CIOA 2 – Carrot Improvement for Organic Agriculture with Added Grower and Consumer Value

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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 to fresh market carrots. **Carrot Improvement for Organic Agriculture 2 (CIOA 2)** builds upon accomplishments of the CIOA 1 project funded by the USDA OREI. 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 trade; 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, seedling vigor and weed competitive 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 access key nutrients under limiting environments and limit heavy metal uptake;

3) inform growers about 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.

United States Department of Agriculture | National Institute of Food and Agriculture

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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 CIOA1 hold promising combinations of traits, including visual appeal, flavor, and agronomic potential, but they are still too phenotypically diverse for commercial release. These populations are being refined in CIOA2 with the goal of delivering elite materials for future 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 conical shaped 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 superior production under organic conditions and are being advanced 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 210 breeding populations are being advanced in the breeding program in 2018. 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 these population releases *we will host a 2-day, hands-on training in the fundamentals of organic carrot breeding to facilitate the successful stewardship and continued breeding efforts of these novel 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 3 years.*

POr1129 to be released

R6636 to be released

Example of rainbow population

New novel population

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 efforts, and train farmers in on-farm variety evaluation. These sites serve as a national testing network for evaluating cultivars that are ready for release and elite materials across highly diverse climates. Farmers and seed company representatives participate in evaluation of these trials to facilitate variety descriptions and recommendations for release, and provide feedback on additional improvements for regional adaptation. ***We train farmers in carrot breeding methods by having farmers participate in root selection and on-farm plant breeding.*** The effectiveness of on-farm trial methods is being evaluated from both research and social learning perspectives. We are comparing various trial plot designs, evaluating statistical significance of data collected, and interviewing farmer and researcher participants to assess the social value of participation in on-farm trials. In the final year of the project we will evaluate the results of the regional (decentralized) versus research station (centralized) selections in replicated trials at the five on-farm participatory host sites and at the Wisconsin and Washington research station sites. The results from these trials will be utilized to assess the gains from selection in decentralized versus centralized selection activities, and to advise future breeding efforts for the resulting populations.

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. *Sensory analysis, including flavor, texture and culinary quality, is being conducted on advanced materials harvested* 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 Wisconsin and Washington.

Selection for carrot flavor will be exercised in promising breeding lines. *Organoleptic evaluation of the trial entries is being performed on all selected roots*, scoring them on a 1-5 scale for sweetness (from not sweet to very sweet), harshness (mild 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. *Six carrot varieties will be chosen for chefs to participate in a sensory evaluation exercise known as "Projective Mapping"* 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.

Mycorrhizae

Arbuscular mycorrhizal fungi (AMF) interact with host plants by colonizing host roots, forming structures called arbuscules (Figure 1). Arbuscules facilitate the movement of water and nutrients, most notably phosphorus, in exchange for plant-derived carbon. AMF can boost host performance and increase growth.

We aim to identify if organically-grown carrot cultivars benefit more from some AMF species compared to others during water-limiting soil conditions (Figure 2).

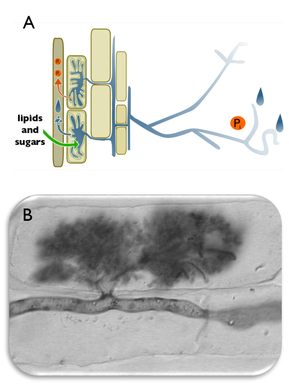

Figure 1. (A) Diagram of nutrient and water flow to host from fungus in exchange for plant-derived carbon; (B) Arbuscule in a plant root cell.

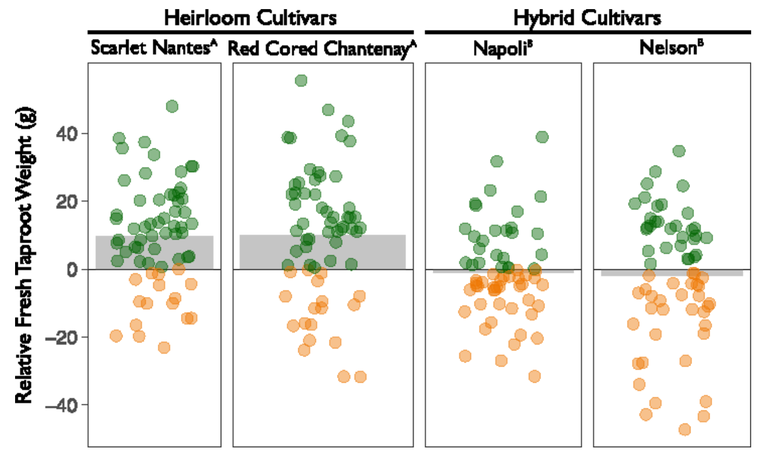

Figure 2. Four organic field studies revealed that heirloom cultivars responded more positively to inoculation than hybrid cultivars across experiments, regardless of late-season water restriction or mycorrhizal isolate. Dots represents mean taproot weight gains (green) or losses (orange) for inoculated cultivars relative to mock-inoculated controls for each treatment within each experiment. Bars show overall means for all experiments combined; $n \leq 24$, type-III Two-way ANOVA followed by Tukey's HSD, p-value < 0.001; differing superscript letters indicate differences.

Nitrogen and Heavy Metal Uptake

During CIOA1, we demonstrated that many microbes inhabiting carrot roots have potential to alter root architecture, fix nitrogen, solubilize phosphorous, scavenge iron, and help plants withstand pathogen stress. While our results indicated that soil type is the dominant factor affecting the composition of carrot root microbiomes, the carrot genotype also plays a role, indicating that it may someday be possible to select for beneficial root microbial relationships.

In CIOA2, we aim to determine whether carrot genotypes differ in their potential to scavenge nitrogen (N) and limit heavy metal uptake, and investigate which root microbiomes play a role in these processes. Obtaining sufficient nitrogen (N) during critical periods of plant growth is challenging 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 microbially-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 microbially-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, ICP-MS to quantify heavy metal uptake, and 16S/ITS 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.

Carrots grow behind a cover crop at South Circle Farm near downtown Indianapolis

Examples of different microbial taxa isolated from carrot roots