Carrot Improvement for Organic Agriculture with Added Grower and Consumer Value

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Introduction

Carrot Improvement for Organic Agriculture (CIOA) is a collaborative breeding project that addresses the critical needs of organic carrot farmers by developing orange and novel colored carrots for organic production. Organic carrot producers need varieties that germinate rapidly with good seedling vigor, compete with weeds, resist pests, are efficient at nutrient uptake, are broadly adapted to organic growing conditions and hold desirable market qualities for organic consumers. This includes superior nutrition and exceptional flavor. In addition to breeding for the key priority traits there is a need to better understand the genetic x environment interaction in organic versus conventional systems in order to advance knowledge of the desirable traits and production practices influencing optimum organic carrot production. The project will deliver improved carrot varieties; improved understanding of the influence of farming systems (organic versus conventional) on variety performance; and develop a breeding model adaptable to other crops for organic systems.

The CIOA website includes a searchable online gallery with information for organic carrot growers about performance of available cultivars and breeding stocks, as well as production practices and commercial availability. Updates of outreach activities, additional resources, and data gathered by this project can be found at **http://eorganic.info/carrotimprovement**.

Table 1. Performance and stability of breeding stocks in the CIOA breeding stocks noting nematode resistance, root weight, top size, and flavor

Entry	Nematode gall ratings (0=res. 8=sus)	Root Weight (1=small, 3=large)			Top size (1=small, 3=large)			Flavor (1= poor, 3 = very good)		
		Less stable		More stable	Less stable		More stable	Less stable		More stable
USDA large top/novel colored populations										
B0114	6-8		2			3		3		
B0191	6-8			3			2			2
B0252	2		3			1			1	
B1129	6-8			2			3			3
B6220	6-8			2			2	3		
B6306	6-8			1			1	1		
B6636	6-8		2				2			3
B8519	6-8			3			2	3		
B9244	6-9			2			1			3
Homs	1 – 4		3		2			1		
Ping Ding	0 - 4			3	2			1		
SFF	1 – 2			2		2				3
USDA nematode resistant/high carotene lines										
B3999	1-2	1			1			2		
B4001	1 - 2		1				1			2
B4002	0 - 1.5		1				2	2		
B8483	1 - 2	1			1			3		
B8503	1 – 1.5		2				2			3
B8524	0 – 2		2			2			3	
B8542	1 - 3			1		1				2

Approach & Methods

The CIOA project includes field trials in California, Indiana, Washington, and Wisconsin for four years in each state to evaluate the performance of 36 diverse carrot cultivars and breeding stocks for field performance (yield, appearance, leaf blight, nematode resistance) and consumer quality (flavor and nutrient content). The project also includes weed competitiveness trials in Wisconsin and Washington, nematode resistance trials in California, and on-farm trials of elite materials in all four states in the final two years. Variation in labile soil organic matter pools, soil microbial activity, and bacterial, fungal and archeal community composition are being quantified at each field site. Also, rhizosphere and endosphere community composition are being evaluated in a subset of carrot entries grown in one of the paired organic-conventional trials to improve understanding of the relationship between soil biological factors and carrot performance. In addition to these trials, research activities included in the CIOA project are expected to determine the genetic inheritance of resistance to nematodes and leaf blights, and further breeding efforts for improved resistance to these pests as well as competitiveness with weeds.

Trials were grown in 2011, 2012 and 2013 in paired organic and conventional locations in all four states. Each location was arranged as a randomized complete block design (RCBD) with 36 entries and three replications. The following traits were measured: plant width and plant height; number of bolting plants at harvest; root weight and top weight at harvest; and flavor. Nematode resistance was evaluated as described by Roberts (1988) and Roberts et al., (2005). Relative carrot top size was categorized by measurements at 35 days and 55 days after planting (or water date as appropriate) and at harvest. Flavor was categorized by a combination of root sweetness and harshness scores (Simon, 2000).

For all traits measured in all environments, analysis of variance (ANOVA) was calculated on plot means using PROC MIXED in the SAS statistics package (SAS Institute, Cary, NC). Trait = Year + Region + System + Year*Region + Year*System + Region*System + Year*Region*System + Entry + Entry*Year + Entry*Region + Entry*System + Entry*Year*Region + Entry*Year*System + Rep (Year*Region*System). Block effects were considered random, with all other effects fixed. For each trait, environments were pooled if there were no environment-by-entry effects, or if a Spearman rank correlation demonstrated that the interaction was due to a change in magnitude and not a change in rank. Prior to calculating mean squares, data were analyzed to ensure adequate normality and equal variance. If entry effects were significant, means and means separations were calculated. Because some entries had missing data or were not represented in all environments, means were calculated using the pdmix800 macro (Saxton, 1998) based on best linear unbiased estimators (BLUEs) using the following linear model that excluded the entry by environment interaction terms: Trait = Year + Region + System + Year*Region + Year*System + Region*System + Year*Region*System + Entry + Rep (Year*Region*System). To determine the relative stability of entries across environments, Shukla's stability statistic was calculated (Shukla, 1972; Cotes et al., 2002).

Results & Discussion

2015-16 is the fourth field season of the CIOA organic and conventional field trials. In the first three years of trials collaborators observed wide ranges in seedling growth rates and canopy sizes. Carrots are one of the slowest crops for growers to establish because of slow seedling growth rate. Once established, growth continues to be slower than most weeds, making weed control often the most expensive costs of organic carrot production. Variation in top height and mass (size) was significant, providing an opportunity to evaluate the role of variable carrot top size in competing with weeds. A weed competitiveness trial was conducted in 2014 and will be repeated in 2015 to further evaluate this trait.

Root color and flavor were also highly diverse in this collection. Novel root color presents organic carrot growers with a broader range of visual variation to attract consumers, and they provide consumers with important nutrients. Desirable flavor is critical to consumers, and often considered to be lacking, particularly in novel (non-orange) colored carrot germplasm. Superior flavor was noted in several CIOA project carrots, including both experimental entries and commercial cultivars.

Durable nematode resistance is critical for organic carrot production, particularly in California. Nematode gall ratings varied widely among entries and several entries demonstrated high levels of resistance. Alternaria leaf blight and other foliar diseases are major carrot pests in virtually all production areas of the world, but especially non-desert regions (du Toit et al., 2005). They injure leaf tissue, reduce photosynthetic area, and consequently reduce root yield and complicate harvest since carrot is commonly harvested by pulling plants from the soil by their tops. Incidence of Alternaria leaf blight varied widely among entries. Other diseases observed in some of the trials were bacterial blight, Cercospora leaf spot, and powdery mildew.

In addition to top height and top mass, differences existed between entries for top width, root weight, sweetness, and harshness. Year by entry and region by entry interactions existed for top height, top width, root weight, top weight, sweetness and harshness, and the relative ranking of entries were not correlated for these traits between some region-year combinations. However, for all of the above traits, the relative ranking of entries was consistent between organic and conventional systems within a region in a given year.

Some carrot entries were more stable in their performance across environments than others, allowing entries to be divided into groups based on their stability. Nematode resistance, relative top size, storage root weight, and flavor observed to date are included in Table 1 (see left). Updates of data gathered by this project can be found at the CIOA website: **http://eorganic.info/carrotimprovement**.

To date, the project has reached approximately 250 farmers with education on organic breeding and variety trials. It has also trained graduate and undergraduate students in plant breeding, trial management, and laboratory techniques.

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

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