Evolutionary breeding of wheat for low input systems

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Abstract – Genetically diverse Composite Cross Populations (CCPs) may be useful in environmentally variable low-input systems as an alternative to pure varieties. They are formed by assembling seed stocks with diverse evolutionary origins, recombining these stocks by hybridisation, bulking the F1 progeny, and subsequent natural selection of the progeny in successive natural cropping environments. CCPs derived from either 10 high yielding parents (YCCPs), 12 high quality parents (QCCPs), or all 22 parents (YQCCPs), were grown at four sites (2 organic, 2 conventional) in the UK. The YCCPs out yielded the QCCPs, which had higher protein concentrations and Hagberg falling numbers. Although the CCPs performed within the range of the parents, they often performed better than the mean of the parents.[1]

INTRODUCTION

One of the major limitations in the production of high yielding, high quality milling and feed wheats in low input systems is the lack of appropriate crop varieties. The absence of agrochemical inputs exposes crop plants to major increases in the diversity and variability of production environments. Individual wheat varieties bred using the pedigree line approach, particularly those selected for high input production, are often unable to cope with such environmental variation.

An alternative approach to wheat production in diverse agricultural environments is to use genetically variable populations that are able to significantly buffer variation. There is evidence to suggest that composite cross populations may be an efficient way of providing heterogeneous crops. In addition the generation of novel genotypes provides scope for the selection of superior pure lines for low input systems.

Composite cross populations are formed by assembling seed stocks with diverse evolutionary origins, recombining these stocks by hybridisation, bulking the F_1 progeny, and subsequent natural selection for mass sorting of the progeny in successive natural cropping environments (Suneson, 1956). The success of such mass-propagated populations depends upon recombination and segregation over many generations, and the relative correlation of such populations with agricultural desirable characteristics (Allard and Hansche, 1964). An example of a successful population was reported by Thomas *et al.* (1991) who found yield improvements in a composite population of wheat of more than 15% over the mean of the parents in pure stands.

One refinement to the idea of composite cross populations was the introduction of male sterility genes into the composite populations to produce hybrid seed beyond the F_2 generation (Suneson, 1951).

This paper reports on the preliminary performance of six composite cross populations developed in the UK relative to the performances of their parents and mixtures of the parent components.

MATERIALS AND METHODS

Elm Farm Research Centre, with the John Innes Centre, developed six populations based on historically successful wheat varieties. They were derived from all possible combinations of 10 high yielding parents (45 crosses), or 12 high quality parents (66 crosses), or intercrosses from all 22 parents (231 crosses). Each of these bulk populations was subdivided into those that did, or did not, contain a range of male sterile crosses (33) developed from naturally occurring male sterile parents crossed with the other varieties.

The first field exposure of the populations was in 2003/04 in the F3 generation. The populations, their parents and mixtures of the high yield, high quality and all parents were sown at 2 organic (Sheepdrove Organic Farm, Berkshire and Wakelyns Agroforestry, Suffolk) and 2 conventional sites (Metfield Hall Farm, Suffolk and Morley Research Centre, Norfolk). In 2004/05, replicated experiments in a randomised block design were established at the same four sites again containing all populations, parents and mixtures. Measurements of crop growth and development were taken throughout the season as well as post-harvest yield and quality assessments.

RESULTS AND DISCUSSION

Yield

There were significant ($P < 0.001$) differences in grain yield among parent varieties, mixtures and Composite Cross Populations with and without male sterility (CCP(ms)) at both conventional sites and at one organic site (Sheepdrove). The Yield CCP(ms)s also had significantly ($P < 0.01$) higher yields than the Quality CCP(ms)s at these three sites (Table 1). The Yield/Quality CCP(ms)s generally yielded be-

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tween the Yield, and Quality CCP(ms)s at the conventional sites, Metfield and Morley (Table 1), whereas at the organic sites the Yield/Quality CCP(ms)s yielded at the same level as Yield CCP(ms).

Grain yields of CCP(ms)s were always within the range of yields attained by the parents. However, it can be seen from Table 1 that at both conventional sites, CCP(ms)s had higher yields than the mean of their parents. This also occurred in the Yield and Yield/Quality categories at the organic sites (Table 1).

An increase in grain yield of CCP(ms)s relative to the mean of the parents was also found in the first year of field exposure (2003/04) at the conventional sites. However, the differences were smaller, and there was no evidence of the effect at the organic sites. Another important difference between the two years was that there were major, and unpredictable, changes in ranking among the parents.

Table 1. Mean grain yields (t Ha^{-1} @ 15% moisture content) of Yield (Y), Quality (Q) and Yield and Quality (YQ) composite cross populations with or without male sterility (CCP(ms)) and their parental means.

Site/ system	Y	Q	YQ	l.s.d.
Metfield				
CCP(ms)	11.4	10.5	11.1	0.49
Parental mean	11.2	10.0	10.6	
Morley				
CCP(ms)	10.5	9.1	9.2	0.90
Parental mean	9.6	8.8	9.3	
Sheepdrove				
CCP(ms)	6.0	5.0	6.1	0.54
Parental mean	5.4	5.4	5.4	
Wakelyns				
CCP(ms)	6.6	5.9	6.7	0.83
Parental mean	6.5	6.3	6.4	
Conventional				
CCP(ms)	10.9	9.8	10.1	0.83
Parental mean	10.4	9.5	9.3	
Organic				
CCP(ms)	6.3	5.5	6.4	0.54
Parental mean	6.0	6.0	5.9	

The Yield CCP(ms)s also had significantly ($P < 0.001$) shorter straw at the conventional sites, and although this also occurred at the organic sites, the differences were not significant. There were, however, significant ($P < 0.05$) differences in harvest index (HI) among categories of CCP(ms) at both organic sites; the HIs of the Yield CCP(ms)s (0.55 and 0.46 at Wakelyns and at Sheepdrove) were higher than those of the Quality CCP(ms) (0.49 and 0.43 at Wakelyns and at Sheepdrove). This was also the case at one of the conventional sites (Morley). However, at Metfield, the other conventional site, despite the Yield CCP(ms)s having higher yields and shorter straw than the Quality CCP(ms)s, there was no difference in HI. These effects may be influenced by the differing applications (timing and active ingredient) of growth regulator at the conventional sites.

Grain quality

There were significant differences in the grain quality parameters of protein concentration and Hagberg falling number (HFN) among varieties, mixtures and CCP(ms)s at both organic and both conventional sites.

Protein concentrations differed significantly ($P < 0.01$) among Yield, Quality and Yield/Quality CCP(ms)s at conventional sites, with Quality and Yield/Quality CCP(ms)s having higher protein concentrations than Yield CCP(ms)s (Table 2). A similar effect could be seen at the organic sites, although the differences weren't significant.

Table 2. Mean protein concentrations (%) of Yield (Y), Quality (Q) and Yield and Quality (YQ) composite cross populations

Site/ system	Y	Q	YQ	l.s.d.
Metfield	12.5	13.5	12.9	0.84
Morley	11.6	12.7	12.4	0.59
Sheepdrove	13.2	13.8	13.1	1.32
Wakelyns	9.6	10.4	10.7	1.22
Conventional	12.1	13.1	12.7	0.57
Organic	11.1	12.1	11.9	1.50

The same trends were also seen in the HFN results, although here the effects were significant at both the organic ($P < 0.05$) and conventional ($P < 0.01$) sites.

Similar differences among CCP categories (Y, Q or YQ) were also seen in the first year of field exposure of the CCPs.

Conclusions

The composite cross populations have performed as expected according to their categories; the Yield composites had higher yields and HIs and the Quality composites had higher protein concentrations and HFNs. Although the populations performed within the range of the parents, they often yielded higher than the mean of the parents. This shift in the performance of the CCPs relative to the mean of their parents would suggest that the winter wheat populations over two seasons in the field have started to evolve according to field conditions of two alternative agricultural systems.

Acknowledgement

This project (AR0914) is sponsored by the UK Department of Environment, Food and Rural Affairs (Defra).

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