Introduction/Overview

Organic growers need vegetable varieties that are adapted to organic growing conditions and have market qualities desired by organic consumers. In carrots, weed competition, nutrient acquisition, parasitic nematodes, and disease pressure are particularly critical challenges faced by farmers. The Carrot Improvement for Organic Agriculture 2 (CIOA 2) builds upon accomplishments of the CIOA 1 project funded by the USDA ORS. Plant breeding is a long-term effort and the proposed project will maximize impacts of prior research by delivering new, improved carrot cultivars and breeding lines to the organic seed industry and developing new breeding populations that combine valuable traits identified during CIOA 1.

The long-term goals of CIOA 2 are to:
1) deliver carrot cultivars with improved disease and parasitic nematode resistance, improved nutrient acquisition, preferential vigor, and weed competitiveness traits, increased marketable yield superior nutritional value, flavor and other culinary qualities, and storage quality for organic production;
2) determine how carrot genotypes interact with, or influence, the root microbiome to assess the impact of different environments and treatments on this association;
3) inform growers about carrot cultivar performance to maximize organic carrot production, markets, and organic seed usage;
4) inform consumers about the positive environmental impacts of organic production systems and about carrot nutritional quality, flavor and culinary attributes; and
5) train undergraduate and graduate students and post-doctorates in issues that are critical to organic agriculture.

Cultivar Development

During this project, we are advancing all stages of the carrot breeding “pipeline” from initial screening of material to delivering finished cultivars. Several populations evaluated in CIOA 1 hold promising combinations of traits, including visual aspects of yield and flavor and genetic potential, but they are still too phenotypically diverse for commercial release. These populations are being refined in CIOA 2 with the goal of delivering elite materials for future carrot cultivar development by the end of the project. In 2018, 61 advanced breeding lines are being tested at 12 locations across the U.S. and Canada. We will release commercially two new open-pollinated colored carrot varieties—one that is a stunning coral colored purple carrot with deep purple skin, purple to orange flesh and an orange core; the other is a beautiful cylindrical red carrot with bright red skin and flesh and a yellow cambium surrounding a red core. Both have been selected for flavor, vigorous top growth, and anterior production under organic conditions and are being evaluated for release to the seed industry.

We are also making new crosses to develop new breeding populations. In response to stakeholder interest, we are creating a highly diverse population that incorporates a “rainbow” of carrot colors. More than 310 breeding populations are being advanced in the breeding program this year. At least six new populations, including the “rainbow mix,” will be developed and seed will be provided to organic seed companies and participatory farmer-breeders in the final year of the project. In conjunction with population release, we will add a CIOA 2 release setting in the fundamentals of organic carrot breeders to facilitate the successful stewardship and continued creative efforts of these new populations. Finally, the USDA collection includes over 500 accessions of geographically and genetically diverse carrot germplasm. Most of this material has been evaluated for bolting sensitivity, nutritional quality, flavor, and preliminary root and top quality but not evaluated in organic systems or for additional traits prioritized for organic production. Each year we are screening this USDA collection in two organic research locations for potential breeding and selection work for 7 years.

On-Farm Trialing

We are conducting on-farm trials with organic farmers and organic seed companies in five regions across the US to assess variety performance under diverse environments, solicit farmer input to inform breeding activities, and train farmers in on-farm variety evaluation. These sites serve as a national testing network for evaluating new cultivars and breeding populations. We are also evaluating advanced populations from replicated research station trials in Wisconsin and Washington. Flavor analysis is conducted each year on all entries. A more comprehensive sensory analysis is conducted each year on a selection of entries from the research station trials in Washington and Wisconsin.

Selection for carrot flavor will be exercised in promising breeding lines. Organoleptic evaluation of the trial entries is performed on all selected root samples, scoring them on a 1-5 scale for sweetness (from not sweet to very sweet), harshness (tart to harsh or turpentiney) and texture (dry or tough to juicy). Selected carrots are being used for subsequent seed production, aiming to select a set of the 12 most promising lines. Between 900 and 1,000 breeding populations are being evaluated for flavor in 2018. Project collaborators receive training to perform flavor analysis and secondary flavor evaluation is being conducted for the selected lines in both Wisconsin and Washington.

Multivariate analysis will be used to analyze the relationship among varieties using their entire flavor profile based upon evaluations by participating project chefs. To secure varieties will be chosen by chefs to participate in a sensory evaluation exercise known as “Project Passport” whereby they independently taste each sample and place the samples on a mapping sheet according to their perception of similarity and dissimilarity. These chef evaluations will be used to produce a consensus map based on their comments and preference ratings to rate flavor of advanced carrot breeding populations in CIOA 2.

Flavor

Assessment of carrot flavor is being integrated into all germplasm evaluations and breeding activities. Flavor is a priority trait necessary for the successful adoption of new cultivars with quality agronomic traits and improved flavor profiles. These advanced populations are being advanced for release to the seed industry.

We aim to identify if organically-grown carrot cultivars hold more from some AMPF species compared to others during water- limiting soil conditions (Figure 2). From our results indicated that soil type is the dominant factor affecting the composition of root carrot microorganisms, the carrot genotype also plays a role, indicating that it may someday be possible to select for beneficial root microbial relationships.

In CIOA 2, we aim to determine whether carrot genotypes differ in their potential to scavenge nitrogen (N) and limit heavy metal uptake, and investigate which root microorganisms play a role in these processes. Obtaining sufficient nitrogen (N) during critical periods of plant growth is a challenging task in organic and low-input farming systems, because most fertility sources must mineralize before they are available for plant uptake. The soil nitrogen cycle is a microbiologically-mediated process and plants can affect this process via interactions with root-associated microbes. At the same time, enhancing bioavailability and uptake of heavy metals in contaminated soils, which can also be microbiologically-mediated, can negatively influence plant and well as human health. Vegetable production in urban areas and other sites where heavy metal contamination can occur is increasing worldwide, and has become an important food safety consideration.

To accomplish our research aims, we are evaluating a diverse set of carrot genotypes in greenhouse trials and using organic substrates labeled with 15N to track mineralization and uptake of N, ICMS to quantify heavy metal uptake, and 16S/15S amplicon sequencing to quantify root microbiomes. We are also working with engineers to identify spectral images that can detect heavy metal contamination in carrot foliage.