Breeding for Organic Field Crops in Canada

An overview of research in the Organic Science Cluster program

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Organic field crop farmers are constantly searching for ways to improve their crop yield. Crop genetics have a significant influence on how plants grow, yield, and respond to stress as well as their quality attributes. Researchers and breeders are trying to understand if there is an advantage to breeding crops specifically for organic production. They also have recognized that the needs and interests of organic farmers may differ from those of conventional farmers.

Over the last 10 years, researchers and breeders involved with the three Organic Science Clusters have been exploring approaches to breeding cultivars suitable for organic management. They have looked at the costs and rewards in organic breeding and the impact these cultivars may potentially have on the industry. Specifically, they have been working toward addressing three questions:

1. Can cultivars that are bred under conventional management with high inputs thrive under organic production?

2. Is it worthwhile to be breeding cultivars under organic conditions for organic farmers?

3. Is it useful to have organic farmers participating in the breeding process?

DEFINITION

Classical or traditional breeding is breeding that relies on phenotypic selection, field based testing and statistical methods for developing varieties/breeds or identifying superior individuals from a population. The steps to conduct breeding include: generation of genetic variability in populations for traits of interest through controlled crossing (or starting with genetically diverse populations), phenotypic selection among genetically variable individuals for traits of interest, and stabilization of selected lines to form a unique and recognizable cultivar/breed. Classical breeding does not exclude the use of genetic or genomic information to more accurately assess phenotypes, however the emphasis must be on whole organism selection.

CHALLENGES IN ORGANIC BREEDING

Our natural landscape is highly variable in its soil, climate and pest pressure across regions and within fields. Natural ecosystems have a diverse range of plants that are genetically adapted to occupying specific environmental niches which give them a competitive advantage over other plants. In agricultural cropping however, a single cultivar of a single species of crop is planted across the entire landscape.

As crop breeding and seed production evolved through the 20th century, farmers typically chose the best cultivars from performance trials in their region. However, these cultivars are largely developed and tested under conditions of high fertility, low weed pressure, and an average soil condition. While the cultivars are adapted to the regional climate, fertilizers and pesticides are used to support the crop across a wide range of niches that may exist in a field or even within a region.

Field crops growing under organic management more typically have lower fertility (or different timing of nutrient availability), higher weed competition which is managed through cultivation, and few options for controlling insects or diseases.

Organic farmers have had to rely on cultivars that have been bred under non-organic conditions. This means that although their field crops are produced and harvested under organic conditions, the cultivars used were not bred under organic conditions. Cultivars bred under conditions supported by synthetic fertilizers and pesticides may not thrive under organic conditions where these practices are prohibited.

DID YOU KNOW?

It takes approximately 10 growing seasons and $1 million to produce a new cultivar under classical/traditional breeding approaches.

Organic farming uses crop rotations and mechanical weeding to control weeds, and sometimes even the competitiveness of the crop itself. With the expectation for organic crops to somewhat take care of themselves, it seems that conventionally bred cultivars may not be the right fit for organic crops. Ultimately, organic farmers have not had access to seed varieties that are best-adapted to their organic farming environment.

A challenge for breeders is finding a location to develop and test new lines of crops that is uniform enough to allow fair comparisons and can be controlled and managed in a cost-effective way while representing the soil types and climate of the target region. Thus, it has been a challenge to develop breeding programs for organic management when such controlled conditions representing organic management did not exist.

Organic breeding programs were dependent on establishing research land under organic management. Dr. Martin Entz led this initiative at the University of Manitoba, establishing land under organically managed crop rotations to provide a platform for breeding programs.

Similar organically managed lands were established at the University of Alberta with Dr. Dean Spaner, and the University of Saskatchewan with Dr. Pierre Hucl. These programs were further supported by the participation of organic farmers who offered their land for trials. Breeders tested each other's lines under different growing conditions- a true collaboration that was essential for development of an organic breeding program.

Another challenging aspect of plant breeding can be the disconnect between the farmer and plant breeding programs. Organic farmers may be looking for traits that breeders are not intuitively considering.

Further, it is difficult to fully simulate organic management conditions such as soil fertility, soil biology and weed profile on small plot research land. Preliminary research results suggest that the variety development process could be improved and possibly even be sped up with the participation of farmers. Instead of researchers making selections on a limited number of sites per year, there could be many farmers on many sites, making selections. Farmer involvement in the breeding process allows evaluation of breeding lines in diverse environments and allows farmers to build observational skills and knowledge about the crop they are growing[1].

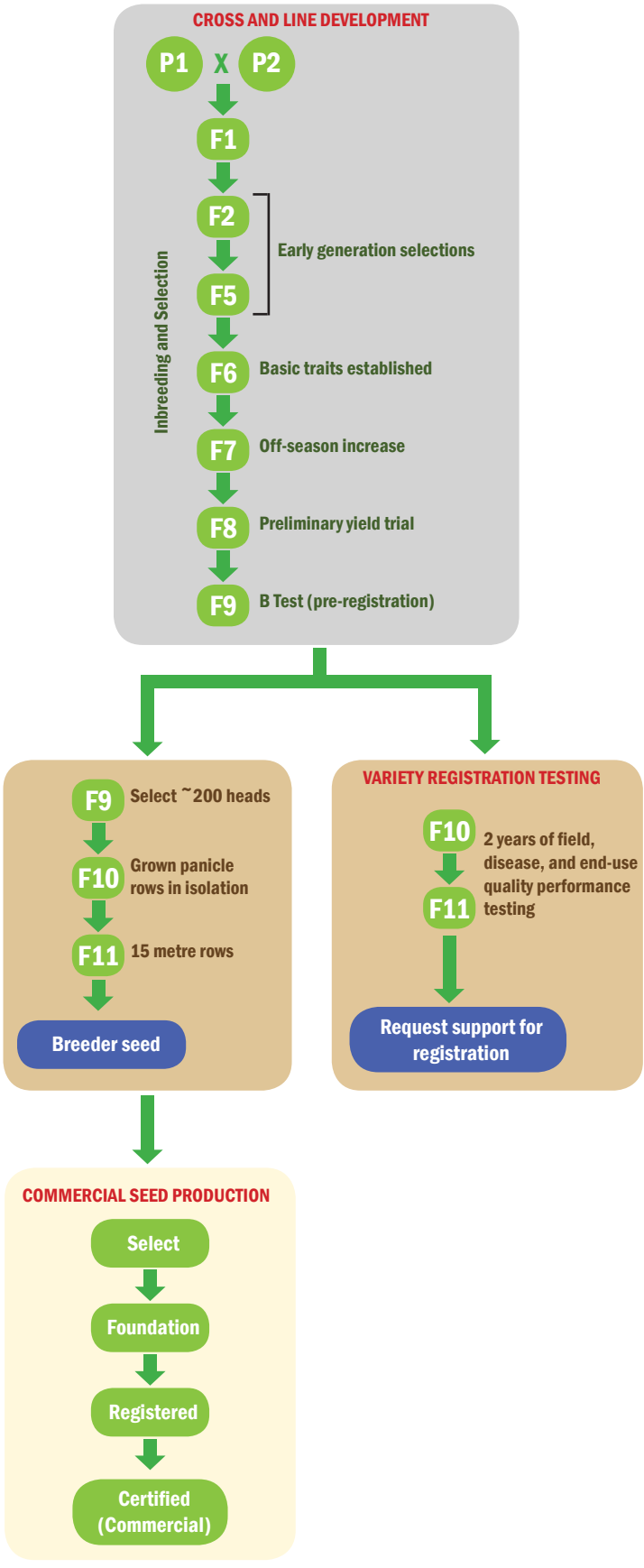

Figure 1: Schematic of a breeding program and cultivar registration

IS IT WORTHWHILE BREEDING CULTIVARS UNDER ORGANIC CONDITIONS FOR ORGANIC FARMERS?

The potential benefits of breeding for organic management are already quite well recognized[2]. New crop cultivar breeding and development can be very costly and time consuming, often taking 10 growing seasons and accumulating costs of $1 million. Thus, breeding specifically for organic requires a long-term commitment and investment. It must be clear that there is a benefit to breeding specifically for organic management in Canada rather than using cultivars developed under conventional management.

Dr. Dean Spaner, a leading wheat breeder in Canada for the Prairie region, specifically addressed this question with his research team. They found "…that indirect selection (in conventionally managed trials) of spring wheat destined for organically managed production would not result in the advance of the best possible lines in a breeding program. This implies that breeding spring wheat specific to organic agriculture should be conducted on organically managed land."[3] Similar benefits were found by Wiebe et al. (2017) in Manitoba who attributed improved yield to better allocation of the head of the plant as opposed to plant growth[4].

Organic wheat breeding plots at University of Manitoba's Glenlea research site.

DEFINITION

Phenotypic selection is the process of selecting plants or seeds based on their observable characteristics which are a result of how the genetics of the plant interacts with the environment.

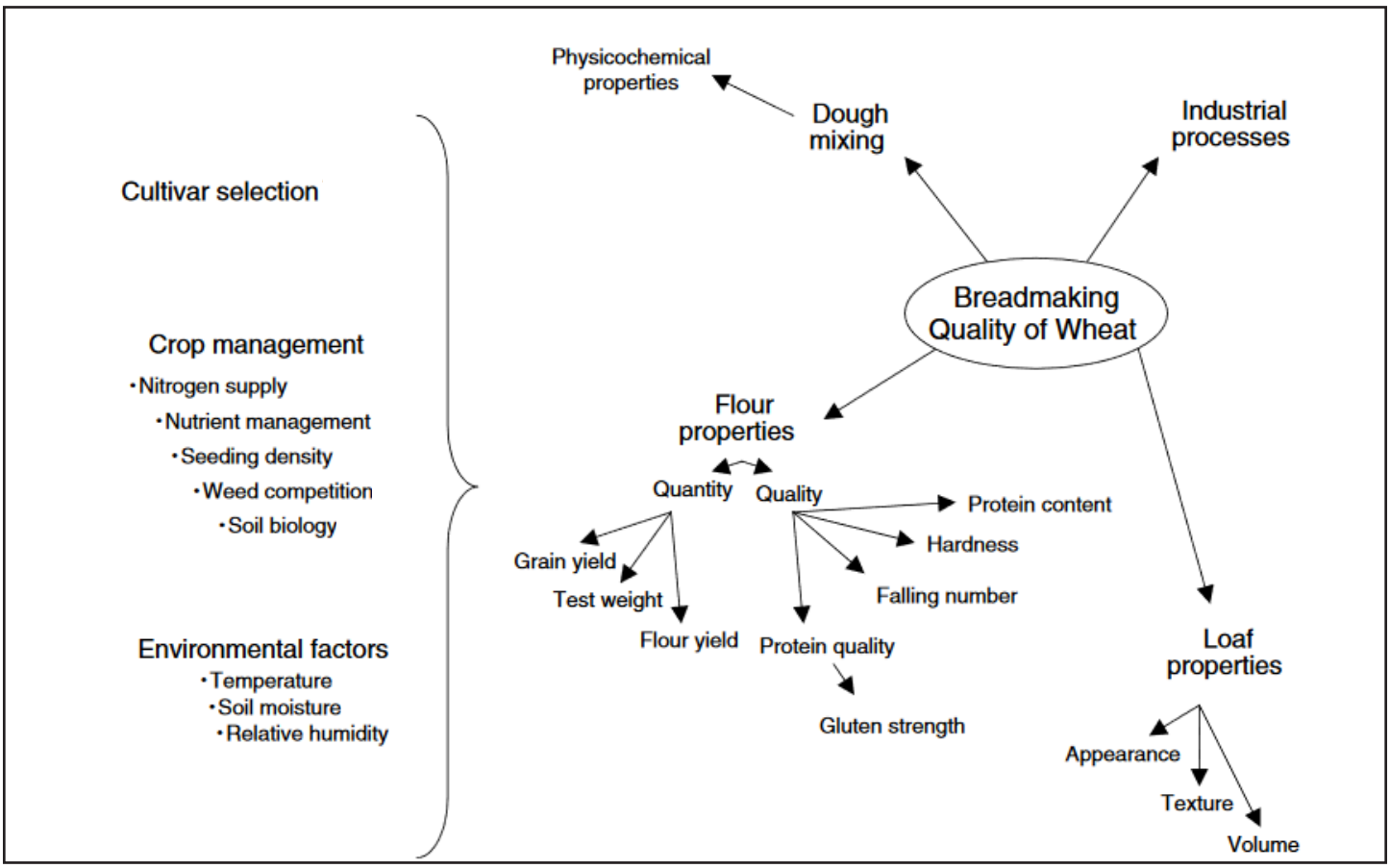

Figure 2: Flow chart describing components that determine breadmaking quality and mediating influences of cultivar selection, cropmanagement and environmental factors. Sourced from Mason et al, 2011[5]

PROGRESS IN ORGANIC OAT, WHEAT AND SOYBEAN BREEDING

Dr. Jennifer Mitchell Fetch of Agriculture and Agri-Food Canada began exploring ways to address the needs of the organic sector with the launch of Organic Science Cluster 1 in 2009, beginning her research with oat breeding under organic management. The overall objective of her organic oat breeding research was to provide producers, processors, food and feed consumers as well as other end users with superior oat cultivars for the Prairies.[6] The Organic Science Cluster program requires the collaboration and contribution of industry partners to support the breeding programs.

The seed produced from initial crosses go through multiple years of selection in small plots to select lines that look promising, eventually leading to yield pre-registration trials. New cultivars must meet or exceed specific performance standards in order to become registered. These traits include yield, heading and maturity dates, height, lodging and disease resistance, and test weight. The seed must also meet quality standards including color, kernel plumpness, and the contents of fibre, oil, protein, and Beta-glucan.

Dr. Mitchell Fetch crossed high performance conventional lines and submitted the progeny from those crosses for selection under organic management as well as under non-organic management. Seeds were selected from the highest yielding lines with resistance to rust and smut for the next generation. The process was repeated for five growing seasons and research continued under Organic Science Cluster 2 (2013-2018).

As a result of this work, Dr. Mitchell Fetch developed and registered the very first organically adapted oat cultivar, AAC Oravena. Bred under organic conditions, this cultivar has attractive milling qualities and disease resistance and performs well under organic growing conditions. The cultivar was licensed to Grain Millers Canada Corp. which carried the seed forward through the commercial seed production stages to finally produce Certified Seed which can then be sold to producers. The Certified Seed became available in the spring of 2018. Following that, a second organic oat cultivar was registered, AAC Kongsore, named after Christian Kongsore, the co-founder of Grain Millers. Given the promising results of her research, Dr. Mitchell

DID YOU KNOW?
Genetic engineering may not be used to develop seed for organic production.

Above: Kathryn Stanley describes organic oat variety trials at AAFC Harrington in P.E.I.

Organic oat breeding requires careful quality evaluation.

Fetch continues to work towards developing improved cultivars for organic production in Organic Science Cluster 3 (2018-2023). She is optimistic that another organic oat cultivar could be registered within the next couple of years. Her research has been supported by funding from AAFC and industry partners including Grain Millers Canada Corp, Nature's Path, Prairie Oat Growers Association and Clif Bar and Company.

Oats are not the only product of the organic breeding program. The early questions of deciding whether breeding for organic management was worthwhile led to the development of a new wheat cultivar selected under organic management. Drs. Stephen Fox and Jennifer Mitchell Fetch also developed the cultivar, AAC Tradition, which was registered in 2014 as a Canadian Northern Hard Red Wheat. It had yields 9% higher and height about 5 cm taller than the reference cultivar in registration trials. This cultivar is now commercially available to growers across the Prairies.

Through Organic Science Cluster 3, Dr. Istvan Rajcan of the University of Guelph is exploring approaches for developing new soybean cultivars using plant breeding for organic growers. The main goal of Dr. Rajcan's research is to build knowledge on how to efficiently develop new

DID YOU KNOW?

If organic seed is not commercially available, untreated seed produced under conventional management may be used providing it was not genetically modified.

soybean cultivars for organic growers to maximize their competitiveness, efficiency and volume of production. This will be achieved by growing superior breeding populations developed from bi-parental crosses of food grade soybean selected on contrasting organic and non-organic farms.

The soybean research is expected to reduce the cost of production and improve the competitiveness and profitability of the organic soybean sector in Canada. It is supported with funding from Grain Farmers of Ontario, Manitoba Pulse and Soybean Growers, Western Grains Research Foundation, Field Farms Marketing Ltd. and the Organic Council of Ontario.

Above and left: Organic soybean trials are evaluating plant growth habits, including rooting and nodulation on organically managed land compared with conventionally managed land.

IS IT USEFUL TO HAVE ORGANIC FARMERS PARTICIPATING IN THE BREEDING PROCESS?

With promising results stemming from the organic breeding programs, Dr. Martin Entz of the University of Manitoba wanted to take these findings one step further through partnership with The Bauta Family Initiative on Canadian Seed Security, a program of SeedChange (formerly USC Canada). His research program, conducted through Organic Science Cluster 2, enabled the farmers to participate in the plant breeding.

Participatory plant breeding is, "a collaboration between researchers and farmers that aims to restore the place of farmers in the plant breeding process."[7] It aims to develop cultivars that meet farmers' needs under varying organic environments by enabling farmers to participate in the plant breeding program. The program also aims to give farmers more control and help them to develop and maintain their own seed varieties.

In summary, the participatory plant breeding process involves the breeder making initial crosses and distributing early generation seed to collaborating farmers. The farmers grow out the seed/planting stock, and select the resulting seed or tubers that are most desirable based on their own preferences and assessment; the process is repeated for several years.

Dr. Entz's participatory research involved farmers from Prince Edward Island all the way to Vancouver Island. In 2014, he and his team worked with 44 farms in almost every province across Canada. Farmers planted their research crops in small plots on their own farms. They were asked to select spikes (wheat), panicles (oat), and tubers (potato) that were resistant to disease, showed early season vigour, and increased yield that were to be carried forward to the next year. After three years of selection, farmers sent their selected materials to researchers who conducted variety trials to compare farmer-selected lines with breeder-developed lines from the same initial genetic pool and standard crop varieties. Researchers found that farmers selected lines that were productive under organic growing conditions.

DEFINITION

Participatory plant breeding (PPB): when farmers are involved in a plant breeding program with opportunities to make decisions at different stages during the process. Farmer's involvement in PPB can include defining breeding goals and priorities, selecting or providing germplasm, hosting trials in their own fields, selecting superior plants for further breeding, engagement in the research design and administration processes as well as the commercialisation of selected lines.

Loic Dewavrin and Michelle Carkner observe a participatory plant breeding wheat crop plot in Les Cedres, QC. (Photo credit: Yann Vergriete)

Participatory plant breeding workshop at Freetown, P.E.I.

DID YOU KNOW?

Certified organic pedigreed seed cultivars (sometimes referred to as double certified) must meet the standards for both organic certification in the final year of seed production as well as meet the seed quality criteria and cultivar development processes set out by Canadian Seeds Regulations.

Preliminary results showed that farmer selected lines of wheat and oats were on average higher yielding than conventional checks. Farmer selected varieties often resulted in increased disease resistance and early season vigour than standard, conventionally bred varieties that are widely available. They also selected for taller plants than the conventional checks.

Results of his project showed that including farmers in a participatory plant breeding process can help researchers develop new lines that are better suited to organic farming conditions.

Foster Richardson and Natasha Tymo (Mill Bay, BC), farmer-breeders who participated in the selection process of the populations of oat. (Photo credit: Michelle Carkner)

Mark Bernard and Dr. Martin Entz assessing performance of wheat lines at Freetown, P.E.I.

Oat trials at AAFC Harrington, P.E.I.

THE FUTURE OF ORGANIC FIELD CROP BREEDING

The research supported through the Organic Science Cluster program along with complementary funding sources has shown that cultivars bred under organic conditions are more likely to thrive in an organic environment.

With two organic oat cultivars and one wheat cultivar already developed and registered, organic farmers can expect to see the development of more cultivars. Breeding under and for organic management results in selection of traits that support good quality and productivity under lower input conditions. These traits can also be advantageous to conventional farmers who want to reduce their input use. Selection for these traits adds genetic diversity to breeding programs which can prove valuable as growing environments and inputs change[8].

Participatory plant breeding programs have demonstrated that farmers can make a valuable contribution to the breeding process. Breeders develop a stronger relationship with farmers, understanding their growing conditions and interests.

At the same time, participating farmers develop stronger skills in observing their crops and better understand how to select cultivars suitable for their farm. The participation of industry partners in this research has also been essential, not only to provide funding support but also to work with breeders to identify traits that will support processing of these grains.

The story of Canada's organic breeding program is one of collaboration among breeders, researchers, farmers and processors.

INDUSTRY PARTNERS

ABOUT THE ORGANIC SCIENCE CLUSTER

This bulletin reports research results from the Organic Science Cluster program which is led by the Organic Federation of Canada in collaboration with the Organic Agriculture Centre of Canada at Dalhousie University. Organic Science Cluster 3 is supported by funding from the AgriScience Program under Agriculture and Agri-Food Canada's Canadian Agricultural Partnership (an investment by federal, provincial, and territorial governments) and over 70 partners from the agricultural community. More information about the Organic Science Cluster Program can be found at, www.dal.ca/oacc.

RESOURCES

Dey et al (2018) Canadian Organic and Ecological Plant Breeding Priorities for Vegetable Crops: 2018 Survey Report. Bauta Family Initiative on Canadian Seed Security and UBC Centre for Sustainable Food Systems. http://www.seedsecurity.ca/images/survey-report/2018-Survey-Report-Canadian-Organic-and-Ecological-Plant-Breeding-Priorities.pdf

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University of Manitoba: Participatory Plant Breeding for Canadian Organic Crop Production. http://www.umanitoba.ca/outreach/naturalagriculture/ppb.html

Organic Agriculture Centre of Canada: Seed Production and Plant Breeding for Organic Agriculture. https://www.dal.ca/faculty/agriculture/oacc/en-home/resources/seed-breed.html

Canadian Seed Institute: Document Library (Seeds Act, Seeds Regulations, Weed Seeds Order, Grade Tables). https://csi-ics.com/seed/document-library

Endnotes

1 Organic Agriculture Centre of Canada- Organic Science Cluster 2: https://www.dal.ca/faculty/agriculture/oacc/en-home/organic-science-cluster/OSCII/theme-a/activity-a1.html

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3 Reid, T.A., et al. 2009. Should spring wheat breeding for organically managed systems be conducted on organically managed land? Euphytica 169:239–52. doi.org/10.1007/s10681-009-9949-9

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6 Presentation by Dr. Jennifer Mitchell Fetch: https://cdn.dal.ca/content/dam/dalhousie/pdf/faculty/agriculture/oacc/en/osc2/OSC2-A.2-Mitchell-Fetch-Presentation-2018.pdf

7 University of Manitoba: http://www.umanitoba.ca/outreach/naturalagriculture/articles/pdf/ppb_wheat-perform_Feb2015.pdf

8 Organic Agriculture Centre of Canada- Organic Science Cluster 2: https://cdn.dal.ca/content/dam/dalhousie/pdf/faculty/agriculture/oacc/en/osc2/OSC2-A1-Entz-Pre-sentation-2018.pdf

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