planning. In addition, reinforcement learning and intelligent optimization algorithms are also used to automatically regulate valves and pumping stations in response to changing field water conditions in real time. Some smart irrigation systems continuously improve their performance through reinforcement learning trial-and-error processes, making it possible to reduce water use while maintaining crop health.

6.3 Application of the internet of things in wheat production

By deploying sensor networks, it is possible to monitor temperature, humidity, soil moisture, and soil nutrients in real time, and the collected data can be transmitted wirelessly to control centers (Jawad et al., 2017). Sensor arrays combined with satellite communication technology allow real-time monitoring of soil moisture in remote farms. Automatic irrigation control systems can operate without direct human supervision. When sensors detect that soil moisture falls below a set threshold, pumps automatically start irrigation, and the pumps shut down automatically after irrigation is completed. Compared with traditional manual irrigation, automated systems reduce human error and improve irrigation accuracy. Some smart irrigation gateways can even use edge computing to run simple decision-making models directly in the field, which further reduces response time.

6.4 Big data and predictive agriculture

Short-term and long-term weather forecasts, drought indexes, and related information provided by meteorological agencies and research institutions can serve as the basis for preparing irrigation plans in advance. By mining historical yield, soil, and climate data, prediction models for crop yield and water demand can be established to support farmer decision-making. For example, long-term experimental data show that the occurrence probability of heat stress in wheat is closely related to crop yield, which can help estimate harvest risks and guide timely adjustments in planting density or irrigation strategies. In terms of water resource allocation, decision-makers can combine hydrological forecasts with crop water demand models to distribute limited water resources, such as groundwater and river water, more scientifically for regional water conservation. Climate warning systems, including drought early warning systems, can also provide guidance for spring sowing plans and water-saving irrigation measures. Big data-based decision support systems are gradually becoming more common, making wheat production more forward-looking and adaptable.

7 Challenges and Future Prospects

7.1 Balancing yield stability and water saving

Under conditions of limited resources, balancing grain yield and water use efficiency remains a major challenge. Excessive pursuit of maximum yield usually depends on large amounts of irrigation, while overly strict irrigation restriction may lead to yield reduction. Future studies should seek a compromise between physiological mechanisms and system optimization. Breeding wheat genotypes with high photosynthetic efficiency and high WUE, combined with moderate deficit irrigation strategies (such as 75% ETc), may help achieve the goal of "moderate stress and efficiency priority" (Wu et al., 2025). At the same time, regional differences should also be considered. For example, winter wheat in southern regions generally requires more water and can rely on rainfall supplementation, while northern arid areas should focus more on soil moisture conservation and the use of drought-tolerant cultivars.

7.2 Climate uncertainty and extreme weather risks

Global warming has increased uncertainty in agricultural production. High-temperature heatwaves and long-term drought events are becoming more common and are now major factors affecting wheat yield. To cope with climate risks, it is necessary to improve the resilience of agricultural systems. This includes establishing drought early-warning systems, adjusting sowing dates and cultivar selection more flexibly, and promoting stress-resistant wheat varieties. For example, planting plans can be developed with the support of multi-model climate simulations. If a heatwave is predicted during flowering, early-maturing and heat-tolerant cultivars can be used to reduce production risks. In addition, "insurance-based agriculture" and regulation mechanisms, such as water storage reservoirs and subsidy policies, can help reduce risks for farmers. Agricultural production systems should also become more flexible. In double-cropping systems, adjusting planting density according to climate conditions can partly offset losses caused by extreme weather.