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Unlocking the Secrets of Special Micronized Wholemeal Flours: A Comprehensive Characterization Study†

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Abstract: This study aimed to characterize special micronized wholemeal flours with a fine granulation size of less than 160 μm. The flours under investigation included wheat, rye, spelt, barley, buckwheat, sorghum, and teff. Various parameters were investigated to characterize the flours, including moisture, energy value, fat, carbohydrates, sugars, total protein, ash, and total dietary fiber (TDF). The falling number of the flours was assessed using the Hagberg-Perten method. Furthermore, the pasting properties of tested flours were analyzed using an amylograph, and a Rapid Visco Analyser (RVA). The water absorption of the wholemeal flours was examined using a farinograph. Additionally, the technological quality of the tested material was assessed based on the water (WRC) and sodium carbonate Solvent Retention Capacity (SRC) profile. Among the analyzed micronized flours, special wheat flour (WWF) had the highest nutritional value and rye flour (WRF) was characterized by the lowest nutrient content and the highest amylolytic activity. The lowest water absorption were found in special teff flour (WTF). The lowest TDF content and amylolytic activity were found in special buckwheat flour (WBWF).

Keywords: wholemeal flours; micronized flours; quality; nutritional composition; rheological properties

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1. Introduction

The demand for cereal products with enhanced nutritional value is on the rise among consumers. One effective strategy to meet this demand is by incorporating wholemeal bread or pseudo-cereal flours. The consumption of whole grains has been associated with a decreased likelihood of developing lifestyle-related conditions like type 2 diabetes, metabolic syndrome, and cardiovascular disease. This connection is attributed to the abundance of bioactive compounds found in whole grains, including fiber, vitamins, antioxidants, and phytoestrogens. Despite the numerous health advantages associated with consuming whole grains, their sensory attributes often do not match those of traditional products. To tackle this challenge, manufacturers are actively seeking innovative approaches to craft wholemeal products that maintain satisfactory sensory qualities [1].

A potential solution to enhance the visual and gustatory aspects of wholemeal bread involves the creation of flour with finer particles. This can be achieved by utilizing advanced milling technologies like impact mills, which were previously underutilized. Employing finely ground wholemeal flour obtained through this gentler milling process significantly diminishes the sensory impact on the final product. Furthermore, it preserves higher levels of easily absorbable dietary fiber and other valuable components due to the delicate grinding technique [2].

Summing up, the fine-grinding of whole grain flours using identical milling parameters as those for conventional flour ensures heightened nutritional benefits and increased water-binding capabilities. This leads to generally enhanced baking attributes and an extended shelf life for the ultimate consumer [2].

The aim of the conducted research was to characterize special micronized wholemeal flours: wheat, rye, spelt, barley, buckwheat, sorghum, and teff.

2. Materials and Methods

2.1. Materials

In the experimental part, selected fine-ground wholegrain flours from wheat (WWF), rye (WRF), spelt (WSF), barley (WBF), buckwheat (WBWF), sorghum (WSGF), teff (WTF) (with fine granulation < 160 μm) provided by the company Perner Svijany Mill, Ltd were used.

2.2. Methods

2.2.1. Chemical composition of raw materials

Flours were determined for: moisture ICC No. 110/1 [3], total protein content – with the Kjeldahl method (ICC No. 105/2) using a Foss Tecator Kjeltec 2400 analyzer (Foss, Hilleroed, Denmark) (WWF, WRF, WSF - N×5.7, WBF, WBWF, WSGF, WTF - N×6.25), ash content – with the ICC No. 104/1, fat - with the ICC No. 136, total dietary fiber (TDF) (Megazyme kit (Ireland) and Fibertec System (Tecator Foss, Sweden)) acc. AOAC 991.43 method [4].

The determination of carbohydrates content was calculated from the dry matter and other nutrients/components of the product (dry matter = carbohydrate + fibre + protein + fat + ash). The content of sugars (mono- and disaccharides) was determined chromatographically after extraction of sugars into aqueous liquor. Anex chromatography (HPAEC-PAD) was used for separation and quantification of sugars, and.

The calculation of the energy value of product was based on its nutritional value (from the content of the nutrients, i.e. protein content, digestible carbohydrate content, fibre content and fat content) and using conversion factors for 1 g of the ingredient. Energy value calculation (kJ/100 g): content of protein (g/100 g, w/w) * 17.2 + content of carbohydrates (g/100 g, w/w) (without fibre) * 17.2 + content of fat * 37 + content of total dietary fibre * 8.4.

The samples were analyzed at least in duplicate, and the results are expressed on a dry matter (d.m.) basis.

2.2.2. Rheological properties of paste and dough

The falling number of flours was determined according to the Hagberg-Perten method (AACC Method 56-81B) [5]. The rheological properties of dough from wholemeal flours were analyzed using a farinograph (Brabender OHG, Duisburg, Germany) (AACC Methods 54-21) [5]. The farinographic analysis allowed determining water absorption of flour (% compared to flour used).

Properties of pastes made of the flours tested were evaluated using an amylograph (Brabender OHG, Duisburg, Germany) according to AACC Methods 22-10. Amylograms obtained were used to read out values of the initial and final pasting temperatures and maximal paste viscosity.

Pasting properties of flours were also determined using a Rapid Visco Analyser (RVA) model 4500 (Perten Instruments, Australia). Distilled water (25 ± 0.01 g) was added to the flours (3.5 ± 0.01 g) in an aluminium RVA canister. The masses of the H_2O and flours were adjusted (±0.01 g) to compensate for the differences in moisture content of each sample. In all the tests a moisture level of 14 % was maintained, resulting in a relative high solid percentage. Clumping was prevented by stirring with a plastic paddle after which pre-programmed profiles were initiated. The profile for flour was used to capture rheological information (RVA curves), time 16 minutes. Each suspension was kept at 50 °C for 1 min and then heated up to 95 °C at 12.2 °C/min (over 4.5 min) and held for 2.0 min at 95 °C. It was then cooled to 50 °C at 11.8°C/min (over 3.5 min) and kept for 5.0 min at 50 °C. All the RVA tests were done in duplicate.

2.2.3. Solvent retention capacity

Technological quality of the tested material was determined according to AACC [5] method 56-11 Solvent retention capacity (SRC) profile, using flour samples of 5 g and the centrifuge Eppendorf 5702 (Eppendorf AG, Hamburg, Germany) and using 5.0 g/100 g sodium carbonate in water (sodium carbonate SRC) and deionized water (water retention capacity WRC). The solvent retention capacity (SRC) is expressed as the weight of solvent retained by the flour after centrifugation of the flour suspension with the solvent under the given conditions. It is expressed as a percentage by weight of flour. The result is based on 14% moisture of flour.

2.3. Statistic analysis

The results presented are mean values. Statistical analysis such as one-way ANOVA were analysed using Statistica 13.3 (StatSoft, Kraków, Poland). Significant differences ($p \leq 0.05$) between the mean values were determined using the Duncan's Multiple Range Test.

3. Results and Discussion

The chemical composition and energy value of micronized wholemeal flours are presented in Table 1. Among the analyzed flours, the highest moisture (11.2%) was found in WTF, and the lowest in WWF – 8.0% and WSF – 8.7%. Very similar results for wholemeal finely granulated flour were obtained by Skřivan et al. [2]. The highest energy value and carbohydrates content was found in WBWF – respectively 356.9 kcal/100g, 68.0 g/100g d.m. and WSGF – respectively 353.4 kcal/100g, 65.0 g/100g d.m. and the lowest amount of energy was provided by WWF (334.8 kcal/100g), WRF (335.3 kcal/100g) and WTF (337.3 kcal/100g). The highest total protein content was found in WWF (14.7 g/100g d.m.) and WSF (14.6 g/100g d.m.), and the lowest in WTF (11.3 g/100g d.m.). Our total protein results were higher than those obtained by Skřivan et al. [2], who also tested micronized flours, but also higher than the results of Lin et al. [6] and Warechowska et al. [7], who analyzed traditional ground wheat and rye wholemeal flours. The highest content of ash and TDF was found in WWF (2.36 and 18.7 g/100g d.m.), and the lowest amount of TDF was obtained for WBWF (4.4 g/100g d.m.). Skřivan et al. [2] obtained lower ash and TDF content for wheat, higher for rye and similar for spelt wholemeal finely granulated flour. Marchenkov et al. [8] noted lower ash content in whole wheat and spelt flours. In the case of buckwheat flour, the TDF content was more than double that obtained in our research. Hussein et al. [9] noted in their research lower content of protein, ash and fat in traditional ground whole wheat flour. The highest content of sugars was recorded for WRF (8.1 g/100g d.m.) and the lowest for WBWF and WTF (1.9 and 2.1 g/100g d.m.).

Table 1. Chemical composition and energy value of micronized wholemeal flours.

Flour type	Moisture [%]	Energy value [kcal/100g]	Total protein content [g/100g d.m.]	Ash [g/100g d.m.]	Fat [g/100g d.m.]	Carbohydrates [g/100g d.m.]	Sugars [g/100g d.m.]	TDF [g/100g d.m.]
WWF	8.0 c	334.8 b	14.7 a	2.36 a	2.8 ab	54.0 b	3.2 b	18.7 a
WRF	9.7 b	335.3 b	11.0 b	1.54 c	1.9 b	62.0 ab	8.1 a	14.6 ab
WSF	8.7 c	345.4 ab	14.6 a	1.63 c	2.3 b	61.0 ab	3.8 b	12.4 b
WBF	9.8 b	340.2 ab	13.8 ab	1.75 c	3.0 ab	59.0 ab	3.3 b	14.1 ab
WBWF	10.2 ab	356.9 a	13.8 ab	2.08 b	2.9 ab	68.0 a	1.9 c	4.4 d

WSGF	10.5 ab	353.4 a	13.4 ab	1.66 c	3.4 a	65.0 a	3.1 b	7.5 c
WTF	11.2 a	337.3 b	11.3b	2.23 ab	2.0 b	62.0 ab	2.1 c	15.9 ab

Values are expressed as the mean (n = 2). Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). WWF – wholemeal wheat flour, WRF - wholemeal rye flour, WSF - wholemeal spelt flour, WBF - wholemeal barley flour, WBWF - wholemeal buckwheat flour, WSGF - wholemeal sorghum flour, WTF - wholemeal teff flour.

Rheological properties of paste and dough and technological quality of flours are presented in Table 2. Among the analyzed flours, WRF was characetrized by the lowest falling numer (200 s), initial and final gelatinization temperatures (54.6 °C and 72.8 °C) and the highest WRC (128.8 g/100g) and sodium carbonate SRC (121.6 g/100g). WBWF had the highest falling number (>900 s) and maximum viscosity (3702 AU). Among the whole-grain rye flours tested by Warechowska et al. [7], two obtained a lower falling number (by 35.5% and 20%), and one obtained a 34% higher value of the tested feature than in our study. WWF was characterized by the highest water absorption (87.4%) and final gelatinization temperature (92.3 °C) and the lowest WRC (68.9 g/100g) and sodium carbonate SRC (82.9 g/100g). The lowest water absorption was found in WTF (58.0%). Higher water absorption values for wholemeal wheat flour were obtained in the studies of Protonotariou et al. [10]. Hussein et al. [9] observed 32% lower, and Warechowska et al. [7] 36% lower flour water absorption in the case of traditional ground whole grain flours. WSF was characterized by the lowest maximum viscosity (353 AU). In the study of Skřivan et al. [2], lower water absorption of wheat, rye and spelt flour and the same for buckwheat flour was noted. However, in the case of the mentioned flours, Skřivan et al. [2] obtained higher values of WRC, sodium carbonate SRC and falling numer (except for buckwheat flour, where the sample weight was reduced). The same authors [2] obtained similar values of amylolytic determination of the analyzed wheat and rye wholemeal flours and slightly higher values for spelt and significantly higher gelatinization temperatures for buckwheat. However, we obtained a much higher maximum viscosity.

Table 2. Rheological properties of paste and dough and technological quality of micronized wholemeal flours.

Flour type	Falling number [s]	Water Absorption [%]	Initial gelatinization temperature [°C]	Final gelatinization temperature [°C]	Maximum viscosity [AU]	Water retention capacity WRC [%]	Sodium carbonate SRC [%]
WWF	324 d	87.4 a	63.5 ab	92.3 a	805 d	68.9 f	82.9 e
WRF	200 f	83.4 b	54.6 c	72.8 d	495 e	128.8 a	121.6 a
WSF	238 e	76.4 c	58.6 bc	80.2 c	353 f	73.4 ef	100.9 c
WBF	389 c	70.6 d	61.0 b	87.2 ab	1234 c	80.5 d	109.4 b
WBWF	>900 a	63.4 e	59.8 bc	88.7 ab	3702 a	89.0 c	90.5 d
WSGF	398 c	63.8 e	65.6 a	86.4 bc	1655 b	77.2 e	92.5 d
WTF	424 b	58.0 f	63.8 ab	85.5 bc	1628 b	99.8 b	105.0 bc

Values are expressed as the mean (n = 2). Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). WWF – wholemeal wheat flour, WRF - wholemeal rye flour, WSF - wholemeal spelt flour, WBF - wholemeal barley flour, WBWF - wholemeal buckwheat flour, WSGF - wholemeal sorghum flour, WTF - wholemeal teff flour.

RVA analysis results are presented in Table 3. The highest pasting temperature was characterized by WWF (89.7 °C) and the lowest by WBWF (74.3 °C). The highest value of peak time was characteristic for WBF and WSGF (6.1 min) and the lowest for WRF (5.1 min). In the case of peak viscosity, the highest values were found for WBF (2670 cP) and WBWF (2729 cP), and the lowest for WRF (846 cP) and WSF (887 cP). When talking about holding viscosity, final viscosity and setback, it should be mentioned that the highest values of these properties were found in WBWF (respectively 2460 cP, 5278 cP, 2818 cP), and the lowest in WRF and WSF. The highest breakdown was found for WBF (1426 cP) and the lowest for WBWF (270 cP).

Table 3. Rapid visco-analysis (RVA) starch pasting profiles of micronized wholemeal flours.

Flour type	Pasting temperature [°C]	Peak time [min]	Peak viscosity [cP]	Holding viscosity [cP]	Final viscosity [cP]	Breakdown [cP]	Setback [cP]
WWF	89.7 a	5.8 bc	1282 c	761 d	2074 d	522 c	1312 cd
WRF	79.9 b	5.1 d	846 d	379 e	1038 e	466 e	658 e
WSF	86.5 ab	5.4 c	887 d	378 e	1022 e	508 d	644 e
WBF	86.4 ab	6.1 a	2670 a	1244 b	2794 c	1426 a	1550 c
WBWF	74.3 c	5.9 b	2729 a	2460 a	5278 a	270 g	2818 a
WSGF	87.2 ab	6.1 a	1914 b	1348 b	3416 b	566 b	2068 b
WTF	84.6 ab	5.8 bc	1354 c	959 c	2030 d	394 f	1071 d

Values are expressed as the mean (n = 2) ± standard deviation. Mean values bearing different letters in the same row denote statistical difference (a > b > c … etc.). WWF – wholemeal wheat flour, WRF - wholemeal rye flour, WSF - wholemeal spelt flour, WBF - wholemeal barley flour, WBWF - wholemeal buckwheat flour, WSGF - wholemeal sorghum flour, WTF - wholemeal teff flour.

4. Conclusions

These findings provide valuable insights into the nutritional composition, rheological properties, and technological characteristics of micronized wholemeal flours, aiding in their potential applications in the food industry and dietary planning.

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