How can we achieve resistance to biotrophic and necrotrophic diseases simultaneously?

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Durable resistance to a disease, even if it is only partial, is highly desirable in plant breeding because it increases the stability of crop productivity and lessens uncertainty in crop management. Some important genes for durable resistance have a broad-spectrum effect against all genotypes of a pathogen species or even several pathogens. Outstanding examples of such genes are *mlo*, which has provided almost complete, durable resistance to powdery mildew (*Blumeria graminis*) in spring barley for over 35 years, and the leaf-tip necrosis (LTN) genes such as *Lr34* and *Lr46* for partial resistance to rusts (*Puccinia* spp.) and mildew in wheat. All these genes are widely used; about half the varieties of spring barley in Europe have *mlo* mildew resistance, while *Lr34* and other LTN genes are present in many spring wheat varieties world-wide.

These genes for durable resistance to biotrophic fungi incur significant costs by increasing susceptibility to non-biotrophic diseases. We have shown that the LTN genes increase susceptibility to Septoria tritici blotch in wheat (*Zymoseptoria tritici*) in both seedlings and adult plants. This trait may be associated with an enhanced rate of senescence in wheat with LTN genes. These genes also increase susceptibility of wheat seedlings to blast (*Magnaporthe oryzae*) and Ramularia leaf spot (*Ramularia collo-cygni*). In barley, *mlo* genes (non-functional alleles of the *Mlo* gene) increase susceptibility to several non-biotrophic fungi. We have shown that enhanced susceptibility of *mlo* barley lines to Ramularia leaf spot is generated by a complex physiological process involving interactions between different pathways leading to cell death. The existence of trade-offs between responses of cereals to biotrophic and non-biotrophic fungi is further demonstrated by the suppression of powdery mildew in plants which have previously been inoculated with virulent isolates of *Z. tritici*.

These trade-offs of genes for durable resistance to biotrophs need to be mitigated in breeding programmes which aim to produce commercially desirable cereal varieties. Their practical significance may vary between regions according to the prevalence of different diseases. Research on the mechanisms by which they increase susceptibility to non-biotrophs may identify opportunities to improve control of those pathogens without losing the benefit of controlling rusts and mildews. Meanwhile, a Darwinian approach in which plant breeders use diverse germplasm and select advanced lines with a combination of desirable traits is improving control of Ramularia leaf spot in spring barley varieties with high yield, excellent quality and *mlo* mildew resistance. A similar approach may offer combined control of both biotrophic and non-biotrophic fungal diseases in wheat varieties with LTN genes. An important consideration is to have access to a range of field trial sites in which elite germplasm can be screened against all important diseases.