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Functional cereals for production in new and variable climates☆

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Adaptation of cereal crops to variable or changing climates requires that essential quality attributes are maintained to deliver food that will be acceptable to human consumers. Advances in cereal genomics are delivering insights into the molecular basis of nutritional and functional quality traits in cereals and defining new genetic resources. Understanding the influence of the environment on expression of these traits will support the retention of these essential functional properties during climate adaptation. New cereals for use as whole grain or ground to flour for other food products may be based upon the traditional species such as rice and wheat currently used in these food applications but may also include new options exploiting genomics tools to allow accelerated domestication of new species.

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Introduction

Food security depends upon the production of sufficient food to provide food for the growing human population that is safe, attractive to increasingly affluent human consumers and with a composition that will support healthy human populations. Improvements in technology to efficiently and sustainably produce food crops in greater quantities are required. Improvements to production of established food crops might be complemented by efforts to diversify food production by domestication of new species. This strategy could contribute to enhanced food security by reducing the heavy current reliance on a few key species. Climate change may force an acceleration of efforts to support the production of both existing and new food crops. Analysis shows increased instability in cereal production [1]. Crop production may need to adapt to a changed or more variable environment or move to new production environments. Remote sensing allows the monitoring of environmental changes [2] and modelling can be used to predict impact on the crop [3].

Demand for cereal based foods

Cereals are key foods providing a significant part of the energy (calories) and protein in human diets globally. The dominance of cereals in human foods makes nutritional attributes of cereals important to the health of human populations. Functional traits influencing the processing or end use quality attributes of cereal based foods are keys to human preferences and consumption. Satisfying global food demand is critically dependant on the two major cereal food crops rice and wheat. These two cereals are consumed in very different ways. Rice is largely eaten as an intact grain while wheat is ground to form flour that is then used to produce foods like bread, noodles or pasta. These two approaches may have resulted from different cooking technologies in east Asia (rice) and west Asia (wheat). Domestication of new species for use as new cereal foods need to be targeted at one of these two distinct types of food; as whole grain food or as a source of flour as a food ingredient.

The growth in demand for food is commonly understood to be driven by human population growth. However the growth in food consumption per capita has been an equally important contributor to growth in food demand. These two factors compound to create a significant challenge. The growth in total food demand is exacerbated by changes in the type of food human populations seek to consume. Overall, the challenge of sustainably feeding the world requires significant innovation in food production strategies before and after harvest if we are to avoid future food shortages. Demand for cereals remains strong. Moves towards increased consumption of meat also increase cereal demand as cereal grains are a primary source of feed for animals. Strategies for increasing cereal productivity [4] must be coupled with more efficient technologies for retaining and enhancing qualitative

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nutritional and functional properties (especially consumer appeal) of cereals and food safety in the context of global climate change [5].

Functional and nutritional quality of cereals

The suitability of cereals as human foods can be assessed in terms of their functional and nutritional quality. The grains must have the properties required to allow efficient production of a food product with the physical and organoleptic properties acceptable or attractive to humans. This is the aspect that drives human consumption but cereals make a significant contribution to both the calories and protein components of human diets and the composition of cereals may influence the health of human populations.

Nutritional impact of cereals in human diets

The major constituents of cereals, starch and protein, can now be readily manipulated by genomic selection. Cereals need to contain sufficient protein to retain their nutritional and functional characteristics. The protein content of grain may be limited by nitrogen nutrition of the plant. Engineering nitrogen symbiosis [6] may become a higher priority option as demand for cereals grows. Engineering C4 photosynthesis [4] may be a pathway to the required increases in nitrogen use efficiency. Starch is the major constituent of cereals and because cereals are often a large part of human diets, the chemical structure of cereals starches may have the potential to make a significant impact on human nutrition and health. The molecular control of starch chemistry is now well understood [7]. The amylose and amylopectin polymers in the starch vary in relative amount, molecular size, degree of branching and length of branches [8]. These chemical differences influence the cooking time and energy requirements, the texture of the food product and the rate of digestion and the proportion of resistant starch (contributing effectively as dietary fibre). These factors may contribute to satiety and to the glycaemic load of the food with potential to impact on human health by influencing the incidence of diabetes and obesity.

Minerals in cereals may be important to people on a very restricted diet and efforts have been made to improve components such as iron. Genomics strategies offer options for genetic improvement of mineral composition. However, cereals will probably remain a poor source of these nutrients. Genetic modification of wheat to reduce the risks of Coeliac disease may also be advanced by applying genomics to increasing knowledge of the molecular structures involved.

Impact of climate change on grain quality

The quality of cereal grains is influenced by genotype and environment and the management of the crop. Climate change threatens to require cereal production in more extreme and more variable environments. Extensive modelling of environmental changes may be used to define the areas that will be suitable for the production of cereals in the future but production in less favourable environments may be necessary especially on a regional basis. This heightens the need to understand the role of environment in determining cereal quality to underpin efforts to develop more climate resilient genotypes and production systems. The nutritional and functional qualities of cereals may be severely impacted by climate greatly compounding losses to total crop yield by reducing the utility of the reduced quantity of grain produced. Factors such as increased temperature and increased carbon dioxide may interact to influence grain quality [9]. Increased temperature during grain filling has been shown to result in cereal starches with higher gelatinization temperatures [10]. Genetic selection can be used to manage the impact of environmental variability on starch properties [11]. The study of genetic variation in wild populations has been proposed as a way to identify options for adapting crop plants to climate change [12]. Comparison of the genomes of wild and domesticated genotypes defines the impact of domestication on climate resilience of crop genotypes [13] and facilitates the targeting of genomic regions responsible for climate adaptation in crop breeding. These studies can support the improved understanding of likely climate impacts on both yield and quality.

Developing new cereal genotypes for future environments

Advances in genomics technology are providing options for accelerating the genetic improvement of cereals in response to climate change [14••,15]. Genomics provides a powerful path to biological understanding that goes beyond that of traditional biochemistry or molecular biology [16]. Genome and transcriptome analysis combined allows the interaction of genotype and environment to be explored [17]. Dramatically increasing volumes of genomics data have become available for plant genetics [18] allowing variations in crop genotypes to be evaluated by whole genome sequence comparison [19]. Genome sequencing [20,21] and re-sequencing [22] supports genome wide association studies [23,24] and identification of functional markers [25]. Three strategies for applying these tools to developing cereals for future environments and climates are explored here;

grain quality defect elimination to accelerate the rate of genetic gain by more rapid deployment of currently adapted domesticated germplasm,
introduction of adaptation from novel wild diversity,
and accelerated domestication of new adapted cereal species.

These represent distinct options for addressing the requirements of cereal food security.