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# WHEAT KERNEL PHYSICAL PROPERTIES AND MILLING PROCESS*

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Abstract. Studies concerning the relations between wheat kernel physical properties and milling properties have been carried out since the beginning of the cereal processing industry. The aim of the present work was to show the application of the most important physical properties of wheat for the evaluation of wheat technological quality, especially of the milling properties. The paper presents the relations between wheat kernel physical properties and the milling process. Such properties as kernel mass, size, shape, vitreousness, density, bulk density and mechanical properties, especially kernel hardness, and their relations between one another and wheat flour milling process and flour properties are described. It can be concluded that such properties as kernel mass, size, shape and bulk density are not always good indices of wheat milling value. Wheat hardness is arguably one of the most important factors in assessing the quality of wheat, especially its milling value. Wheat hardness has a great influence on the milling process, especially on tempering, grinding and sieving, and thus on the properties of obtained flour. Mills designed for grinding both very soft and very hard wheat always involve compromises in design that will affect either flour quality or flour yield. Thus the relations between wheat hardness and milling process are described very precisely

Keywords: wheat, physical properties, hardness, milling

## INTRODUCTION

Wheat is one of the world's most important grains, with annual world production of about 600 million tons. Approximately 70% of wheat is used for food production [9]. Milling is very important in wheat processing. Wheat is milled into flour which is then made into products such as bread, cakes, cereal, macaroni, and noodles. Hard and soft wheat flours with a high protein content (>11%) are preferred in wet-milling to co-produce vital gluten and starch. Wheat starch is used

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to produce modified starch [2]. Other uses include the manufacture of alcohol, gluten, and livestock feed. Flour milling is considered to be an art. The miller applies experience accumulated over many generations. The miller has two main aims: first, to supply the customer with the specified product quality and, second, to efficiently separate the endosperm from the bran. The flour yield and flour properties, among other things, are strongly related to wheat kernel properties, especially to the mechanical properties. Beside the mechanical properties, also others, such as kernel colour, vitreousness, mass, shape, test weight, density, size and size uniformity, are taken into consideration during wheat milling value evaluation. These properties depend on many factors, such as genetic heritage, agro-technical methods or agro-environmental conditions. On the basis on these properties we can also conclude about the end use of wheat.

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## BULK DENSITY AND MASS OF KERNEL

Test weight (also called bulk density) is one of the most often used and the oldest wheat quality index. Test weight of wheat cultivars is an index of the density and the soundness of kernels. As a general rule, the higher the test weight the better. It is important that the wheat classes meet certain specified minimum test weight. Test weight is influenced by many factors, including fungal infection, insect damage, kernel shape and density, foreign materials, broken and shriveled kernels, agronomic practice and the climatic and weather conditions [20]. Williams [61] classified wheat according to test weight in six classes from extra light (test weight below 640 kg $m^{-3}$) to very heavy (test weight above 800 kg $m^{-3}$). Lower test weight can by caused by infestation of kernel by insects [7] or by late harvest time [8].

Grundas *et al.* [26] looked for relations between kernel susceptibility to mechanical damage and the technological properties of wheat. They found that as the test weight increased, the level of mechanical damage decreased. Michniewicz *et al.* [41] showed that as the wheat test weight increased the flour yield increased too. We obtained similar results for rye. We also found a positive correlation between rye test weight and average particle size of grinding stock. It can be caused by greater ratio of endosperm to bran layer for kernels with higher test weight [21]. Kernels with higher bran layer content are more difficult to grind and yield lower flour extraction rates [20]. Lin and Czuchajowska [33] investigated

200 cultivars of Soft White Winter Wheat (SWWW) and 75 cultivars of White Club Wheat (WCW). They found positive correlation between the test weight and the flour yield for SWWW but not for WCW. Shuler *et al.* [53] showed positive correlation between kernel bulk density and protein content (r = 0.54), but they did not find any significant relation between test weight and flour yield.

On the basis of the literature review one can say that wheat test weight is not always a good index of wheat quality. Only on the basis of very low or very high test weight we can conclude about wheat milling properties. The reason of this is that the bulk density is influenced by many factors. Gaines *et al.* [21] showed that rain causes wheat kernels to swell. However, subsequent drying does not return some layers of the pericarp to their original pre-rain size, leaving some of the pericarp layers to exhibit a loose or puffed appearance. These changes cause decrease of grain density and test weight, but do not influence the flour yield.

More accurate information about wheat milling value is obtained through the evaluation of kernel density. However, evaluation of kernel density is more complicated then determination of bulk density, and hence the test weight, as a fast and cheap method, is the most often used. Dobraszczyk *et al.* [12] found that kernels of soft wheat cultivars showed a broad distribution of density, with medians in the range form 1280 to 1395 kg $m^{-3}$, while kernels of hard wheat cultivars exhibited much narrower distributions and higher mean density, with a median at around 1410 kg $m^{-3}$. They also showed that kernel hardness increased non-linearly with increasing density. Martin *et al.* [38] found that the type of wheat kernel significantly affected mean density; healthy kernels averaged 1280 kg $m^{-3}$, sprout-damaged kernels averaged 1190 kg $m^{-3}$, and scab-damaged kernels averaged 1080 kg $m^{-3}$. However, wheat class (Hard Red Winter Wheat and Soft Red Winter Wheat) did not exert a significant influence on single-kernel density. Tkachuck [59] investigated five Canada Western Red Spring Wheat cultivars fractionated on specific gravity table. They found that the most dense fractions also had the best flour-milling potential and the best baking quality.

In some cases the 1000 kernel weight (TKW) is used as an index of wheat milling value. TKW is a good parameter for evaluation of kernels used as seed material. Some authors showed that TKW is a poor index of kernel milling properties [5]. Only in the case of very low or very high TKW the wheat milling value can be evaluated [54]. However, some authors showed positive correlation between TKW and flour yield. The reason of this is that TKW is strongly heritable in wheat and TKW as an index of milling value should be used only for the same wheat varieties, but cultivated under different agro-environmental conditions [29]. For durum wheat the 1000 kernel weight is associated with semolina yield and test weight. The acceptable 1000-kernel weight for durum wheat is 35-40 g [1].

## VITREOUSNESS

Vitreousness is natural kernel translucence and a means of description of wheat kernel appearance. Vitreous kernels have a dark, translucent, glassy appearance, as opposed to mealy kernels which have a light, opaque appearance. Mealy wheat kernels have a lower density than vitreous kernels. Dobraszczyk *et al.* [12] found that all kernels with density below 1360 kg $m^{-3}$ were completely mealy (non-vitreous) in appearance, while all grains above the density of 1400 kg $m^{-3}$ were completely vitreous. Denser kernels are much more resistant to water penetration during tempering. This is the reason why vitreous kernels need longer tempering time prior to milling. Vitreous kernels are harder and have higher protein content that mealy kernels, but it is not a general rule and sometimes it can be a big mistake to assume that a non-vitreous wheat kernel is a soft wheat kernel [56]. Vitreousness and hardness are frequently confused. These terms are used to describe endosperm texture and structure. However, hardness is a mechanical property that does not result directly from vitreousness. The differences in structure between hard and soft kernels are more apparent when studied using scanning electron microscopy (SEM) or transmission electron microscopy (TEM). The cut surface of mature hard wheat examined under SEM reveals a compact uniform endosperm structure with starch granules firmly embedded in the surrounding protein matrix. In contrast, mature soft wheat has a much more disordered structure with the protein matrix in many cases being pulled away from the starch granules [60]. Vitreousness is strongly related to agro-climatic conditions whereas the hardness characteristic is controlled essentially by the genetic factor [27]. The differences of microstructure of mealy and vitreous kernels within the cultivar are smaller than those in the microstructure of different wheat types [52]. In the milling industry, for common wheat (*T. aestivum*) we distinguish cultivars with high percentage of vitreous kernels (vitreousness above 60%) and mealy kernels, when vitreousness is below 40%. Michniewicz *et al.* [41] showed that vitreousness had an influence on break flour and sizing flour (r = 0.79 and 0.98, respectively). They also found a dependence between vitreousness and flour water absorption (r = 0.90). However, Phillips and Niernberger [48] concluded that the degree of vitreousness had no effect on flour yield.

Vitreousness is a very important parameter for the evaluation of durum wheat quality, especially of the milling properties. There are fundamental differences between milling common wheat and durum wheat. While common wheat is milled to produce flour, the objective of milling durum wheat is to produce semolina and to minimize the production of durum flour. Semolina is the coarse, granular particles of endosperm used for pasta processing. Vitreousness is used as one of the major quality attributes in grading. In the USA there are three official subclasses of durum wheat; each one of these subclasses is determined by the percentage of vitreous kernels of amber colour. These subclasses are Hard Amber Durum, Amber Durum, and Durum wheat with high (above 75%), medium (between 60 and 75%), and low (below 60%) percentage of hard vitreousness, respectively [45]. Dexter *et al.* showed that fully starchy kernels are significantly softer than vitreous durum wheat kernels, but partially vitreous (piebald) kernels, which are considered non-vitreous, are almost as hard as fully vitreous kernels [11]. Kernel vitreousness is associated with semolina granulation, colour, and protein content; the less vitreous the kernel, the finer the granulation and the lower the protein content. Kernels that are less vitreous will produce more finer particles (flour), thus resulting in less semolina product [47]. Laskowski *et al.* [32] showed that as the wheat vitreousness increased the specific grinding energy increased, too ($r^2$ = 0.91). We must remember that the determination of vitreousness is tedious and subjective. We should also know that vitreousness could disappear when we are wetting the kernels [58]. To obtain more objective information about the endosperm structure, such methods as SEM or TEM should be used.

## KERNEL SIZE AND SHAPE

Kernel shape depends not only on wheat genus or species but also on wheat variety and agro-climatic conditions. Wheat kernel shape was the subject of several publications. Dziki and Laskowski [15] found positive correlation between kernel size and kernel sphericity. In the works of Marshall *et al.* [36,37], simple geometric models of wheat kernels were analyzed to determine the effects of changes in shape and size on volume per unit surface area and hence potential milling yield. The shape and size of kernels of Australian cultivars were measured and found to be significantly different from the optimum required to maximize volume per unit surface area (spherical shape). They found that increases in kernel weight and volume were usually due more to increases in kernel length than in kernel width or height. For this reason, as grain volume increases, there will be a correlated change in grain shape away from the optimum required to maximize volume per unit surface.

The investigations of many researchers showed that kernel size had an influence on wheat milling and baking properties. However, their results are not clear-cut. Shutton *et al.* [57] showed that as the wheat kernel size increased the flour yield and protein content increased too. They also showed that bread obtained from small kernels had the lowest volume. Posner [49] found the highest protein content in middle size wheat kernels and they showed significant differences between wheat flour dough rheological properties in relation to kernel size. Dziki and Laskowski [14] showed that kernel size had the largest influence on grinding process in the first grinding stage. The fraction of small kernels (2.0-

2.5 mm thick) was more difficult to grind than the fraction of large kernels (3.1-3.5 mm thick). After the first grinding stage of small kernels, the highest values of the average particle size of grinding stock and grinding ability index, and the lowest values of flour yield were observed. It was also found that kernel size had an influence on the total flour yield and on the flour ash content. The highest flour yield with the lowest ash content was obtained for the large kernels. On the basis of these results it can be concluded that the operating parameters of the grinding rolls should be adjusted to kernel size. Gaines *et al.* [20] evaluated the influence of kernel size on soft wheat quality. They showed that, besides kernel size, kernel shriveling should also be taken into consideration. Shriveling greatly reduced test weight and decreased the amount of flour produced during milling. Compared to sound kernels, shriveled kernels had greater flour protein content, increased flour ash and kernel softness. Small, non-shriveled kernels had slightly better baking quality then large non-shriveled kernels. Tkachuck *et al.* [59] showed that large sound wheat kernels were characterized by a higher density. The reduced density allows for the separation of shriveled kernels from sound kernels using controlled air flow. In many countries and also in Poland there is no distinction between small sound kernels and small shriveled kernels and both are used as a feed. It seems that separation of small sound kernels from small shriveled kernels can improve flour yield and quality.

Beside these, kernel size uniformity is very important to the wheat milling industry, especially in such processing as cleaning, conditioning, debranning or grinding. It is difficult to select optimum working parameters of machines for the mixture of very large and very small kernels. Hence not only kernel size, but also kernel uniformity should be taken into consideration for the evaluation of wheat milling properties.

Kernel size and shape can be precisely described by using Digital Image Analysis (DIA). This method can by used for the wheat milling properties evaluation (flour or semolina yield) [4,43].

## MECHANICAL PROPERTIES

There are many methods for the determination of wheat kernel mechanical properties, and these methods are very often determined as wheat hardness [19, 44]. Wheat hardness has no universally accepted definition. Some authors define hardness as the mechanical property of the individual wheat kernel [40] or fragments of endosperm [27], or the resistance to deformation or crushing [19], whilst others define hardness as the property of a mass of kernels [22,62]. Some authors define hardness in terms of cultivar or genetic differences, with certain wheat varieties being classified as hard and others as soft. [25,42]. Such a large amount of methods is caused by difficulties with wheat hardness evaluation. These difficulties result from complicated kernel structure and shape, small size, diversity in geometrical properties and the presence of the crease in the kernel. The mechanical properties of individual parts of the kernel (germ, bran layer, endosperm) are also different and these properties also strongly depend on the water content [17,34]. Hence we can find in the literature many methods of wheat hardness measurement and they are different form those used for the evaluation of the hardness of constructional materials such as metals. However, those methods are correlated with each other and they are used in the milling industry to classify wheat cultivars according to the desirability of their milling and bread making properties [46].

In the United States wheat has been generally classified into three major hardness classes: soft, hard hexaploid, and durum [35]. Wheat kernel hardness is one of the most important factors in determining the functionality of wheat. The hardest wheat varieties are commonly used for semolina or farina production. Varieties with medium hardness are a main source for bread flour production and soft wheat varieties are a good raw material for cookies or cakes flour production [61].

Wheat hardness has the greatest influence on the milling process and this parameter should be determined before milling. Kernel texture influences power consumption during milling. Hard wheat cultivars require more power to grind the kernels than do soft wheat cultivars [16]. Kilborn *et al*. [31] found that the total specific grinding energy ranged from 46 kJ $kg^{-1}$ for soft wheat cultivars to 124 kJ $kg^{-1}$ for durum wheat. Millers can find real problems when they attempt to grind very soft wheat on a mill designed for harder wheat or they attempt to make hard wheat flour on a mill designed for softer wheat. The differences between soft wheat flour milling and hard wheat flour milling concern the conditioning, grinding and sifting. In general, hard wheat cultivars are usually tempered to about 16-16.5% moisture, and soft wheat cultivars to 15-15.5% [18]. The objective of the milling process is to dissociate the bran from starchy endosperm. The moisture content has a different influence on endosperm and bran layer properties. Glenn *et al.* [24] showed that as the moisture content of wheat endosperm increased, the compressive strength, elasticity and energy to compressive failure decreased, with hard wheats giving greater decreases. The hard wheat endosperm is more elastic and compact than soft wheat endosperm [23]. By contrast, the elasticity and plasticity of the bran layers increase with increasing moisture content [34]. This is the reason why moistening the kernels before milling caused bran layers to grind with difficultly and for larger size of particles than was the case with endosperm. After that the bran particles are separated by using sieve separator. Wheat hardness also has an influence on the tempering time. Mills designed for softer wheat cultivars often have a relatively short tempering time (usually a few hours). Hard wheat is typically conditioned for 12 to 24 hours. Accordingly, values of hardness and desired milling moisture are used to determine rest time. Soft and hard wheat cultivars do not differ in the path of water entry to the interior of the kernel, which is mainly through the germ side. However, soft wheat endosperm is not vitreous and dense. The softer endosperm structure allows tempering water to be absorbed by soft wheat at a faster rate than by hard wheat, and hence for soft wheat the time of tempering is shorter [49]. If we attempt to grind soft wheat after tempering the wheat for a relatively long period of time, we may find that the endosperm has literally sucked the water out of the bran and into the endosperm. This results in brittle bran and "gummy" endosperm. The brittle bran can cause flour colour and flour ash problems, but the main effect is that the "gummy" endosperm results in sifting and flow problems in the mill. On the other hand, if we attempt to mill hard wheat after only a short tempering time, we find that the endosperm is still very hard. This means that very high roll pressures will be required to break the endosperm and these same high forces are enough to fracture the bran and germ. Because of this, soft wheat mills grinding hard wheat cultivars often have problems with flour colour and flour ash [56]. Wheat hardness has also a great influence on the grinding process. The production ratio between the break and the reduction flour may vary substantially according to the wheat hardness. The milling of soft wheat gives approximately the same percentage of break flour and reduction flour, whereas with hard wheat break flour forms only about a quarter of the reduction flour yield. In fact, harder wheats tend to grind down to coarser particles referred to as semolina whereas soft varieties give flour particles directly [3,27]. The bran layer of hard wheat is usually more susceptible to grinding than the bran layer of soft wheat [29]. Hard wheat kernels grind better during the reduction stage than soft kernels, and bran includes little endosperm. The harder the wheat the more shear is encountered during milling and, therefore, the more damaged starch is produced [22]. Damaged starch significantly affects flour water absorption and wheat dough properties [51,55], and thus the degree of starch damage influences the flour baking properties. It is very difficult to achieve high degrees of starch damage on a soft wheat mill. If the flour is intended for applications where higher water absorption is important, it is necessary to reduce the load on the rolls in order to achieve the desired result [56] or use to a special grinding machine [30]. The amount of obtained flour at the individual grinding stages depends also on wheat hardness. The milling of soft wheat gives more break flour than hard wheat [6,28,39]. The flour particle size distribution depends also on wheat kernel hardness [10]. Examination of the total percentage of flour with particle size of less then 50 μm shows considerable differences between soft and hard wheat. Approximately 50% of total flour produced from soft wheat is smaller than 50 μm whereas the figure is only 25% in hard wheat. In fact, hard wheat cultivars display single-mode particle size distribution whereas soft wheat cultivars have bimodal distribution with the first mode at about 25 μm [6,27].

Soft wheat flour particles tend to stick to other surfaces and to other flour particles, causing sifting problems. Hard wheat flour is of a much higher average particle size than soft wheat flour. This makes the sifting, the materials transport, and the packing relatively easy. But milling of hard wheat on a soft wheat mill can cause the quality problems due to too much sifting. Oversifting can cause flour colour and flour ash problems. Thus, hard wheat mills usually have less overall sifting surface than soft wheat mills and they avoid the use of aggressive sifting techniques except where absolutely necessary. When hard wheat must be milled on a soft wheat mill, the miller usually "overloads" a mill in order to avoid the flour quality problems. This inevitably results in a lower extraction rate. On the other hand, when soft wheat must be milled on a hard wheat mill, the miller should decrease the load to the mill by 10 to 20 percent in order to allow the sifters to perform adequately [56].

We can also find some relations between kernel hardness and wheat flour baking properties [46]. We found negative correlation between PSI hardness index and such alveograph parameter as dough tenacity [13]. The recent study confirmed this correlation. Besides, we also found relations between wheat kernel hardness and dough extensibility.

For these reasons, wheat hardness is arguably one of the more important factors in assessing the quality of wheat, especially milling value, but is often neglected by grain-processing plants. Mills designed for grinding both very soft and very hard wheat always involve compromises in design that will affect either flour quality or mill capacity or both.

## CONCLUSIONS

1. The example of wheat kernel shows that the physical properties of raw materials provide information on both their technological suitability and optimum treatment in the production process. Certainly the determination of the physical properties of raw materials cannot be the only method of grain evaluation or designation for particular purposes. However, it can perfectly supplement other methods.
2. An understanding of the interactions between raw material properties and the production process is indispensable for its optimization. Methods for measurement of physical properties are constantly being improved, thus providing more and more valuable data within a shorter and shorter period of time. This in turn enables optimization of the production process on a regular basis.

3. It can be concluded that in order to fully use the potential of raw materials and obtain best-quality products it is necessary to create a database which enables to evaluate raw materials end-use on the basis on their properties.

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## WŁAŚCIWOŚCI FIZYCZNE ZIARNA PSZENICY A PROCES PRZEMIALU

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Streszczenie. Prace dotyczące powiązań pomiędzy właściwościami ziarna pszenicy a cechami przemiałowymi trwają od początków przemysłowego przetwórstwa zbóż. Celem pracy było omówienie najważniejszych właściwości fizycznych ziarna wykorzystywanych do oceny wartości technologicznej pszenicy, a w szczególności cech przemiałowych. Omówiono takie właściwości ziarna, jak kształt, wielkość, masa, gęstość, gęstość usypowa, szklistość oraz cechy mechaniczne, a w szczególności twardość oraz związki tych cech z procesem przemiału, a także z właściwościami uzyskanych produktów. Na podstawie analizy danych literaturowych można stwierdzić, że takie parametry, jak masa, wielkość, kształt czy gęstość usypowa ziarna nie są zawsze dobrymi wskaźnikami cech przemiałowych pszenicy. Najważniejszą cechą ziarna pszenicy, jest twardość. Parametr ten ma ogromny wpływ na przemiał, a w szczególności na kondycjonowanie, rozdrabnianie i przesiewanie, a przez to na właściwości uzyskiwanej mąki. Młyny zaprojektowane do przemiału pszenicy zarówno o twardym, jak i o miękkim bielmie zawsze stanowią pewien kompromis pomiędzy cechami jakościowymi mąki oraz jej wyciągiem. Dlatego też szczególnie dokładnie omówiono związki twardości ziarna pszenicy z procesem przemiału.

Słowa kluczowe: pszenica, właściwości fizyczne, twardość, przemiał