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Breeding for Climate Change: Future-Proofing the Scottish Barley Industry

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1. Key points

- Compared to other cereals, barley is an inherently resilient crop with great potential for adaptation, not only to climate change, but also for new uses, particularly human food.
- Nevertheless, climate change is likely to affect the stability of barley yield through increased agronomic problems with waterlogging in winter and water stress in drier, warmer summers.
- Management strategies designed to maximise yield potential can lead to profligate and inefficient use of soil resources leading to increased yield instability.
- Greater resource-use efficiency is a high priority to increase yield potential without associated increases in fertiliser and water requirements.
- Pathogen threats to production will generally increase but temporal and spatial distribution patterns of specific pathogens will change, requiring renewed emphasis on durable polygenic resistance.
- The availability and continuing development of the barley functional sequence resource must be supported to identify robust molecular markers for selection of economically and environmentally important resilience traits for continued breeding progress.
- Continued characterisation of germplasm, through robust genotyping and phenotyping and bioinformatics resources and knowledge are key to providing cultivars that can produce sustainable crops that meet end-user needs in Scotland's changing climate.

2. Overview

The growing cycle of barley is perfectly suited to both Scotland's highly productive and more marginal land and environments. It is of considerable economic importance for animal feed and alcohol production where Scotch Whisky accounts for a quarter of the UK total exports in the food and drink sector. Whilst the overall importance of barley as a human food is minor, historically it was an essential part of early civilisation's diets, being used on Orkney at least 5,000 year ago. There is now much potential for new uses exploiting the health benefits of whole grain and beta-glucans in food products. The barley supply chains are complex and show added value at many stages. Germplasm resources for barley are considerable, with much potential for exploitation of its biodiversity available through the use of recently developed genomic and breeding tools. Consequently, substantial gains in crucial sustainability characteristics should be achievable in the future, together with increased understanding of the physiological basis of many agronomic traits, particularly water and nutrient use efficiency.

Barley's ability to adapt to multiple biotic and abiotic stresses will be crucial to its future exploitation and increased emphasis on these traits in elite germplasm is needed to equip the crop for environmental change. Similarly, resource use efficiency should become a higher priority to ensure the crop's sustainability in the long-term. Clearly barley is a resilient crop with much more potential to be realised and its importance to Scotland's agricultural productivity in future is considerable.

3. Examples of recent research

- **Integrated crop protection strategies** and recommendations for growing barley with ever-changing pathogen and climate pressures have been developed. These make best use of varieties, crop protection products, agronomy changes, and epidemiological information, much of it derived from the coordinated Scottish Government Workpackages, recently summarised in a peer-reviewed paper[9]. Strategies are disseminated through a range of knowledge exchange channels by SRUC and JHI.
- Genotypic **variation in root characteristics** offers scope for genetic improvement of nutrient and water capture, but this must be developed with increased understanding of interactions with agronomic practice and soil properties. These are current research activities at JHI and SRUC together with other research collaborators. A crop simulation model with 3-dimensional root architecture has been developed at SRUC to help understand these complex below-ground interactions and to guide selection of desirable root traits.
- The NUE Crops project has revealed that whereas the **nitrogen uptake efficiency** of 6 row varieties is greater than that of 2-rows, more nitrogen is accumulated in the grain of the 2-rows compared to the 6-rows. This highlights advances that can be made in the efficiency of nitrogen utilisation by barley.
- **Robust molecular markers** have been developed through strategic research partnerships between all industry stakeholders and the research community in Scotland focussed on economically and environmentally important resilience traits are ensuring continued breeding progress and must be supported. These include disease resistance and quality traits.
- The **epiheterodendrin marker** developed at JHI enables breeders to select for the GN non-producers now required for varieties to achieve malting recommendation on the HGCA Recommended List. This helps safeguard the barley supply for the malt whisky industry.
- **Bioinformatic resources** have been and continue to be developed at JHI that enable continued development of tools for the cereal breeding industry, ensuring the continued improvement in varieties suitable for the Scottish changing agricultural environment.
- We have recently identified a gene responsible for the adaptation of barley to Northern climates. Mutations at the **Eam6 locus** can alter the flowering time of barley by as much as 7 days and thus be used to fit the life cycle of the crop to the growing season.
- Assembly of the sequence of over **26,000 barley genes** provides a resource for researchers and breeders to utilise in identifying sequence variants associated with key economic traits in the crop, thereby providing strategies for future improvement of the crop.

4. Analysis undertaken

We reviewed barley as a crop, paying particular attention to its resilience traits in order to assess its strengths and weaknesses in the context of food security[8]. This was assessed in a world context as it is a commodity traded internationally, ranked fourth amongst the cereals after maize, rice and wheat but critically better adapted to abiotic stresses than any of the top three. We assessed its production, distribution and trade and its uses worldwide, then investigated supply chain issues for its end-users. We then reviewed barley's biodiversity in terms of germplasm resources and their potential as well as the tools used to characterise them. The agronomy and crop physiology was assessed in the context of its potential for sustainable production, moving on to look at nutrient and water use efficiency in particular. The current and potential abiotic and biotic (pests and diseases) stress threats were fully reviewed and evaluated. The scope for variety breeding to address all these challenges was then assessed. Much of this research is lead and carried out at JHI and SRUC in collaboration with industrial and international research partners.

5. Policy implications

- Scotland's climate change adaptation framework[2] - The research will deliver barley varieties and agronomy that will require reduced inputs (relative to yield) in terms of fertilizer and water with a commensurate reduction in energy use and GHG emissions per unit of grain yield.
- Food Security[1] - The research will deliver improved barley cultivars through UK and European cereal breeding companies to the Scottish barley industry thereby ensuring economic sustainability.
- Food security & process efficiency – developing improved winter malting quality cultivars will provide a greater supply of malting barley for the same cropping area due to the higher yield of the winter crop. This will help secure the supply chain for the distilling industry at a time when the demand for malting barley in Scotland is increasing. Even if demand falls, it means that more land is available for food production.
- Waste[3] - By delivering barley cultivars that are adapted to the changing climate and extreme events leading to reduced waste.
- Water[4] - The development of cultivars and agronomy for better water use efficiency and improved soil structure will mean a reduced likelihood of fertilizer runoff and the pollution of water courses.
- Common Agricultural Policy[5] - The development of more resource use efficient cultivars delivers directly into the proposed "greening" of direct payment by strengthen the environmental sustainability of agriculture. It should be noted that the Commission is proposing to spend 30% of direct payments specifically for the improved use of natural resources.

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