O.02 - Breeding for disease resistance as an integral component of crop protection

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Abstract

Plant breeding has a crucial role in protecting crops against disease. It is most effective when the performance of lines in breeders' trials is a reasonably good predictor of their future performance in farmers' fields. As global climate change accelerates, the predominant parasites will also change. It will become increasingly difficult for breeders to predict how their varieties will perform when grown on farms but new methods of genetic analysis will help breeders to respond quickly to new threats. Crop varieties will need to have robust resistance to diverse parasites and it will be even more important than it is now for resistant varieties to be incorporated into a system of integrated pest management, including pesticide applications and appropriate agronomy.

Plant breeding as an evolutionary process

Plant breeding has been one of the most successful technologies of the last century. Among its many achievements has been the release of crop varieties with resistance to disease which is not readily overcome by pathogens. The genetic basis of durable resistance varies [1], as does the degree of knowledge about resistance. The Green Revolution originated with control of stem (black) rust of wheat (*Puccinia graminis*) through the use of the *Sr2* gene in cultivars bred by the International Maize and Wheat Improvement Centre (CIMMYT) in the 1940s [2]. By contrast, powdery mildew of wheat (*Blumeria graminis*) in the UK has been controlled by breeding even though almost nothing is known about the genetics of durable resistance to it, save that it is controlled by many genes of small effect [3].

The process of plant breeding reflects that of natural selection (Fig. 1A). Breeding is most efficient at producing commercially successful varieties if the plant material used by breeders contains plenty of variation, methods of selection are reliable and the breeding process is rapid and efficient (Fig. 1B). If so, the trait will almost certainly be advanced in new varieties. It is particularly important that the environment in a breeding programme predicts conditions on farms – in fact, conditions a few years in the future, when the varieties will actually be grown.

New diseases and new pathogen genotypes present a tough challenge for breeders because they make the future performance of varieties harder to predict. Ramularia leaf spot (*Ramularia collo-cygni*), for example, was almost unknown until the late 1990s but has since become one of the most important diseases of barley in Europe [4]. Accelerating climate change is expected to change the profile of many crop diseases [5] and will therefore make the future performance of varieties even harder to predict. A crucial role for plant pathologists is to contribute to breeding crop varieties with robust disease resistance in an increasingly unpredictable environment.

Resistance of wheat to septoria tritici blotch

Septoria tritici blotch of wheat (*Mycosphaerella graminicola*) represents an example of the challenges involved in breeding for disease resistance and of current progress. It is the major foliar disease of wheat in many countries. Many wheat varieties in the UK now have moderate resistance to it [6] but fungicides are essential to achieve acceptable disease control. Farmers cannot rely on fungicides alone because

precise timing of applications is required [7] and insensitivity to fungicides is spreading in the pathogen population [8,9]. Economic production of wheat is best achieved by an integrated approach, growing a variety which is at least moderately resistant, to reduce disease and spread of the fungus, and applying an effective fungicide once or twice to the crop. Improved resistance is therefore highly desirable but it must be combined with high yield and good quality.

Some important older wheat varieties in the UK, such as Cappelle Desprez and Bersée, had good resistance to septoria but many of those released in the late 1960s and 1970s were susceptible. There has been some improvement over the last 15 years so that many modern varieties have moderate resistance to septoria [6]. If lines with different resistance genes can be identified, they can be crossed to breed new varieties with superior resistance.

Association genetics of disease resistance

A conventional genetic analysis of a cross between a pair of varieties can provide detailed information about the genetic basis of a trait in those two varieties (Fig. 1C). A significant limitation of such an analysis is that it provides no information about resistance genes across the whole range of current germplasm. Association genetics is a comparatively new approach which analyses the genetics of important traits in a much wider range of varieties, often numbering in the hundreds ([10] Fig. 1D). An essential set of information is the degree of relatedness of each pair of varieties. This is comparable to the knowledge that in a conventional bi-parental cross, all progeny lines are siblings of one another. Relatedness can be estimated either from the varieties' pedigrees or from the distribution of marker alleles [11]. One can determine which of a large set of varieties have genes for a trait such as disease resistance and, even more importantly, which varieties have different genes and so can be crossed to produce superior varieties. A limitation of association genetics is that any identification of a gene is to some extent tentative, so it should ideally be followed up by analysis of selected bi-parental crosses to test the existence of each gene postulated.

Association genetics is being used to identify genes for resistance to septoria in 226 wheat varieties, including those on the Recommended List in the late 1990s and their progenitors back to the origin of scientific wheat breeding in the 1860s. Varieties released in the 1980s and 1990s which are resistant to septoria and have different resistance genes have been identified [6]. As these varieties have been used extensively in wheat breeding, there are probably current varieties which have those genes. If so, varieties with different genes can be crossed to further improve resistance to septoria.

Improvement of many traits

Control of disease in general, let alone control of any one disease, is never sufficient for a crop variety to be commercially successful. Adequate disease resistance is desirable to reduce farmers' costs but high yield and marketable quality are essential, as are agronomic properties such as good standing power and appropriate flowering time [12]. It is rare for disease resistance to take priority over these more important traits in a breeding programme.

It is impractical for breeders to select for excellent resistance to all diseases. It may even be impossible, because there is increasing evidence for trade-offs in disease resistance, as mechanisms for resistance to one disease may increase susceptibility to others [13]. Instead of selection for excellent resistance to the most important diseases, a more realistic goal may be selection against susceptibility to all diseases which are currently significant. Highly susceptible varieties not only become heavily diseased themselves but also spread disease to fields of less susceptible varieties. Elimination of super-susceptible varieties, combining adequate resistance (or non-susceptibility) with other desirable traits – yield, quality, agronomy – can be achieved by selection for each trait separately in environments which reflect, so far as possible, normal farming situations.

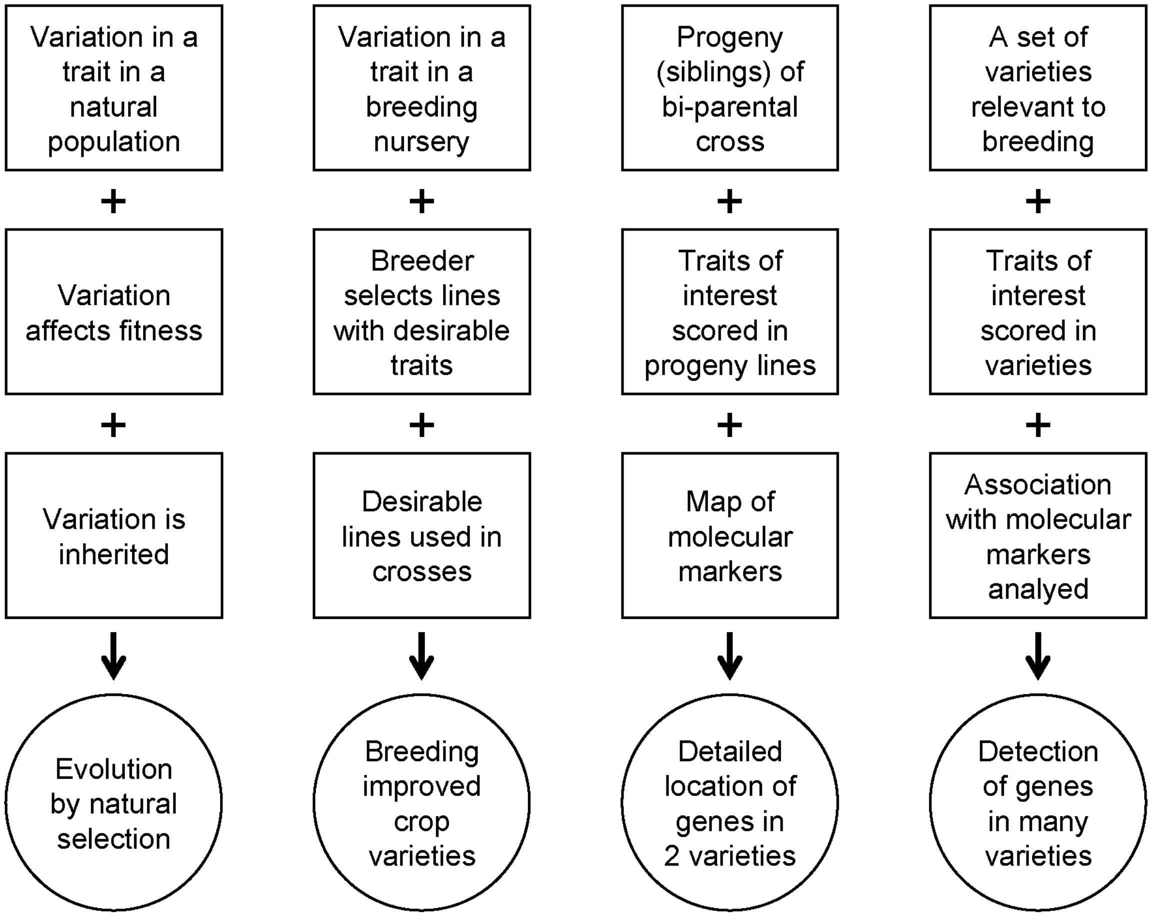

Fig. 1. *An evolutionary view of plant breeding and genetics.* ***A:*** *In a natural population, if there is phenotypic variation beween individuals which affects fitness in terms of survival, reproduction or the viability of progeny and is inherited, the trait will evolve by natural selection in any reasonably large population.* ***B:*** *Plant breeding mimics natural selection. If there is phenotypic variation in the germplasm used by a breeder, if the breeder can select lines with desirable traits and if superior lines are used as parents, improved varieties will be produced.* ***C:*** *In a conventional genetic analysis, the progeny of a cross between two plant varieties segregate for a trait. Using scores of the progenies' phenotypes and a genetic map, the location of the genes can be determined in detail.* ***D:*** *In an association genetic analysis, there is phenotypic variation in a set of lines relevant to a breeding programme. By analysing the correlation of phenotypes and molecular markers of which the map location is known, genes in a large set of varieties can be postulated.*

Much of the work involved in association genetics lies in setting up the database of varieties, markers and information about relatedness. An existing system can be used to analyse other traits at a relatively small additional cost. Association genetics therefore has the potential to become a powerful weapon in the fight against new and emerging diseases. By contrast, the conventional approach of genetic analysis of bi-parental crosses requires a set of varieties first to be screened for variation in the trait of interest, as in association genetics; only then can genetic analysis proceed by study of contrasting pairs of varieties. There is consequently a trade-off between the speed of the association approach and the precision of the

conventional approach. As statistical methods improve and more molecular markers become available, the precision of association genetics will surely increase.

Plant breeding as a component of integrated disease control

Breeding for durable resistance has often been successful but is only one component of an integrated approach to crop management, alongside agronomic practices which minimise the establishment and spread of disease and the use of pesticides to control disease within crops. There are three ways in which pesticides, in particular, complement resistant varieties.

First, no breeder – indeed, no-one involved in farming – can predict the emergence of a new disease. Ramularia has been mentioned as a new challenge for barley production. It took several years for the industry to be sure that it was not a transient issue and that investment in controlling it would be needed. It has taken several more years to start to identify resistant germplasm [14]. For the last ten years, the only effective way of controlling ramularia has been with fungicides [4], and this will be the case for perhaps ten years more. As the climate changes, it will become even harder for breeders to keep up with changes in pathogen populations, so farmers will more than ever need access to effective pesticides with broad-spectrum activity against multiple parasites.

Second, even when breeding for resistance is well-established, it is rarely possible to rely completely on resistant varieties. It may nowadays be possible to breed varieties so resistant to septoria that they do not need spraying against septoria in areas of low to moderate disease risk. This could only be done, however, if septoria resistance were emphasised to the exclusion of yield, quality, agronomy and even resistance to other diseases. The need to maintain food production in an age of diminishing food security demands that farmers must be able to use every available tool to control disease, such as triazole fungicides, which are effective against septoria as well as many other diseases and have a low risk to human health and the environment.

Third, resistance to a few diseases has been so well advanced that in some areas, a formerly important pathogen is no longer a major target for pesticide applications. Such is the case with powdery mildew of wheat in much of the east of England. Even so, fungicides are needed in regions with a greater risk of mildew, such as the west of England, which has a damper climate, in eastern areas which are prone to mildew, near the coast for example, and also in years when mildew is unusually severe. Removing the option of using effective, broad-spectrum fungicides will increase the variability of input costs and thus make crop production less sustainable.

Conclusion

Accelerating climate change will almost certainly make it harder than ever to produce crops profitably because the biological threats to crop production will increase and become less predictable. Plant breeding has a vital role in controlling pests and diseases and recent advances in genetic analysis, such as association genetics, will support breeders' efforts to do this. Yet the choice of variety is only one of several components of robust crop production. In future, it will be more necessary than ever to use integrated crop management, including disease-resistant varieties, effective agronomy and broad-spectrum pesticides, to maintain the level of crop production needed by an increasingly hungry world.

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