CIOA 3

Carrot Improvement for Organic Agriculture with Added Grower and Consumer Value

Introduction/Overview

Organic growers need varieties that are adapted to organic growing conditions and markets. Plant breeding is a long-term effort and Carrot Improvement for Organic Agriculture 3 (CIOA 3), funded by the USDA-OREI program, 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 and 2.

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The long-term goals of CIOA 3 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) leverage healthy soil microbiomes to promote nutrient use efficiency, prevent pests, and improve the nutritional quality and storability of carrot roots;

3) inform growers about cultivar performance to maximize organic carrot production, markets, and organic seed usage;

4) inform consumers about the positive environmental impact of organic production systems and about carrot nutritional quality, flavor, and culinary attributes; and

5) train undergraduate, graduate, and post-doctorate students in critical organic agriculture issues.

Cultivar Development

We are advancing the breeding "pipeline" from initial screening of material to delivering elite breeding lines and finished cultivars. We will release several new open-pollinated colored carrot varieties with stunning combinations of purple, yellow, red, orange colors selected for flavor, vigorous top growth, and superior production under organic conditions.

We are also developing new breeding populations, including a highly diverse population that incorporates a "rainbow" of carrot colors. Breeding populations, including the "rainbow mix", will be provided for testing to organic seed companies and farmer-breeders. The USDA collection includes over 500 accessions of geographically and genetically diverse carrots. Most of this has been evaluated for bolting sensitivity, nutritional quality, flavor, and preliminary root and top quality, but not in organic systems or for traits prioritized for organic production. We are screening this collection in organic research locations to generate information for breeding.

POr1129 to be released

Example of rainbow population

R6636 to be released

Participatory Trialing

We conduct on-farm trials with organic farmers and organic seed companies across the US to assess variety performance, solicit farmer input, and train farmers in on-farm variety evaluation. Coordination of trials through SeedLinked online platform facilitates broad participation and sharing of trial results. This testing network evaluates cultivars that are ready for release as well as elite materials across highly diverse climates. Farmers and seed company feedback guides recommendations for release, and provides additional suggestions for improved qualities and regional adaptation.

Flavor and Texture

Flavor is a priority trait necessary for the successful adoption of new cultivars. Sensory analysis, including flavor, texture and culinary quality, is being conducted on advanced materials harvested from replicated trials in Wisconsin and Washington.

Organoleptic evaluation of the breeding lines is being performed on all selected roots, scoring them on a 1-5 scale for sweetness (from not sweet to very sweet), harshness (harsh or turpentiney to mild) and texture (dry or tough to juicy). Selected carrots are being used for subsequent seed production and breeding. Using the least squared means generated for the variety:location:treatment interaction through the mixed model ANOVA, a principal component analysis (PCA) will be performed to visualize the relationship among varieties using their entire quality profile

Carrot texture analysis methodology development is underway with the use of two high-resolution texture analyzers in evaluation of multiple factors that may affect phenotyping, especially root handling variables and tissue puncture logistics. The protocol has been implemented in phenotyping a small set of genotypes and will be expanded to a larger set to gain a broader understanding of the complexity of carrot texture and the underlying genetics.

Nematode resistance

Resistance traits for M. hapla, M. incognita and M. javanica were identified

Cultivar releases

More than 45 new populations advanced and number varieties released with various combinations of priority traits including improved flavor, nutrient concentration, color, top growth size and vigor, Alternaria Leaf Blight (ALB) resistance, nematode resistance, and cavity spot resistance.

Microbiome

Carrot roots are colonized by an abundant and diverse assortment of bacteria and fungi with greater diversity in organic management than conventional soils. Carrot genotype affected endophyte abundance in taproots and potential for individual isolates to affect seed germination, seedling growth, and ALB tolerance were evaluated.

On-farm Trial Network

A decentralized network of nearly 100 farmers trialed CIOA lines across the US and Canada and shared results through the SeedLinked platform (www.seedlinked.com)

Outreach

A project website hosted through eOrganic served to disseminate research updates, timely articles, and related project events (http://eorganic.info/carrotimprovement). The Organic Seed Commons networking site also serves to share outreach, convene carrot conversations and deliver webinars in coordination with eOrganic (www.organicseedcommons.org)

Learn more about this project on the CIOA page!

Microbiome

Rhizosphere research

One mechanism by which plants can recruit a beneficial microbiome is through varying the chemical composition of their root exudates. Using metabolomics (i.e., the high-resolution chemical characterization of low molecular weight carbon compoints), we have observed that novel carrot cultivars produced through CIOA3 release chemically distinct exudates into the soil that differentially recruit microbial communities near the root surface (i.e., the "rhizosphere") from the bulk soil. Some microbial taxa that were in especially high abundance in the rhizosphere were of obvious functional importance for plant health (for example, responsible for nitrogen mineralization). Ongoing work is determining how consistent these associations are across two different soil types using a more high-resolution approach to measure the metabolome across a gradient of breeding intensity.

Alternaria resistance

Alternaria dauci is a fungal pathogen of carrots that can dramatically reduce the yield and quality of carrot taproots. Consequently, we hypothesize that resistance to *A. dauci* is mediated, at least in part, by recruitment of a distinct set of microorganisms, and that suppressive activity will be greater in soils with greater populations of these microbes due to soil-building activities. To test these hypotheses, we are collaborating with organic carrot farmers to evaluate relationships between soil health, carrot root and leaf microbiomes, and resistance to *A. dauci* and other pathogens that could affect the yield and quality of carrot taproots. On-farm trials are underway in five diverse environments (WI, CA, VI, IN, MN). Another on-farm participatory trial is underway in IN, investigating whether foliar sprays can further modify carrot microbiomes and enhance disease resistance and end-use quality. Finally, greenhouse trials will be conducted to verify the role of carrot microbiomes in mediating nutrient uptake, *A. dauci* resistance, and end-use quality of roots.

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).

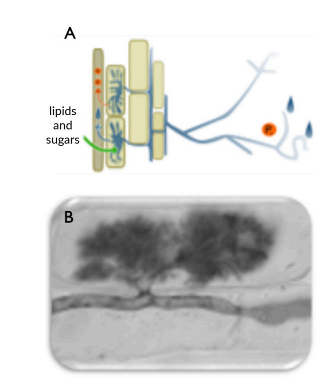

Figure 1. (A) Diagram of nutrient and water flow to host from fungus in exchange for plant-derived carbon; (B) Arbuscule in a plant root cell.

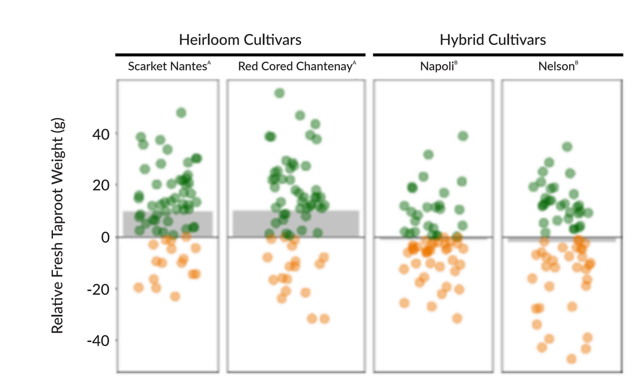

Figure 2. Four organic field studies revealed that heirloom cultivars responded more positively to inoculation than hybrid cultivars across experiments, regardless of late-season water restriction or mycorrhizal isolate. Dots represent mean taproot weight gains (green) or losses (orange) for inoculated 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.

Nematode Resistance

In CIOA 2 we identified several sources of resistance to nematodes, Meloidogyne incognita, M. javanica and M. hapla. We will continue screening diverse genotypes for resistance in infested field sites containing each species separately at University of California research stations in Parlier, Irvine, and Thermal, and the WSU Othello Research Farm. We will also develop resistance markers by isolating total genomic DNA from freeze-dried leaves, and GBS-derived SNP markers for the suite of nematode multi-species resistance QTL identified by the project team.

Trial carrot foliage

2024 carrots in El Centro, CA

Kevser Özel evaluating carrots

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