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Genetic Enhancement of Wheat for Pasta Production

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Abstract High-quality wheat is the core raw material for pasta production, and its key quality traits play a decisive role in the cooking and processing quality of pasta. However, the complex genetic basis, multi-gene regulation mode and significant gene-environment interaction of these traits pose great challenges to breeding. This study reviews the key quality requirements and genetic basis of high-quality pasta wheat, discusses in detail the application progress of genetic improvement technology in wheat quality improvement, and focuses on the research results in the fields of molecular marker development, gene editing and multi-omics data integration. At the same time, the technical bottlenecks and challenges in the current genetic improvement of high-quality wheat are analyzed, including the complexity of phenotypic measurement, gene-environment interaction in multi-environment experiments, and the need for variety development to adapt to climate change conditions. Future breeding strategies based on the comprehensive utilization of genetic and environmental factors are proposed, and the potential value of genomics and multi-omics technologies in promoting pasta-specific wheat breeding is envisioned. This study provides an important scientific reference for global food security and the sustainable development of the pasta industry.
Keywords Pasta wheat; Quantitative trait loci (QTL); Marker-assisted selection; Gene editing; Multi-omics integration; precision breeding

1 Introduction

The story of pasta is actually quite interesting - you may not know that there are many tricks behind the colorful packaging in supermarkets now. The case of durum wheat (Beres et al., 2020) is a typical example. In the past, farmers did not consider so many things when growing wheat, but now it is different. Consumers suddenly began to pay attention to this nutrition and that quality, so that breeding experts had to adjust their strategies accordingly. Speaking of which, although the global market is indeed expanding, the tastes of each place are actually quite different. Some people like chewier ones, while others prefer softer ones. This change has come very quickly. There were not so many considerations ten years ago. Now even how to grow wheat has to consider sustainability. Times have really changed.

Speaking of wheat for making pasta, it's actually quite interesting - you may not know that ordinary flour doesn't work at all, it has to be durum wheat. This kind of wheat has a very high protein content (Kroupina et al., 2023), and the dough kneaded out is very chewy. But then again, even for durum wheat, different varieties are quite different. Some make very chewy noodles, while others are easy to cook. Scientists have discovered that this has a lot to do with genes such as Glu-A1 and Glu-B1 in wheat. Now breeders are thinking about how to combine these good genes together all day long. After all, who doesn't want to eat better-tasting pasta? Although it's easy to say, it's not a simple matter to improve the variety.

Durum wheat breeding is easier said than done. Farmers are most concerned about yield, but protein content is important for making pasta (N'Diaye et al., 2018), and they often lose one of the two. What's more troublesome is the weather-in drought years, protein levels go up, but yields drop. Fusarium head blight often occurs in the fields, and once it spreads, it spreads to a large area. Breeding experts are also having a headache. There are only so many materials in the existing wheat variety gene bank, and the results of repeated matching are limited. However, I heard recently that some people have begun to try some new methods (Haugrud et al., 2024), such as finding disease-resistant genes in wild wheat or using molecular markers to assist selection. In my opinion, the most important thing in this industry is a bit of luck. Who knows, one day you may come across an excellent combination that is both high-yielding and disease-resistant.

This time we mainly want to improve the genes of durum wheat, to put it bluntly, we want to make the flour for making pasta more useful. In fact, this is quite interesting - you see, some pasta on the market is very chewy, while others become mushy when boiled. The key lies in the wheat protein. We plan to turn all the wheat with high-protein genes upside down. If we can really come up with a few new varieties, not only will the noodles taste better, but we may also help farmers save some money on fertilizers and pesticides. Pasta is so popular all over the world now, if we can mix our wheat into it, we will make a lot of money. Of course, whether it will succeed in the end depends on the experimental data. Who can say for sure when doing scientific research?

2 Quality Requirements for High-Quality Pasta Wheat

2.1 Protein content and its impact on gluten quality

When it comes to wheat for pasta, protein is a particularly interesting thing. Did you know that protein in flour is like steel bars in a construction site - the higher the content, the chewier the noodles. However, it's not enough to just look at the total amount, it's also important to know which specific proteins are at work. Little guys like gamma-protein (Samofalova et al., 2022), although not present in large quantities, have a particularly large impact on the taste of noodles. Interestingly, wheat from different origins can have very different tastes even if the protein content is similar. Breeding experts are now studying these proteins with a magnifying glass, after all, who doesn't want to breed varieties that are both high-yielding and delicious? Of course, laboratory data and actual taste sometimes don't match up, which is probably the charm of agricultural research.

2.2 Starch properties and their role in cooking quality of pasta

In fact, many people don’t know that starch is the key to making pasta. Think about it, whether the noodles are soft or hard, or whether they are sticky, the starch is secretly working behind the scenes. Those high-quality pasta that look shiny (Roselló et al., 2018) are made of coarse flour that is particularly exquisite - grinding too fine is not good. But this matter is quite subtle. Starch and protein are like dancing a duet (Wang and Fu, 2020). If one takes a big step, the other must follow suit. Sometimes farmers have a good harvest, the wheat grows full, and the starch content is high, so the noodles made are more likely to be overcooked. So, when a good pasta chef looks at flour, he not only focuses on the protein, but also has to think about the little temper of starch.

2.3 Grain hardness and processing adaptability

When you see professional pasta chefs choosing flour, the first thing they do is to grab a handful of wheat grains and squeeze them - they are actually testing the hardness! This seemingly simple characteristic is very particular. The coarse flour ground from hard, glassy wheat grains (Sarkar and Fu, 2022) is different, and it is particularly good for making noodles. But God always likes to play tricks. Sometimes the same batch of seeds grows hard in one field and soft in another, which even breeders are at a loss. The mill masters understand this best. They have to adjust the machine at any time according to the hardness of the wheat grains, just like an old Chinese doctor taking a pulse and prescribing a prescription. It's strange that the pasta sold in supermarkets now looks similar, whether it's expensive or cheap, but it turns out to be the same when it's cooked - in the final analysis, it's the hardness of the wheat grains that's the problem.

2.4 Regulation of wheat quality by environmental factors

Planting wheat is a matter of fate. You may not expect that the same bag of seeds may produce chewy pasta this year, but not so good next year - it all depends on the combination of rain and temperature. Applying more nitrogen fertilizer will increase protein (Sieber et al., 2015), but if it is rainy, the hardness of the wheat grains may drop. This is the biggest headache for breeding experts now: the newly selected varieties perform well in the test fields, but they change when they are in the farmers' fields. Especially the glassy characteristic, which is easy to change when the humidity is high, making it like opening a blind box. Therefore, breeding now not only depends on the yield, but also on whether the variety can maintain its quality in dry land and flooded land. In my opinion, wheat for making pasta is the same as wine grapes. The terroir conditions are not good at all.

3 Genetic Basis of Wheat Quality Traits

3.1 Major genes and QTLs controlling protein content and gluten characteristics

Anyone who is engaged in wheat breeding knows that protein is a particularly troublesome thing - it's not just about finding a high-protein variety for hybridization. Recently, it was discovered that there is a key switch hidden on chromosome 5A (Solonechna et al., 2022), and a simple switch can change the protein content. But what's even more amazing is that some gene loci, such as hap_2B_9, can actually manage several things at the same time, affecting both protein content and loss rate. It's like playing Tetris. After all, it's hard to eliminate a row, but new problems may arise. Now the laboratories are busy mapping these QTLs. After all, finding the right gene combination may be able to breed perfect wheat that is both high-yielding and chewy. But then again, whether these genetic markers work well in actual breeding depends on field performance. After all, the laboratory and the wheat field are completely different things.

3.2 Genetic loci associated with starch properties and cooking quality

When it comes to the quality of pasta, the little secrets hidden in the chromosomes are very interesting. Look at the chromosomal loci 1B and 4B (Rapp et al., 2019), which are like color palettes and timers - some control whether the color of the noodles will darken, and some control how long it takes to cook to be chewy. The most amazing one is the 7B locus, which not only affects the color, but also has a relationship with the protein content (Mulugeta et al., 2023). It's like finding a universal remote control that can adjust several parameters at the same time with one click. Now breeding experts are focusing on these key loci to make a fuss. After all, who doesn't want to breed perfect wheat that doesn't get mushy when cooked, has bright colors, and tastes good? However, these gene loci often compete with each other. It may change the color but affect the chewiness. Breeding is like playing a balancing act, and you have to slowly explore the most suitable combination.

3.3 Genetic regulation mechanisms of grain hardness

The hardness of wheat grains is not something that can be simply described as "hard" or "soft". Guess what? The gene loci that control hardness (Dagnaw et al., 2022) are like a group of nosy aunts - not only do they control the hardness of wheat grains, but they also intervene in matters such as the water absorption of dough and the kneading time. For example, there is a particularly active QTL on chromosome 5D. Once it changes, the entire processing flow must be adjusted. What's more troublesome is that these gene loci are particularly susceptible to environmental influences. The same genotype can produce a lot of different hardness when grown in arid and humid areas. The complex interactions in Figure 1 are dizzying, but if you want to breed good wheat, you really have to understand them. In the final analysis, hardness is a troublesome thing that affects the entire body, but it is also the key to making good pasta.

4 Application of Genetic Improvement Technologies in High-Quality Wheat Breeding

4.1 Marker-assisted selection (MAS)

Breeding work is very different now. It is no longer necessary to select wheat by observing wheat ears with the naked eye. Scientists are now playing the game of "gene detective". Through those magical molecular markers (Wijerathna-Yapa et al., 2022), it is possible to predict in the laboratory which wheat will be more disease-resistant and which will make noodles more chewy in the future. I remember that breeders had to wait until the wheat matured before making a judgment. Now they can know the result by taking a leaf test at the seedling stage (Bassi et al., 2016). Of course, this method is not omnipotent. Sometimes the marker prediction is perfect, but the wheat grown is not very good. But overall, this "cheating" breeding method has indeed made the cultivation of high-quality wheat much faster, at least it does not have to rely on luck like before.

4.2 Genomic selection (GS)

Wheat breeding is becoming more and more high-tech. Whole genome selection (GS) is like "genetic fortune-telling" for wheat - you don't have to wait for the wheat to grow up, just scan the gene spectrum to predict what kind of material it will be in the future (Trono et al., 2022). The most powerful thing about this trick is that it can accurately calculate the yield and quality, which are often "fighting" traits. In the past, the biggest headache for breeders was that the high-yield flour was not good, and the high-quality flour was not enough. Now GS directly looks at the genes to make decisions (Li et al., 2021). However, it is not that simple in actual operation. After all, there are always errors between genetic prediction and field performance, just like weather forecasts. But it is undeniable that this method has indeed shortened the breeding cycle a lot, at least we don't have to try our luck year after year as before. Interestingly, even machine learning is now involved. Maybe one day AI will be able to help us design perfect wheat.

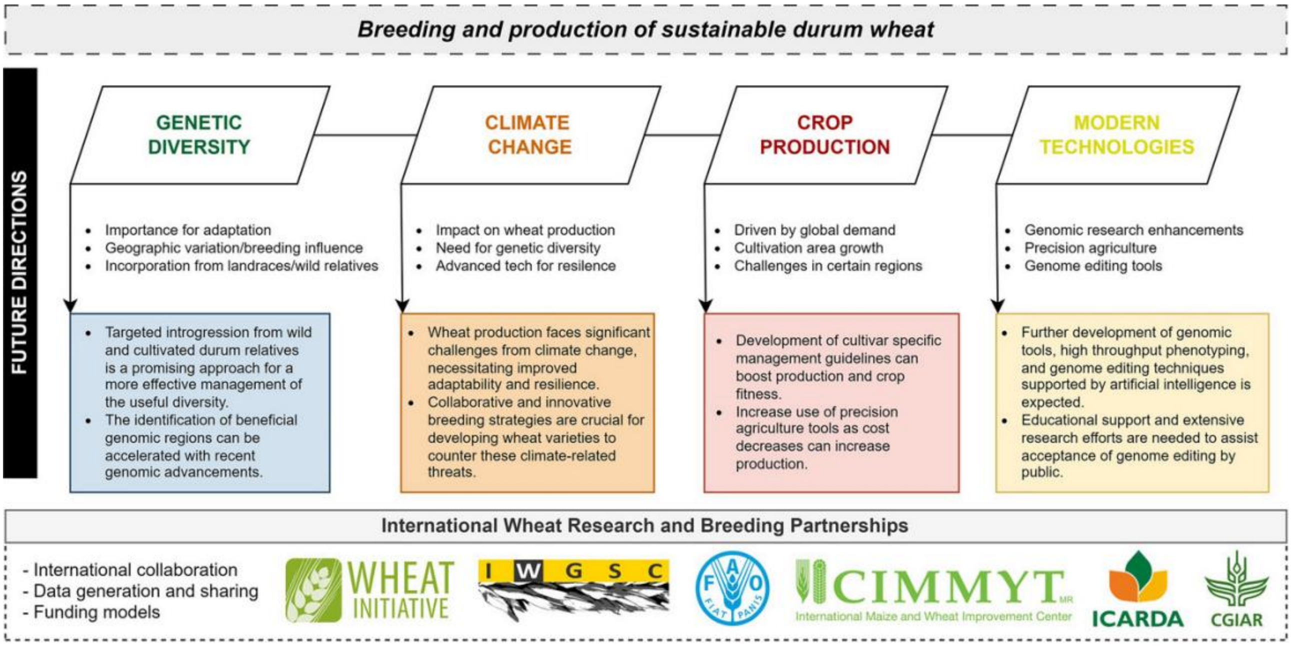

Figure 1 Breeding and production of durum wheat (Adopted from Haugrud et al., 2024)

4.3 Gene-editing technologies

Gene editing is now the "scalpel" of wheat breeding. The CRISPR system (Merrick et al., 2022) is like a robot with molecular scissors, which can accurately find the location to be modified among billions of bases. The most amazing thing is that last year a team changed two letters of a drought-resistant gene in wheat (Shrawat and Armstrong, 2018), and the yield of the new variety in dry land doubled. However, farmers are still a little skeptical about these "high-tech wheats" and always feel that they are not as reliable as traditional breeding. But to be honest, compared with the breeding method of relying on radiation mutagenesis in the past, this kind of precise editing is more controllable. The guys in the laboratory are still thinking about how to increase the protein content of wheat. Maybe next year they can make an edited variety specifically suitable for making pasta!

5 Multi-Omics Integration and Quality Improvement Strategies

5.1 The role of transcriptomics, metabolomics, and epigenetics in wheat improvement

Studying wheat is no longer just about looking at its appearance - scientists have started playing the "molecular detective" game. Take transcriptomics for example (Krasileva et al., 2017), which can tell us how wheat "screams for help" on dry days and which genes are working desperately. Even more amazing is metabolomics, which can even pull out those tiny chemicals in flour that affect the taste. The most mysterious is epigenetics (Alotaibi et al., 2020). Obviously, the genes have not changed, but there are a few more small marks, and the character of wheat is completely different.

The omics technologies shown in Figure 2 are like different means of investigation - some are responsible for monitoring the call records of genes, some are responsible for checking the metabolic bills of cells, and some are responsible for deciphering those mysterious genetic code markers. Putting this information together can be regarded as truly understanding the "instruction manual" of wheat. But to be honest, too much data is also a sweet trouble. Now the computers in the laboratory often smoke!

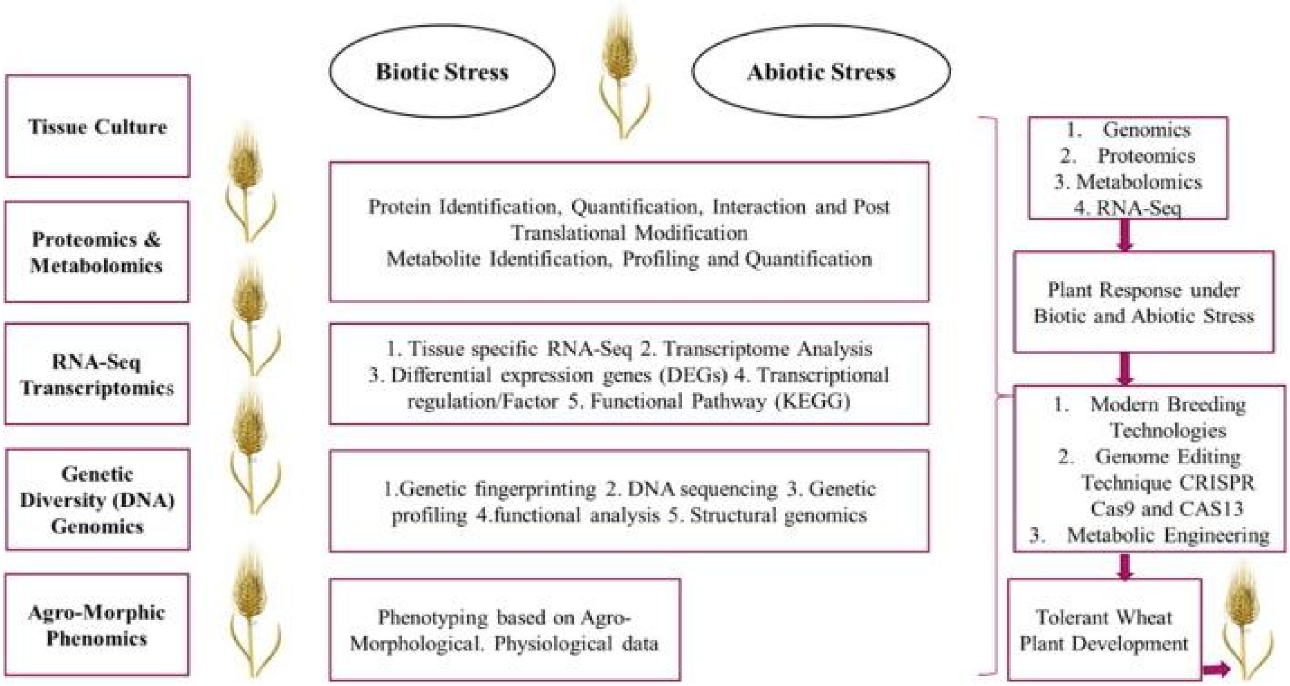

Figure 2 Comprehensive pathways to understanding wheat stress mechanisms (Adopted from Alotaibi et al., 2020)

Image caption: Application of genomics, proteomics, metabolomics, and transcriptome analysis results enable researchers and scientists to figure out the gene of interest at a specific stage of plant growth and development. Moreover, genome editing techniques also facilitate the knockout desired gene of interest and transformation for the successful development of wheat cultivars under stresses and ultimately yield (Adopted from Alotaibi et al., 2020)

5.2 Integration of high-throughput phenotyping and multi-omics data

Studying wheat now is like doing a full-body checkup on a patient-it takes both an X-ray of the genome and a blood sample of the metabolome. Drones fly over the fields every day to perform physical examinations on the wheat fields (Maccaferri et al., 2019), and even the tilt angle of each leaf is clearly recorded. The laboratory is even busier, with a new generation of sequencers running 24 hours a day, reading the genetic code of wheat over and over again. Interestingly, sometimes the abnormality of a certain metabolite can explain why a certain variety is particularly drought-resistant. This "heaven-earth linkage" research method is really amazing. Last year, someone accidentally discovered a key gene that affects the fullness of the grain by analyzing the 3D imaging data of wheat ears. However, the more data there is, the easier it is to be dazzled. What is most lacking now is a "wheat translator" who can understand this data.

5.3 Molecular breeding strategies based on multi-omics

Wheat breeding is now becoming more and more like a high-tech detective solving a case - whole genome selection (GS) is like a fortune teller (Yang et al., 2021), and DNA markers can be used to predict the performance of wheat when it grows up. Especially for key indicators of making pasta, such as protein content and gluten strength (Juliana et al., 2019), now there is no need to wait for the wheat to mature, and a blood test in the laboratory can tell the results. Even more amazing is the system biology approach, which treats wheat as a sophisticated network system to study which genes and which metabolites are secretly communicating. Last year, a team used this method and accidentally discovered that drought resistance and flour quality actually share the same metabolic pathway. However, these high-end technologies will eventually have to be verified in the fields. After all, no matter how beautiful the laboratory data is, it is not as convincing as the actual results of farmers.

6 Comprehensive Approaches for Improving High-Quality Pasta Wheat

6.1 Integration of genetic improvement and environmental management

To make high-quality pasta wheat, it is not enough to just tinker with genes in the lab - field management and variety characteristics must be combined. Those old Ethiopian varieties (Kroupin et al., 2023) look unremarkable, but the protein quality is surprisingly good, and now they are popular among breeders. Interestingly, the same variety grown in Italy and the United States can produce noodles with very different tastes, which is the so-called "water and soil incompatibility". Recently, scientists have focused on several QTLs that control protein concentration (Stella et al., 2023), but found that their performance varies under different climatic conditions. Therefore, breeding now has to design planting plans, which is like tailoring a "growth strategy" for each wheat variety. In the final analysis, if you want to make top-quality pasta, you have to let good genes meet a good land that understands it.

6.2 Comprehensive consideration of market promotion and consumer demand

When it comes to wheat breeding for pasta, it all depends on whether consumers will buy it. The high-end pasta on supermarket shelves now often advertises "high protein" and "chewy and smooth" on the packaging (Fradgley et al., 2022), which shows that the market buys this. Canada is quite interesting. The durum wheat varieties they cultivated directly put all the good genes together - just like collecting stamps, collecting favorable alleles one by one. However, climate change is quite annoying. Last year's European heat wave caused many traditional varieties to overturn, so now breeders are looking for wild wheat materials that are resistant to high temperatures all over the world (Kusunose et al., 2022). After all, no matter how good the variety is, if it can't withstand extreme weather, it will only be used as a specimen in the paper. After all, it's really not easy for breeders to please consumers and deal with the temper of God.

6.3 Breeding high-quality wheat under climate change scenarios

Wheat breeding is like fighting a guerrilla war against climate change. Today's drought-resistant varieties may have to be flood-resistant tomorrow. Experts from the International Agricultural Research Institute (Requena-Ramírez et al., 2023) are now running around the world, looking for drought-resistant genes in the dry land of Mexico and digging cold-resistant materials on the hillsides of Turkey. CIMMYT recently released a new variety that is quite interesting. It does not wilt in the 35-degree high temperature in the morning, does not collapse in the heavy rain in the afternoon, and can maintain protein at night. To say that the current technology is indeed advanced, the use of molecular marker-assisted selection is like installing a weather forecast system for wheat, which shortens the breeding cycle a lot. But farmers are the most practical. They don't care about any genomic tools. They only care about whether good wheat can grow in the field. So, no matter how high-tech the variety is, it will eventually pass the field test. After all, wheat ears don't lie.

7 Current Challenges and Solutions

7.1 Bottlenecks and difficulties in current breeding technologies

Durum wheat breeding is becoming more and more difficult. First of all, the gene pool is so small that breeding is almost like inbreeding (Mondal et al., 2016). What's more terrible is the bad weather - it was dry yesterday and it rained heavily today, forcing breeders to look all over the world for varieties that can withstand the roller coaster weather. You may not believe it, but the hexaploid genome of wheat (Li, 2024a) is as complicated as a Russian nesting doll. It is more difficult to accurately modify a gene than to find the exit in a maze. The old way of relying on the weather is completely out of date now. Young people in the laboratory are now playing with high-tech tricks such as gene editing. But then again, no matter how powerful the technology is, it has to pass the test of the farmers. After all, wheat counts only when it is planted in the field.

7.2 Adaptability and promotion barriers for high-quality wheat in production

The promotion of high-quality wheat is a mess. In the arid regions of Africa (Ficco et al., 2016), new varieties must first pass the "Flame Mountain" test - 40 degrees high temperature during the day, pests and diseases party at night, and only tough guys can survive. Small farmers are even more troubled. They know that the new varieties are good, but they can't afford seeds and fertilizers, and they only see technicians a few times a year (Pinel et al., 2023). Interestingly, in some places, farmers get drought-resistant wheat seeds and cook them for meals - there is no other way. When you are hungry, who cares what to plant next year? These practical problems are much more difficult than gene editing in the laboratory. After all, no matter how good the varieties are, they must first pass the poverty line. Now the aid projects of international organizations have also begun to learn to be smart. Not only do they send seeds, but they also have to teach technology and help with sales, and slowly they can open up the situation.

7.3 Sustainable solutions for global food security and the pasta industry

To feed the world's growing love of pasta, the old methods alone are not enough. Scientists are now holding genetic scissors in their left hand (Tadesse et al., 2019) and flipping through the ancient wheat genealogy of Ethiopia with their right hand, trying to come up with super varieties that can withstand extreme weather and are rich in nutrition. But this matter cannot be done in the laboratory alone - the drought-resistant genes grown in the smoking fields of Africa may be more effective than any artificial editing. Recently, the experts at CIMMYT have been very busy, flying around all day to act as "wheat matchmakers" and match breeding plans from various countries together (Li, 2024b). After all, the gray rhino of climate change will not wait for anyone. The varieties that work in Morocco today may not adapt to the local climate in Mexico tomorrow. In the final analysis, to feed the world, we have to let the high-tech in the laboratory and the folk methods in the field have a cross-border love affair.

8 Concluding Remarks

The story of pasta wheat breeding is actually a genetic treasure hunt spanning thousands of years. Think about it, from the accidental discovery of wild wheat to the precise gene editing in the laboratory today, humans have been struggling with the protein in wheat grains. Although the old Ethiopian varieties have low yields, the protein quality is surprisingly good, and they have become the "gene bank" for modern breeding. Interestingly, scientists have found that the gene loci that control gluten strength are often closely related to drought resistance, which is probably the wonderful code written by nature. Now with whole genome selection technology, we can predict quality without waiting for wheat to ear, and the breeding cycle has been shortened by more than half. But then again, no matter how accurate the gene prediction is, it still has to pass the "tip of the tongue test" of the pasta chef. After all, it all depends on whether the noodles are chewy enough.

Durum wheat breeding is really in good times now - once gene sequencing technology is developed, we can look up the genetic code of wheat like looking up a dictionary. What excites breeders the most is that now they no longer have to wait for wheat to mature season by season as before, and they can find good genes for high protein and strong gluten in the laboratory. But the most amazing thing is to go to the remote mountainous areas of Ethiopia to "treasure hunt". The stress resistance genes hidden in those wild relatives are simply a natural solution to climate change. Now with high-throughput phenotyping analysis, even the 3D morphology of wheat ears can be digitized, and the breeding efficiency has doubled directly. But in the final analysis, no matter how advanced the technology is, it has to return to the taste of noodles - after all, consumers don't care about molecular markers, they only recognize good pasta that is not overcooked and chewy.

In the future, wheat breeding will have to learn to "walk on two legs"-it must use the black technology of the transgenic group, but it must not lose the real skills in the fields. Whole genome association analysis is very popular now, just like a full-body CT scan of wheat, even the most hidden yield-related genes are nowhere to hide. But interestingly, the experts at CIMMYT recently found that combining genomic data with farmers' decades of seed selection experience is more effective than relying solely on laboratory data. The most fashionable thing in breeding now is "tailoring" and customizing varieties according to different farming environments - for example, equipping drought-resistant genes for arid areas and disease-resistant programs for rainy areas. Of course, no matter how good the variety is, it must be matched with a suitable planting plan, just like a good horse with a good saddle. In the final analysis, if you want to feed the mouths of people who love pasta all over the world, you still have to rely on the "dream linkage" of laboratories and farmlands.

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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.

References

Alotaibi F., Alharbi S., Alotaibi M., Mosallam M., Motawei M., and Alrajhi A., 2020, Wheat omics: classical breeding to new breeding technologies, Saudi Journal of Biological Sciences, 28: 1433-1444.
https://doi.org/10.1016/j.sjbs.2020.11.083

Bassi F., Bentley A., Charmet G., Ortiz R., and Crossa J., 2016, Breeding schemes for the implementation of genomic selection in wheat (*Triticum* spp.), Plant Science, 242: 23-36.
https://doi.org/10.1016/j.plantsci.2015.08.021

Beres B., Rahmani E., Clarke J., Grassini P., Pozniak C., Geddes C., Porker K., May W., and Ransom J., 2020, A systematic review of durum wheat: enhancing production systems by exploring genotype, environment, and management (G×E×M) synergies, Frontiers in Plant Science, 11: 568657.
https://doi.org/10.3389/fpls.2020.568657

Dagnaw T., Mulugeta B., Haileselassie T., Geleta M., and Tesfaye K., 2022, Phenotypic variability, heritability and associations of agronomic and quality traits in cultivated ethiopian durum wheat (*Triticum turgidum* L. ssp. *Durum*, Desf.), Agronomy, 12(7): 1714.
https://doi.org/10.3390/agronomy12071714

Ficco D., De Simone V., De Leonardis A., Giovanniello V., Del Nobile M., Padalino L., Lecce L., Borrelli G., and De Vita P., 2016, Use of purple durum wheat to produce naturally functional fresh and dry pasta, Food Chemistry, 205: 187-195.
https://doi.org/10.1016/j.foodchem.2016.03.014

Fradgley N., Bacon J., Bentley A., Costa-Neto G., Cottrell A., Crossa J., Cuevas J., Kerton M., Pope E., Swarbreck S., and Gardner K., 2022, Prediction of near - term climate change impacts on UK wheat quality and the potential for adaptation through plant breeding, Global Change Biology, 29: 1296-1313.
https://doi.org/10.1111/gcb.16552

Haugrud A., Achilli A., Martínez-Peña R., and Klymiuk V., 2024, Future of durum wheat research and breeding: Insights from early career researchers, The Plant Genome, 18(1): e20453.
https://doi.org/10.1002/tpg2.20453

Juliana P., Poland J., Huerta-Espino J., Shrestha S., Crossa J., Crespo-Herrera L., Toledo F., Govindan V., Mondal S., Kumar U., Bhavani S., Singh P., Randhawa M., He X., Guzmán C., Dreisigacker S., Rouse M., Jin Y., Pérez-Rodríguez P., Montesinos-López O., Singh D., Rahman M., Marza F., and Singh R., 2019, Improving grain yield, stress resilience and quality of bread wheat using large-scale genomics, Nature Genetics, 51: 1530-1539.
https://doi.org/10.1038/s41588-019-0496-6

Krasileva K., Vasquez-Gross H., Howell T., Bailey P., Paraiso F., Clissold L., Simmonds J., Ramirez-Gonzalez R., Wang X., Borrill P., Fosker C., Ayling S., Phillips A., Uauy C., and Dubcovsky J., 2017, Uncovering hidden variation in polyploid wheat, Proceedings of the National Academy of Sciences, 114: E913-E921.
https://doi.org/10.1073/pnas.1619268114

Kroupin P., Bespalova L., Kroupina A., Yanovsky A., Korobkova V., Ulyanov D., Karlov G., and Divashuk M., 2023, Association of high-molecular-weight glutenin subunits with grain and pasta quality in spring durum wheat (*Triticum turgidum* spp. *durum* L.), Agronomy, 13(6): 1510.
https://doi.org/10.3390/agronomy13061510

Kroupina A., Yanovsky A., Korobkova V., Bespalova L., Arkhipov A., Bukreeva G., Voropaeva A., Kroupin P., Litvinov D., Mudrova, A., Ulyanov D., Karlov G., and Divashuk M., 2023, Allelic variation of *Glu-A1* and *Glu-B1* genes in winter durum wheat and its effect on quality parameters, Foods, 12(7): 1436.
https://doi.org/10.3390/foods12071436

Kusunose Y., Rossi J., Van Sanford D., Alderman P., Anderson J., Chai Y., Gerullis M., Jagadish S., Paul P., Tack J., and Wright B., 2022, Sustaining productivity gains in the face of climate change: a research agenda for US wheat, Global Change Biology, 29: 926-934.
https://doi.org/10.1111/gcb.16538

Li J.Q., 2024a, Harnessing natural genetic diversity: the impact of wild rice alleles on cultivated varieties, Rice Genomics and Genetics, 15(3): 132-141.
https://doi.org/10.5376/rgg.2024.15.0014

Li S., Zhang C., Li J., Yan L., Wang N., and Xia L., 2021, Present and future prospects for wheat improvement through genome editing and advanced technologies, Plant Communications, 2(4): 100211.
https://doi.org/10.1016/j.xplc.2021.100211

Li Y.Z., 2024b, Starch biosynthesis and engineering starch yield and properties in cassava, Molecular Plant Breeding, 15(2): 63-69.
https://doi.org/10.5376/mpb.2024.15.0008

Merrick L., Herr A., Sandhu K., Lozada D., and Carter A., 2022, Utilizing genomic selection for wheat population development and improvement, Agronomy, 12: 522.
https://doi.org/10.20944/preprints202202.0042.v1

Mondal S., Rutkoski J., Velu G., Singh P., Crespo-Herrera L., Guzmán C., Bhavani S., Lan C., He X., and Singh R., 2016, Harnessing diversity in wheat to enhance grain yield, climate resilience, disease and insect pest resistance and nutrition through conventional and modern breeding approaches, Frontiers in Plant Science, 7: 991.
https://doi.org/10.3389/fpls.2016.00991

Maccaferri M., Harris N., Twardziok S., Pasam R., Gundlach H., Spannagl M., Ormanbekova D., Lux T., Prade V., Milner S., Himmelbach A., Mascher M., Bagnaresi P., Faccioli P., Cozzi P., Lauria M., Lazzari B., Stella A., Manconi A., Gnocchi M., Moscatelli M., Avni R., Deek J., Biyiklioglu S., Frascaroli E., Corneti S., Salvi S., Sonnante G., Desiderio F., Marè C., Crosatti C., Mica E., Özkan H., Kilian B., De Vita P., Marone D., Joukhadar R., Mazzucotelli E., Nigro D., Gadaleta A., Chao S., Faris J., Melo A., Pumphrey M., Pecchioni N., Milanesi L., Wiebe K., Ens J., Maclachlan R., Clarke J., Sharpe A., Koh C., Liang K., Taylor G., Knox R., Budak H., Mastrangelo A., Xu S., Stein N., Hale I., Distelfeld A., Hayden M., Tuberosa R., Walkowiak S., Mayer K., Ceriotti A., Pozniak C., and Cattivelli L., 2019, Durum wheat genome highlights past domestication signatures and future improvement targets, Nature Genetics, 51: 885-895.
https://doi.org/10.1038/s41588-019-0381-3

Mulugeta B., Tesfaye K., Ortiz R., Geleta M., Haileselassie T., Hammenhag C., Hailu F., and Johansson E., 2023, Unlocking the genetic potential of Ethiopian durum wheat landraces with high protein quality: sources to be used in future breeding for pasta production, Food and Energy Security, 13(1): e511.
https://doi.org/10.1002/fes3.511

N'Diaye A., Haile J., Nilsen K., Walkowiak S., Ruan Y., Singh A., Clarke F., Clarke J., and Pozniak C., 2018, Haplotype loci under selection in Canadian durum wheat germplasm over 60 years of breeding: association with grain yield, quality traits, protein loss, and plant height, Frontiers in Plant Science, 9: 1589.
https://doi.org/10.3389/fpls.2018.01589

Pinel P., Emmambux M., Bourlieu C., and Micard V., 2023, Nutritional contributions and processability of pasta made from climate-smart, sustainable crops: a critical review, Critical Reviews in Food Science and Nutrition, 65(2): 21-31.
https://doi.org/10.1080/10408398.2023.2271952

Rapp M., Sieber A., Kazman E., Leiser W., Würschum T., and Longin C., 2019, Evaluation of the genetic architecture and the potential of genomics-assisted breeding of quality traits in two large panels of durum wheat, Theoretical and Applied Genetics, 132: 1873-1886.
https://doi.org/10.1007/s00122-019-03323-2

Requena-Ramírez M., Rodríguez-Suárez C., Ávila C., Palomino C., Hornero‐Méndez D., and Atienza S., 2023, Bread wheat biofortification for grain carotenoid content by inter-specific breeding, Foods, 12(7): 1365.
https://doi.org/10.3390/foods12071365

Roselló M., Royo C., Álvaro F., Villegas D., Nazco R., and Soriano J., 2018, Pasta-making quality QTLome from mediterranean durum wheat landraces, Frontiers in Plant Science, 9: 1512.
https://doi.org/10.3389/fpls.2018.01512

Samofalova N., Ilichkina N., Bezuglaya T., Kravchenko N., Ivanisova A., Kabanova N., and Dubinina O., 2022, Correlation between quality traits of kernels, hard semolina, pasta of durum winter wheat, Grain Economy of Russia, 4: 62-69.
https://doi.org/10.31367/2079-8725-2022-82-4-62-69

Sarkar A., and Fu B., 2022, Impact of quality improvement and milling innovations on durum wheat and end products, Foods, 11(12): 1796.
https://doi.org/10.3390/foods11121796

Shrawat A., and Armstrong C., 2018, Development and application of genetic engineering for wheat improvement, Critical Reviews in Plant Sciences, 37: 335-421.
https://doi.org/10.1080/07352689.2018.1514718

Sieber A., Würschum T., and Longin C., 2015, Vitreosity, its stability and relationship to protein content in durum wheat, Journal of Cereal Science, 61: 71-77.
https://doi.org/10.1016/J.JCS.2014.10.008

Solonechna O., Riabchun V., Muzafarova V., Vecherska L., and Bohuslavskyi R., 2022, Trait collection of spring durum wheat by pasta properties as a source of valuable starting material for breeding, Genetični Resursi Roslin (Plant Genetic Resources), 30: 5.
https://doi.org/10.36814/pgr.2022.30.05

Stella T., Webber H., Rezaei E., Asseng S., Martre P., Dueri S., Guarin J., Pequeno D., Calderini D., Reynolds M., Molero G., Miralles D., Garcia G., Slafer G., Giunta F., Kim Y., Wang C., Ruane A., and Ewert F., 2023, Wheat crop traits conferring high yield potential may also improve yield stability under climate change, in silico Plants, 5(2): diad013.
https://doi.org/10.1093/insilicoplants/diad013

Tadesse W., Bishaw Z., and Assefa S., 2019, Wheat production and breeding in Sub-Saharan Africa: challenges and opportunities in the face of climate change, International Journal of Climate Change Strategies and Management, 11: 696-715.
https://doi.org/10.1108/IJCCSM-02-2018-0015

Trono D., and Pecchioni N., 2022, Candidate genes associated with abiotic stress response in plants as tools to engineer tolerance to drought, salinity and extreme temperatures in wheat: an overview, Plants, 11(23): 3358.
https://doi.org/10.3390/plants11233358

Wang K., and Fu B., 2020, Inter-relationships between test weight, thousand kernel weight, kernel size distribution and their effects on durum wheat milling, Semolina Composition and Pasta Processing Quality, Foods, 9(9): 1308.
https://doi.org/10.3390/foods9091308

Wijerathna-Yapa A., Ramtekey V., Ranawaka B., and Basnet B., 2022, Applications of in vitro tissue culture technologies in breeding and genetic improvement of wheat, Plants, 11(17): 2273.
https://doi.org/10.3390/plants11172273

Yang Y., Saand M., Huang L., Abdelaal W., Zhang J., Wu Y., Li J., Sirohi M., and Wang F., 2021, Applications of multi-omics technologies for crop improvement, Frontiers in Plant Science, 12: 563953.
https://doi.org/10.3389/fpls.2021.563953