the value of the control flour. The highest increases had been observed in the case of oat flour addition (1.173 and respectively 3.52 versus 0.250 in wheat flour), followed by barley (0.877, respectively 1.670) and millet (0.453, respectively 0.807) flour addition.

The *dough elasticity index (Ie)* dropped significantly in the case of oat flour addition to 40.3%, for 15% variant (t=6.325 **), reaching the value of 0 at 30% oat flour addition. In the case of millet and barley flours, the value of the dough elasticity index increased significantly, relative to wheat flour. Increases were higher for barley flour.

Conclusions

The effect of the different cereals whole flour addition, to wheat flour, on the main quality parameters, varied significantly, depending on the flour assortment and the used quantities.

The pH of flour mixtures did not significantly change by the addition of whole oat and millet flours to wheat flour; the addition of whole barley flour (both 15% and 30%) significantly decreased the pH of the flour mixtures relative to wheat flour.

For all studied variants, the protein content and wet gluten content of the flour mixtures were significantly lower than for the control flour. The most important decreases were recorded in the case of millet and oat flours addition, less in the case of whole barley flour addition.

The mineral content (ashes) did not change significantly in the case of the addition of whole oat, barley or millet flours (15%), to wheat flour. With the addition of 30% whole oat flour, the ash increased significantly. The addition of whole millet flour, significantly decreased the ash from 0.993% to 0.923% (t=3.963*). The addition of 30% barley flour did not change the ash content.

The water absorbtion (farinographic hydration capacity) of flour mixtures increased in relation to the water absorbtion of wheat flour (especially for the addition of whole oat flour), except for the wheat-millet flour mixture, which had a lower fiber content.

The development time and dough stability were lower for all flour mixtures than for the control wheat flour. Dough stability decreased most to oat-wheat mixtures and development time to millet-wheat mixtures.

Alveographic resistance of dough increased and extensibility decreased in fiber-rich flour mixtures, with oat and barley, relative to control flour. The addition of millet flour did not alter dough resistance and slightly decreased extensibility.

The dough mechanical work increased with the addition of whole barley flour ($+39x10^{-4}$ J/g, in the variant with 15% and $+74x10^{-4}$ J/g in the variant with 30%) and 15% whole oat flour ($+16x10^{-4}$ J/g, t=2.800 *). Millet flour, 30% in wheat flour, significantly decreased the value of mechanical work ($47x10^{-4}$ J/g, t=6.896 **).

The results are a solid basis for guiding future research studies into increasing the using potential of new assortments of fiber-enriched flours in the bakery industry. Moreover, the results can support local bread-making entrepreneurship, in order to develop new products, linked to modern trends in market progress and consumers' exigencies.

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