Integrated management of biotrophs and necrotrophs

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In many climates, cereal production is threatened by necrotrophs and biotrophs, so effective control of two or more contrasting pathogens is required. Unfortunately, effective disease control applies an evolutionary pressure selecting for pathogen strains which are insensitive to fungicides and/or virulent. Here we consider how integration of host resistance and fungicides can help to maximize efficacy and minimise evolution.

Integration for efficacy: The need for fungicide treatment and the economic optimum fungicide dose is determined primarily by disease severity and the yield loss per unit severity (Phytopath. 91, 708-716). The former is reduced by host resistance and the latter by disease tolerance (Ann. App. Biol. 154, 159-173). If the combination of resistance and tolerance is sufficiently effective, or the environment is not conducive to epidemic development, the optimum dose becomes zero. But in practice treatment is often required. Moreover, a single fungicide mode of action or a single resistance gene seldom provide a commercially acceptable level of disease control, and single control methods often prove insufficiently durable when deployed alone. Hence fungicides are often mixed, resistance genes pyramided, and both integrated. This results in vast numbers of possible combinations of cultivars (of differing host resistance) and fungicides, from which to choose effective combinations. Fortunately, the joint action of mixtures of modes of action and the efficacy of pyramiding increasing numbers of resistance QTL (against biotrophs and necrotrophs) are both reasonably predictable from their individual efficacies, using a multiplicative survival model (Pl. Path. Doi 10.1111/ppa.12288). The same approach also predicts the joint action of sequential fungicide applications (Pl. Path. 52, 638-647). Combinations of host resistance and fungicide which should deliver the required level of control can therefore be identified by field experiments and calculation.

Integration for durability: A key determinant of durability of host resistance is the rate at which one or more virulent strains are selected for in a pathogen population, thus increasing in frequency until control is eroded. Similarly the effective life (durability) of a fungicide mode of action is determined substantially by the rate of selection for insensitive strains. Principles governing the selection of fungicide insensitive strains have been derived and tested extensively against experimental data (Ann. Rev. Phytopath. 52, 175-195). These principles show that reducing the difference in the per capita rate of increase of sensitive and insensitive strains, slows selection. The difference can be reduced by slowing the rate of increase of both strains, for example, by adding a second fungicide mode of action which is effective against both strains. By extension, it can be inferred from the governing principles that: (i) partial (rate-limiting) host resistance, which is effective against fungicide sensitive and insensitive strains should slow selection for fungicide insensitivity, and (ii) fungicide treatment, which is effective against avirulent and virulent strains, should slow selection for virulence. Complete reliance on either host resistance or fungicide is likely to be less durable than an integrated approach, but experimental evidence is required for this hypothesis.

Reconciling high efficacy and low selection: Deploying more than one fungicide mode of action in a mixture creates concurrent selection for strains which may be insensitive to either or both (Phytopath.

103, 690-707). Similarly, deploying a 'mixture' of fungicides with host resistance genes, creates concurrent selection for strains which may be insensitive and virulent. The need for high efficacy and low selection can, in principle, be best reconciled by an integrated approach, where most of the control is obtained from the control method at lowest risk of erosion by pathogen evolution. Pathogens differ markedly in their propensity to evolve insensitivity and virulence. Such contrasts could be exploited, through integrated strategies, to deliver effective and durable control of biotrophic and necrotrophic pathogens.