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Preliminary Investigations on the Use of a New Milling Technology for Obtaining Wholemeal Flours

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Abstract: Wholemeal flours from various cereals and pseudocereals are a valuable source of nutritionally important fiber components, especially beta-glucans and arabinoxylans, as well as bioactive substances accompanying dietary fiber. Most types of whole-wheat flours have unfavorable baking and sensory properties. The finest granulation of bran particles in the flour has a significant effect on reducing or eliminating these deficiencies. Special disintegration equipment is required to achieve fine granulation of the bran particles. In this study, we have tested a special type of impact mill (originally intended for grinding of plastics) to produce special finely ground wholemeal flours with lower starch damage and higher farinographic absorption. Moisture content in the studied flours was significantly lower (7.4–9.8%) than is common in standard flour (13–14%). According to the results of flour analyses obtained from several cereal sources, it seems that especially in rye and wheat, this technology is suitable for both achieving fine granulation of bran particles and in terms of not very substantial damage of starch granules.

Keywords: wholegrain flour; wholemeal flour; milling technology; granulation; starch damage

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1. Introduction

The production of wholemeal flours is the oldest method of mill processing of cereals. It has been replaced by the production of flours containing mostly the endosperm over the centuries. The other anatomical parts of grain (hulls and germ) separate in a different way and these by-products are often traditionally used as feed ingredients for farm animals. The most efficient procedures of endosperm separation from the coating layers of the grain and the production of white flours are achieved in the case of wheat. White wheat and bread wheat flours consisting mostly of endosperm particles are the most widespread type of flours in Europe, USA, and currently also in the majority parts of the world [1,2].

The endosperm separation reduces the spectrum of flour components to starch and storage proteins. In the case of wheat, starch (a digestible polysaccharide) accounts for about 80% of the dry matter of bakery flours and the remaining components are the proteins of gliadin and glutenin fraction. Virtually all dietary fiber and fiber accompanying substances with proven health benefits then become a component of the by-product (bran) and only a very low proportion, in the order of units of percent, remains in the standard bakery flours. The higher content of fiber, minerals, vitamins, phenolic compounds, and other bioactive compounds can be found in darker (bread) flours. This also applies to rye, another bread cereal used mainly in Central, Eastern, and Northern Europe, albeit in this case, the endosperm separation is less effective than in the case of wheat and thus rye bread flour contains higher proportions of fiber (up to 10%) [3–6].

The most important components of fiber contained in the hulls of wheat, rye, and other cereals and pseudocereals in terms of nutritional benefits are cereal beta-glucans and arabinoxylans, and the most significant accompanying substances are phenolic compounds, showing for the most part antioxidant properties [7] and also some B-group vitamins and minerals [8–10].

For that reason, wholemeal flours are considerably more beneficial from the nutritional point of view than standard bakery flours. Their major problem is that for the production of basic types of bread and pastries of the Euro-American type, wholemeal flours are technologically less suitable and less sensorially acceptable [11,12]. Not to be overlooked is the fact that wholemeal flours are potentially more risky in terms of the content of contaminants, in particular mycotoxins and pesticide residues [13,14].

Standard wheat and rye wholemeal flours are produced in principle in two ways. In the first, most common case, the basis of the disintegration process is a simple impact mill that can be followed by a rolling mill for granulation treatment. The second method of production is the reconstitution of wholemeal flour from common mill products, which is used if the main production program of the mill is the standard composition of products (bakery flours) and wholemeal flour is a minor product. An example of such a product is Graham wheat flour. Even in the case of reconstituted flour, granulation treatment is usually carried out after the fractions have been assembled [1,2].

In both cases, despite the granulation treatment, insufficiently disintegrated particles of the tough outer layers remain in the flour, which are responsible for the specific sensory properties of the flour and bakery products. These particles absorb water and swell in the dough differently than the endosperm particles, making the dough denser and less homogeneous. The partially swollen bran particles then prevent the formation of a light, finely fibrous, porous dough structure during maturation and leavening, which is typical of wheat bread and pastries and is required by consumers. Even in the case of rye breads, where the structure of the dough is generally much more compact than in the case of wheat doughs, a higher proportion of common rye wholemeal flour has a negative effect. Typical Central European rye-wheat bread is as difficult to make from common wholemeal flour as wheat bread [15,16].

It turns out that granulation of particles of outer layers (bran particles) has a fundamental influence on technological behavior and sensory properties. If a sufficiently fine granulation is achieved, which is close to the average granulation of common very fine flours (below 150–200 μm), the sorption capacity (water binding) of such dough is significantly increased, but its mechanical and sensory properties change minimally. Such finely ground wholemeal flours can then replace conventional flours much better, and at the same time, thanks to the higher water binding, a significantly higher yield of dough and products is achieved.

A major problem to keep in mind in the case of production of such flours is the risk of too high a degree of damage to the starch granules. In other words, it is necessary to use a technique that reliably disintegrates the outer layers into very fine fractions, but at the same time does not cause extensive mechanical and especially thermal damage to the starch granules [15].

Damage to starch during disintegration is of two types: (a) mechanical, due to pressure, shear forces, and crash; and (b) thermal, especially due to friction. The deformation to which the grain and its internal structure are subjected during disintegration differs fundamentally depending on the type of mill and grinding parameters used. Grinding in roller mills has a different impact, depending on the parameters (advance, down pressure, specific load) and surface treatment of the rollers (grooving) and their mutual position. In the case of impact mills, other mechanical forces act, and grinding can be both very gentle and very destructive to starch granules, depending on the design of the mill and the process parameters [1,2].

When the grain is disintegrated in any way, partial deformation and damage to the starch granules always occurs. For bakery purposes, where fermentation is one of the key processes, a certain degree of starch damage is desirable because it becomes more amenable to the amylases present and a sufficient amount of substrate is created for yeast or lactic acid bacteria. In the case of flour for the production of wafers and biscuits, confectionery or pasta, damage to starch is not beneficial. However, with extensive damage, complications also arise in ordinary bakery production (stickiness of the dough, poor structure of the bread crumbs, etc.).

Starches of cereals and pseudocereals are easily broken down in the upper part of the human digestive tract. Most starches are completely resorbed in the small intestine, and only some starches may be partially resistant and are classified as indigestible polysaccharides [17,18]. Starch is gradually cleaved by amylases present in saliva and especially in pancreatic juice to oligosaccharides, which are further hydrolyzed to glucose monosaccharide. In the small intestine, glucose is actively absorbed into body fluids.

Dietary starch intake results in a significant increase in blood glucose. Glycaemia is the concentration of glucose in the blood, the value of which in fasting should not exceed 5.5 mol/L (in venous blood) according to the current approach [19]. Starch resorption is rapid, and its rate increases with the degree of damage to the native starch structure. Starch damage can occur biochemically (by enzymatic hydrolysis), chemically (by acid hydrolysis), mechanically, and thermally. The higher the starch resorption rate, the higher the glycemic index (GI) of the food in question [20].

The wholemeal flours tested in this study were produced in a special mill. Physical and chemical analyses of the flours were conducted and the impact of grinding technology on microstructure and properties of the flours was evaluated. What is essential for this work is the assessment of the extent to which the grain disintegration technique used leads to intensive comminution of the grain outer layers (bran particles) into fine granulation without significant damage to the starch granules.

2. Materials and Methods

Cereal grains (*Triticum aestivum* L., *Triticum spelta* L., *Secale cereale* L.) and a pseudocereal (*Fagopyrum esculentum* Moench) were decontaminated (cleaned) and then disintegrated in a special impact mill. Finely granulated wholemeal flours as final products were subsequently analyzed. The flours used were as follows: finely granulated wholemeal flour of wheat (wheat WM FG), rye (rye WM FG), spelt (spelt WM FG), and buckwheat (buckwheat WM FG).

2.1. Flour Production

The flours tested in this study were produced on a special mill from Mahltechnik Görgens GmbH (Dormagen, Germany). It is an impact mill with a vertical axis of rotation, which was not originally intended for grain processing, but which was included in a special production line in the company Mlýn Perner Svijany (Svijany, Czech Republic) and from which the grinding of cereals and pseudocereals into wholemeal flours achieves remarkable results.

The principle of the grinding process is the disintegration of the grist between specially shaped grinding segments rotating in several levels above each other and a specially modified inner shell of the wall of the grinding device (Figure 1). The material is kept suspended in the air stream throughout the disintegration, while it is possible to regulate the residence time of the grist in the grinding chamber and thus also its granulation. Thanks to this arrangement, the flour is not exposed to such thermal stress as when grinding on conventional grinding and roller mills.

The temperature in the grinding chamber ranges from 50 to 90 °C, while the temperature of the grist is in the range of 30–80 °C depending on the setting of the parameters of the special mill. The residence time of the grist in the grinding chamber is regulated by setting the parameters of the screen of the control plansifter located behind the mill. With sensitive control of the mill parameters, it is possible to achieve, on the one hand, very fine granulation of the bran parts, but on the other hand, there may not be more extensive damage to the starch granules either mechanically or thermally. The aim of our work was to verify these assumptions on selected samples of flour.

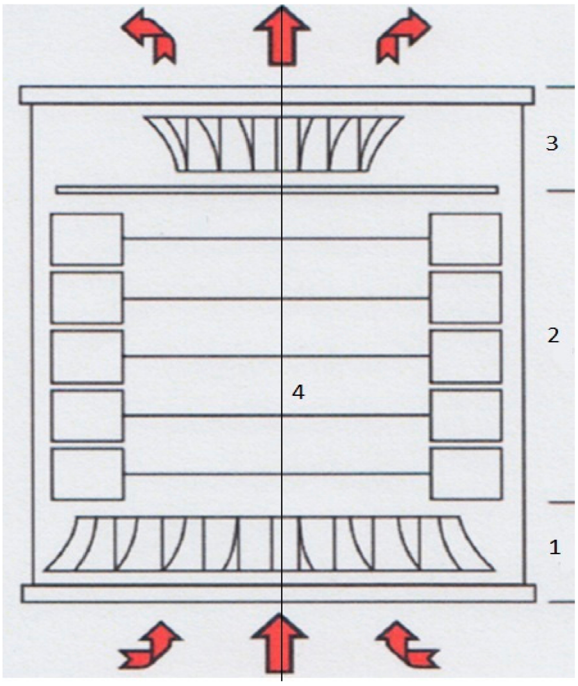


Figure 1. Scheme of grinding equipment. Description of the equipment parts: 1—grain input; 2—grinding zone; 3—sieving zone, regulation of the granulation; 4—rotation axis.

2.2. Determination of Moisture, Ash, Protein, and Fiber

The moisture content was determined by standard ICC (International Association for Cereal Science and Technology) No. 110/1, content of ash was specified by ICC No. 104/1, and protein content was measured using the Kjeldahl method (factor 5.7) (ICC No. 105/2). Soluble (SDF), insoluble (IDF), and total (TDF) fiber content was determined using a commercial Total Dietary Fiber enzyme kit from Megazyme (Ireland) according to the approved AOAC (Association of Official Agricultural Chemists) 991.43 method (determination of fiber by enzymatic-gravimetric method) on the Fibertec system (Tecator Foss, Höganäs, Sweden). The results of duplicates of moisture, ash, protein, and fiber determination were repeated three times.

2.3. Flour Granulation

The sieve analysis was performed according to previously valid Czechoslovak state standards. The sample weight amounted to 100 g, and it was sieved using a KS 1000 rotary sieve (Retsch, Haan, Germany) at a frequency of 100 rpm for 5 min. The set of sieves, equipped with chains, consisted of sieves with mesh sizes of 400, 300, 250, 200, 180, 150, 125, and 90 μm. Sieve analysis was performed in triplicate for each sample and the results were averaged.

2.4. Solvent Retention Capacity Profile

The physical-and-chemical test profile of retention capacity (SRC) was determined according to the AACC (American Association of Cereal Chemists) 56-11 methodology. 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. Four solvents are used independently to profile the SRC values: SRC water (demineralized water), SRC aqueous sucrose solution (50% *w*/*w*), SRC aqueous sodium carbonate solution (5% *w*/*w*), and SRC aqueous lactic acid solution (5% *w*/*w*). By combining these four SRC values, the quality profile of the flour can be determined, and its baking and technological properties can be predicted. In general, lactic acid SRC is associated with glutenin characteristics, sodium carbonate SRC with damaged starch levels, and sucrose SRCs with pentosans characteristics. The SRC of water is affected by all these components of flour. The results of duplicates of SRC profile parameters determination were repeated three times.

2.5. Determination of Falling Number

Estimation of alpha-amylase activity and degree of starch damage was performed using a Falling Number instrument (type 1400, Perten Instruments, Hägersten, Sweden). The procedure corresponded to the EN ISO 3093 standard, i.e., the weight of the flour sample corresponded to the current value of the flour moisture. An appropriate laboratory shaker of Polish origin (Wytrząsarka type SZ, biogenet, Józefów, Poland) was used to create the suspension. The results of two experiments of determination of Falling Number were verified (the results may differ not more than 5% of their mean value). There were three replicates performed in the same way for the statistical evaluation.

2.6. Farinographic Water Absorption

Farinographic binding of samples of flours and their mixtures was performed according to ISO 5530-1 with the connection of the Farinograph TS device (Brabender, Duisburg, Germany), allowing the addition of distilled water with regard to the current value of flour moisture and the repetition of the test with corrected binding. The measurement was performed in one replicate; the previously determined repeatability of the farinographic water absorption determination is 0.2 percentage points.

2.7. Amylographic Measurements

An AS-type amylograph (Brabender, Duisburg, Germany) was used to evaluate the viscosity behavior of flour suspensions during heating from 25 to 95 °C as a simulation of dough processes during baking. The test methodology was based on the international standard ICC 126/1, when the standard weight of flour and water was 80 and 450 g. The evaluated features were the onset temperatures and gelation maximum (°C) as well as the amylographic maximum (viscosity) in customary Brabender units (BU).

2.8. Scanning Electron Microscopy

The scanning electron microscope works with a stream of electrons in a vacuum in the case of conductive samples or at very low pressures for non-conductive samples. The interaction of the electron beam with the mass (sample examined) creates a visible image. The generated signals carry information about the topography of the sample and its material composition. The scanning electron microscope can provide comprehensive information about the microstructure, chemical composition, and other properties of the examined sample.

Secondary electrons (SE) and/or backscattered electrons (BSE) are most often used to monitor the microstructure of a flour sample. Images were taken on a TESCAN VEGA3 LMU microscope (tungsten cathode, SE and BSE detector) at different magnifications (500× and 2500×). The measurement was performed in UNIVAC mode (pressure 10 Pa) using a BSE detector. The accelerating voltage of the electrons was 20 kV. The flour samples were applied to a double-sided carbon tape and placed on the plates of a metal holder. Prior to scanning, the samples were covered with a continuous layer of 5 nm gold in a Quorum 150 coater.

2.9. Statistical Data Processing

The results of analytical and rheological measurements were statistically analyzed with STATISTICA software version 12.0 (StatSoft, Tulsa, OK, USA). One-way analysis of variance (ANOVA) at $p \leq 0.05$ was calculated and groups were estimated according to Duncan's new multiple range test (MRT).

3. Results and Discussion

The main research was focused on wheat flour (both sown wheat and spelt), rye, and buckwheat produced on the Görgens mill.

3.1. Chemical Analyses of Flours (Moisture, Ash, Protein, and Fiber Content)

In the case of ash, protein, and fiber content, the flours show the expected values corresponding to the individual raw materials. Moisture, ash, protein, and fiber content in the analyzed wholemeal flours are shown in Tables 1 and 2.

Table 1. Content of moisture, ash, and protein in the wholemeal finely granulated flours (WM FG). Data are the means of three replicates (±standard deviation).

Flour	Moisture (g/100 g)	Ash (g/100 g d.m.)	Protein (g/100 g d.m.)
Wheat WM FG	7.4 ± 0.1 a	1.62 ± 0.02 b	11.71 ± 0.52 b
Rye WM FG	9.4 ± 0.1 b	1.61 ± 0.03 b	8.39 ± 0.61 a
Spelt WM FG	9.0 ± 0.2 b	1.66 ± 0.03 b	13.44 ± 0.22 b
Buckwheat WM FG	9.8 ± 0.3 b	2.11 ± 0.04 c	12.70 ± 0.44 b
Wheat white (T530)	13.3 ± 0.1 c	0.56 ± 0.01 a	12.59 ± 0.11 b

Data represent the means of three replicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

Table 2. Dietary fiber content expressed as soluble (SDF), insoluble (IDF), and total fiber (TDF) in the wholemeal finely granulated flours (WM FG). Data are the means of three replicates (±standard deviation).

Flour	SDF (g/100 g d.m.)	IDF (g/100 g d.m.)	TDF (g/100 g d.m.)
Wheat WM FG	2.1 ± 0.2 b	8.8 ± 0.5 b	12.0 ± 0.8 b
Rye WM FG	5.3 ± 0.6 c	13.0 ± 0.3 d	18.2 ± 0.8 c
Spelt WM FG	2.5 ± 0.2 b	9.6 ± 0.9 c	12.4 ± 0.9 b
Buckwheat WM FG	3.2 ± 0.2 b	6.6 ± 0.2 b	9.7 ± 0.4 b
Wheat white (T530)	0.8 ± 0.1 a	2.7 ± 0.2 a	3.3 ± 0.3 b

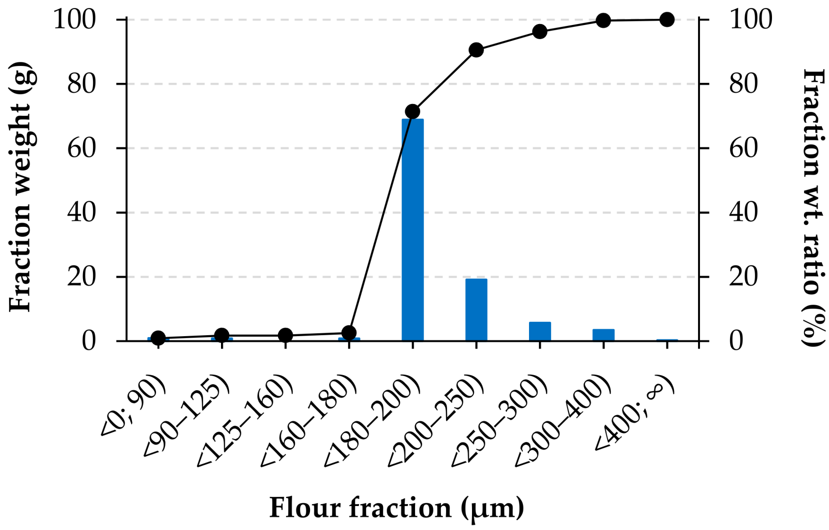
Data represent the means of three replicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

It should be noted that the moisture content of the flour samples examined is significantly lower than is usual for standard flours. With standard flours, the humidity values are usually in the range of 13–14%, while flours produced on a special Görgens mill most often have a humidity in the range of 7–10%. This is due firstly to the fact that the grain is not tempered before this method of grinding and at the same time it is also due to the disintegration method, especially by keeping the flour suspended in an air stream of 60–70 °C (Figure 1). At these air temperatures, with the usual residence time of the grist in the grinding chamber for several tens of seconds, the flour is heated to temperatures of 40–50 °C. The impact of this intervention on the starch structure is the subject of our investigation. The residence time of the individual particles in the grinding chamber varies according to their size. Coarse particles that do not pass through the control sieve return and their residence time is therefore longer. It does not exceed 1 min at the parameters set during the experimental production of the flours examined.

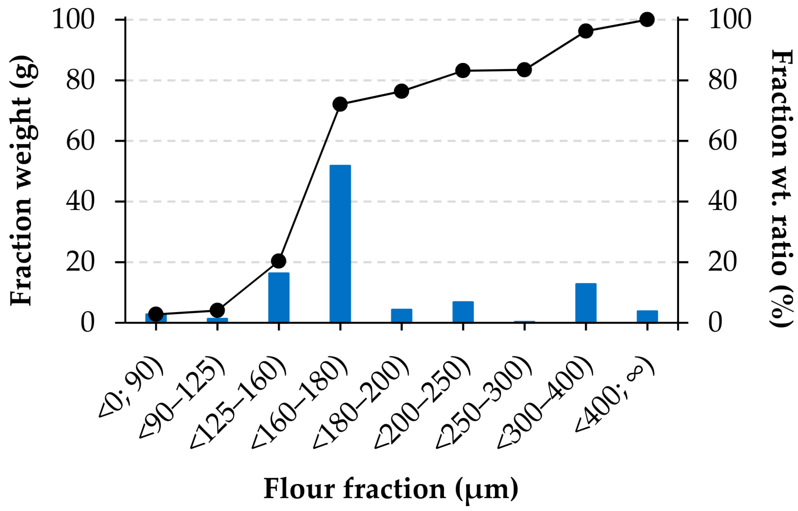
3.2. Flour Granulation

The method of grinding and the conditions in the grinding zone, which resulted in reduced moisture of the flours, are closely related to the achieved granulations of the individual flours, which represent the subsequent granulation spectra. Granulation spectra of the studied wholemeal flours are present in Figure 2.

In our case, two basic factors have a fundamental influence on the result of disintegration in terms of particle size (granulation): mechanical properties of the disintegrated material and grinding intensity, which in this case is given by the residence time of the grist in the grinding zone of the mill. Due to the fact that on the one hand there was the finest possible granulation of flours (and especially hull particles), but on the other hand also the effort to minimize interference with the structure of the endosperm, especially starch, the above conditions were chosen (residence time and related temperature environment and material). Under these conditions, the properties of the disintegrated grain are fully manifested because the disintegration conditions are the same and relatively gentle.

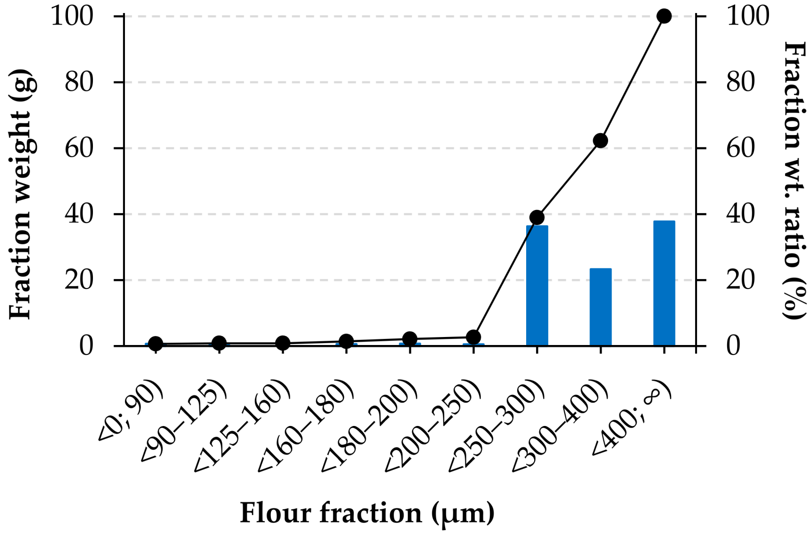


(**a**)



(**b**)

Figure 2. *Cont.*



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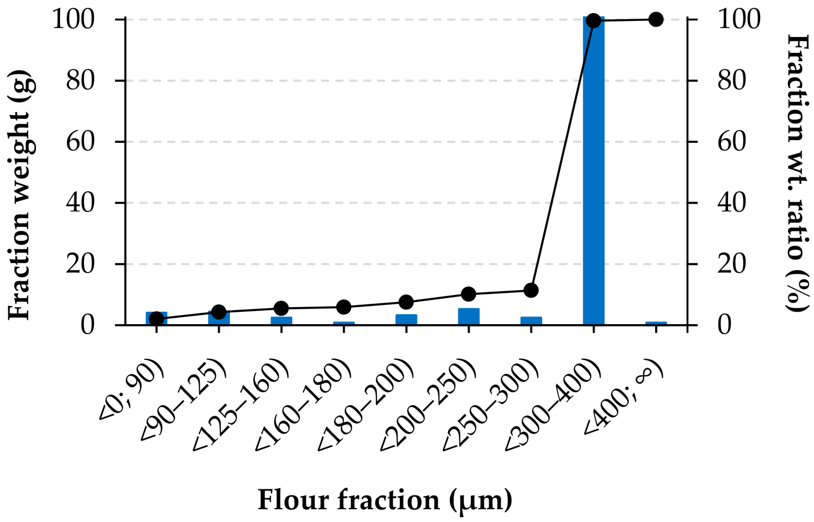


(**d**)

Figure 2. Granulation spectra of wheat (**a**), rye (**b**), spelt (**c**), and buckwheat (**d**) wholemeal finely granulated flours.

From this point of view, rye grain yields best to disintegration (particles 160–180 µm predominate) (Figure 2b), followed by common wheat (with a maximum frequency of particles of 200 µm without significant presence of coarser fractions) (Figure 2a). The situation is different for spelt and particularly for buckwheat (Figure 2c and 2d, respectively). A more intensive grinding process would be needed to achieve fine granulation comparable to rye or wheat flour. Especially, why buckwheat provides such a high yield of relatively coarse fraction (300–400 µm) (Figure 2d) will require further investigation.

3.3. Farinographic Water Absorption

Calculated farinographic water absorption of the analyzed wholemeal flours is shown in Table 3.

Table 3. Recalculated farinographic water absorption of the wholemeal finely granulated flours (WM FG). Data are the means of three replicates (±standard deviation).

Flour	Water Absorption (%)
Wheat WM FG	78.0 ± 0.1 b
Rye WM FG	59.2 ± 0.2 a
Spelt WM FG	70.0 ± 0.2 b
Buckwheat WM FG	63.4 ± 0.3 a
Wheat white (T530)	60.5 ± 0.1 a

Data represent the means of three replicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

The binding of wholemeal flours was determined in a mixture with standard wheat flour of known binding (the proportion of wholemeal flours was 30% by weight) and recalculated according to the mixing tolerance index. The bindings of wholemeal flours are unsurprisingly higher, which is due to their composition (presence of a higher proportion of biopolymers, especially polysaccharides with hydrocolloid properties). In all cases, the water absorption of these flours is around 60 or more percent. This, of course, has an impact on the processing (baking) properties. The water absorption did not fully correlate with the granulation of individual flours.

3.4. Solvent Retention Capacity Profile of Flours

While previous results relate to the physical impacts of the disintegration process, the SRC method is intended to outline a rough picture of the state of the microstructure of the endosperm after disintegration. SRC values of the analyzed wholemeal flours are presented in Table 4.

Table 4. SRC values of the wholemeal finely granulated flours (WM FG). Data are the means of three replicates (±standard deviation). SRC values are expressed as percent of flour weight, on a 14% moisture basis.

	SRC Values (%)			
Flour	Water	Sucrose	Lactic Acid	Sodium Carbonate
Wheat WM FG	89 ± 2 b	125 ± 2 b	101 ± 1 a	114 ± 2 c
Rye WM FG	133 ± 3 c	113 ± 2 a	117 ± 2 b	123 ± 2 c
Spelt WM FG	80 ± 2 b	106 ± 2 a	95 ± 2 a	102 ± 2 c
Buckwheat WM FG	96 ± 4 b	143 ± 3 b	103 ± 4 a	98 ± 4 b
Wheat white (T530)	59 ± 1 a	94 ± 2 a	114 ± 1 b	71 ± 2 a

Data represent the means of three replicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

Within the bounds of possibility provided by this method, the following can be stated. The SRC values in water correspond to a higher farinographic water absorption, although the results of farinographic binding are more balanced for individual flours. The SRC values for the sucrose solution correspond to the content of pentosans (arabinoxylans) and are relatively high, which is not a problem. High values for the lactic acid solution correspond to a higher presence of glutenins proteins in whole-wheat flours (both in common wheat and in spelt); in rye, endosperm proteins have different properties than in wheat, and in buckwheat they are practically absent.

For our research, the most significant values were those of SRC in sodium carbonate solution, which correspond to the degree of starch damage. From their values, the degree of starch damage in the examined wholemeal flours appears to be higher in comparison with the values for common flours in both wheat and spelt, as well as in the case of rye. The values for buckwheat are difficult to interpret in relation to wheat or rye because its flours behave very differently when determining SRC values (there was a partial separation of the layers during determination in sodium carbonate solution). Why it occurs still needs to be investigated in future research.

3.5. Determination of Characteristics of the Saccharide–Amylase Complex Using Falling Number and Amylograph

Values of Falling Number (FN) of the analyzed wholemeal flours are listed in Table 5.

Table 5. Falling Number values of the wholemeal finely granulated flours (WM FG). Data are the means of three replicates (±standard deviation).

Flour	Falling Number (s)
Wheat WM FG	368 ± 2 c
Rye WM FG	242 ± 3 a
Spelt WM FG	256 ± 3 a
Buckwheat WM FG	* 359 ± 3 c
Wheat white (T530)	316 ± 1 b

* Sample weight 4.40 g. Data represent the means of three replicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

This method indirectly informs about the amylolytic activity of the investigated material and the degree of damage to starch, which occurs during disintegration, affects only secondarily. Rather, if other methods indicate a higher degree of starch damage, the FN values illustrate to what extent it is enzymatic damage and to what extent physical. With examined wholemeal flours in the case of wheat, spelt, and rye, the FN values do not indicate increased amylolytic activity. Irrelevant values arise and the sample weight must be changed in order to obtain the FN values common to wheat, in the case of buckwheat under the conditions of the method for wheat or rye.

Amylographic evaluation provides a more comprehensive view of the state of the saccharide–amylase complex or starch, respectively. The values of amylolytic determination of the analyzed wholemeal flours are presented in Table 6.

Table 6. Values of amylographic measurements of wholemeal finely granulated flours (WM FG). Data are the means of duplicates (±standard deviation).

	Amylograph (%)			
Flour	Starting Temperature (°C)	Gelatinization Temperature (°C)	Gelatinization (BU)	Gelatinization Modified (BU) *
Wheat WM FG	64.0 ± 0.1 b	89.5 ± 0.1 b	746 ± 5 b	-
Rye WM FG	55.1 ± 0.1 a	71.9 ± 0.2 a	430 ± 1 a	-
Spelt WM FG	62.5 ± 0.1 b	81.2 ± 0.5 b	341 ± 4 a	-
Buckwheat WM FG	85.8 ± 0.2 c	101.9 ± 0.7 c	2370 ± 15 c	* 395 ± 5
Wheat white (T530)	60.1 ± 0.0 a	82.5 ± 0.1 b	677 ± 4 b	-

* Sample weight 40 g. Data represent the means of duplicates. Small letters in the same column denote significant differences according to Duncan's new multiple range test (MRT) ($p \leq 0.05$).

The determination of the amylographic maximum in the case of whole-wheat flours from common wheat shows rather a lower degree of starch damage even in comparison with common white wheat flour, which was also confirmed by control measurements using the RVA method (Rapid Visco Analyzer) (data unpublished). In the case of spelt or rye, on the basis of this indicator, the degree of starch damage appears to be rather higher, but not substantially so.

The problem is again in the case of determining amylographic indicators for buckwheat, similar to the determination of FN. Thus, the amylographic indicators of the examined wholemeal flours (especially in the case of sown wheat) also point to a relatively low degree of mechanical and thermal damage to starch, which does not differ significantly from the degree of damage caused by the standard grinding method.

The confrontation and the discussion with other studies was not possible because there are no available literature data on the grinding of cereals on this particular type of mill, which was not originally intended for their processing. Although similar types of grinding machines have already been used for these purposes, there are still relatively few literature data and each of the principally similar mills has its own specifics, for which comparison is difficult.

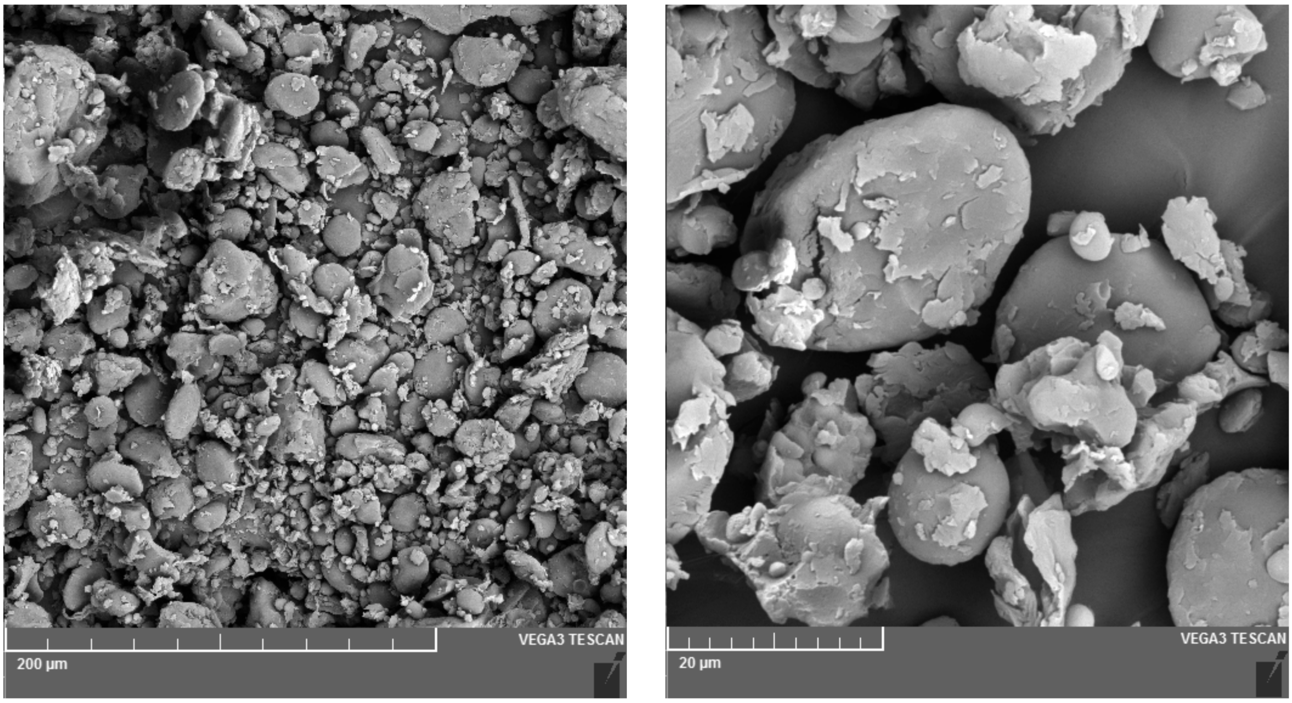
3.6. Scanning Electron Microscopy and Microstructure of Wholemeal Flours

The abovementioned methods of examining the degree of damage to the microstructure of the endosperm, especially starch granules, as well as other methods that we did not use in our work (e.g., amperometric measurement of damaged starch content according to ICC No. 172/1, on SDmatic, Chopin Technologies, Villeneuve-la-Garenne, France) always affect some aspect that occurs in the condition of starch in the given flour.

Therefore, the samples of the examined flours were subjected to scanning electron microscopy, which (at different levels of magnification) clearly shows both the condition, shape, and constitution of individual flour particles and (at higher magnification, 2500×) shape and possible deformation of individual starch granules. Scanning electron microscopy of samples of examined wholemeal flours are shown in Figure 3a–d.

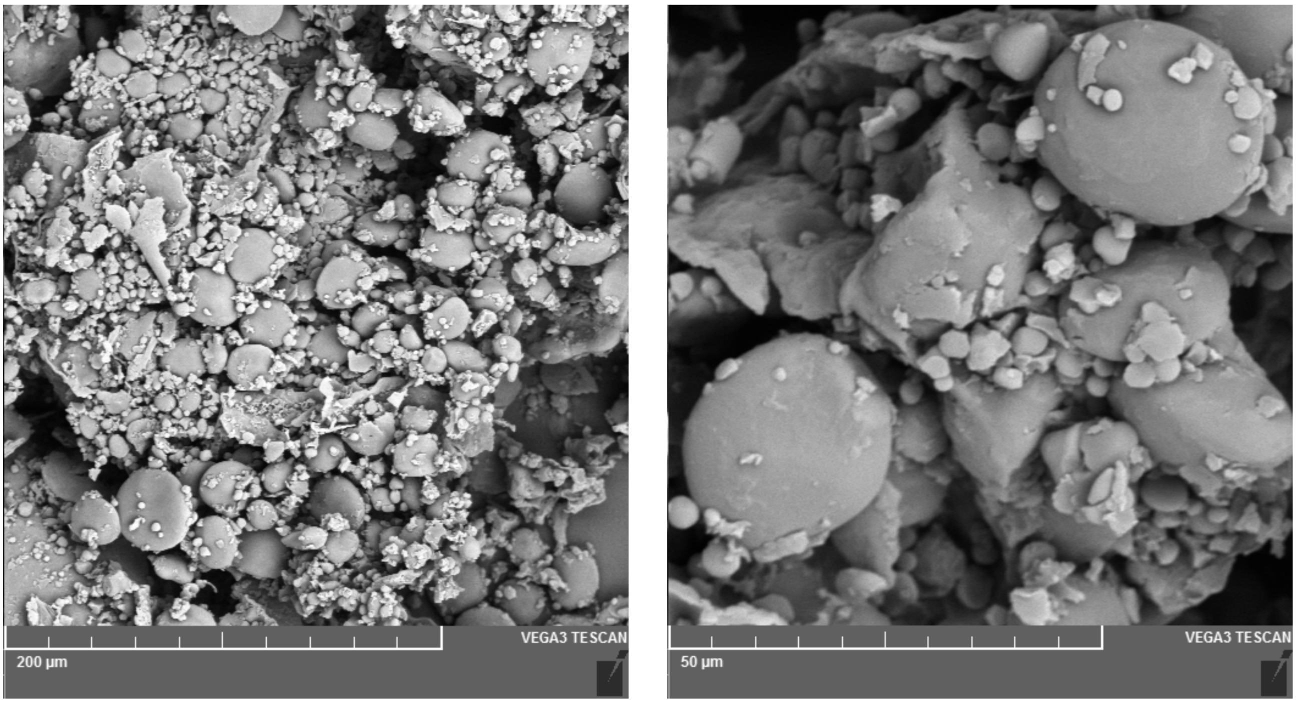
The spherical particles represent starch (small and large starch grains). Some large starch grains are slightly deformed and damaged mechanically on their surface. The other particles were fragments of the disintegrated portions of the outer and inner coating layers of the cereal grains. The portion of the protein matrix was also visible.

In summary, the images show that with the relatively gentle setting of the disintegration parameters mentioned above (residence time and resulting heating of the flour particles), the grain disintegration is relatively uniform and starch granules are not significantly damaged (e.g., compared to the standard roller grinding process).

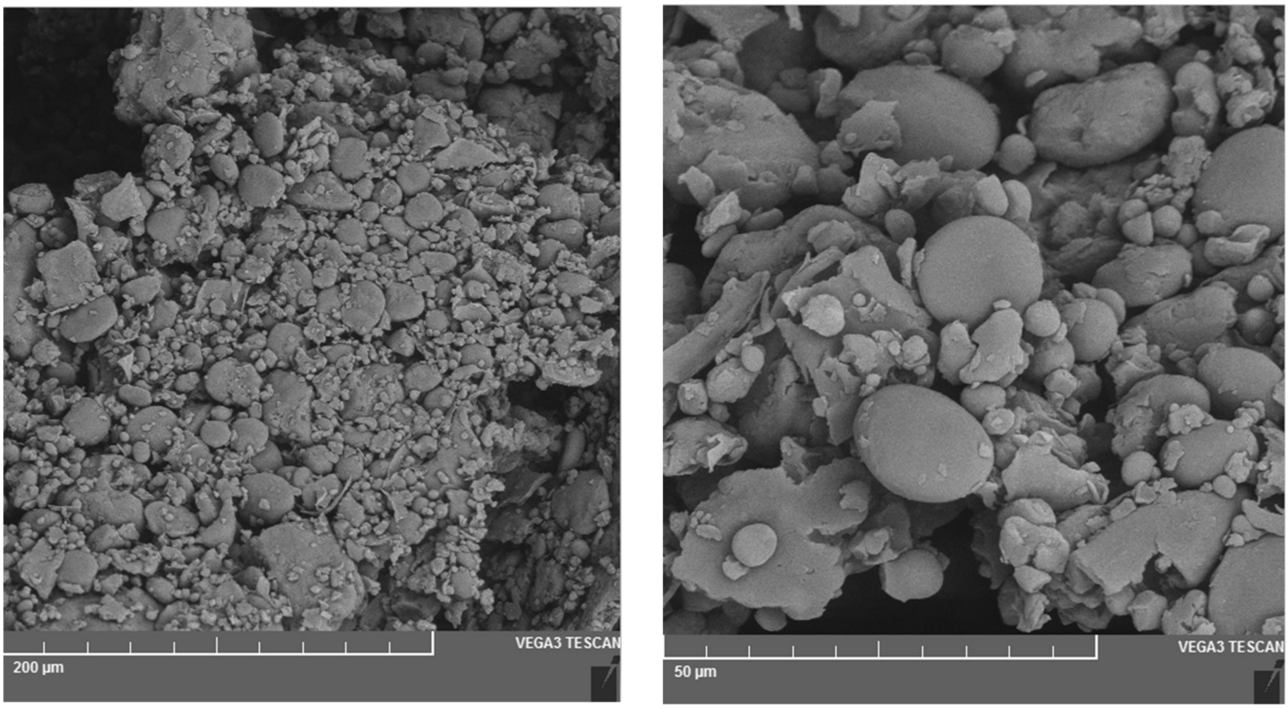


(**a**)

Figure 3. *Cont.*

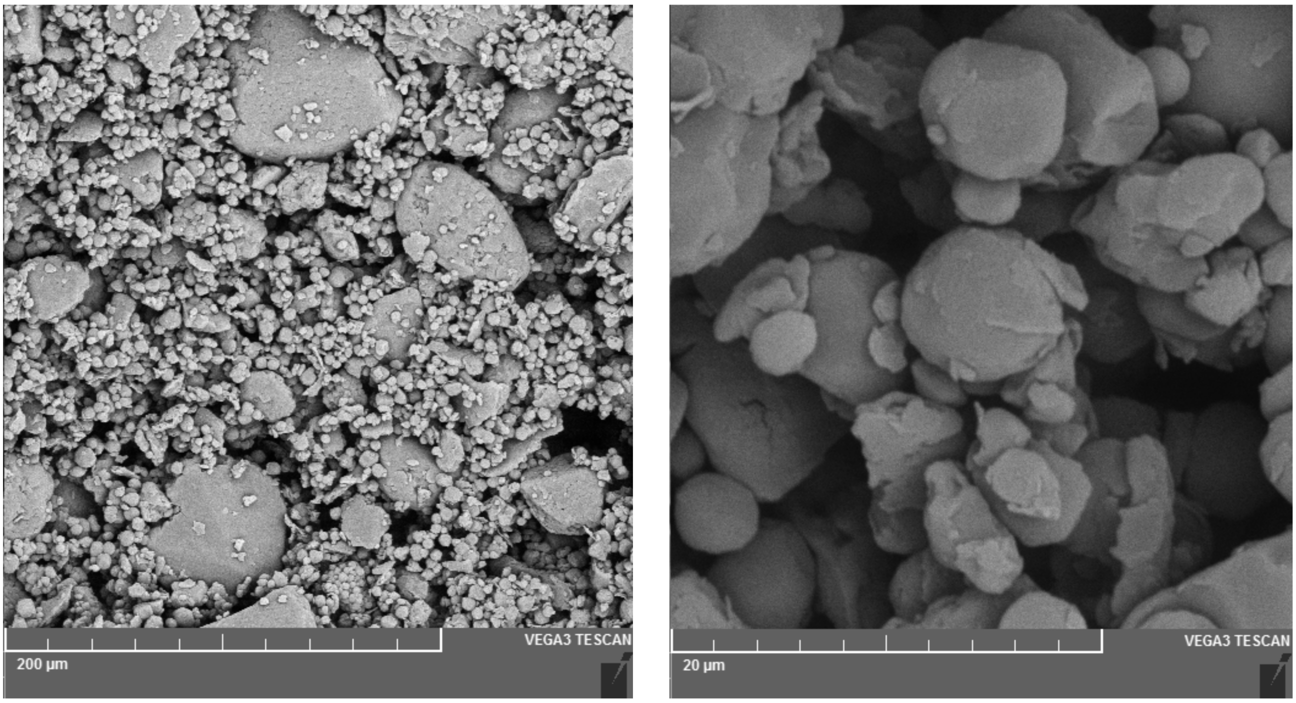


(**b**)



(**c**)

Figure 3. *Cont*.



(**d**)

Figure 3. Images of microstructure of wheat (**a**), rye (**b**), spelt (**c**), and buckwheat (**d**) wholemeal finely granulated flours from scanning electron microscopy.

4. Conclusions

The evaluation of the structure and properties of wholemeal flours produced in the Mahltechnik Görgens GmbH grinding device, depending on the disintegration conditions and the type and properties of the raw material, is currently still at the beginning. Several types of these flours were examined, depending on the source: common wheat, spelt, rye, and buckwheat flours. It turns out that when the mill was set to the abovementioned retention time of the grist in the grinding zone, there was easy and fast disintegration of rye and common wheat. The disintegration of spelt and buckwheat grains was more complicated and not sufficiently fine granulation was achieved under the given conditions.

The study results of the impact of the disintegration process on the microstructure of the endosperm, especially in the degree of damage to starch granules, show that disintegration in this mill may indeed appear promising. We can achieve fine granulation of flours, including fine granulation of bran particles for some cereals and other grains. At the same time, an undesirable degree of damage to the microstructure of the endosperm was not caused.

Further investigation of the influence of parameters of this type of disintegration process on the quality of the resulting flours will be definitely needed, as well as exploring the possibility of technological applications of these special wholemeal flours.

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