

Organic Farming Research Foundation Final Grant Report

Seeding a culture of innovation in organics: Farmer-led breeding of peppers, broccoli and cucumber

Grantee name: Ecological Farmers Association of Ontario (EFAO)

Grant lead: Dr. Sarah Hargreaves

Farmer-researchers: Annie Richard, Kathy Rothermel, Rebecca Ivanoff, Kim Delanie, Greta Kryger, Nathan Klassen

Grant duration: April 15, 2020 - April 15, 2021

1. Project Summary

The purpose of this project was to develop open-pollinated vegetable varieties bred under organic conditions for southern Ontario and northeastern US. Specifically, this project supported breeding red and yellow bell peppers by the SeedWorks Plant Breeding Club, heat tolerant broccoli by Greta Kryger, and seedless English cucumber by Nathan Klassen.

The objective of the pepper breeding project was to release a mass selected flavourful red bell pepper, and work towards the final stages of releasing uniform lines of yellow and red bell peppers. The focus of the broccoli and cucumber breeding projects was the beginning - and often more finicky - stages of breeding. For the broccoli breeding project, the objective was to create new genetic diversity from diverse germplasm. For the cucumber project, the objective was to successfully produce F1 seed, and adapt a method for on-farm breeding that allows the farmer to force male flowers on plants that otherwise only produced female flowers to create F2 seed.

The main findings of the pepper project include the release of a mass selected red bell pepper, Renegade Red, that is protected through an Open Source Seed Initiative (OSSI) pledge. Despite the pandemic and weather storms, there was significant progress towards the uniform yellow lines, with plans to release this variety in late fall 2021. Due to weather set-backs, learning new information about other similar breeding efforts, and a deeper commitment to genetically diverse varieties, the SeedWorks decided to discontinue selection on the uniform red pepper lines.

The main findings of the broccoli project was the production of some highly variable F1 seeds for future breeding work, and a great understanding of the challenges associated with breeding broccoli in southern Ontario. The main finding from the cucumber breeding project is that creating a cucumber cross on a working organic farm has many challenges, such that it is important to find simpler ways to create crosses from varieties that easily create seed.

Overall, this project as a whole shows the challenges and successes of local breeding efforts. EFAO and the farmer-breeders are grateful to the Organic Farming Research Foundation for supporting breeding work in all stages of development.

2. Introduction to Topic

The need to breed crop varieties suitable for organic farming is a critical area of research for organic farmers and seed security. It is estimated that more than 95% of organic production is based on crop varieties that were bred for the conventional high-input sector, and that these varieties lack important traits required under organic and low-input production conditions (1). This need is especially timely with climate change bringing new challenges such as weather extremes and pest pressures (2). In the US, the need for development of organic varieties was identified in the 2016 National Organic Research Agenda (3). The need for organic vegetable breeding is further intensified in Canada, as there are no research institutions focused on developing organic vegetable varieties.

To meet this need, we used a farmer-led approach to breeding three locally adapted varieties. Farmer-led - or participatory - approaches work well for organic systems, given the special traits required for organic systems and because the small organic market is not always attractive for commercial plant breeders (4).

In cooperation with EFAO's Farmer-Led Research Program, six organic farmers in Ontario worked on three projects to breed sweet bell peppers, heat tolerant broccoli, and seedless English cucumbers that are adapted to organic growing methods in southern Ontario and northeast US.

The pepper project addresses the expressed need from market farmers for an early ripening, red, blocky bell pepper that is bred for organic growing systems for southern Ontario and the US northeast. This need was identified through the Northern Organic Vegetable Improvement Collaborative (NOVIC) surveys (5), the ecological plant breeding priorities for vegetable crops survey (6), and personal communication with farmers in their

regions. Similarly, breeding a heat tolerant broccoli was identified as the top priority for growers in this region through the Breeding, Research, and Education Needs Assessment for Organic Vegetable Growers in the Northeast, Cornell University (7) and the ecological plant breeding priorities for vegetable crops survey (6). This project works off of Dr. James Myer's participatory breeding program for broccoli at Oregon State University (1, 8), however, there are no other projects of its kind in Canada and there are no comparable commercial varieties for the region. The seedless cucumber project is adopting an innovative method to on-farm seed production, thus reducing seed costs and increasing seed security.

3. Objectives Statement

PEPPER Project

The overall objectives of the pepper project were to breed early ripening, blocky red and yellow peppers with good yield and flavour that are locally adapted to organic growing systems.

The original specific objectives of the project were to:

- P.1)** release a genetically diverse but relatively uniform, flavourful, red bell pepper bred for organic field conditions;
- P.2)** release a uniform flavourful red bell pepper suited for organic field conditions;
- P.3)** release a uniform flavourful yellow bell pepper suited for organic field conditions.

P.1) was unchanged as the project proceeded. **P.2)** was attempted but, due to damaging weather events, progress was not met. Further, after conversations with other breeders who are working on a similar variety, the farmers decided to discontinue this objective moving forward. *See Project Results for more details.* **P.3)** was changed to working towards the release of a uniform yellow bell pepper, with release now scheduled for winter 2021.

BROCCOLI Project

The goal was to breed a stress tolerant heading broccoli that has broad genetics to be adaptable to climate variability and is bred for organic systems.

The original specific objective of the broccoli project for 2020 was to:

- B.1)** create new genetic diversity by cross pollinating a large selection of germplasm.

No changes to the objectives were made.

CUCUMBER Project

The overall objective of this project was to start to breed an open pollinated seedless English cucumber with excellent flavour and good yield that is adapted to growing in soil under organic greenhouse conditions.

The original specific objectives for 2020 were to:

- C.1)** adapt a method for on-farm breeding that allows the farmer to force male flowers on otherwise female flowers; and
- C.2)** create F2 seed.

Because Nathan was unable to produce F1 seed in 2019, the objectives for 2020 was changed to: **C.1)** allow for the pollination and fertilization of a parthenocarpic female Tyria flower with Hofstetter pollen; and **C.2)** the creation of viable F1 seed.

4. Materials and Methods

PEPPER Project

Kim Delaney and Greta Kryger are owners of two of the oldest organic seed companies in Ontario. Annie Richard and Kathy Rothermel operate a new successful seed company, with over 30 years of cumulative farming experience. Rebecca Ivanoff farmed organic vegetables for 7 years, is currently the Ontario Coordinator for the Bauta Initiative on Canadian Seed Security, and grows crops at the community gardens at Ignatius Farm. All farms are certified organic.

P.1) Mass Selected Red Pepper

From seed saved from their mass-selected red peppers in 2019, Annie sowed 90 plants on April 4, 2020 and Greta sowed 120 on March 29, 2020. They separated the mass selected population from all other populations/varieties on their farm and neighbouring farms by at least 45 meters. Annie transplanted June 3 and Greta on June 10. Annie and Greta planned to plant Ace F1 and Aristotle F1 as checks but this was not possible (see Findings for more details).

The group also further compared Renegade Red against other commercial varieties as part of the Canadian Organic Vegetable Improvement (CANOVI) Project - a collaboration between the Centre for Sustainable Food Systems at the University of British Columbia and the Bauta Family Initiative on Canadian Seed Security. Specifically, Annie on Wolfe Island, along with two other farms near Kitchener and Thunder Bay, grew Yankee Bell, King Arthur,

King Crimson, Ace, King of the North (Fedco strain), Red Knight, and Sprinter. The Ace plants from these trials were to act as check varieties for the mass selected population.

P.2) Uniform Red Pepper

In hopes of speeding up the breeding process, Annie planned to grow the red progeny lines in a heated greenhouse over the winter of 2019-2020. She then planned to plant out the best of the red progeny lines in 2020, cover to allow peppers to self pollinate, observe which of these lines have the most uniformity in plant architecture, early maturity, pepper shape and size, and test which is most flavourful.

P.3) Uniform Yellow Pepper

Kim also planned to work with a local grower with a heated greenhouse to grow their favourite 2019 yellow progeny lines during the winter of 2019-2020, grow them out and continue the selection process in 2020.

BROCCOLI Project

Greta allowed crosses to occur from a large population of varieties that were both open pollinated and hybrid (those without cytoplasmic male sterility). A list of germplasm that Greta used can be found in Table 1.

Table 1. Broccoli Varieties used in Greta's Broccoli Project

Variety Name	OP/F1	Source
Covina	F1	High Mowing
Green Goliath	F1	Southern Seeds
Atlantic	OP	Fedco
Burney	F1	Bejo/Fedco
NOVIC	OP	Cornell/Fedco
Solstice	OP	Fedco
Limba	OP	Fedco
Umpqua	OP	Adaptive seeds
Calinaro	OP	Meadowlark Hearth
Nutribud	OP	Adaptive seeds
OSU	OP	Dr. James Myer at Oregon State University
De Cocco	OP	High Mowing

Waltham	OP	High Mowing
East Coast OP population	OP	Ken Ettlinger at Long Island Seed Project
High Sierra	F1	USDA
Florette	F1	USDA
Greenbelt	F1	USDA
Atlantic	OP	USDA
Atlantic	OP	USDA
Packman	F1	USDA
Green Comet	F1	USDA
C B verde Calabrese	OP	USDA
C B Ramoso Calabrese	OP	USDA
C B Frevarota	OP	USDA
Kilamipich	OP	USDA
C B Rizza	OP	USDA
C B Precoce	OP	USDA
B Grande Precoce	OP	USDA
C B Ramoso Calabrese	OP	USDA
C B Marzullo	OP	USDA
B Natale Pied Grande Liscio	OP	USDA
Broc 3	OP	USDA
Big Sur	F1	USDA
Zeus	F1	USDA

In order to have the broccoli flowering before the heat of the summer, Greta sowed 2-3 plants of 35 varieties of broccoli in February 2020. In April she then potted up the plants into 1 gallon pots in her unheated greenhouse. By May, they were already 18 inches tall in her unheated greenhouse and at the end of May Greta had moved the plants outside. At this stage no heads were forming. Greta removed one plant that looked like it was a kale (she thinks it was one of the Italian varieties from the USDA (GRIN) system).

By the end of June, 3-4 varieties were blooming and she moved the pots around so that those flowering were closer to each other in hopes that they'd cross pollinate. By July 1, the

weather was really hot, so Greta moved the pots into a basement under the lights in hopes they would produce seed under these less hot conditions. By the end of August she moved the plants outside again as some were continuing to flower and others had unripe seed that needed to mature.

CUCUMBER Project

As planned, Nathan planted his two parent cucumber varieties in one of the farm's earliest plantings and in a location less prone to attack from striped cucumber beetles. However, only one plant from the Tyria parent variety survived the first planting; Nathan replanted Tyria and three plants survived this second planting.

5. Project Results

PEPPER Project

P.1) Mass Selected Red Pepper

As planned for 2020, the group saved seed from their favourite blocky, flavourful, red peppers from within this population for 2021 stock seed. They also harvested seed from additional early ripening, blocky flavourful peppers, which could be sold when these seeds were released in winter 2020. At Annie's, there were 4 plants of yellow peppers within this population of 90 plants this season. The first ripe red peppers were observed on August 18, 2020, or 76 days after transplant or days to maturity (DTM). At Greta's, she observed no plants with yellow peppers within her population of 120. Greta observed the first ripe fruit on August 10, or 61 days after transplant (DTM) (Table 1). They selected sweet and crunchy peppers from the best 7 peppers as stock seed. For distribution to the seed houses, Greta also collected seeds from the next 15 best peppers.

Unfortunately, the mass-selected red pepper population at Kitchen Table Seed House was hit by an early first frost in September. The leaves died and only a handful more peppers managed to ripen after that. Up to this point, Annie had collected a big bin full of fruit that matched the red blocky and early characteristics. She tasted each fruit and saved the seeds from only the really tasty ones, tossing the bland ones to the compost. All in all, Annie was unable to save as many seeds as she had planned; from Kitchen Table Seed House they ended up with only about 100 packets of 25 seeds each from the mass selected red pepper population.

Unlike previous years, due to the global pandemic, the farmers were unable to hold blind taste tests with consumers and friends to confirm more broadly that selections are more

flavourful than other red pepper varieties. However, they tasted each pepper before choosing to save seed from it.

To add insult to injury for the year, the CANOVI trials at Kitchen Table Seed House were destroyed by the severe hail storm on June 7, 2020. This set-back not only reduced the number of sites for this provincial trial to two, but also meant that Annie did not have any checks for comparison. In addition, Greta was not able to order Ace F1 and Aristotle F1 seed, so was also unable to plant check varieties in 2020. Not having checks did not change how the selection process would happen, but it did mean that they could not observe how different their selections were from the parents in this cross.

In the fall of 2020, their early-maturing, blocky red bell pepper with broad genetics was released commercially as 'Renegade Red' pepper. 'Renegade Red' is pledged with the OSSSI and available for the 2021 growing season from Kitchen Table Seed House and Greta's Organic Gardens!

In the CANOVI trials, the mass selection had 84 DTM (4 days longer than Ace) at one farm in Zone 5b, and 92 DTM (same as Ace) in Zone 3a. This was a lot longer than was experienced at Kitchen Table Seed House (76 DTM) and at Greta's Organics (61 DTM).

P.2) Uniform Red Pepper

Due to novel and unexpected shifts in priorities at the beginning of the global pandemic, Annie had to move the red progeny lines that she had planted in the heated greenhouse during the winter of 2019-2020 before they had produced ripe peppers. This meant that in spring 2020, she planted 12 plants from the best two red lines (lines # 2 and #22) from summer 2019 instead of having one season of further selection over the winter.

Unfortunately, the peppers from the red progeny lines were destroyed by the hail storm at Kitchen Table Seed House on June 7, 2020. The leaves on the plants were shredded by the hail leaving only the main stems. Nevertheless Annie left the plants to see if they would bounce back. They did indeed, only to be attacked by caterpillars. It was not a good year to be a pepper on Wolfe Island! Luckily, there were a few fruits that managed to ripen that Annie harvested and saved seed from.

Given the difficult year for progress with the red progeny lines, and after conversations with others in the seed community, the farmers decided to discontinue our work with the red progeny lines and focus on the mass selected red pepper population and the yellow

pepper lines. Specifically, their mentor Michael Mazourek and colleague Daniel Brisebois are planning to release pure line red peppers that came from the same Ace F1 and Aristotle F1 cross. Further, they feel that the mass-selected peppers with broad genetics are more in line with their current desires for varieties with broad genetics (i.e. landraces).

P.3) Uniform Yellow Pepper

Due to unprecedented demand for seed at the beginning of the pandemic in early 2020, Kim was also unable to secure a spot to grow the yellow progeny lines in a heated greenhouse. During the summer of 2020, Kim planted lines G1, K1, K2 of the yellow progeny lines, while Greta planted lines G1 and G2 with 12 plants each under row cover so that they self-pollinate. Kim had space for about 65 of each of these lines, all of which she kept under row cover.

The farmers saved seeds from all lines but concluded yellow progeny line G1 performed the best at both locations. They saved seed from the best plants in the G1 line that were most uniform and flavourful to grow out in 2021.

Table 2. *Planting details and date to first ripe fruit for the SeedWorks pepper lines in 2020.*

	Red Progeny Lines at Kitchen Table Seed House (Lines # 2 and #22)	Red Mass Population at Kitchen Table Seed House	Red Mass Population at Greta's Organics	Yellow Progeny Lines at Greta's Organics (Lines G1 and G2)	Yellow Progeny Lines at Hawthorn Farm Organic Seeds (Lines G1, K1, K2)
Date seeded	April 4	April 4	March 29	March 29	April 2,
Date transplanted into the field	June 2	June 3	June 10	June 10	June 12
Number of plants transplanted	8 of each	90	120	12 of each	200 (three lines G1, K1, K2)
Date of first ripe fruits (Days to Maturity)	n/a	August 18(76 DTM)	August 10 (61 DTM)	August 10 (61 DTM)	September 3(83 DTM)

BROCCOLI Project

B.1) Create new genetic diversity of broccoli germplasm

After the moving and positioning the potted plants around as described under *Methods*, and because of the limited space and nutrients in the 1 gallon pots, the broccoli did not form large heads but went straight to flowering. This means that there was no selection for heading broccoli at this stage. She observed that some had white flowers while others had yellow flowers.

Greta harvested seeds as they matured over August and September. Some of the side shoots and some whole plants (around 15-18) were still flowering in October! Greta wonders if these could be biennial broccoli varieties. She noted that, due to their seed growing methods, she might be narrowing genetics to an annual broccoli; and that the group may want to be aware of this as they continue this work.

Once Greta cleaned the seed, she was able to collect only about 400-500 seeds in total, as a lot of empty seeds were winnowed out. She saved this collection of highly variable F1 seeds for future breeding work.

CUCUMBER Project

C.1) Seed production

Two cucumbers on one of the Tyria plants matured. Nathan hoped that they had been pollinated by their neighbouring Hofstetter. Nathan did not hand pollinate the flowers, but instead intercropped the two varieties in an area where pollinators could move between the flowers.

C.2) F1 seed production

Nathan good seed from the Hofstetter cucumbers which he left to mature. These were not a cross because Tyria does not produce male flowers with pollen. Nathan observed that the Tyria that did mature were pollinated, as there were immature seeds visible, but they were not viable when he did a germination test on them. Overall, there was no successful pollination; and thus no production of F1 seed.

6. Conclusions and Discussion

PEPPER Project

The farmers as part of the pepper breeding project achieved a significant milestone with the commercial release of 'Renegade Red', an open pollinated, early-maturing, blocky red bell pepper. To do this, they selected the Open Source Seed Initiative (OSSI) model for 'Renegade Red', as the OSSI pledge "preserves the rights of farmers, gardeners, and

breeders to freely use, save, replant, and improve seed” of this variety while preserving SeedWorks’ ability to maintain its quality and identity.

During the 2021 season, they are growing Renegade Red for seed at Kitchen Table Seed House and Greta’s Organics, and continue to select the peppers that mature the earliest and taste the best. They also continue to feel strongly that heterogeneous food crops with broad genetics are needed as we face climate change, and are excited to be able to talk about this when describing their newly released Renegade Red pepper population (9)!

In addition to Renegade Red, they continue to select uniform progeny lines of blocky yellow peppers. They are growing out the G1 line (variety name to be decided) at Hawthorn Farm Organic Seeds, Kitchen Table Seed House, and Greta’s Organics during the 2021 season. During this season, Pocket Seeds is doing a variety trial of the G1 line compared to other field bell peppers (Admiral F1, Brocanto F1, Elsa F1, Golden California Wonder, Sweet Sunrise F1) recommended by farmers and organic seed companies. They plan to release a yellow progeny line in late fall 2021 and plan to also protect this line through an OSSI pledge.

The members of SeedWorks would like to thank the peppers for participating in this co-evolutionary dance with them, and to all those who have saved seeds from these peppers over the last 6,500 years as they have travelled from hand to hand around the globe. They’d like to thank their colleague Micheal Mazourek for teaching them some of the dance steps to this process, and to Rachel Hultengren for doing the initial cross at the start of this project. They’d also like to thank the Bauta Initiative on Canadian Seed Security for creating opportunities for learning together which led to the formation of SeedWorks Plant Breeding Club, and the Ecological Farmers Association of Ontario for supporting them with protocols and funds associated with this grant.

BROCCOLI Project

Resilient seed systems are a balance between growing what can be produced in a region and networking with seed growers further abroad. With the learnings from Greta’s experience in 2020, she and the other members of the SeedWorks Plant Breeding Club have paused seed work to focus more on gathering more information about broccoli breeding in southern Ontario - with its hot summers that prevent good broccoli seed production in addition to head selection.

Towards this learning, they are working with others across Ontario and Quebec to organize trainings with prominent open-pollinated broccoli breeders, such as Tim Peters, to develop best next steps for this project. They are also working with others in their network to grow seed from additional broccoli varieties that do not have cytoplasmic male sterility. For example, Evalisa McIlfaterick is growing Munchkin broccoli seed in northern Ontario, where it tends to be less hot.

CUCUMBER Project

Nathan is very interested in continuing this work, but is frustrated that he is unable to get a cross from which to start selection. He is wondering about trying different parent lines. He is happy with the Hofstetter parent but is wondering about another parthenocarpic variety such as a variety called Lisboa F1. EFAO staff have also suggested that perhaps we can support him by seeing if someone as a university or institution could help make the initial cross from which Nathan can then select. This is how the pepper project started and it worked well.

7. Outreach

All Projects

Outreach for three projects included research announcements in the Spring 2020 print publication and EFAO blog (<https://efao.ca/organic-farming-research-foundation-grant/>), which we shared through the EFAO e-newsletter and social media posts.

Due to the pandemic, we did not organize or host any in-person or virtual field days around these projects. Results from the Pepper Project will be highlighted at the 2021 Research Symposium, which is scheduled for November 29, 2021.

PEPPER Project

For the Pepper Project, we published a Research Report, which is attached at the end of the report and is available for free online in the EFAO Research Library (https://efao.ca/wp-content/uploads/EFAO_PepperBreeding_2020.pdf).

The pepper project was also featured in the Organic Grower Magazine (Ontario growers release new organic seed, Renegade pepper (<https://organicgrower.info/article/ontario-growers-release-new-organic-seed-renegade-pepper/>), and Annie Richard briefly discusses the pepper work in her podcast on Seed Heads (<http://www.seedsecurity.ca/en/resources/seedheads-podcast/annie-richard>).

8. Financial accounting

Please refer to the spreadsheet attached.

9. Leveraged resources

No additional funding or resources were leveraged as a result of this grant. However, we will highlight the pepper project and the OFRF funding in a Farmer-Led Research Highlights webinar aimed at funders that we are planning for fall 2021.

10. References

- 1) Lammerts van, E.T. et al. 2011. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. *NJAS - Wageningen Journal of Life Sciences*, 58 (3-4): 193-205.
<https://doi.org/10.1016/j.njas.2010.04.001>.
- 2) Østergård, H. et al. 2009. Time for a shift in crop production: embracing complexity through diversity at all levels. *Journal of the Science of Food and Agriculture*
<https://doi.org/10.1002/jsfa.3615>.
- 3) Jerkins, D. and Ory, J. 2016. National Organic Research Agenda. Organic Farming Research Foundation.
https://ofrf.org/wp-content/uploads/2019/09/NORA_2016_final9_28.pdf.
- 4) Dawson, J.C. et al. 2008. Decentralized selection and participatory approaches in plant breeding for low-input systems. *Euphytica*, 160(2): 143-154.
- 5) Silva, E. and Bruce D. 2016. Variety Trial Report: 2016 Northern Organic Vegetable Improvement Collaborative. UW-Madison Organic Research and Extension Program.
<https://varietytrials.eorganic.info/sites/eorg-variety7/files/NOVIC%20Pepper%20Report.pdf>
- 6) Dey, A., et al. 2018. Canada Organic And Ecological Plant Breeding Priorities For Vegetable Crop.
<http://www.seedsecurity.ca/images/survey-report/2018-Survey-Report-Canadian-Organic-and-Ecological-Plant-Breeding-Priorities.pdf>.
- 7) Hultengren, R., Glos, M. and Mazourek, M. 2016. Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast. Cornell University.
https://ecommons.cornell.edu/bitstream/handle/1813/44636/Breeding_Research_Education%20_Northeast.pdf?sequence=9&isAllowed=y.
- 8) Myer, J. 2016. Broccoli Breeding, Evaluation. Oregon State University.
<https://horticulture.oregonstate.edu/sites/agscid7/files/horticulture/oregon-vegetab>

[les/16%20OPVC%20Broccoli%20Report.pdf](#).

- 9) Ceccarelli, S., and Grando, S. 2020. Evolutionary Plant Breeding as a Response to the Complexity of Climate Change, iScience, Volume 23, Issue 12, <https://doi.org/10.1016/j.isci.2020.101815>.

11. Photos and other addenda

PEPPER Project

- See Research Report (attached)

BROCCOLI Project

Photo 1: One of the first broccoli plants to start flowering at Greta's Organic Gardens. You can see how closely Greta could have the plants in their one gallon pots.



Photo 2: White flowers on a broccoli at Greta's Organic Gardens.



Photo 3: Yellow flowers on a broccoli at Greta's Organic Gardens. You can see here how the broccoli plant is small compared to a field broccoli and now it has gone straight to flower before forming a large head.



Additional materials

- Pepper Project Research Report (attached)

**Organic Farming Research Foundation
Research Grant: Final Financial Report**

PI NAME: Sarah Hargreaves

INSTITUTION/ORGANIZATION NAME: Ecological Farmers Association of Ontario

PROJECT NAME: Seeding a culture of innovation in organics: Farmer-led breeding of peppers, broccoli and cucumber.

EXPENSES

Item	Budgeted Amount	Actual Spent	Detail
EFAO Research Coordinators' time and fringe	\$9,956	\$10,613	Research Coordinator, Rebecca Ivanoff: 375 hours @\$28CAD/hour; Research Director, Dr. Sarah Hargreaves: 65 hours x \$40/hour + 7% of the time in-kind.
Research report for PEPPER TRIAL; outreach in print publication for all trials	\$342	\$1,472	Template design, layout and revisions; and an additional \$1,250 for printing and mailing of project information to the EFAO members.
Landscape fabric, insect netting for pollination isolation and conduit hoops for PEPPER TRIAL	\$570	\$471	BLACK 3.2 OZ GROUND COVER 4' X 300'; AGRYL P17 2,2X250M; 40 x ½" x 10' conduit
Potting mix for PEPPER TRIAL	\$43	\$43	
Greenhouse rental for PEPPER TRIAL	\$380	\$39	
Postage to mail seed to CANOVI trial for PEPPER TRIAL	\$228	\$4	2 other sites in Ontario
Insect netting and pots for BROCCOLI TRIAL	\$429	\$488	
Potting mix for BROCCOLI TRIAL	\$76	\$79	
Greenhouse rental for BROCCOLI TRIAL	\$532	\$83	
Seed for BROCCOLI TRIAL	\$23	\$0	No seed costs incurred
Stipends for farmers x 6	\$4,560	\$4,624	4 for PEPPER TRIAL, 1 for BROCCOLI TRIAL, 1 for CUCUMBER TRIAL
Travel/Mileage	\$754	\$0	No travel due to COVID-19
Giberellic acid for CUCUMBER TRIAL	\$23	\$0	None claimed by farmer
TOTAL EXPENSES:	\$17,916	\$17,916	

FIRST PAYMENT AMOUNT RECEIVED: \$16,124

TOTAL OWED FOR FINAL PAYMENT: \$1,792

Justification for Variances: *Please summarize and provide justification for any variances between budgeted and actual expenses. This includes explanation for funds not spent, or how expenses beyond what were budgeted were covered.*

- USD prices based on average exchange rate for 2020 of 0.7462.
- For expenses charged Canadian Harmonized Sales Tax (HST) of 13%, EFAO expensed 30.31% of the HST. Example: 5/6 farmers charged HST, which is why the \$6,000 CND does not equal \$6000*0.7462.
- Budget for outreach materials exceeded budget, with the publication of the research announcement in the EFAO's print publication.
- Equipment and rental costs were generally in-line with budget, except for greenhouse rental costs which were less than budgeted. This was because the onset of the pandemic disrupted the farmers' greenhouse plans and reduced their rental costs for the pepper and broccoli trials.
- The farmer incurred no cost for broccoli seed and the farmer did not submit receipts for giberellic acid for the cucumber trial.
- Due to travel restrictions during the pandemic, we were unable to spend the travel and mileage funds.

RESEARCH REPORT

Southern Ontario Participatory Pepper Breeding Project

Farmer-Researchers

Annie Richard & Kathy Rothermel
Kitchen Table Seed House
Frontenac County

Greta Kryger
Greta's Organic Gardens
City of Ottawa

Rebecca Ivanoff
Pocket Seeds
Wellington County

Kim Delaney & Aaron Lyons
Hawthorn Farm Organic Seeds
Wellington County

IN A NUTSHELL

Continuing our work that began in 2016, members of the SeedWorks Plant Breeding Club worked together to breed and release an early, blocky sweet red pepper with good

flavour that is adapted to ecological growing systems in southern Ontario. We continue to select for a yellow sweet bell pepper for release in fall 2021/winter 2022.

MOTIVATION

If you were a farmer 100 years ago you were also a seed saver and, as part of this process, you were also adapting and selecting seed for your preferred agricultural and cultural qualities. Many farming communities have never lost this skill, especially where traditional or peasant agriculture remains. In places like Ontario, where the industrial agricultural system is dominant, farmers like us are reclaiming the knowledge of selection to create varieties that are adapted to changing climatic conditions and the complex environmental stresses that are present in organic and low-input systems. As farmers who have direct contact with those who cook and eat the food, we are producing selections that also have the right characteristics for high quality food (1).

Growing seed, we are acutely aware of the realities of a changing climate, like late killing frosts, hail

storms, increased frequency of heavy rains, periods of extreme heat, and extreme temperature fluctuations. These challenges are further compounded by their influence on the spread, growth, and survival of crop pathogens (2). Breeding for performance under a changing climate is a difficult objective because of its "complexity, its unpredictability, and its location specificity" (3). One strategy is to increase the agrobiodiversity within our fields and farms - as well as within our varieties.

Genetically diverse, locally adapted, and locally celebrated plant populations have been historically maintained by farmers worldwide, though these populations are currently threatened (4). Inspired by the work of Farmer Agricultural Research Committees (known as CIALs) in Honduras, our Haudenosaunee farming neighbours in the region, and the work of Raoul

Robinson, Carol Deppe, and Joseph Lofthouse, the SeedWorks Plant Breeding Club breeds vegetables that are locally adapted to southern Ontario, that are great tasting and have broad genetics, and that can flourish in low-input agricultural systems during a time of climate change.

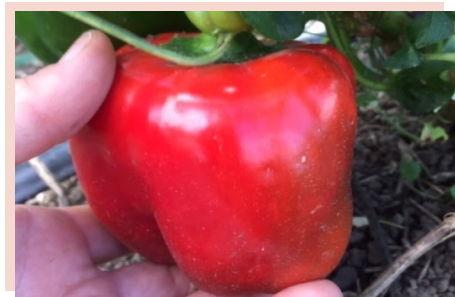


Photo 1. The first pepper to ripen in the mass population grow-out at Kitchen Table Seed House, Aug 18th, 2020.



The five of us began working together after meeting at events organized by the Bauta Family Initiative on Canadian Seed Security. We chose to focus on an early maturing, blocky, sweet bell pepper because all of us had experiences that told us that this was a gap in what was available to organic market growers. The breeding need for this type of pepper also came up in the Northern Organic Vegetable Improvement Collaborative (NOVIC) and the *Canadian Organic and Ecological Plant Breeding Priorities For Vegetable Crops* report by the Bauta Family Initiative on Canadian Seed Security, which found that the key traits for improvement for peppers were productivity/yield (including larger fruits), eating quality, and earliness.

With this focus, our pepper project started in 2016 using seed from a cross made between commercial varieties Ace F1 and Aristotle F1 by Rachel Hultengren, a graduate student in Dr. Michael Mazourek's breeding program at Cornell University. She chose these two hybrids because they represented the earliest ripening (Ace F1) and the most blocky red pepper (Aristotle F1) as identified through the work of NOVIC - a collaboration among Cornell University, University of Wisconsin-Madison, Oregon State University, and the Organic Seed Alliance (5). We grew the first crosses in Ottawa, Wolfe Island, Battersea, and Acton.

In Autumn 2018, we formed the SeedWorks Plant Breeding Club; and this project, along with other breeding work, continues forward under its auspices. The 2020 season was the fifth year we grew the Ace F1 x Aristotle F1 cross at three different locations in the province (this year in Ottawa, Wolfe Island, and Palmerston).

OBJECTIVES

In spring 2020, our objectives for this project were to:

1. Release a genetically diverse but relatively uniform, flavourful, red bell pepper bred for organic field conditions;
2. Release a uniform flavourful red bell pepper suited for organic field conditions;
3. Release a uniform flavourful yellow bell pepper suited for organic field conditions.

DESIGN

Kim Delaney and Greta Kryger are owners of two of the oldest organic seed companies in Ontario. Annie Richard and Kathy Rothermel operate a new successful seed company, with over 30 years of cumulative farming experience. Rebecca Ivanoff farmed organic vegetables for 7 years, is currently the Ontario Coordinator for the Bauta Initiative on Canadian Seed Security, and grows crops at the community gardens at Ignatius Farm. All farms are certified organic.

Objective 1 - Mass Selected Red Pepper

1a) From seed saved from our mass-selected red peppers in 2019, Annie sowed 90 plants on April 4, 2020 and Greta sowed 120 on March 29, 2020. They separated the mass selected population from all other populations/varieties on their farm and neighbouring farms by at least 45 meters. Annie transplanted June 3 and Greta on June 10. Annie and Greta planned to plant Ace F1 and Aristotle F1 as checks but this was not possible (see Findings for more details).

1b) We further compared Renegade Red against other commercial varieties as part of the Canadian Organic Vegetable Improvement (CANOVI) Project - a collaboration between the Centre for Sustainable Food Systems at the University of

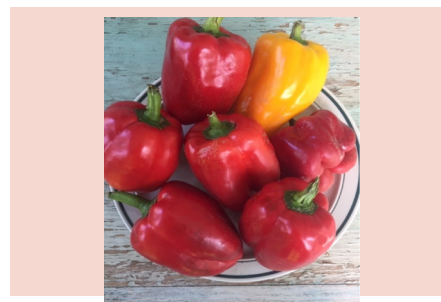


Photo 2. "Varietal" photo of the selected peppers of mass population in 2020. This photo is used on the Kitchen Table Seed House online store. Since the seed will occasionally produce yellow peppers, we chose to include the yellow pepper in the profile photo.

British Columbia and the Bauta Family Initiative on Canadian Seed Security. Specifically, Annie on Wolfe Island, along with two other farms near Kitchener and Thunder Bay, grew Yankee Bell, King Arthur, King Crimson, Ace, King of the North (Fedco strain), Red Knight, and Sprinter. Annie planned to use the Ace plants from these trials as check varieties for the mass selected population at Kitchen Table Seedhouse (see Findings for more details).

Objective 2 - Uniform Red Pepper

In hopes of speeding up the breeding process, Annie planned to grow the red progeny lines out in a heated greenhouse over the winter of 2019-2020. She then planned to plant out the best of the red progeny lines in 2020, cover to allow peppers to self pollinate, observe which of these lines have the most uniformity in plant architecture, early maturity, pepper shape and size, and test which is most flavourful.

Objective 3 - Uniform Yellow Pepper

Kim also planned to work with a local grower with a heated greenhouse to grow our favourite 2019 yellow progeny lines during the winter of 2019-2020, grow them out and continue the selection process in 2020.



FINDINGS

Objective 1 - Mass Selected Red Pepper

1a) As planned for 2020, we saved seed from our favourite blocky, flavourful, red peppers from within this population for 2021 stock seed. We also harvested seed from additional early ripening, blocky flavourful peppers, which could be sold when these seeds were released in winter 2020. At Annie's, there were 4 plants of yellow peppers within this population of 90 plants this season. The first ripe red peppers were observed on August 18, 2020, or 76 days after transplant or days to maturity (DTM). At Greta's, she observed no plants with yellow peppers within her population of 120. Greta observed the first ripe fruit on August 10, or 61 days after transplant (DTM). They selected sweet and crunchy peppers from the best 7 peppers as stock seed. For distribution to the seed houses, Greta also collected seeds from the next 15 best peppers. '

Unfortunately, the mass-selected red pepper population at Kitchen Table Seed House was hit by an early first frost in September. The leaves died and only a handful more peppers managed to ripen after that. Up to this point, Annie had collected a big bin full of fruit that matched the red blocky and early characteristics. She tasted each fruit and saved the seeds from only the really tasty ones, tossing the bland ones to the compost. All in all, Annie was unable to save as many seeds as she had planned; from Kitchen Table Seed House we ended up with only about 100 packets of 25 seeds each from the mass selected red pepper population.

Unlike previous years, due to the global pandemic, we were unable to hold blind taste tests with consumers and friends to confirm more broadly that selections are more flavourful than other red

pepper varieties. However, we tasted each pepper before choosing to save seed from it.

To add insult to injury for the year, the CANOVI trials at Kitchen Table Seed House were destroyed by the severe hail storm on June 7, 2020. This set-back not only reduced the number of sites for this provincial trial to two, but also meant that Annie did not have any checks for comparison. In addition, Greta was not able to order Ace and Aristotle seed, so was also unable to plant check varieties in 2020. Not having checks does not change how the selection process would happen, but it does mean that we could not observe how different our selections were from the parents in this cross.

In the fall of 2020, our early-maturing, blocky red bell pepper with broad genetics was released commercially as 'Renegade Red' pepper. 'Renegade Red' is pledged with the Open Source Seed Initiative (OSSI) and available for the 2021 growing season from Kitchen Table Seed House and Greta's Organic Gardens.

1b) In the CANOVI trials, the mass selection had 84 DTM (4 days longer than Ace) at one farm in Zone 5b, and 92 DTM (same as Ace) in Zone 3a. This was a lot longer than was experienced at Kitchen Table Seed House (76 DTM) and at Greta's Organics (61 DTM).

Objective 2 - Uniform Red Pepper

Due to novel and unexpected shifts in priorities at the beginning of the global pandemic, Annie had to move the red progeny lines that she had planted in the heated greenhouse during the winter of 2019-2020 before they had produced ripe peppers. This meant that in spring 2020, she planted 12 plants from the best two red lines (lines # 2 and #22) from summer 2019 instead of having one season of further selection over the winter.

Unfortunately, the peppers from the red progeny lines were destroyed by the hail storm at Kitchen Table Seed House on June 7, 2020. The leaves on the plants were shredded by the hail leaving only the main stems. Nevertheless Annie left the plants to see if they would bounce back. They did indeed, only to be attacked by caterpillars. It was not a good year to be a pepper on Wolfe Island! Luckily, there were a few fruits that managed to ripen that Annie harvested and saved seed from. Given the difficult year for progress with the red progeny lines, and after conversations with others in the seed community, we decided to discontinue our work with the red progeny lines and focus on the mass selected red pepper population and the yellow pepper lines. Specifically, our mentor Michael Mazourek and colleague Daniel Brisebois are planning to release pure line red peppers that came from the same Ace and Aristotle cross. Further, we feel that the mass selected peppers with broad genetics are more in line with our current desires for varieties with broad genetics (i.e. landraces).

Objective 3 - Uniform Yellow Pepper

Due to unprecedented demand for seed at the beginning of the pandemic in early 2020, Kim was also unable to secure a spot to grow the yellow progeny lines in a heated greenhouse. During the summer of 2020, Kim planted lines G1, K1, K2 of the yellow progeny lines, while Greta planted lines G1 and G2 with 12 plants each under row cover so that they self-pollinated. Kim had space for about 65 of each of these lines, all of which she kept under row cover.

We saved seeds from all lines but concluded yellow progeny line G1 performed the best at both locations. We also identified the best plants in lines that were most uniform and flavourful to grow out in 2021.



Table 1. Planting details and date to first ripe fruit for the SeedWorks pepper lines.

	Red Progeny Lines at Kitchen Table Seed House (Lines # 2 and #22)	Red Mass Population at Kitchen Table Seed House	Red Mass Population at Greta's Organics	Yellow Progeny Lines at Greta's Organics (Lines G1 and G2)	Yellow Progeny Lines at Hawthorn Farm Organic Seeds (Lines G1, K1, K2)
Date seeded	April 4	April 4	March 29	March 29	April 2
Date transplanted into the field	June 2	June 3	June 10	June 10	June 12
Number of plants transplanted	8 of each	90	120	12 of each	200 (three lines G1, K1, K2)
Date of first ripe fruits (Days to Maturity)	n/a	August 18 (76 DTM)	August 10 (61 DTM)	August 10 (61 DTM)	September 3 (83 DTM)

TAKE HOME MESSAGE

We achieved a significant milestone with the commercial release of 'Renegade Red,' an open pollinated, early-maturing, blocky red bell pepper. To do this, we selected the Open Source Seed Initiative (OSSI) model for 'Renegade Red,' as the OSSI pledge "preserves the rights of farmers, gardeners, and breeders to freely use, save, replant, and improve seed" of this variety while preserving SeedWorks' ability to maintain its quality and identity.

NEXT STEPS

During the 2021 season, we are growing Renegade Red for seed at Kitchen Table Seed House and Greta's Organics, and continue to select the peppers that mature the earliest and taste the best. We also continue to feel strongly that heterogeneous food crops with broad genetics are needed as we face climate change, and are excited to be able to talk about this when describing our newly released Renegade Red pepper population!

In addition to Renegade Red, we continue to select uniform progeny lines of blocky yellow peppers. We are growing out the G1 line (variety name to be decided) at Hawthorn Farm Organic Seeds, Kitchen Table Seed House, and Greta's Organics during the 2021 season. During this season, Pocket Seeds is doing a variety trial of the G1 line compared to other field bell peppers (Admiral F1, Brocanto F1, Elsa F1, Golden California Wonder, Sweet Sunrise F1) recommended by farmers and organic seed companies. We plan to release a yellow progeny line in late fall 2021 and plan to also protect this line through an OSSI pledge.

We continue to work together to breed other vegetable crops on our farms in partnership with the plants themselves and our generous seed community.



Photo 3. SeedWorks Plant Breeding Club members Rebecca Ivanoff, Greta Kryger, Annie Richard and Kathy Rothermel (missing Kim Delaney) in 2017.



This project was funded by Organic Farming Research Foundation



Photo 4. Pepper plants covered at Kim Delaney's farm in 2019.



Photo 5. Example of Renegade Red compared to parent varieties Aristotle and Ace ca. 2019.

ACKNOWLEDGEMENTS

We'd like to thank the peppers for participating in this co-evolutionary dance with us, and to all those who have saved seeds from these peppers over the last 6,500 years as they have travelled from hand to hand around the globe. We'd like to thank our colleague Michael Mazourek for teaching us some of the dance steps to this process, and to Rachel Hultengren for doing the initial cross at the start of this project. We'd also like to thank the Bauta Initiative on Canadian Seed Security for creating opportunities for learning together which led to the formation of SeedWorks Plant Breeding Club, and the Ecological Farmers Association of Ontario for supporting us in creating protocols and financially through researcher stipends.

REFERENCES

1. Dawson, J.C., P. Rivière, J.F. Berthelot, F. Mercier, P.D. Kochko, N. Galic, S. Pin, E. Serpolay, M. Thomas, S. Giuliano, & I. Goldringer (2011). Collaborative plant breeding for organic agricultural systems in developed countries. *Sustainability*, 3(8), pp.1206-1223. <https://www.mdpi.com/2071-1050/3/8/1206>
2. Rosenzweig, C., A. Iglesias, A.B. Yang, P.R. Epstein & E. Chivian (2001). Climate change and extreme weather events - implications for food production, plant diseases, and pests *Glob. Change Hum. Health*, 2 (2001), pp. 90-104 <https://link.springer.com/article/10.1023/A:1015086831467>
3. Ceccarelli, S. & S. Grando (2020). Evolutionary Plant Breeding as a Response to the Complexity of Climate Change, *iScience*, Volume 23, Issue 12, <https://doi.org/10.1016/j.isci.2020.101815>. (<https://www.sciencedirect.com/science/article/pii/S2589004220310129>)
4. Maxted, N., J.M. Brehm, & S. Kell (2013). Resource Book for the *Preparation of National Plans for Conservation of Crop Wild Relatives and Landraces*. Food and Agriculture Organization of the United Nations. Retrieved February 18, 2021, from http://www.fao.org/fileadmin/templates/agphome/documents/PGR/PubPGR/ResourceBook/TEXT_ALL_2511.pdf
5. Hultengren, R.L. (2017). Establishing Breeding Priorities And Developing Cultivars For Organic Vegetable Growers In The Northeast. MSc Thesis. Cornell University. Ithaca, New York. <https://doi.org/10.7298/X4>