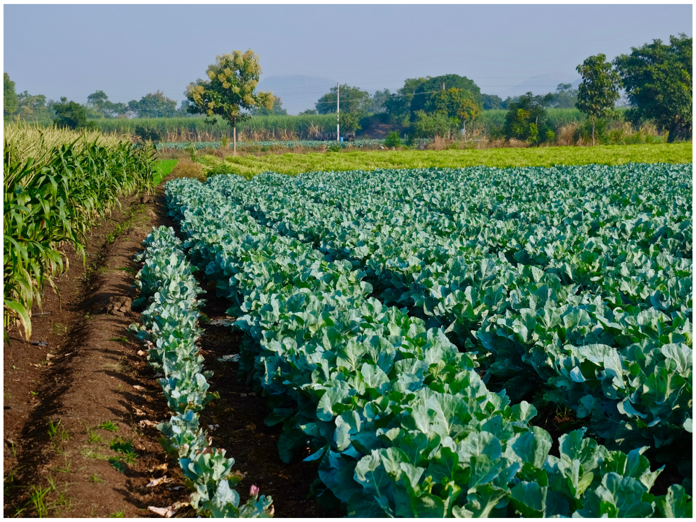
Beyond Yield
The Many Goals of Organic Plant Breeding

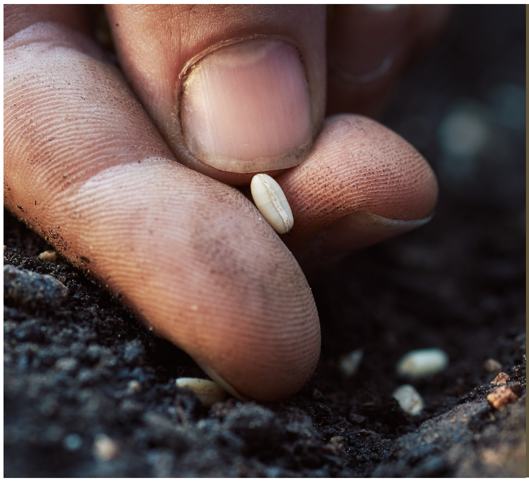
Part 3 | March 2023



A crop can do so much more than just produce a yield. For example, crops can improve the soil, fix nitrogen, control weeds, and support beneficial organisms. Crops can deter pests, protect the soil from erosion, and reduce the potential for nutrient loss. These functions are particularly valuable for organic growers. Whereas a conventional grower might rely on synthetic chemicals to provide nutrients, kill weeds, and control pests, organic farmers can use their crops to fulfill these functions. A well-designed crop rotation is critical but variety choice is also important.

The vast majority of cultivars in circulation today have been bred to perform well under high-input, conventional farming conditions. The situation is changing, however. As part of the Organic Science Cluster (OSC), plant breeders and farmers across Canada are developing crop varieties for organic farmers.

In this fact sheet, we will discuss the Organic Science Cluster's Participatory Plant Breeding programs, as well as the related OSC plant breeding projects that look beyond yield as the ultimate goal. For more information, see Part 1: Crop Varieties for Canada's Organic Farmers and Part 2: Developing vegetable varieties for Canada's organic farmers- Canadian Organic Vegetable Improvement (CANOVI) .



Participatory Plant Breeding (PPB)

What is PPB?

In conventional plant breeding, most varieties are developed by professional plant breeders and trials are conducted at research stations under ideal conditions. In contrast, participatory plant breeding (PPB) is largely conducted on farms by farmers. Varieties developed through PPB often better suit the needs of growers because the farmers themselves identify the characteristics they value and evaluate the performance of accessions on their own farms.

PPB "demands a different, innovative way of addressing human needs that goes well beyond the aim of increasing productivity. Its goals are achieving productivity increase, diversity enhancement, and empowerment."[6] PPB is most appropriate:

- "In marginal, stress-prone regions;
- "In agroecologically or socio-culturally heterogeneous regions;
- "When productivity and diversity are twin goals;
- "When diversity maintenance and enhancement is the main goal."

Canada is an agroecologically and socio-culturally heterogeneous region which, one could argue, is now stress-prone as we face climate change. Maintaining and enhancing genetic diversity is particularly important for organic growers at this time given the lack of varieties bred for organic production and the changing climate.

Organic Science Cluster PPB

All across Canada, organic growers have been planting, comparing, and selecting for the most promising accessions of field crops (including wheat, oats, soybeans, corn, and potatoes) and vegetables (primarily carrots and peppers).This participatory plant breeding has been supported by the Organic Science Cluster (OSC) since 2009.

PPB work is conducted on a number of farms with diverse growing conditions (e.g., soil type, climatic constraints, pest pressure) and a variety of management methods (e.g., irrigation, pest control, soil amendment practices). As a result, the varieties being developed from PPB are expected to be better able to perform well in a range of conditions, and likely better suited to adapt to climate change.[7] All the farms involved in the OSC work are organic or ecological farms and consequently the varieties developed through this process are well suited to organic conditions.

The initial PPB targets of the Organic Science Cluster are outlined in Table 1. The PPB work has been conducted in conjunction with The Bauta Family Initiative on Canadian Seed Security at SeedChange, the University of Manitoba, the University of British Columbia- Agriculture, independent researchers, Agriculture and Agri-Food Canada, and farmers across the country. The vegetable research evolved into the Canadian Organic Vegetable Improvement (CANOVI) project which includes a combination of participatory plant breeding and participatory variety trials. With grain, the OSC researchers conducted both on-farm participatory plant breeding and variety trials, as well as more traditional plant breeding conducted under organic farming conditions.

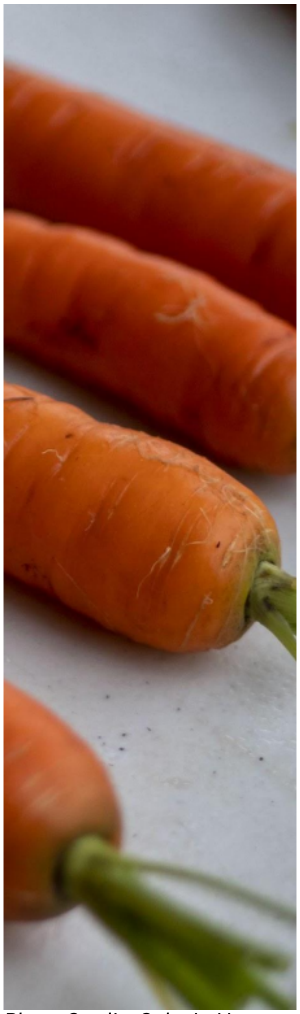


Photo Credit- Solveig Hanson

Table 1: Initial PPB Targets

Table reprinted from The Bauta Family Initiative on Canadian Seed Security (2013).[8]

Crop	Challenges	Selection criteria and research objectives
Potato	Lack of nutrition and flavour in modern varieties, vulnerability to fungal diseases, in particular in organic production	Late blight resistance, quality, taste, nutrient use efficiency, disease resistance, storability, drought stress
Maize (corn)	Input-intensive production requires large quantities of synthetic fertilizer and pesticides which have deleterious impacts on the ecosystem (including human health)	Open-pollinated varieties for human food adapted to an organic production systems Hybrid varieties (GMO-free) adapted to organic production systems, free of GMO contamination, and with good performance in short growing seasons
Wheat	Decreased biodiversity, and increasing reports of allergic responses to the forms of the gluten protein commonly found in modern varieties	Good yield, seed protein, milling and baking qualities, and disease resistance under organic conditions
Oats	Fungal diseases, such as rust, and poor competition against weeds (particularly in hulless varieties)	Disease resistance, end-use quality traits, competitive, and disease-resistant hulless varieties

Plant breeding is a slow process; however, the Organic Science Cluster's plant breeding activities have, as of 2023, produced sound results. Two oat varieties (AAC Oravena and AAC Kongsore) and one variety of red bell pepper (Renegade Red) have been developed for organic farmers. The potato, carrot, and wheat selections are still ongoing but the farmer-selected strains are promising.

The participatory plant breeding has produced more than just promising genetic material, it has also cultivated a great interest in variety choice and seed production. A network of seed growers has developed to share and exchange knowledge with each other about seed production, variety trials, and plant breeding. In a survey conducted by The Bauta Family Initiative on Canadian Seed Security among program participants (which includes growers involved in the PPB field crop program and the CANOVI program), 88% of respondents stated they improved their abilities related to organizing and implementing variety trials, and 80% improved their abilities related to plant selection and on-farm plant breeding.[9]

To learn more about the Organic Science Cluster's plant breeding activities, see:

Part 1. Crop Varieties for Canada's Organic Farmers

Part 2. Developing vegetable varieties for Canada's organic farmers- Canadian Organic Vegetable Improvement (CANOVI)

Breeding for Organic Field Crops in Canada (https://cdn.dal.ca/content/dam/dalhousie/pdf/faculty/agriculture/oacc/en/2021/FINAL-%20Field%20Crop%20Breeding.pdf)

Selecting for growth characteristics - breeding crops for no-till mulch

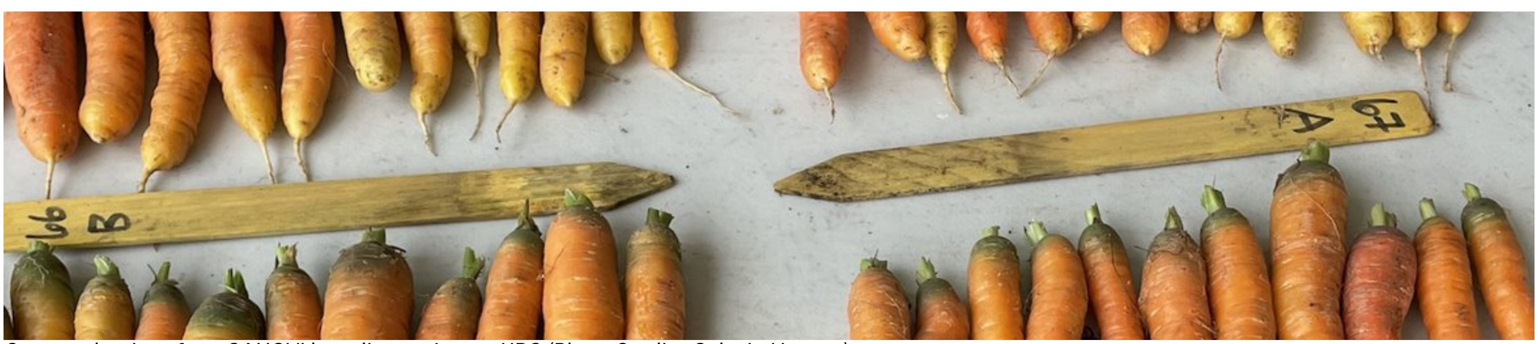
Canadian researchers Drs. Jamie Larsen and Raja Ragaputhy are thinking outside of the box with their grain breeding project, which is conducted with support from the Organic Science Cluster. They are developing fall rye (cereal rye) and triticale varieties to be used in organic minimum-till or no-till production.

Organic farmers use many approaches to control weeds, including cover crops, crop rotation, strategic timing of seeding, and careful nutrient management. Tillage, however, remains a key tool. Due to the negative effects of excessive tillage, many organic growers are looking at ways to reduce or even eliminate tillage. One promising method involves using fall-planted cover crops that are terminated by a roller crimper.

In Pennsylvania, home of the Rodale Institute that developed the technique, this method generally has the following steps:

1. Seed a winter-hardy cover crop, such as hairy vetch or fall rye in the fall (note that hairy vetch is only hardy to Zone 4).
2. At the crop's late flowering stage, a roller crimper is used to kill the cover crop and leave a thick mulch.
3. Seed the next crop, such as soybeans or corn, into the mulch.

In much of Canada, this system does not work well for long-season, heat-loving crops like soybeans and corn. Due to our longer winters, the rye isn't ready to be crimped until early June and the thick mulch keeps the soil cool for an extended period of time. With a shorter frost-free season, there may not be time to wait for the soil to warm up before planting these crops.



Carrot selections from CANOVI breeding project at UBC (Photo Credit - Solveig Hanson)

Drs. Jamie Larsen and Raja Ragaputhy are addressing this issue in an innovative way[10] by breeding fall cover crops that can be rolled/crimped earlier.This could be accomplished by crops that flower earlier or crops that be crimped before flowering without a risk of regrowth. In addition to fall rye, the researchers are trialling varieties of triticale for the roller-crimper system.

For more details see, "Breeding Winter Cereals for Mulch Cover Proves Transformational" https://swcdc.ca/wp-content/uploads/2020/12/Organic-Agriculture.pdf.

A Mixed Bag: Combining Wheat Varieties in Eastern Canada

Canada is renowned for producing high-quality milling wheat with the great majority of the country's wheat grown on the prairies. What about wheat from Eastern Canada? With the increase in consumer demand for local, organic products, interest in milling wheat has grown in Quebec and other Eastern provinces. The choice of wheat varieties, however, is limited.

Growing varieties with pest resistance is critically important to the success of organic grain crops, but the insects and diseases that affect Eastern wheat differ a lot from common prairie pests. Fusarium Head Blight is usually a serious problem in the East, whereas there is substantial year-to-year variation in the pressure of many other pests, including leaf spot pathogens, stem diseases (take-all, eyespot), insects (midge and hessian fly), Barley Yellow Dwarf Virus, and rusts. Unfortunately, almost all of the varieties that thrive on the Prairies are too susceptible to Fusarium to thrive in Quebec, and otherwise poorly adapted to Quebec's soils and climate.

PPB wheat plots at the University of Alberta (Photo Credit - Talon Stokes)

With support from the Organic Science Cluster, Julie Anne Wilkinson, André Comeau, and fellow researchers at CETAB+ (Centre d'expertise et de transfert en agriculture biologique et de proximité) explored the potential of variety mixtures in collaboration with La Milanaise and Moulins de Soulanges. Their research involved:

- Comparing mixtures of two, three, four or six varieties to single varieties
- Soliciting feedback on the mixtures from the 'end users' of the wheat: millers and bakers.

After five years of research, the researchers have found that the choice of varieties is critical - only certain mixes are productive. The team is fine-tuning the selection of mixes. The results are promising in that several mixtures can provide good yields of high-quality wheat. Mixtures also seem to increase the predictability of good overall performance.

Although the final results have not yet been published, the input from the flour mill's laboratory has already been invaluable. For example,their lab measures flour protein levels and falling numbers (a measure of the crop's resistance to weathering), and their bread making tests can reject a variety as unsuitable if the dough had a tendency to stick to the equipment. Those lab tests also measure many more parameters that are critical to predictable bread making. For example, the dough must absorb water and rise at the ideal rhythm, and be able to tolerate long fermentation.

Advantages of Variety Mixes

Planting a mix of varieties is one way to increase diversity on your farm. Combining varieties provides greater diversity than growing a monoculture of one variety but less diversity (and fewer complications) than intercropping with two or more types of crops. The advantages include the following:

Greater Yields. Variety mixtures often produce slightly higher yields than monocultures of one variety for some of the reasons described in more detail below.[11] For example, mixing wheat varieties has often led to an increase in wheat yields due to mixing varieties, particularly in low-pesticide or organic conditions.[12]

Greater Stability in Yields and Greater Resilience. Using variety mixes can lead to more stable yields.[13] A mix of varieties is more likely to contain at least one variety that will thrive in the particular conditions faced by the crop each season. As weather becomes increasingly unpredictable, the ability of a crop to withstand a range of conditions is becoming more critical. By seeding, for example, a mix that includes both a drought-tolerant variety with a variety that thrives in wetter conditions, you can minimize the risk of crop failure. A mix of shallow-rooted with deep-rooted varieties is also valuable in unpredictable weather: deep-rooted varieties can take advantage of spring moisture and heavy rain, whereas the shallow-rooted varieties can use the moisture from light rainfalls.

Better Use of Resources. When combining varieties that have complementary characteristics, the crop can more efficiently use resources, including sunlight, moisture, and nutrients. For example, seeding shallow-rooted and deep-rooted wheat varieties will allow the crop to use water and nutrients that are near the soil surface as well as those deeper in the soil profile.

Greater Pest Control. Mixing varieties can reduce the overall impact of pest insects and diseases in several ways.

-If pests are attracted to one variety but not another, the mix will dilute the impact of the pest compared to just using the susceptible cultivar. For example, solid-stemmed wheat varieties are resistant to damage by sawfly larvae. However, there is a limited number of solid-stemmed cultivars and they tend to have lower yields than hollow-stemmed cultivars. In areas with moderate sawfly damage, seeding a mix of solid-stemmed with hollow-stemmed wheat varieties can limit the impact of the pest while still providing a marketable crop.

-Varieties may vary in their defences against pests, and the plants with active defences may protect the more vulnerable ones.

-A greater cultivar diversity can increase the diversity of habitat for the beneficial organisms that prey upon or parasitize pests. For example, parasitoids and predators of pests preferred barley mixes compared to barley monocultures.[14]

Improved Soil Biodiversity. Cultivars may differ in their impact on soil life, such as releasing different rates/or compositions of root exudates (which are consumed by soil organisms) or their ability to form symbiotic relationships with mycorrhizal fungi. A greater diversity of varieties may lead to a greater diversity of soil microorganisms, which can improve the resilience of the soil to disturbances and extreme weather.[15]

Greater Nutritional Value. Different varieties may have different nutritional profiles and researchers have found that a mix of varieties can lead to higher levels of nutrients and phytochemicals linked to human health.[16]

More Ecosystem Services. Varietal mixtures can improve weed suppression, and the support of natural insect enemies and pollinators, and lead to "improved soil quality, and reduced nitrogen leaching to ground and stream water."[17]

How to Mix Varieties:

The goal is to find varieties that will complement, not compete with, each other. The first step is identifying what you hope to achieve by combining varieties and then choosing a combination of varieties that will meet those goals.

General tips include:

- Choose varieties with complementary growth patterns - such as tall, slender varieties with shorter, leafier ones.
- Combine varieties with complementary rooting systems - such as a deep-rooted variety with a shallow-rooted one, or a tap-rooted variety with one with a more extensive root system.
- Mix early, mid-season and late varieties to hedge your bets or have an extended harvest season (e.g., for crops with ongoing harvests).
- Seed a variety that is highly competitive with weeds with one that is less competitive, if the less competitive one has other desirable traits.
- Consider the most serious pests in your area, both insect pests and diseases. Mix resistant with susceptible varieties if the susceptible varieties have other advantages.

Considerations:

- Do the varieties complement each other in terms of strengths and weaknesses?
- Will the mix create additional work or expenses for you as described below or in other ways?
- Can you easily seed the varieties together?
- If the mixed varieties don’t mature at the same time, will that cause problems when harvesting?
- Do you have a market for the end product? Is the mix acceptable to your buyers, processors, and/or consumers? If not, can you easily separate the varieties?


Photo Credit - Tierra Stokes

Selecting for 'Functional Traits'

Plant breeding involves a series of trade-offs: breeders are constantly having to prioritize traits by choosing some characteristics over others. As discussed earlier, good flavour and high nutritional value may be lost in the drive for high yields.

There is another approach: plant breeders could select varieties and accessions not just for the obvious characteristics farmers want, but also for traits that are indirectly linked to positive attributes, like the thickness and density of root hairs.

The trade-offs involved in crop development aren't new. For millennia during the domestication of wild plants, people have selected the traits they wanted. For example, wild relatives of today's crops often have thicker roots than modern varieties (with the exception of root crops). This might reflect a trade-off. For example, cereal crops that put less energy into their roots might put more resources into seeds, which leads to higher grain yields.

The results of selection and plant breeding also reflect the growing environment. Long before modern plant breeding, people have saved seeds from the plants that grew well on their farms, thereby selecting for plants that thrive in their growing conditions.

Breeding varieties to perform well in organic systems can involve more than just direct selection of plants that yield well on organic farms. Breeders can also select for traits that help plants perform well in organic systems. For example, fast emergence and rapid canopy closure help plants compete with weeds in the absence of herbicides. On organic farms, other beneficial attributes include abilities to acquire nutrients from the soil and develop symbiotic relationships with soil life, particularly mycorrhizal fungi.

As part of the Organic Science Cluster, Dr. Marney Isaac and her team investigated crop root traits and their functions that are linked with acquiring nutrients. The researchers found that root traits changed as wild plants became domesticated. Older crop varieties appear to be more likely to form symbiotic relationships with arbuscular mycorrhiza in various soil conditions, whereas modern varieties are more likely to form these relationships only in low-nutrient conditions. These mycorrhizal relationships can help plants access more nutrients and water, a valuable ability on organic farms and any farm experiencing dry conditions. The symbiosis also helps to prevent nutrient loss and the resulting risk of water pollution.


Renegade Red Field Day: Viewing Renegade Red pepper breeding plots during a 2019 field day at Kitchen Table Seed House, ON (Photo Credit - Aabir Dey)

As part of the participatory plant breeding project, farmers were asked to submit carrot samples for various crop traits. This "farmer-based citizen science" enabled researchers to obtain data from a number of locations. Having a dataset from multiple farms enables scientists to better understand how crop performance is influenced by environmental factors. Researchers also visited farms across Canada to collect traits of multiple varieties of one crop. They show that the links between soil fertility, crop traits, and performance can change among varieties. Functional traits of crops help us understand why plants respond in different ways in different environmental conditions. This information can help guide breeding programs for organic agriculture.[18]

Did you Know?

Corn can Fix N

After finding a wild relative of corn that fixes nitrogen (in symbiosis with bacteria), the Mandaamin Institute has been developing corn varieties for organic farmers that form strong symbiotic relationships with soil life and can better extract N from the soil and air. The corn from these varieties has higher protein levels, better protein quality, and higher carotenoid content than conventionally bred corn. Also, these varieties naturally prevent GE pollen from growing on their silk, thereby preventing pollination by GE corn.

Seed security relies on an abundance of open-pollinated (not hybrid) varieties. If you follow the proper seedsaving procedures to avoid cross-pollination, the seed you save from open-pollinated varieties will resemble the original plants. If you save seed from a hybrid, however, the next generation will be an unpredictable mix – not necessarily the same as the hybrid or even like its 'parents.' Even if you don't save your own seed, you can help keep more varieties available for the common good by buying open-pollinated seed. This way other farmers can save their own seed or you can partner with a seed grower to develop your own seed supply.

Quick Fact:

"Most modern crop species and genotypes are adapted to exploit nutrient-rich habitats through traits that confer fast growth and rapid rates of nutrient uptake." [19]

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ABOUT THE ORGANIC SCIENCE CLUSTER

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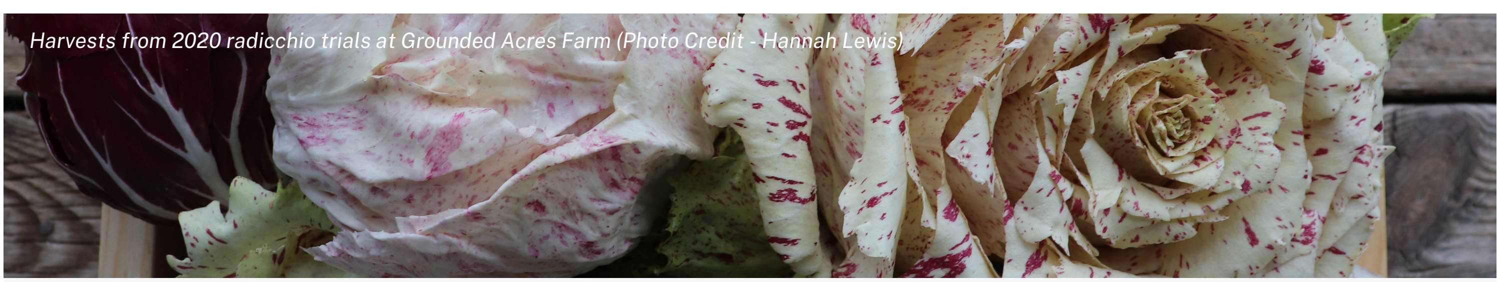

Harvests from 2020 radicchio trials at Grounded Acres Farm (Photo Credit - Hannah Lewis)

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