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Breeding Wheat Varieties for Specific End-Uses

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Abstract Wheat is an indispensable crop in the global agriculture and food industry. Its diverse uses have put forward specific requirements for the quality and processing performance of different varieties. This review summarizes the latest progress in the breeding of wheat varieties for specific purposes, analyzes the key traits of specific purpose varieties (such as gluten strength, protein content, processing performance, etc.), and evaluates the combination of traditional breeding methods with modern technologies, including marker-assisted selection (MAS), genomic selection (GS), gene editing technology (such as CRISPR/Cas9) and the potential of hybrid breeding. Successful cases are further discussed, such as the improvement of gluten quality in bread wheat, protein optimization in durum wheat, and the solution of nutritional deficiency problems by zinc- and iron-enriched wheat. This review shows that the introduction of modern technologies has significantly improved breeding efficiency, but technical and economic limitations, the impact of climate change on trait performance, and the diversification of market demand remain major challenges. In the future, the sustainable development of wheat varieties for specific purposes will be further promoted through the integration of multi-omics data, the application of precision agriculture technology, and the sharing of global breeding resources. This review provides a comprehensive guide for the breeding of wheat varieties for specific purposes, which is of great significance to the sustainable development of the global wheat industry.

Keywords Wheat; Specific use; Biofortification; Genomic selection; Precision breeding

1 Introduction

It's no exaggeration to say that wheat is the backbone of agriculture—after all, billions of people around the world rely on it to feed themselves. But you may not know that different wheat varieties are quite different (Mondal et al., 2016; Subedi et al., 2023). For example, durum wheat, which is used to make pasta, has a high protein content and hard grains, but for cakes and biscuits, softer wheat is more suitable (Bushuk, 2004). Of course, the food industry cannot do without it, after all, the nutrition is there, but the key is to cultivate new varieties that meet different needs.

Breeding special wheat varieties is actually quite interesting - it is not something that can be done randomly. You see, the requirements for wheat for making bread and noodles are different, and indicators such as grain hardness and protein content must be strictly controlled (Fradgley et al., 2023). But then again, these characteristics are not determined by genes alone, and environmental factors such as weather and soil also play a role. Fortunately, breeding technology is much more advanced now, such as new methods such as marker-assisted selection and genomic selection (Merrick et al., 2022; Paux et al., 2022), making the breeding of special varieties much more reliable. In the final analysis, if you want good quality wheat products, the key is to start from the root of the variety (Zhang et al., 2024).

Wheat breeding is easier said than done. High yield and good quality are often compromised - not to mention climate change (Mondal et al., 2016). In fact, there is a potential problem. The gene pool of the wheat varieties currently promoted is very narrow, and they may not be able to withstand pests and diseases one day. However, there are always more solutions than problems. Recently, experts have been thinking about how to dig out the excellent genes of wild wheat, a "distant relative", and use them (Sharma et al., 2021). In my opinion, relying on the old breeding methods alone is definitely not enough. New technologies must be combined with traditional experience so that the wheat industry can develop in the long run.

This review is going to talk about the breeding of special wheat - to be honest, there has been a lot of activity in this field in recent years. Breeding is really different now than in the past. New technologies are emerging one after another (you know, those genomic tools), making it much easier to breed high-quality wheat. But having said that, although there has been great progress, there are also many problems. We need to take a good look at the successful experiences and see which hurdles have not been overcome. After all, it is not easy for breeders to achieve both yield and quality, and to consider climate change. But from another perspective, these challenges have spawned a lot of innovative methods. This article wants to sort out these new ideas and think about what to do in the future - after all, it is related to the global food problem, so we can't be careless. If I can provide you with some useful references, it will be worth writing.

2 Classification of Wheat Varieties Based on Use

Did you know that the bread, noodles and biscuits we eat are actually made from wheat with different "characters". Just like people are tall, short, fat and thin, wheat is also divided into different grades - some have high protein content and are suitable for making chewy pasta; some have soft grains and are soft enough to make cakes. The key lies in three indicators: the amount of protein, the hardness of the grains, and whether the gluten is chewy enough (in other words, the "toughness" of the flour). Food factories pay the most attention to this, after all, making bread and making biscuits are completely different things!

2.1 Bread wheat varieties

The key to making bread wheat is its "bones" - whether the gluten content is high enough. This determines whether the dough can hold up and whether the baked bread is fluffy enough. In fact, the most important thing here is the proteins called "high molecular weight gluten subunits" (experts call them HMW-GS), and many people have studied them (Bushuk, 2004). Now breeders have a way to use high-tech methods such as electrophoresis and liquid chromatography, just like giving wheat a "physical examination", to specifically screen out high-quality gluten genes (Fradgley et al., 2023). Although sometimes there is a bad thing about the decline in gluten content, fortunately, the gene pool of bread wheat is still rich in recent years. To be honest, if we hadn't always paid attention to maintaining diversity, the taste of bread might not be so good now.

2.2 Pasta and durum wheat varieties

When it comes to wheat for pasta, it is really a "tough guy" in the wheat world - the grains are particularly hard and the protein content is ridiculously high. The semolina ground from this durum wheat is perfect for making pasta! Not only does it have a chewy texture, it also has a beautiful light yellow color (Bushuk, 2004). In fact, this wheat has two unique features: one is that it contains special storage proteins, and the other is that it is rich in yellow pigments. These two things determine whether the pasta is chewy enough and the color is good. Interestingly, these characteristics are quite "stubborn" and can basically be determined by genetics (Subedi et al., 2023). Now breeders have tricks, such as focusing on the γ-gluidin 45 marker to select seeds, so that good seedlings can be picked out at an early stage. Although it sounds high-tech, it still uses the old traditional breeding method, but it is more precise.

2.3 Biscuit and pastry wheat varieties

Wheat for making biscuits and cakes is completely different from bread wheat - their main feature is the word "soft"! The protein content is low and the grain texture is also soft, so that the baked snacks will be soft and delicious (Bushuk, 2004). Interestingly, the focus of breeding this kind of wheat is to "weaken" certain characteristics. Breeders have to be careful and make the grains soft enough without reducing the protein too much. Every time a new variety is cultivated, it must be tested repeatedly. After all, if the biscuits are too hard or the cakes are not fluffy enough, consumers will not buy them. The successful pastry wheats on the market now have been screened layer by layer. From the laboratory to the food factory, every link must be strictly controlled to ensure that the snacks made meet industry standards and satisfy the taste buds of foodies (Subedi et al., 2023).

2.4 Specialty wheat varieties

Now more and more people are beginning to miss the wheat that their "ancestors" ate - ancient varieties such as spelt and emmer wheat have become very popular recently! They are different from modern wheat. Not only are they richer in protein, but they also contain more essential amino acids and trace elements for the human body (Bao et al., 2019). However, these "antique" wheats are also difficult to serve. To ensure the purity of the variety, you must also ensure that it is suitable for specific purposes. It is not enough to rely on human eyes to identify it. Now scientists have come up with a new trick: using hyperspectral imaging technology to "take a CT scan" of wheat, combined with chemometric analysis, even the slightest differences can be found (Zapotoczny, 2011). What's more, some people have developed an AI system that can identify grain textures. Through digital image analysis, even twin wheats can be distinguished! These black technologies are not for show. Just think about it, if the "organic ancient wheat flour" you bought at a high price is adulterated, how upset you would be. Therefore, figuring out the "identity cards" of these specialty wheats is a good thing for growers, processing plants and consumers.

2.5 Industrial use wheat varieties

The breeding standards for industrial wheat are very different from those for edible wheat-they are more like "special forces" on the assembly line. These varieties are usually large in size and high in yield, and the characteristics of the grains are tailored for the factory production line. For example, for starch production, you have to choose those that are easy to decompose; for ethanol fuel, you have to choose those with high sugar conversion rates. Now factories are playing with intelligent sorting: "photographing" wheat with high-definition cameras, and then using AI to analyze more than 20 characteristics such as grain shape and size (Figure 1). This system is very fast and can process thousands of grains in one minute, with a higher accuracy rate than the old master (Lingwal et al., 2021). Interestingly, even the "appearance" of wheat is particular-seemingly inconspicuous features such as grain surface texture and color depth may affect the final output rate. These technological breakthroughs are not just for show. You know, choosing the right variety can increase starch extraction efficiency by 15% and ethanol production by 20% (Laabassi et al., 2021). Now more and more factories are starting to build their own wheat variety databases, just like assigning the most suitable "employees" to different workstations to make the entire production line run more smoothly.

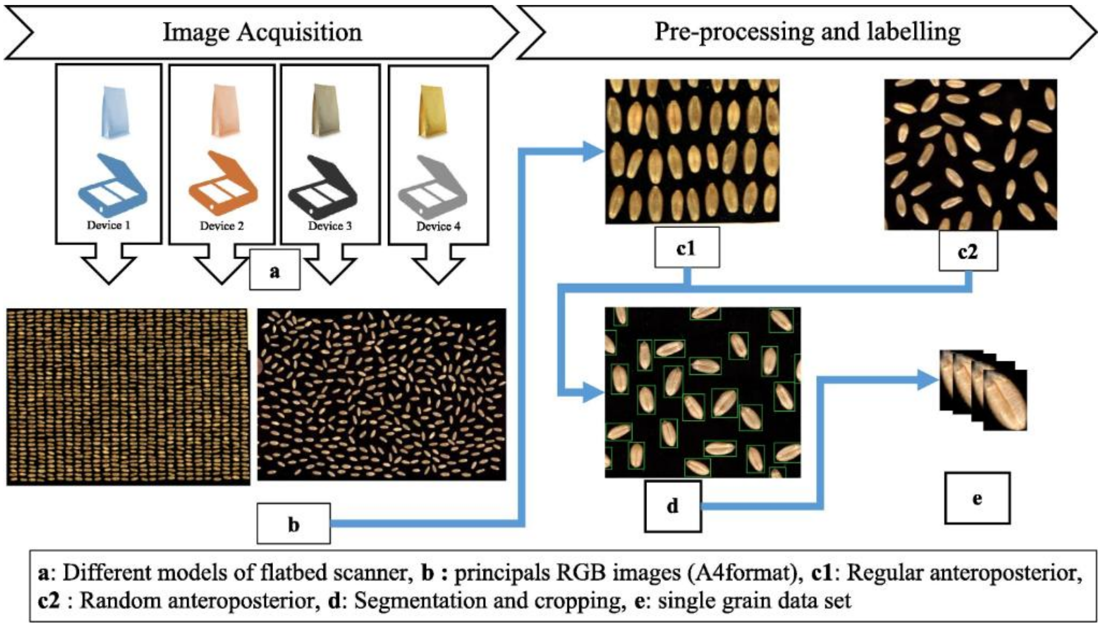

Figure 1 Image acquisition and pre-processing of wheat seeds in industrial applications (Adopted from Laabassi et al., 2021)

3 Key Traits for Breeding Wheat Varieties for Specific Uses

3.1 Grain quality traits

The quality of wheat grains is like its "personal signature" - gluten strength, protein content and grain hardness are three key indicators that directly determine what it is best suited for (Huang et al., 2006). Let's talk about gluten strength first. This thing is like the "spring" of dough. Only dough with sufficient strength can envelop the fermentation gas and bake fluffy bread. Scientists have locked on to gene loci such as Glu-B1 and Glu-A1, and have discovered more genetic markers that can enhance gluten (Mérida-García et al., 2019). Protein content is also quite interesting. In the past, breeders often had a headache about the problem of "having their cake and eating it too" - increasing protein content often led to reduced yields. But now with multi-trait genomic selection technology, it can actually have the best of both worlds (Michel et al., 2019). As for grain hardness, it is very particular: too hard is difficult to grind, and too soft affects the taste. Fortunately, through genetic testing, the hardness level can be predicted at the seedling stage (Wang et al., 2020). These breakthroughs are not just theoretical. For example, several new varieties launched last year not only maintained their high-yield characteristics, but also increased their protein content by 2 percentage points (Sandhu et al., 2021). It seems that many of the problems encountered in traditional breeding are being solved one by one by modern genomic technology.

3.2 Agronomic traits

Anyone who is engaged in wheat breeding knows that stable yield is the real skill - it is not acceptable to have a bumper harvest this year and a total failure the next year (Huang et al., 2006). Now experts have figured out the tricks. Indicators that seem insignificant, such as thousand-grain weight and ear length, actually hide the secret of stable yield. Several QTL loci newly discovered last year have enabled new varieties to maintain good yields in both drought and flood years (Zhao et al., 2023). When it comes to drought resistance, it is really a science forced out by climate change. Some wheats are born "water-saving experts". Not only do they have a well-developed root system, but they can also activate special antioxidant mechanisms (Shahid et al., 2022). The new varieties recently tested in Xinjiang did not reduce their yields much when they were watered 30% less. What's even more amazing is that those "all-round players" perform well whether they are planted in the black soil of Northeast China or the loess slopes of Northwest China (Chairi et al., 2020). This is not good luck, but breeders deliberately selected genotypes with strong adaptability. For example, the variety promoted in 2022 has a stable yield of more than 400 kg per mu, even at a latitude difference of 15 degrees from south to north (Paux et al., 2022). It seems that if we want to keep our jobs, we have to cultivate this kind of hard-core wheat that can survive anywhere.

3.3 Nutritional traits

Consumers today are becoming more and more picky - they not only want to eat enough, but also want to eat healthily. Wheat breeding has also followed this trend and started to play with "nutrition upgrades", focusing on improving "plus points" such as dietary fiber, iron, and zinc (Wang et al., 2020). To be honest, this matter was quite difficult ten years ago. But now it is different. With new tools such as genomics, breeders are like getting a "nutrition code book". For example, last year a research team successfully increased the iron content in wheat by 40% by editing specific genes (Paux et al., 2022). What's even better is that these "fortified" wheats are not only more nutritious, but also have the same taste. This wave of operations can be said to kill two birds with one stone: it not only captures the attention of the high-end consumer market, but also provides solutions to global health problems such as iron deficiency anemia. It seems that in the future, wheat must not only have high and stable yields, but also be a "nutritional supplement".

3.4 Processing traits

The processing characteristics of wheat are like its "professional skill certification"-directly determining the employment prospects in the food industry. Let's talk about the hurdle of milling first. If the grain is too hard, it will waste electricity, and if it is too soft, the flour yield will be low. Fortunately, scientists have found several key QTL loci, just like mastering the "knob" to adjust the hardness of the grain (Huang et al., 2006). The dough characteristics are the real "interviewer". If the gluten is too strong, the biscuits will be as hard as bricks, and if it is too weak, it will not be able to support the skeleton of the bread. Now breeders have learned to be smart and use genomic prediction models for screening in the early stage to avoid wasted work in the later stage (Michel et al., 2019).

The famous breeding project in Kansas, USA is very interesting. They have set up a "five-level" screening system-tracking the entire process from genetic testing to actual baking (Figure 2) to ensure that the new variety can be put into use directly after it comes off the production line. The most amazing thing is the "ultimate test" of bread volume. Last year, a new variety of flour was found that, due to the optimization of a certain gene marker, the bread baked was 15% larger than the normal one (Sandhu et al., 2021). These breakthroughs are not just a number game in the laboratory. Many high-end flours sold in supermarkets now have the shadow of this precision breeding technology behind them (Zhang-Biehn et al., 2021).

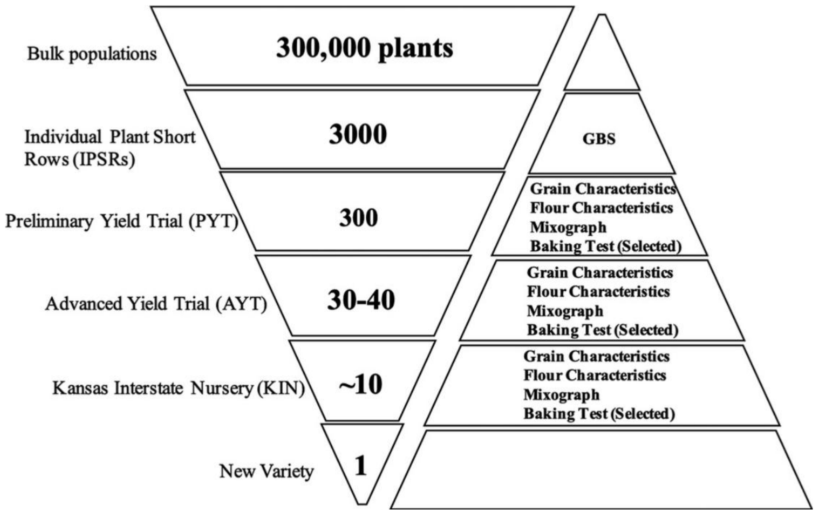

Figure 2 Kansas State University wheat breeding program diagram and end-use quality traits evaluated at different stages, GBS, genotyping-by-sequencing (Adopted from Zhang-Biehn et al., 2021)

4 Traditional and Modern Breeding Methods

4.1 Traditional breeding

When it comes to wheat breeding, the old methods are still quite useful (Ma and Cai, 2024). Farmers and breeders care most about hard indicators such as high yield and strong disease resistance, especially for wheat used for making bread, and characteristics such as gluten content cannot be neglected. But what's interesting is that although the traditional method of hybrid breeding is time-consuming and labor-intensive (Bushuk, 2004; Mondal et al., 2016; Li, 2020), key traits such as grain hardness and protein content really have to be improved slowly from generation to generation. Of course, it doesn't mean that all characteristics can be perfectly inherited, and sometimes there will be some unexpected situations. But it is undeniable that the high-quality bread wheat varieties on the market are basically cultivated little by little.

4.2 Marker-assisted selection (MAS)

The breeding circle is now using a new method called marker-assisted selection (MAS), which is to use genetic markers to select good seedlings (Bushuk, 2004; Alam et al., 2024). In the past, you had to wait until the wheat grew up to see whether it was good or bad. Now, by directly testing DNA markers in the laboratory, you can know which seedlings will have good gluten quality in the future - especially those gluten subunits that determine the taste of bread. But then again, this technology is not omnipotent, and some complex traits still need to be combined with traditional methods. But it is undeniable that using MAS to screen out high-quality materials in the early stages of breeding does save a lot of time, and the selection is more accurate. For wheat specifically used for making bread, breeders now attach great importance to this technology.

4.3 Genomic selection (GS)

There is a new and popular trick in the wheat breeding circle now called genomic selection (GS). Simply put, it is to use the data of the entire genome to calculate and predict in advance what the wheat will grow like (Merrick et al., 2022; Paux et al., 2022; Rempelos et al., 2023). In the past, breeding had to rely on experience and trial and error. Now with this technology, complex traits can be predicted to be almost accurate. Of course, it is not that simple in actual operation. It is a headache to calculate when the amount of data is large. However, it can indeed save breeders a lot of time, especially for those traits that require several generations to stabilize. Now, the effect may be seen in one or two seasons. Now many breeding projects are trying to combine GS with traditional methods. It is said that the parent materials selected in this way will not only increase the yield of the offspring, but also have better quality. But then again, the specific effect depends on the actual planting performance. After all, there may still be a gap between genetic prediction and the wheat that grows in the end.

4.4 CRISPR and gene-editing technologies

Speaking of gene editing, CRISPR technology has been very popular in recent years (Shrawat and Armstrong, 2018). In particular, the CRISPR/Cas9 system is like a pair of molecular scissors that can cut whatever you want. It used to be very difficult to modify genes in complex crops like wheat, but now this technology can accurately locate key genes that affect yield or disease resistance (Sedeek et al., 2019; Alotaibi et al., 2020). However, the actual operation is not as simple as it sounds, and sometimes off-target conditions occur. But it is undeniable that compared with traditional methods, this technology is indeed much faster. For example, Li's team has achieved a lot of results in the past two years (Li et al., 2021a; 2021b). If you don't know how to use CRISPR, you feel like you are almost out of touch with the times. Of course, whether it can be applied to actual planting in the end depends on field performance and regulatory approval.

Recently, the breeding circle has been discussing an interesting phenomenon - using CRISPR technology to adjust the flowering time of wheat can actually directly affect the quality of flour (Ansari et al., 2020). This is quite magical. Originally, I just wanted to control the flowering time, but I found that the processing characteristics of flour also improved. The Li team mentioned it in several papers (Li et al., 2021a; 2021b). They made wheat flour more suitable for making different types of pasta by precisely editing specific flowering genes. Of course, some unexpected situations will be encountered in actual operations. For example, the flowering time of some strains is adjusted correctly, but other traits have problems. But in general, this method of fixed-point editing has indeed opened up a new path for special wheat breeding. Now those who make noodles and bread are all watching this technology, waiting to cultivate wheat varieties that better meet their needs.

4.5 Hybrid wheat development

Breeders have actually been thinking about hybrid wheat for many years (Okada et al., 2019). Everyone knows that hybrid varieties tend to grow stronger, have higher yields, and better disease resistance - this is the so-called hybrid vigor. But wheat, as a crop, is naturally self-pollinating, which makes hybrid breeding particularly difficult (Chen et al., 2020). I remember that in the past few years, the process of emasculating hybrid wheat alone could make people exhausted. However, the situation has changed recently. Once gene editing technology comes out, it can directly manipulate the reproductive characteristics of wheat. Although the success rate is not too high now, at least there is hope. Some laboratories have begun to try to use CRISPR to modify the floral structure of wheat. Maybe in a few years, hybrid wheat can be promoted on a large scale like hybrid rice.

When it comes to hybrid wheat, CRISPR/Cas9 has been a great help (Okada et al., 2019). The biggest headache in the past was how to produce a stable male sterile line. Now, this problem can be solved by simply knocking out the key gene Ms1 with gene editing (Chen et al., 2020). However, it is not that simple in practice. Sometimes the editing efficiency is not stable and repeated experiments are required. But it is indeed much faster than the traditional methods. For example, the article published by Lyzenga and others last year showed new progress (Lyzenga et al., 2021). Now the success rate of cross-pollination in hybrid seeds has been significantly improved. Interestingly, different regions have very different requirements for wheat quality. Some regions require strong gluten for bread, while others require weak gluten for biscuits. Through this precise editing method, it may be possible to cultivate "customized" hybrid wheat varieties in the future. Of course, to truly promote planting, it still has to pass the yield and quality tests, but at least there is new hope now.

5 Successful Case Studies in Specific-Use Wheat Breeding

5.1 Bread wheat breeding

The wheat variety "Norin 10" is truly a legend. In the 1950s and 1960s, no one expected that this dwarf variety introduced from Japan would cause such a sensation (Worland and Sayers, 1995). The most amazing thing about it is its short stature - even though the plant has become shorter, its yield has actually increased. Breeders in Mexico and the United States were overjoyed and used it as a parent material to cultivate high-yield star varieties such as

Gaines. But to be honest, when it was first promoted, farmers were quite hesitant. After all, who had ever seen such a short wheat? But it turned out that these new varieties were not only resistant to lodging, but also particularly "loved fertilizer". The more fertilizer was applied, the more yield was increased. Although these semi-dwarf varieties are now very common, they completely changed the pattern of wheat cultivation around the world at that time.

In recent years, the breeding of bread wheat has been focusing on the hard indicator of gluten quality. It is interesting to say that although the old variety "Norin 10" is known for its short stalks (Worland and Sayers, 1995), the genetic diversity it brings is still playing a role. Breeders are now more sophisticated and directly focus on the gene loci that control dough elasticity and stability for selective breeding. The article published by Sertse's team last year mentioned (Sertse et al., 2023) that molecular marker-assisted screening can indeed breed wheat that is more suitable for modern baking technology. However, the reality is that old-fashioned bakeries and industrial production lines have different requirements for flour. Some require good ductility, while others focus on water absorption. Fortunately, with these new technologies, it may soon be possible to breed all-round wheat varieties that can "meet all" baking needs. Of course, in the end, it depends on whether the baked bread is delicious.

5.2 Durum wheat breeding

When it comes to durum wheat for making pasta, there are many tricks involved. This golden wheat is different from ordinary bread wheat. It is mainly grown in specific areas such as the Great Plains of North America and the Mediterranean coast (Figure 3) (Haugrud et al., 2024). The two indicators that breeders care about most are the carotene content that makes the noodles appear beautiful golden yellow, and the protein level that determines the chewy taste. Interestingly, as early as the last century when "Norin 10" triggered the Green Revolution (Worland and Sayers, 1995), people found that these traits were particularly difficult to improve. However, the situation has changed in recent years. New breeding techniques such as those used by Sertse and others (Sertse et al., 2023) have greatly improved the efficiency of screening high-protein and high-pigment varieties. Now the high-end pasta in supermarkets basically uses strictly selected durum wheat varieties. Although the noodles made from wheat from different producing areas have their own unique flavors, they all have to meet the hard standard of "tough to the bite and not mushy after cooking for a long time".

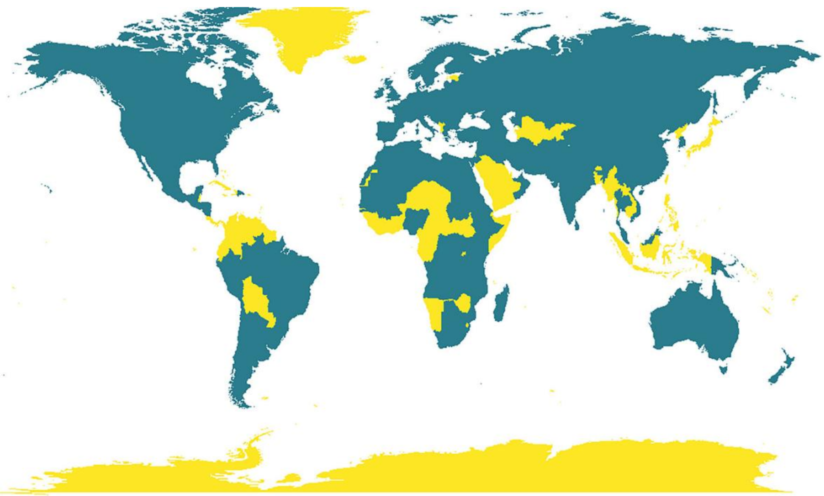

Figure 3 World Map displaying countries that are reported to produce durum wheat based on the World Integrated Trade Solutions website from the years 2015~2022 (Adopted from Haugrud et al., 2024)

Image caption: Countries colored in dark blue have reported durum production and those in yellow do not have any durum production reported (Adopted from Haugrud et al., 2024)

5.3 Nutrient-enriched wheat breeding

When it comes to wheat fortification, there is actually a very sad reason behind it - in many developing countries where pasta is the staple food, although people are well fed, zinc and iron deficiency are particularly serious. You may not think that the content of these trace elements in ordinary wheat is actually very limited (Worland and

Sayers, 1995). However, the breeding industry has made new breakthroughs in this regard recently. For example, the research published by Sertse and others last year is quite interesting (Sertse et al., 2023). Through the combination of traditional breeding and molecular markers, the zinc and iron content in wheat grains has been increased a lot. Of course, this process is not easy. Some high-yield varieties lose their yields once they are fortified with trace elements, and they have to be screened and balanced repeatedly. Now places such as India and Pakistan have begun to test this type of fortified wheat. Although the taste is no different from ordinary wheat, it may be very helpful to improve children's development and prevent anemia and other health problems. However, in order to make farmers willing to plant and ordinary people willing to eat, we must solve the problems of variety adaptability and market promotion.

5.4 Industrial use wheat breeding

Now the industry has suddenly become more interested in high-starch wheat, which is related to the environmental protection trend. You may not know that the starch content of ordinary wheat is about 60-70%, but specially cultivated high-starch varieties can exceed 75% (Worland and Sayers, 1995). Although this kind of wheat is not very good for making steamed bread, it is suitable for producing ethanol or bioplastics. Through hybridization and molecular marker-assisted selection (Sertse et al., 2023), several genes that control starch synthesis were put together. However, it is quite troublesome to operate in practice. When the starch content goes up, the protein content often goes down. Now some factories in Europe and North America have begun to try these high-starch wheats as raw materials. After all, it is a general trend to replace petroleum products with renewable resources. It’s just that farmers are not very motivated to grow them, unless they can guarantee that the purchase price is much higher than that of ordinary wheat-this depends on the market situation of biofuels.

6 Challenges in Specific-Use Wheat Breeding

6.1 Trade-offs between traits

Wheat breeding is like playing on a seesaw. It is difficult to achieve perfection in all excellent traits. When you try hard to increase the yield of wheat ears (Foulkes et al., 2011), the straw will become fragile, and a heavy rain may cause the entire wheat field to fall. Disease-resistant breeding in the past two years has also faced a similar dilemma, especially against "old opponents" such as rust and fusarium head blight (Miedaner and Juroszek, 2021). Disease-resistant varieties that perform well in the laboratory may have a greatly reduced resistance level when planted in fields in different regions. Interestingly, breeders are now starting to change their thinking - no longer pursuing single champions, but "all-round players". For example, some varieties may not have the highest yield, but they win in stable yield; some varieties may not have the strongest disease resistance, but they can take into account three or four major diseases. This balancing strategy is easier said than done, and it often takes five or six generations of breeding to find the best combination. But then again, it is these complex trait games that make wheat breeding both challenging and particularly interesting.

6.2 Environmental variability

It is becoming increasingly difficult to grow wheat now because the weather has become too unreliable. The temperature rises when it should, and it doesn't rain when it should, causing the quality of wheat to fluctuate (Fradgley et al., 2022). Take the UK for example, some places are too hot in the summer, so wheat doesn't grow well, but other places are not so serious. Breeding experts have been thinking about this recently (Cooper and Messina, 2022), and they think they need to find a solution from the old varieties. Cheng et al. (2023)'s research is quite interesting. Although those traditional wheats have low yields, they are particularly durable. Speaking of which, nowadays, choosing varieties is not only about yield, but the key is whether they can withstand the weather. The previous breeding ideas are really not enough in the current climate that changes at any time.

6.3 Market and consumer demands

Wheat breeding is becoming more and more difficult nowadays - farmers want yield, consumers want quality, and environmentalists want sustainable development. The current breeding goals are like solving a multivariate equation. It is not a simple hybridization that can solve the problem of making wheat more nutritious while reducing the use of fertilizers. However, what is interesting is that the new generation of genomic tools has helped a lot (Paux et al., 2022; King et al., 2024), at least allowing breeders to screen out materials that meet the requirements more quickly. But then again, market tastes change faster than the weather. The whole wheat flour that was popular last year may be out this year. So when making breeding plans now, you have to leave some flexibility. Who knows what new requirements consumers will have next year?

6.4 Technical and economic limitations

Wheat breeding is becoming more and more expensive. Although new technologies such as genomic selection sound great (Mondal et al., 2016), in practice, it costs a lot to buy equipment, not to mention the need to employ a group of professional technicians. To make good use of these high-tech tools (Lopes et al., 2015), different teams must cooperate with each other and share data (Paux et al., 2022). But the problem is that it takes seven or eight years to breed a new variety, during which time it is necessary to repeatedly screen and test and combine various excellent genes together. Sometimes you may invest millions of dollars and end up with a few barely usable lines. What's worse is that by the time you finally breed it, the market situation may have changed. So now many breeders are worried: if they don't use new technologies, they can't keep up with the times, but if they use them, they can't afford it. It's really a dilemma.

7 Future Directions in Specific-Use Wheat Breeding

7.1 Integration of multi-omics approaches

There is a new trend in the wheat breeding circle now - using genomic, transcriptomic and proteomic technologies in a package. It is easier said than done. Although Mahmood et al. (2022) showed good results, data integration often goes wrong in actual operations. Interestingly, with the addition of machine learning algorithms, these multi-omics data suddenly become easy to use, at least helping breeders understand those complex traits faster. But then again, the equipment investment is not cheap, and small laboratories can't handle it at all. Yang et al. (2021) has emphasized before that only by truly connecting these technologies can we accurately find the relationship between genes and phenotypes. Although the process is a bit cumbersome, this method is indeed useful for breeding new drought-resistant and high-yield varieties-at least it is much better than blind hybridization in the past.

7.2 Precision agriculture

Now, "precision customization" has also begun to be used in farming, which is quite interesting. Genomic selection (GS) technology is like doing environmental matching tests for wheat varieties (Merrick et al., 2022), but the actual operation is more complicated than imagined. It is not enough to just look at the genetic data, it must be combined with the actual planting performance to be reliable (Li et al., 2021b). Studies have shown that the varieties bred by this method not only have stable yields, but also unexpectedly reduce the use of fertilizers and pesticides (Paux et al., 2022). Although the initial investment is not small, it may be a good idea for those production areas where the weather changes at any time. In the final analysis, this kind of precision agriculture is like finding the most suitable wheat "clothes" for different plots, which saves resources and increases the yield.

7.3 Sustainable breeding practices

Now, when it comes to wheat breeding, it is not enough to just focus on yield. With climate change being so severe, we need to find ways to breed more "hardy" varieties (Paux et al., 2022). For example, some wheats are naturally drought-resistant, while others are highly resistant to diseases, and these traits are becoming increasingly valuable. Recent studies have shown that these traits can be precisely adjusted through gene editing technology (Li et al., 2021b). But then again, it is not enough for new varieties to be disaster-resistant, they also have to save water and fertilizer. Interestingly, breeding technology has indeed made great progress in the past two years, allowing wheat to adapt to extreme weather and improve resource utilization efficiency. Although the effect is a bit slow, this sustainable breeding approach may be a way out for ensuring food security.

7.4 Global collaboration

When it comes to wheat breeding, you can't do it alone. Remember the BREEDWHEAT project that Europe launched a few years ago? It was through the cooperation of various countries that many new tools were developed. It's interesting to say that if you put the drought-resistant genes in Africa and the high-yield varieties in

Asia together, you may be able to breed new varieties that are both drought-resistant and high-yielding (Paux et al., 2022). However, in actual operation, data sharing is quite troublesome, and each country keeps a close eye on its own resources. But then again, the climate is so abnormal now that anyone's wheat may suffer a disaster. Instead of hiding it, it's better to work together to find a solution. After all, food security is a global problem, and it can't be solved by a few countries alone.

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Conflict of Interest Disclosure
The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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