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

Philipp Simon (PI), *United States Department of Agriculture, Agricultural Research Service and University of Wisconsin–Madison*; Micaela Colley, *Organic Seed Alliance*; Lindsey duToit, *Washington State University*; Lori Hoagland, *Purdue University*; Sahar Abdelrazek, *Purdue University*; Laurie McKenzie, *Organic Seed Alliance*; Joe Nunez, *University of California Cooperative Extension*; Philip Roberts, *University of California–Riverside*; Erin Silva, *University of Wisconsin–Madison*; Michelle Keller-Pearson, *University of Wisconsin–Madison;* Tim Waters, *Washington State University*; Jared Zystro, *Organic Seed Alliance*; Cathleen McCluskey, *Organic Seed Alliance*

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## Introduction/Overview

Organic growers need vegetable varieties that are adapted to organic growing conditions and have market qualities demanded by organic consumers. In carrots, weed competition, nutrient acquisition, 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; developing new breeding populations that combine critical traits identified during CIOA 1.

The long-term goals of CIOA 2 are to:

**1) deliver carrot cultivars** with improved disease and 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 critical organic agriculture issues.

USDA United States Department of Agriculture · National Institute of Food and Agriculture

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## Cultivar Development

During this project, ***we will advance 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 diverse phenotypically for commercial release. These populations will be refined in CIOA2 with the goal of delivering elite materials for future cultivar development by the end of the project. ***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.*

***We will also make new crosses to develop new breeding populations***. In response to stakeholder interest, *we will create a highly diverse population that incorporates a "rainbow" of carrot colors*. 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 will screen this USDA collection in two organic research locations for potential breeding and selection work.*

POr1129 to be released

R6636 to be released

Example of rainbow population

New novel population

## On-Farm Trialing

***We will conduct 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 will 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 will participate in evaluation of these trials to facilitate variety descriptions and recommendations for release and to provide feedback on additional improvements for regional adaptation. ***We will also 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 will be evaluated from both research and social learning perspectives. We will compare various trial plot designs, evaluate statistical significance of data collected, and interview farmer and researcher participants to assess the social value of participation in on-farm trials. In the final year of the project we will conduct an evaluation of 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 will be 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 will be conducted on advanced materials harvested* from replicated research station trials in Wisconsin and Washington. Flavor analysis will be conducted each year on all entries. A more comprehensive sensory analysis will be conducted each year on a selection of entries in 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 will be 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 will be used for subsequent seed production, aiming to select a set of the 12 most promising lines. Project collaborators will be trained to perform flavor analysis and secondary flavor evaluation will be 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 using their comments and preference ratings to rate flavor of advanced carrot breeding populations in CIOA 2.

## Mycorrhizae

Arbuscular mycorrhizal fungi (AMF) beneficially 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 sugars. AMF can boost host performance during drought and other stresses.

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).

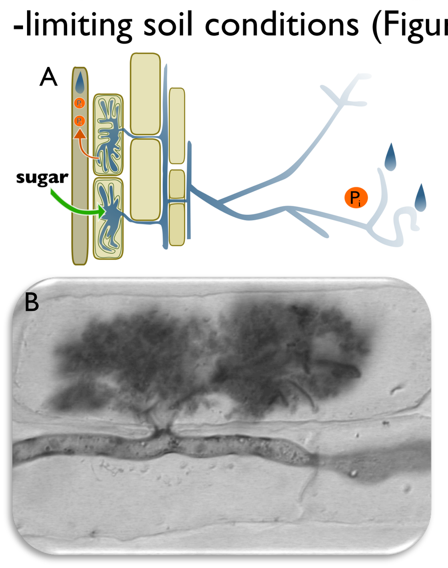


**Figure 1.** (A) Diagram of nutrient and water flow to host from fungus in exchange for plant-derived sugars;
(B) Arbuscule in a plant root cell.

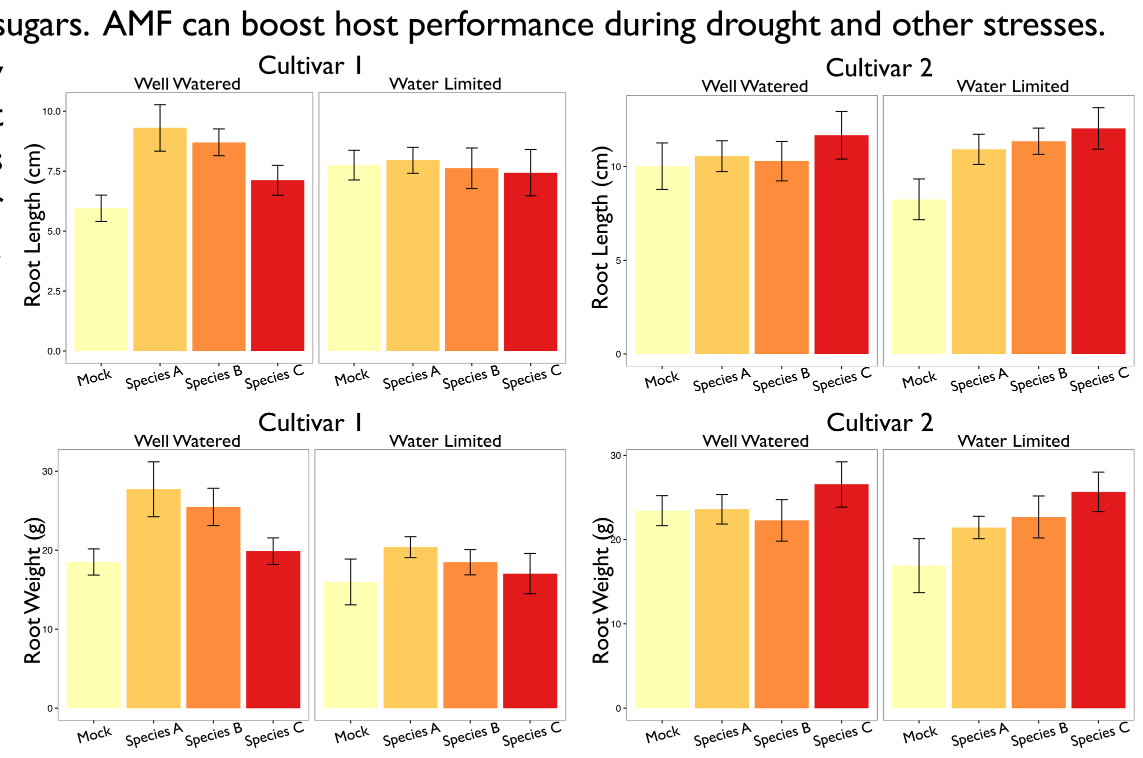


**Figure 2.** In a greenhouse study (n=6; preliminary data shown) comparing cultivar performance under varying soil water regimes, cultivars differed in their response to water limitation. Carrots were grown in pasteurized organic soils inoculated with arbuscular mycorrhizal species. Benefits to carrot growth differed according to cultivar-mycorrhizal species pairing. Cultivar 1 reaps the greatest mycorrhizal rewards during well-watered conditions whereas cultivar 2 benefits when soils are more dry.

## Nitrogen and heavy metal uptake

Uptake of sufficient nitrogen (N) during critical periods of plant growth is challenging in organic farming systems. At the same time, as production in urban and marginal areas increases worldwide, heavy metal uptake from contaminated soil has become an important food safety consideration. Root traits including architecture, plasticity, rhizodeposition, and interaction with soil microbes that mineralize organic materials and/or fix atmospheric N have potential to improve N acquisition and influence heavy metal uptake. We have observed differences in root architecture and microbial community structure among carrot genotypes (Abdelrazek and Hoagland, unpublished). Genotypic differences in N and heavy metal uptake have also been observed in carrot, but their relationship with various root characteristics has not been determined.

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

*Specific goals of this CIOA project component include:*

•Identifying carrot genotypes that can acquire N efficiently while limiting heavy metal uptake in low-input systems.

•Identifying carrot root characteristics that facilitate N acquisition and restrict heavy metal uptake.

•Identifying practical approaches to integrate selection for beneficial root ideoptyes into carrot breeding programs.

To accomplish these goals, we are evaluating a wide range of carrot germplasm and tracking N and carbon (C) partitioning among soil and root components using stable isotopes ($^{13}$C and $^{15}$N). Functional root characteristics are being identified using root imaging, analytical chemistry and microbial community profiling.

Examples of different microbial taxa isolated from carrot roots