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Advances in Water-Saving and High-Yield Cultivation Technologies for Winter Wheat under Climate Change

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Abstract Winter wheat is one of the major food crops in the world and plays an important role in ensuring global food security. However, extreme weather events and water shortages caused by climate change have created serious challenges for winter wheat production. The water demand of winter wheat changes greatly at different growth stages. Water demand is highest during the jointing-booting stage and grain filling stage, while the demand is relatively low during winter dormancy. Water deficit can cause stomatal closure and reduced transpiration, which further suppresses photosynthesis and accelerates leaf senescence. Combined high-temperature and drought stress can shorten the grain filling period and reduce thousand-grain weight. Improving water use efficiency (WUE) is the key to achieving both high yield and water saving. The rational use of deep soil water, efficient regulation of photosynthesis, and stress "memory" mechanisms can enhance the drought resistance of wheat. This study systematically reviews the physiological basis, cultivation technologies, and breeding progress of water-saving and high-yield cultivation of winter wheat under climate change conditions. It also discusses future development directions by combining digital agriculture and regional practices, providing references for coping with climate change and water resource crises.

Keywords Winter wheat; Water-saving cultivation; High yield; Climate change; Water use efficiency

1 Introduction

Winter wheat is one of the most important crops in the global food system and an important source of dietary energy and plant protein for people living in temperate agricultural regions. Compared with rice and maize, wheat has a wider adaptation range, more processing and utilization methods, and more active international trade. It plays an irreplaceable role in ensuring food security, stabilizing agricultural product supply, and maintaining the resilience of agricultural economies. Shiferaw et al. (2013) pointed out that wheat is not only an important staple food for people in developing countries, but also a key crop supporting agricultural livelihoods in many arid and semi-arid regions.

Rising temperatures, changes in the spatial and temporal distribution of precipitation, and the increasing occurrence of heat waves and drought events are changing the water–heat matching pattern in traditional winter wheat production areas (Jägermeyr et al., 2021). Especially in arid and semi-arid regions such as the North China Plain, northwest dryland areas, South Asia, and the Middle East, winter wheat often faces the contradiction between increased water demand during rapid spring growth and insufficient precipitation combined with enhanced evapotranspiration. Traditional irrigation methods have supported high wheat yields for a certain period, but they have also caused problems such as groundwater overexploitation, low irrigation efficiency, and intensified competition for agricultural water use. Improving water use efficiency has become an urgent goal in winter wheat production. The development of technologies such as remote sensing, unmanned aerial vehicles, and multi-angle spectral monitoring has also made dynamic monitoring of winter wheat water status and water use efficiency possible.

In actual production, high yield of winter wheat usually depends on sufficient water and nutrient supply, while water saving requires reducing irrigation frequency and total irrigation amount. This creates an internal contradiction between yield goals and resource limitations. Water-saving and high-yield production of winter wheat does not simply mean "less irrigation." Instead, based on the water demand characteristics at different