Seed germination phenotyping in controlled conditions to measure genetic diversity and address climate change.

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Seed deterioration occurring during seed maturation on the mother plant or after harvest during storage is mostly responsible for a decline in the rate of germination and ultimately germinability loss in many crops. Some cultivars could be more susceptible to seed ageing when environmental conditions change. Germination time courses have been widely used by seed physiologists (Bewley *et al*., 2013) to assess changes in the pattern of germination of single seeds. These time courses determinations have been automated using digital imaging (Ducournau *et al.*, 2004 ; Demilly *et al.*, 2014), which facilitates their use in seed testing laboratories and helps to develop rapid vigour testing methods (Matthews et al., 2012).

Automation of germination curves allows a high throughput assessment of many germination traits for a cultivar, seed lot or ecotype and therefore may help breeding or genome-wide association studies for seed traits at early stages of plant development. The link between genotyping and phenotyping dynamic traits related to germination and growth is illustrated through three examples of collaborative projects using automated tools of the phenotyping platform PHENOTIC under abiotic optimal or stress conditions.

The automated germination data, analysed for at least 100 samples per species, were computed by plotting together all samples analysed to get the mean time course of germination at a specified temperature under a continuous watering of testing blotters. Pooling together the slowest germinating seeds and the quickest ones gave two virtual curves representing respectively minimum and maximum border ideotypes per species and temperature.

In sunflower, cold screening of genetic resources makes it possible to consider extending the production areas of this crop. The germination and growth data of extreme genotypes among 200 seed lots from hybrids and parental lines produced in same locations showed that the two stages of germination and seedling growth did not respond in the same way to low temperature.

In winter rape, germination phenotyping of a collection of old and modern varieties produced in two conditions showed that genetic progress for erucic acid-free oil and glucosinolate-free oilcake (00 varieties) had resulted in slower germination and therefore sometimes difficult field establishment (Hatzig et al., 2018). Further phenotyping was carried out on 12 varieties having contrasted behaviour in optimal conditions and their response to water-stress was measured. Combining seed and seedling phenotyping into crop modeling allowed to assess 5 genotypes for their field emergence performance in a large range of conditions (Dürr et al., 2016).

In *Medicago truncatula*, the Legume model species, a moderate heat stress was applied during seed development to study genes regulation on seed germination in heat stress tolerance (Chen et al., 2021). 177 accessions have been used to calculate a phenotypic index of plasticity of seed traits obtained in the two contrasted seed production conditions.

Digital imaging has improved germination phenotyping accuracy and increased its throughput. Nowadays AI technologies with deep machine learning continue to explore plant traits in order that phenotyping reaches the same efficiency as genotyping for wider plant science.

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