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Enhancing Resilience Through Plant Breeding Requires an Integrated and Interdisciplinary Approach

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Step by step, the organic sector has developed organic seed production and breeding activities. It started in the 1970s with the notion that seed should be produced organically and should not be treated chemically after harvest. A subsequent question was which of the available conventional varieties were suitable for organic seed production; variety testing under organic growing conditions also became important to compose an organic seed catalogue. Seed producers became aware that some varieties could perform well under organic ware production but not under organic seed production conditions due to seed-borne diseases. This knowledge induced changes in the assortment of many farmers who relied on 'conventional' varieties and forced seed producers to add a new selection trait to the list of requirements for varieties suitable for organic agriculture: the ability to produce organic seed.

Next to organic seed production, small organic breeding activities also got started to fill gaps in the assortment where certain characteristics were missing or varieties were bred with breeding techniques that do not comply with the organic values. Organic breeding programs generally aim at regional adaptation and yield stability under low-input growing conditions where high nutrient levels and chemical biocides can no longer mask the variation in growing conditions. Breeding for organic agriculture requires many additional traits, such as increased levels of disease resistance, weed suppressiveness and nutrient-use efficiency.

On top of these challenges in organic breeding the need to optimize crop management has become even greater as climate change results in more erratic and unpredictable weather patterns, for example resulting in prolonged periods of heavy rains or drought. Unpredictable weather patterns call for strategies to maximize yield stability and to enhance resilience. Holling (1973) defined stability as the ability of an ecological system to return to an equilibrium state with as little fluctuations as possible after a temporary disturbance; resilience is then the ability of a system to absorb changes and persist the relationships within a system through maintaining flexibility.

Translating these abilities into breeding goals that can support the organic farming system under future global change conditions results in the need for varieties that enhance both yield stability as well as the resilience. Resilience requires varieties that can cope with unpredictable and varying growing conditions within one growing season through multiple strategies. Our research on developing breeding strategies for improved robustness in lettuce made us aware that resilience is not a matter of improving one trait (e.g., root length density) as we observed that different varieties use different physiological mechanisms to cope with stress conditions. We found that it was not a matter of more roots but of flexible root formation and functioning to rapidly respond to periods of abiotic stress. So we might need to select for 'flexible' varieties with a diverse toolbox of various buffering mechanisms in response to varying growing conditions.

Moreover, we need to go a step further in developing breeding strategies for resilience. The focus in breeding for resilience should not merely be on varieties that are adapted to varying, low-input and organic growing conditions, but also on variety characteristics that allow the farming system as a whole to become resilient. How to create 'systems' varieties that can contribute to long term durability and support functional ecosystem services such as increasing water holding capacity by contributing to soil organic matter through the crop residues (stubble and root biomass) after harvest? Genetic variation was found among grass varieties in root biomass independent of above-ground biomass. Researchers noticed that modern breeding had neglected flower architecture of grain-legumes causing problems with sufficient pollination and called for the need to recover and improve functional floral traits as a tool to enhance both environmental and production services of grain legumes.

These examples show that crop improvement can enhance crop productivity and enhance long-term ecosystem services and resilience at the same time. But how to stimulate '*systems*' breeding? We already faced problems in changing priorities in conventional breeding programs to enlarge the chance for varieties better adapted to organic farming conditions. The scale of organic agriculture makes breeding for organic farming purposes economically unattractive for conventional breeding companies; moreover, systems traits are often complex. We need to design other business models and involve other chain actors than only farmers in making breeding for small areas economically feasible. Besides, regulations need to be adapted such as the compulsory variety testing in Europe for cereals to allow varieties to enter the market that are not yielding higher than currently available varieties but have more disease resistance or better baking quality under low nitrogen conditions. In some European countries governments support adapting protocols for variety testing under low-input growing conditions.

Many alternative breeding initiatives are under way, supported by research funding or otherwise. But not much attention has yet been paid to the question of how to maintain such organic breeding programs when the external funding ends or the leading farmer-breeder or professional breeder retires without successor to take over the breeding program. Interesting is how the pioneers of Johnny's Selected Seeds have transformed this private company into an employee-owned enterprise to secure the future aims and values. Maybe we need to broaden the scope of farmer- or chain-based breeding to 'community-based' breeding following the community supported agriculture (CSA) approach to provide the necessary community embedding to secure the long-term continuity (and resilience!) of breeding initiatives both at social and financial level? Some initiatives even experiment with Open-Source Arrangements instead of claiming breeder's rights or patents considering seeds as common good.

In summary, the point I want to stress in this discussion on how to enhance breeding for resilience is that we need to bear in mind that breeding is not only a technical activity improving certain desired variety traits but that breeding priorities are also determined by the organizational system based on cultural values anchored in specific socio-economic and legal constructions. So, if we want to stimulate breeding for a regionally diverse assortment of varieties of crops that both enhances short-term needed productivity and long-term improved resilience within the frame of the organic principles of health, ecology, fairness and care, we will need to address both the technical and organizational aspects in an integrated and interdisciplinary approach.