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THE LATEST INNOVATIONS IN WHEAT FLOUR MILLING: A REVIEW

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ABSTRACT

The milling process has evolved over time, employing various techniques to produce flour with different particle sizes and applications. This paper discusses the advancements in the wheat flour milling process and examines their impact on flour quality. The concept of wheat milling value is also introduced, which refers to the ability of wheat to produce flour with desirable properties and high yield. The importance of wheat cleaning in the milling process is highlighted, along with technological advancements such as color sorting machines and debranning of wheat grains before grinding, which facilitate efficient cleaning and increase flour yield. The progress of wheat conditioning in preparing wheat for milling is also discussed, along with current trends in grinding the wheat kernel. These advancements collectively contribute to enhancing flour quality, production efficiency, and overall milling performance.

Introduction

Wheat is a crucial cereal crop that holds immense significance in terms of food globally with the largest producers being China, India, and the United States (Tian et al., 2022b). Wheat is grown in a variety of climates and soils and is adaptable to different growing conditions (Zubko et al., 2022). It has played a significant role in shaping human civilization and remains an integral part of our daily lives as a vital food source (Turky et al., 2023). The various types of wheat, which encompass 14 species globally, are categorized based on their chromosome count. These classifications include diploid wheat with 14 chromosomes, such as einkorn wheat, tetraploid wheat with 28 chromosomes, like durum wheat and emmer wheat, and hexaploid wheat with 42 chromosomes, such as common or bread wheat (Wrigley, 2009). Each type of wheat has its own characteristics and is suited for specific uses. The common wheat (*Triticum aestivum*), is the predominant species cultivated worldwide and serves as the primary source of flour for bread production. For thousands of years, humans have consumed wheat extensively, and more than half of the world's population heavily depends on it as a major protein and carbohydrates source. Wheat is used for a variety of purposes, with the most common being the production of flour for bread, pasta, and other baked goods. It is also used as a feed grain for livestock and as a raw material for the production of ethanol. Especially whole wheat grain is an excellent source of complex carbohydrates, dietary fiber, and various vitamins and minerals, making it a valuable food crop for human consumption (Mathews and Chu, 2021). Wheat flour is the most widely used form of wheat grain processing, as most flour-based products are made using it (Gómez et al., 2020).

Wheat milling is a crucial process in the production of many types of flour which are excellent raw materials for the preparation different kinds of cereal products. Wheat kernels consist of three main parts: endosperm, bran and germ. From the center to the external zone the outer layers making up the bran and germ are richer in dietary fibre and bioactive components including lipids which are therefore unevenly distributed in the grain (David et al., 2015). Wheat kernel consists of three main constituents: endosperm, bran and germ. Endosperm is the major constituent and contains mainly starch granules embedded in a proteinaceous matrix and accounts for 81–84% of the grain. Germ contains embryo and scutellum and amounts to 2–3% of the grain. Bran, which forms 14–16% of the grain, consists of all outer layers including the aleurone layer, which is usually removed along with the other bran layers during milling (Inamdar and Suresh, 2014). Wheat flour milling enables the extraction of the primary part of the wheat grain, known as the starchy endosperm, which contains valuable technological functional components. This separation is achieved by separating the bran and germ from the endosperm (Carcea et al., 2022).

The milling techniques influence the composition of all components present in the flour, thus affecting its nutritional quality. Additionally, they also affect the size of particles, which plays a crucial role in determining the functional and nutritional properties of the flour (Cappelli and Cini, 2021). Wheat milling involves several steps, including cleaning, conditioning, grinding, and sifting. Each step determines the yield and properties of the flour. There are many milling techniques that use different grinding and sifting machines. Roller milling is the most common method of refined wheat flour production. This process consists of the gradual separation of endosperm from the bran and germ, followed by progressively decreasing the size of the endosperm particles accompanied by sifting between grinding stages (Cappelli et al., 2020b). However, in some countries, stone milling is also used (Carcea et al., 2020).

The milling results strongly depend on wheat grain properties, proper preparation for milling, and the grinding technique employed (Kalitsis et al., 2021). Progress in fast methods of grain testing, cleaning, and refinement in milling techniques has improved milling efficiency and flour quality in recent years. Moreover, the ultra-fine grinding method of wheat flour and flour by-products has evolved and been recently developed. As a consequence of this, many kinds of flours and bran powders with unique properties and applications are produced (Lin et al., 2021; Lai et al., 2023).

Aim and scope of work

The aim of this review is to summarize the recent progress in wheat flour milling. Recent advancements in wheat milling value were also discussed and the innovation in wheat cleaning, conditioning and grinding were presented.

Progress in wheat milling value evaluation

In the context of grain processing, milling value of wheat can refers to the quality and quantity of flour that can be obtained from a particular type of grain or wheat. Consequently, the milling value of wheat is determined by its ability to produce flour with desirable baking properties, such as good dough handling, volume, and texture, as well as its yield, which is the amount of flour obtained from a given quantity of wheat. The milling value is often measured by analyzing the flour's protein content, ash content, and other factors. However, from the miller's point of view, the milling value of wheat is mainly determined by the ability of wheat to produce a high flour yield with low ash content. Consequently, it can be calculated using the following equation (Dziki et al., 2017):

$$\mathrm{MEI} = \frac{FY}{FA} \tag{1}$$

where:
MEI is milling efficiency index,
FY represents the flour yield, (%)
FA is a flour ash content, (%)

The higher MEI value the better. Depending on milled wheat and grinding technique it can change in a wide range, usually between 50 and 100 (Konopka and Piłat, 2020; Dziki et al., 2017). The example of the relation between the FA and FA was presented on Fig. 1. Millers often are mainly interested to produce white wheat flour the ash content up to 0.5%. Taking into account the data presented on Fig. 1 the maximum yield of such flour usually did not exceed about 70%. However, for a mill with a high capacity even 1% higher yield of white flour is a big difference from the economical point of view.

The milling value of grain can be indirectly determined by evaluating the physicochemical properties of the grain that show correlations with the extraction rate and ash content of flour (Dziki and Laskowski, 2005; Bożek et al., 2022) or by conducting laboratory grain milling (Dziki et al., 2014). Although the latter method provides a more comprehensive assessment of the milling value of the grain, it is time-consuming. Therefore, modern analytics has developed several methods for rapidly testing the physicochemical properties of the grain. One such method is the Single Kernel Characterization System (SKCS), which is a system for characterizing individual grain kernels (Przyborowski et al., 2020; Cwiklinska et al., 2021). The equipment is designed to gauge the physical characteristics of 300 wheat grains during the single measurement such as their weight, diameter, moisture level, and hardness. All procedure for one sample takes a few minutes. The most important parameter is hardness. The hardness index (HI) value, which determines the hardness of the kernel, is measured using the SKCS and ranges from -20 to 120, with higher values indicating greater hardness. Based on their HI value, kernels are categorized as hard, semi-hard or semi-soft, or soft. Soft wheat typically has SKCS values of approximately 25, whereas durum wheat has SKCS values higher than 80 (Morris, 2019). Hardness is one of the most important factors that determine wheat milling properties (Fig. 2). It influences the tempering process, flour particle size, starch damage, and grinding energy requirements (Dziki and Laskowski, 2005).

Additionally, hardness serves as an indicator of wheat's end-use and is often positively correlated with grain protein content (Tu and Li, 2020). Wheat with a higher protein content gives it a greater ability to form gluten and makes it suitable for products that require elasticity, such as bread. In contrast, soft wheat has usually a lower protein content and is better suited for products that require a more delicate texture, such as cakes and pastries (Kostetska and Yevchuk, 2016). Although some authors indicate associations between grain hardness and protein content, it should be noted that hardness is not so much related to protein content as it is to its type (Przyborowski et al., 2020). The primary factor responsible for determining the quality of wheat is predominantly linked to the Hardness locus, which contains the genes responsible for encoding puroindoline A (PINA) and puroindoline B (PINB) (Geneix et al., 2020).

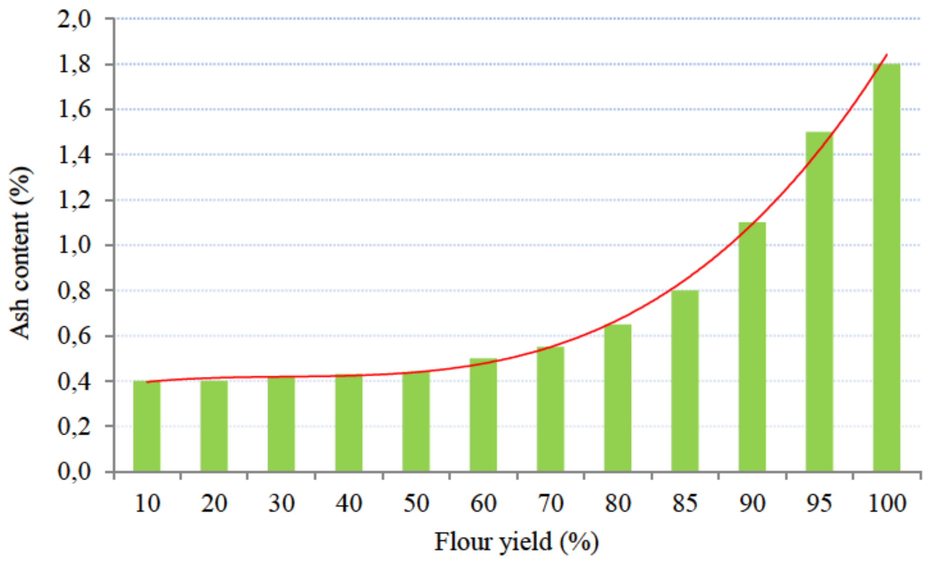

Figure 1. Relation between wheat flour yield and the ash content

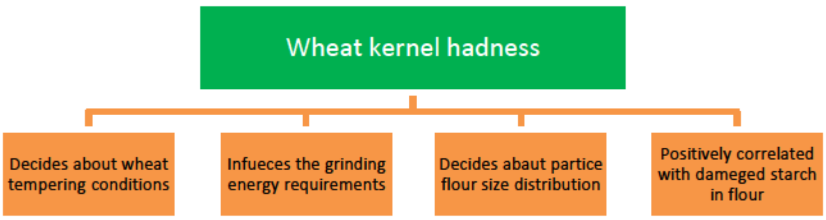

Figure 2. The relationship between grain hardness and the milling process

Another modern measurement technique that can be used for rapid assessment of grain hardness is the near infrared spectroscopy (NIR). The application of NIR technique has become increasingly significant in recent times. It has experienced rapid growth and success across various sectors, including pharmaceuticals, cosmetics, textiles, and agriculture (Iqbal et al., 2022). This technique is renowned for being non-invasive, non-destructive, and simple to use. It eliminates the need for sample preparation for both ground and unground samples. As a result, NIR spectroscopy has continuously expanded since its introduction and has established itself as a reliable method for assessing the quality of wheat (Caporaso et al., 2018), including wheat hardness (Erkinbaev et al., 2019).

Summing up this chapter, it can be concluded that especially the SKCS and NIR methods can provide fast and useful preliminary quality characteristics of wheat grain for evaluating its milling value.

Wheat cleaning

Wheat cleaning is a crucial step that takes place before the milling process. During harvesting, wheat grains can become contaminated with impurities such as dirt, stones, straw, and other grains. These impurities can negatively affect the milling process by damaging equipment or decreased the quality of the final product. Wheat cleaning involves the use of various machines and techniques to remove these impurities and ensure that the wheat is clean and ready for milling (Krzysiak et al., 2017). The efficiency of the wheat cleaning process can have a significant impact on the quality and yield of the final flour product. Therefore, it is essential to carry out this step carefully and thoroughly to achieve high-quality flour. As the technology for cleaning grains progressed, machines that combined various cleaning principles, such as sieving, density separation, and aspiration, were introduced. These combination machines allowed for more efficient wheat cleaning in a smaller area, which helped reduce the cost of constructing new mills or expanding existing ones. Moreover, recent innovations in wheat cleaning have reintroduced the benefits of sifting and grading wheat based on its size while eliminating impurities. These modern advancements in wheat cleaning incorporate the latest technology and materials to meet the increasing demand for higher operational capacity, better cleaning efficiency, and lower operating and maintenance costs (Sarkar and Fu, 2022).

In recent years, the progress in wheat grain cleaning has been related to the utilization of color sorting machines. The initial utilization of color sorting in grain processing can be traced back to its application in rice milling. However, in the wheat milling industry, the adoption of color sorting began with durum processors seeking an effective solution to remove ergot-contaminated wheat and ensure the production of a safer product. The early versions of color sorters were monochromatic, relying on shades of black and white to sort grains. Technological advancements then introduced high-resolution bichromatic cameras alongside the standard monochromatic cameras, enabling inspection across a broader color spectrum. This enhanced technology facilitated the detection of more subtle defects and impurities in the grains. The modern wheat color sorter utilize digital cameras to examine grains and eliminate impurities using compressed air based on differences in color (Inamdar and Suresh, 2014). This technology has been widely utilized in the rice milling industry for a long time. However, in recent years, color sorters have also been increasingly used in durum semolina milling and wheat flour mills (Sarkar and Fu, 2022). In the wheat cleaning process, color sorters are used to identify and remove various impurities such as ergot wheat, black tip, fusarium, burnt grains, discolored grains, and other internal contaminants (Carmack et al., 2021). Modern color sorters are now more durable, compact, require less maintenance, and consume minimal energy. As a result, color sorting has become a mature and reliable technology that should be considered for use in any modern wheat cleaning plant. Furthermore, optical sorters are gradually replacing traditional disc and indented separators in the wheat milling process (Inamdar and Suresh, 2014). Overall, color sorting machines have proven to be effective and efficient tools for enhancing the wheat cleaning process.

While the vibrating sifter, destoner machine, and magnetic separator effectively eliminate a majority of impurities found in wheat grain, there are still residual contaminants such as dust, wheat hair, microorganisms, and insect eggs present on the wheat's surface and within its ventral groove. Consequently, wheat scouring becomes essential to address these remaining impurities, as it effectively removes contaminants like earth, dust, and sand from the wheat grain through the use of a grain scourer. The scourer is a device that consists of a central rotating shaft with inclined beaters surrounded by a wire mesh jacket. It operates by feeding wheat at one end and subjecting it to repeated beating. This process generates friction between the beaters and the grains, as well as between the grains themselves and the jacket, as the wheat moves towards the opposite end. As a result, the outer bran, crease dirt, and small broken wheat particles pass through the wire mesh, while the intact wheat kernels are directed to an aspirator for the separation of lighter materials (Qi et al., 2022). Over time, the principle of wheat scouring has also experienced technological advancements. Initially, wheat scouring was used to wash wheat and remove impurities such as dirt, sand, and stones. As technology progressed, wheat washing gave way to dry scouring, which was aimed at eliminating dust and fine dirt particles that clung to the surface of the wheat kernel, especially in the creases. With further improvements, the wheat scouring process became more intensive, leading to the debranning or peeling of the outer layers of the bran coat from the wheat kernel without breaking or grinding it (Magyar et al., 2019; Ficco et al., 2020). Currently, wheat debranning is a method where the bran layers of wheat are eliminated through a series of friction and abrasion processes using modified rice polishers. Debranning installed in a conventional wheat milling produces several changes in the physical behavior of kernels as well as physicochemical and rheological changes in the produced flours. In summary, debranning technology has several benefits for the milling industry (Fig. 3) (Barroso Lopes et al., 2022), among other thing it increases flour extraction ratio and improves the microbiological purity of the flour (Tibola et al., 2019). These advantages contribute to enhancing the quality and functionality of the final flour products. Moreover, debranned fractions of wheat bran can be used as a functional additive to cereal products (Opine. et al., 2015; Parizad et al., 2020; Zanoletti et al., 2017).

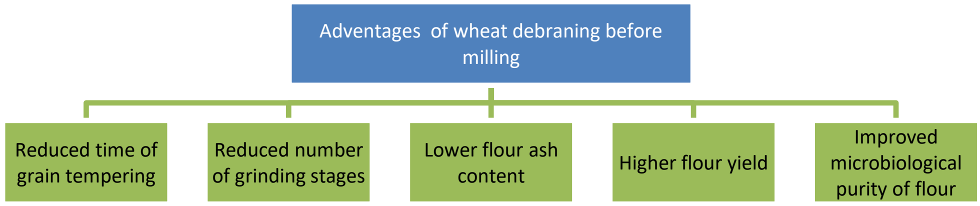

Figure 3. Advantages of implementing wheat debranning prior to the milling process.

To sum up, the progress in wheat grain cleaning before milling has brought significant advancements. Advanced technology, such as color sorting machines, has been introduced to efficiently remove discolored grains and foreign objects. Additionally, the debranning of wheat grains before grinding has gained attention for improving cleaning efficiency and increasing flour yield. These advancements have enhanced the overall cleanliness of the wheat grain, resulting in improved flour quality and milling efficiency.

Wheat conditioning

The crucial stage in preparing wheat for milling is conditioning (tempering), which typically involves the addition of water to the wheat and allowing it to rest in tempering bins until the moisture is evenly distributed throughout the kernels. This step is essential for achieving the optimal texture of the wheat for grinding (Warechowska et al., 2016). Conditioning is the process of adding water to wheat to increase the moisture content to an average 14.5-17.0% to improve the efficiency of flour extraction (Gruppi et al., 2017). The recommended grain moisture content before milling depends strongly on grain hardness and it should be 14.5-15% for soft wheat, 15.0-15.5% for semi soft grain, 15.5-16.0% for semi hard grain, and 16-17% for hard wheat (Alfin, 2020). Tempering serves multiple purposes, including strengthening the bran by allowing it to absorb moisture and become more resilient and harder to crush. It also softens the endosperm, making it easier to mill. Moreover, tempering aids in the separation of the bran from the endosperm and results in a final flour that has an adequate moisture content ranging from 14% to 15% (Abo-Dief et al., 2019). Without conditioning, the bran of the wheat would become brittle and break into small pieces during grinding, resulting in an increased ash content in the flour produced and consequently decrease the quality of flour (Yamaguchi et al., 2021). Sometimes, whole-meal wheat flour is made by milling unconditioned or very dry wheat. Such milling allows to obtain more fine flour and save energy for grinding. Because dry grain is brittle and easy for size reduction (Hassoon et al., 2021). This type of milling enables the production of finer flour while saving energy during the grinding process. Dry grain is inherently brittle, making it easier to break down into smaller particles (Dziki, 2008).

The calculation of the conditioning water rate (CWR) can be determined using the equation (Alfin, 2020):

$$CWR = C\frac{M_f - M_i}{M_f}\ (\text{l}\cdot\text{h}^{-1}) \qquad (2)$$

where:

C – is the capacity of grain flow through the dampening machine, ($\text{l}\cdot\text{h}^{-1}$)
M_f is a target moisture content, (%)
M_i is the initial moisture content of grain, (%)

Recent studies have demonstrated that the time of tempering has a significant influence on the quality of wheat flour and bread properties (Suprabha Raj et al., 2023; Kurt and Dizlek, 2022). To produce high-quality flour and, consequently, highly acceptable pan bread, wheat grain is typically tempered for a duration of 12 to 24 hours (Abo-Dief et al., 2019). However, the tempering time can be reduced by employing different methods of grain pretreatment before milling, such as debranning (Dexter and Wood, 1996), hot-tempering (Chen et al., 2020b), or using modern dampening equipment (Abo-Dief et al., 2022; Fowler, 2013). The extended tempering time of 24 hours can be beneficial for microbial growth and reproduction. Therefore, some authors carry out this process using hot water or steam. In a recent study, Chen et al. (2020b) demonstrated that the use of steam as a conditioning method for wheat grains prior to milling resulted in accelerated water distribution within the grain and significantly reduced tempering time. This steam tempering process had notable effects on various characteristics of the resulting flour, including flour yield, particle size, ash content, and damaged starch content. Additionally, steam tempering led to protein aggregation and partial gelatinization of starches, resulting in increased dough development time and improved flour stability. Overall, the findings suggest that steam tempering has the potential to reduce tempering time and enhance certain qualities of the flour. Moreover, the process of steaming wheat kernels before milling was found to decrease lipase activity and hydrolytic rancidity during storage, while having no impact on starch and gluten components (Poudel and Rose, 2018). Ultrasonic technology and vacuum impregnation are also modern techniques that allow for the reduction of wheat grain tempering time and enhance the quality of flour (Yüksel and Elgün, 2020; Rydzak et al., 2017).

The goal of modern dampening equipment is to minimize the time required for tempering. This is achieved by using high-frequency vibrations to reduce the surface tension of water, enhancing its ability to penetrate the grains. By improving water dispersion and penetration into the kernels, this equipment effectively achieves its purpose without causing damage, as it does not involve a scouring process. The current trend in improving the conditioning process is the use of intensive dampeners. The prevalent tempering systems are currently the intensive dampener and inclined intensive dampener. Intensive dampeners utilize a high-speed mixer to rapidly tumble the wheat with added water, ensuring even distribution of water throughout each kernel. This method allows for up to 7% water addition in a single step and reduces the necessary tempering bin capacity compared to multi-step methods (Fowler, 2013). Additionally, intensive dampening scours the wheat bran and lowers water surface tension, promoting faster water penetration into the kernel (Fowler, 2013; Abo-Dief et al. 2022).

Some authors have employed an enzymatic wheat conditioning process using cellulase, xylanase, and pectinase (Jha et al., 2020). These methods aim to reduce the time and cost of tempering, decrease energy consumption during subsequent milling stages, increase milling yield, and modify the composition of the fiber fraction (Gruppi et al., 2017; Jha et al., 2020). The recent methods for reducing the tempering time of wheat kernels before milling are presented in Figure 4.

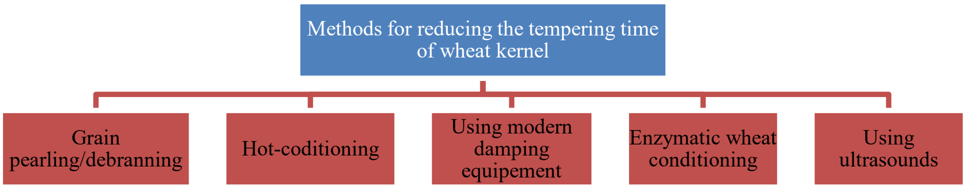

Figure 4. Methods for reducing the tempering time of wheat kernels before milling

In conclusion, it can be summarized by stating that the conditioning stage in wheat grain preparation before milling is crucial for achieving optimal texture and improving flour extraction efficiency. Conditioning strengthens the bran and softens the endosperm, aiding in their separation during milling. Without conditioning, the bran would become brittle, resulting in increased ash content in the flour. Recently, different methods, such as debranning, hot-tempering, and steam tempering, enzymatic condition, have been explored to reduce tempering time and enhance flour quality. Modern dampening equipment, such as intensive dampeners, improves water dispersion and penetration into the grains and minimizing tempering time.

Wheat grinding

Today, wheat grinding is primarily done using modern industrial milling machines that employ a variety of grinding techniques to produce different types and grades of flour. In modern times, various milling methods have emerged, each offering its own advantages. Among these methods is stone milling, an early and straightforward approach that is well-suited for both whole grain and refined grain flour production (Tian et al., 2022a). This technique, considered the oldest form of attrition mill for flour production, is still used in many countries (Carcea et al., 2020; Liu et al., 2015). In stone milling, wheat is crushed between two stones, resulting in whole wheat flour that encompasses all the kernel fractions, including the endosperm, bran, middlings, and germ. Stone milling is a simple and highly efficient method. If the goal is to produce whole wheat flour, the process concludes at this stage. However, when aiming for refined white flour, the resulting output undergoes sifting. This final stage yields three distinct fractions: refined white flour, bran, and middlings (Cappelli et al., 2020b).

One major advancement in wheat grinding has been the development of roller mills, which utilize a series of rollers to crush the wheat grains and separate the various parts of the wheat kernel, including the bran, germ, and endosperm (Prabhasankar et al., 2000). Roller milling is the prevailing method used to produce various types of refined flour based on their chemical properties and intended applications (Lewko et al., 2023; Hu et al., 2022; Chen et al., 2020a). Roller mills can produce flour of consistent quality and have significantly increased the efficiency of wheat grinding (Carcea et al., 2022). Cleaned and conditioned wheat grains undergo a sequential passage through a series of rolls, accompanied by sifting between each stage. In the classical roller milling process, there are three primary stages: break, sizing, and reduction. The break system is the most important operation. The main goal of the miller in the break system is to achieve a high extraction rate of flour with low ash content. To do this, the miller's initial objective is to crack open the wheat kernel and liberate clean endosperm particles in larger sizes, which will be used for sizing and middlings. Meanwhile, the bran should remain in larger particles, while the production of flour should be minimized (Cappelli et al., 2020b).

The sizing and reduction systems in the milling process aim to transform sizing and middlings into flour. In the sizing system, the objective is to classify the endosperm particles into different grades, resulting in a narrower range of particle sizes. This process optimizes the performance of the reduction system, which further refines the endosperm particles and ultimately converts them into flour (Alfin, 2019).

The rolls can be smooth or fluted, depending on the specific stage of the process. In the case of fluted rolls, the corrugations are arranged in a spiral pattern to facilitate a scissor-like cutting action, rather than being aligned parallel to the long axis. Fluting can possess either a sharp or dull profile, and the rolls can be arranged in four different sequences: dull-to-dull, sharp-to-sharp, dull-to-sharp, or sharp-to-dull. The type of fluting employed significantly influences the particle size distribution of the resulting flour (Cappelli et al., 2020b).

Roller milling offers versatility in adjusting the degree of grinding and achieving the desired flour texture. By controlling the settings of the rolls and the sifting process, it allows for the production of various types of refined flour with specific characteristics, such as fineness and consistency. This method has become the predominant choice in modern flour production due to its efficiency, consistency, and ability to produce high-quality flour on a large scale (Cappelli et al., 2020a).

Another achievement in recent years is the automated roll gap adjustment system (Alfin, 2019). This system has plays a crucial role in facilitating remote operations, allowing for seamless adjustments of the roll gap during the transition between different wheat mixes. Furthermore, contemporary roller mills are equipped with advanced sensor technology that enables the measurement of grinding force. Together with flow-rate data, this ensures the maintenance of stable grinding performance, resulting in the production of consistently high-quality end products (Sarkar and Fu, 2022). Additionally, double grinding of mill streams without intermediate sieving, known as the eight-roller milling system, is a modern grinding technique that provides opportunities for significant reduction of capital costs compared to conventional wheat flour milling systems (Fistes and Rakić, 2015).

Besides the conventional wheat roll milling technique, superfine grinding and ultra-fine grinding (micronization) are frequently employed to decrease the particle size of grain flour and improve the physicochemical characteristics of the fine powder, which has a significant impact on the quality of flour-based foods. The primary objective of ultrafine grinding is to enhance the surface area and reactivity of the material, leading to improved properties and performance. By reducing the particle size, a larger surface area is exposed, which can enhance the dissolution, chemical reactivity, and bioavailability of substances (Wang et al., 2014). Recent research suggests that superfine grinding methods can substantially enhance the quality of whole wheat flour by significantly reducing the size of powder particles, which are typically less than 40 μm (Guan et al., 2020). This process also affects the properties of wheat flour, such as an increase in water absorption and alterations in dough rheological properties, ultimately influencing the properties of cereal products. Additionally, ultrafine grinding is used to decrease the particle size of flour, with jet milling producing small particles (< 10 μm) that have a high solubility, leading to more delicious foods (Protonotariou et al., 2021). There are several methods employed for ultrafine milling, each with its own advantages and limitations. The most common are jet milling and ball milling. Jet milling is commonly used to produce particle sizes usually between 1 and 10 μm (Protonotariou et al., 2021). Jet milling utilizes high-speed jets of compressed air or gas to impart kinetic energy to particles, causing them to collide and break apart. It is well-suited for fragile and heat-sensitive materials (Protonotariou et al., 2014). Lazaridou et al. (Lazaridou et al., 2018) discovered that using jet milling can decrease the median particle size of wheat flour by up to 12 μm, depending on the feed rate. Interestingly, this process does not impact the molecular structure and size of soluble arabinoxylans found in the wheat endosperm. These arabinoxylans play a crucial role in breadmaking, as they contribute to the functional properties of polysaccharides and have physiological effects, such as regulating postprandial blood glucose and insulin levels (Zannini et al., 2022). As the particle size of the flour decreased through jet milling, there was a noticeable increase in damaged starch. However, when the flour particle size reached median size 21 μm using jet milling, the level of damaged starch was comparable to that achieved through traditional milling methods. Additionally, reducing the particle size of the flour through jet milling resulted in various changes in the rheological behavior of the dough. These changes included increased elasticity, resistance to deformation, hardness, adhesiveness, relaxation time, zero shear and elongational viscosity, as well as a decrease in apparent starch gelatinization enthalpy and dough relaxation rate (Lazaridou et al., 2018). These differences in dough rheology could lead to flours with a wide range of functional properties, enabling the production of tailored bakery items with diverse dough handling properties and high-quality end products. Jet milling can be also useful technique in the production of whole wheat flour (Protonotariou et al., 2020).

Another method that can be used to decrease the particle size of flour is ball milling. In the ball milling technique, materials are milled in a rotating cylindrical chamber with grinding media such as balls or beads. The collision between the media and particles results in size reduction (Tian et al., 2022a). Tian et al. (2022c) used vibration ball milling to study the grinding process of pure wheat endosperm and examined the resulting structural changes in wheat starch. The grinding process significantly reduced the size of the endosperm granules to approximately 30 μm and increased the damaged starch content, indicating a positive correlation between grinding time and starch damage. In terms of *in vitro* digestion results, it was found that the mechanical modification induced irregular defects within the wheat starch crystals, making them more susceptible to enzymatic activity. This increased sensitivity to enzymes led to a three-fold increase in the hydrolysis rate and a 50% increase in maximum starch hydrolysis. In another study by Liu et al. (2021), the structure and function of wheat gluten were modified using planetary ball mill. The study found that utilizing ball grinding technology for a duration of 40 minutes resulted in a reduction of particle size from 85.9 μm to 32.3 μm. Additionally, an increase in the whiteness of gluten was observed. These findings suggest that ball grinding technology enhances the functional characteristics of wheat gluten and broadens its range of possible applications.

In summary, ultrafine grinding significantly modifies the baking properties of wheat products and allows for the production of wheat flour with unique properties.

Conclusions

Wheat flour milling has undergone significant advancements over the years. The implementation of technologies like NIR spectroscopy, SKCS system, and imaging technology, have enabled millers to swiftly and accurately measure the physicochemical properties of grains, which determine the milling value. Moreover, there has been significant progress in wheat flour milling, thanks to advancements in technology and research. Wheat milling has evolved over time, and modern mills are highly automated, efficient, and capable of producing large quantities of high-quality flour. Traditional milling techniques have been enhanced with modern equipment and processes, resulting in improved flour quality and increased efficiency. The introduction of automated milling systems has led to better quality control, reduced waste, and higher throughput. Furthermore, research in the field of flour milling has led to the development of novel milling methods, such as superfine grinding and ultra-fine grinding, that produce flours with superior physicochemical properties, resulting in higher quality food products. Overall, the progress in wheat flour milling has been significant, leading to the production of more consistent, high-quality flours that serve as essential ingredients in a wide range of food products.

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NAJNOWSZE TRENDY W PRZEMIALE ZIARNA PSZENICY

Streszczenie. Sposób przemiału ziarna pszenicy ewoluował na przestrzeni ostatnich lat, poprzez wykorzystanie nowych technik, pozwalających na uzyskanie mąki o zmiennym składzie granulometrycznym i różnych zastosowaniach. W niniejszej pracy omówiono najnowsze trendy związane z produkcją mąki pszennej, analizując wpływ różnych metod i technologii na jej jakość. Omówiono także wartość przemiałową ziarna, pod kątem otrzymywania mąki o wysokim wyciągu i pożądanych właściwościach wypiekowych. Skupiono się również na innowacjach w procesie oczyszczania pszenicy, omawiając maszyny do sortowania ziarna względem barwy oraz urządzenia do obłuskiwania. Przeanalizowano także postęp w procesie kondycjonowania i rozdrabniania ziarna pszenicy. Wszystkie omówione innowacje przyczyniają się do poprawy jakości mąki oraz efektywności i wydajności produkcji mąki.

Słowa kluczowe: pszenica, wartość przemiałowa, mąka, czyszczenie, kondycjonowanie, rozdrabnianie, mikronizacja.