WHEAT BREEDING

Benefits to low-input agriculture

A comprehensive analysis of genetic gains in winter wheat, spanning 50 years of breeding and conducted under a wide range of cropping systems, validates the inherent efficiency of breeding for optimal environments.

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The relative merits of high versus low input cropping systems have been discussed for decades[1,2]. Embodied in this debate is the question of whether breeding of cultivars for high-input systems (optimized environments in terms of inputs for fertility, water supply, disease and pest control) is detrimental to their performance under low-input systems. In this issue of *Nature Plants*, Voss-Fels et al. provide a comprehensive body of evidence that cultivars bred over five decades, for one of the most intensive cropping systems in western Europe, deliver parallel genetic gains at low levels of agronomic inputs[3]. Given that wheat is the most widely grown crop in the world, sown annually on around 220 million ha and providing approximately 20% of human calories and protein, the social and economic implications are large.

The study was nothing if not rigorous; conducted at six different locations over two seasons, under three cropping systems representing low, medium and high inputs of fertilizer and plant protection chemicals. In addition, subsets of treatments were included at a low water-availability site to assess the potential for adaptation to a drier climate. The study demonstrated that modern breeding practices aimed at high-input systems — that is, where cultivars more fully express their yield potential — have promoted both genetic gains and yield stability across a wide range of environments and management conditions. Furthermore, under reduced-nitrogen or fungicide-free conditions, varieties registered specifically for organic agriculture did not generally yield more than conventionally bred cultivars.

The data contradict a commonly held belief that breeding for intensive systems is actually detrimental to performance under more marginal growing environments. Previous studies have looked at specific factors such as nitrogen-use efficiency and reached similar conclusions, namely that modern cultivars perform at least as well if not better under low nitrogen compared to landraces[4]. Similarly, genetic gains in wheat lines not protected by fungicide far exceed those expressed in lines with protection over a historical time frame, due to the incorporation of durable rust resistance genes into modern wheat[5]. However, the research of Voss-Fels et al. goes further than previous work in terms of comprehensiveness, directly measuring a wide range of commercially and biologically important traits. These include end-use quality, disease resistance and a range of key physiological traits related to performance characteristics. Furthermore, the authors demonstrate that groups of genes (haplotypes) with negative or neutral effects on key traits have been consistently reduced over time in response to selection under optimal conditions.

The implications of these insights into haplotypes are highly significant for determining options to combine positive haplotypes in the future, including for hybrid breeding. Moreover, the results together deliver an encouraging message for food security, specifically that the task of winter wheat breeding can be focused on those environments where productivity is highest while having broad benefit across a wide range of cropping systems and input levels, thereby validating the efficiency of a more centralized breeding model. A similar phenomenon has been shown in spring wheat breeding for less developed countries where centralized breeding efforts, in combination with a global network of

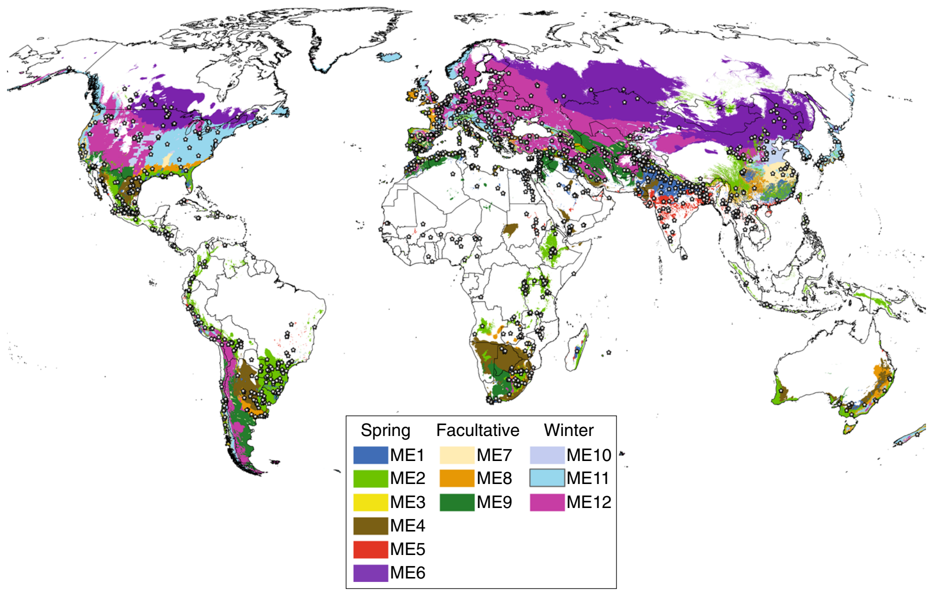

Fig. 1 | Mega-environments and testing sites of the International Wheat Improvement Network. Breeding is directed towards 12 different mega-environments (MEs), representing a range of temperature, moisture and disease profiles. Spring wheat: ME1, irrigated, high yield; ME2, high-rainfall, disease-prone environments; ME3, acid soils; ME4, water limitation; ME5, heat stress; ME6, temperate, high latitude. Facultative wheat: ME7, irrigated, moderate cold; ME8, high rainfall, moderate cold; ME9, low rainfall, moderate cold. Winter wheat: ME10, irrigated, severe cold; ME11, high rainfall/irrigated, severe cold; ME12, low rainfall, severe cold. Figure adapted from ref. [10] (Burleigh Dodds Scientific Publishing, 2019) by Kai Sonder.

publically funded breeders and small private seed companies, have delivered benefits to resource-poor farmers[6]. While still targeting a number of key environmental factors, such as day-length, water and temperature constraints (Fig. 1), these centralized breeding programs have demonstrated a massive impact in terms of both food security and returns on investment[7].

Wheat is grown over a wider range of environments, altitudes and latitudes than any other crop (Fig. 1), and at highly contrasting levels of agronomic inputs. Therefore, this work has broad practical implications in terms of the collateral benefits of breeding for yield potential generally. This has been a major contention of the Green Revolution since its inception, with many critics arguing that breeding should be highly targeted, some even suggesting that resource-poor farmers should participate in breeding varieties[8]. Certainly, the idea has its merits, but it is impractical on a global scale without massive investment, especially given low crop commodity prices. Furthermore, due to climate change, weather variation over years at a single farm can be greater than that of an entire breeding target region in a given year, making such finely-tuned breeding superfluous in many environments.

This highlights an interesting undercurrent of the work, namely the debate that arises from challenging widely held beliefs even when the evidence is asymmetrical. In the case of something as fundamental to society as agriculture, beliefs are influenced by issues ranging from the livelihoods of rural communities and the role of corporate agribusiness in shaping the future of food security for mankind, to the potential of Earth's natural resource base to sustain 10 billion people. The work by Voss-Fels et al. is extremely valuable, but it should by no means be interpreted as a rubber stamp for all things 'high-input'. A recent study in the Ethiopian Central Rift Valley showed a clear benefit of growing wheat under the microclimate of native *Faidherbia* trees[9], and it would be interesting to know if investment in breeding for such an extreme niche would have a cost-benefit. If the climate worsens, as it seems destined to, we must certainly be open to new ways of doing business in crop improvement, while having the common sense to embrace proven technologies. ❐

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Competing interests

The authors declare no competing interests.