United States Department of Agriculture

Final Report

Title:	**Identifying phenotypes, markers, and genes in carrot germplasm to deliver improved carrots to growers and consumers**

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Program Code: SCRI **Program Name:** Specialty Crop Research Initiative

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Recipient Organization

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Non-Technical Summary

The traditional orange carrot is the richest plant source of provitamin A in the U.S. diet and one of the most widely consumed and nutritious vegetables in the world, but in spite of the known health benefits attributable to carrots and other vegetables, the 2010 Dietary Guidelines for Americans indicated that vitamin A is under consumed, and overall vegetable consumption is less than 40% of that recommended by nutritionists. A survey of carrot stakeholders was conducted and a meeting was held to identify key traits important for improved carrot quality and productivity. This effort revealed that the carrot industry needs breeding stocks and genomic tools that can be used to develop carrots with improved field performance including disease and pest resistance, and abiotic stress tolerance; and improved flavor and nutritional quality to better meet consumer needs. Given this critical stakeholder input, the goals of this project are to: 1) phenotype diverse carrot germplasm and breeding stocks to discover and characterize previously uncharacterized variation for traits important for improving carrots for the US market; 2) develop

an expanded carrot genomic and phenotypic database for breeders to catalogue genomic variation and track genes underlying important traits; 3) initiate the development of breeding pools from diverse germplasm and breeding stocks that include alleles for improved crop production and consumer quality traits, and test them on-farm with growers and for flavor and nutritional value for consumers; and 4) evaluate the market value and impact of carrot traits on grower and consumer decisions.

Accomplishments

Major goals of the project

Research (RES) and Outreach (OUT) Objectives of the Project:

1 - Phenotype diverse carrot germplasm and breeding stocks to discover and describe previously uncharacterized variation for traits important for: improving carrot disease and pest resistance (ALB, PCS, RKN); reliable crop production and tolerance to environmental stress (premature bolting, drought tolerance, stand establishment); enhanced consumer quality (sweet flavor, mild flavor); and superior color and nutritional value (conferred by orange, red, and yellow carotenoid pigments, and purple anthocyanins). RES: Phenotype the USDA-NPGS carrot germplasm collection (PI collection) and breeding stocks; evaluate consumer acceptance of color and flavor, and bioavailablity of pigments; catalog information at the Carrot Bioinformatics Database (CBD); provide access to the phenotype database via CBD; report on database and research at meetings and workshops open to all stakeholders, and in publications and reports.

2 - Develop an expanded carrot genomic database for breeders to catalogue genomic and phenotypic variation and track genes underlying important traits so that the genomics of carrot can be applied to practical breeding programs. RES: Resequence or GBS phenotyped plants in the PI collection and breeding stocks; catalog information at the CBD. OUT: Provide access to the genomic information via CBD; report on database and research at meetings and workshops open to all stakeholders, and in publications and reports.

3 - Initiate development and evaluation of breeding pools from diverse germplasm and breeding stocks that include alleles for improved crop production and consumer quality traits identified in Objective 1. RES: Intercross plants with favorable /extreme phenotypes. OUT: Field test these pools on stakeholder farms for field traits; release broad-based germplasm to stakeholders.

4 - Evaluate the economic impacts of new carrot traits on grower practices and costs, and consumer decisions. RES: Assess impact of science-based innovations on production practices and costs; and on consumer responses and market value. OUT: Provide information to industry stakeholders; report results at meetings/workshops open to all stakeholders; in publications.

What was accomplished under these goals?

Carrots are a high-value crop worth $750M to US growers and the largest crop source of vitamin A in the US diet. Approx. 86% of the carrot production area and 94% of crop value is in fresh market carrots, with 85% of fresh market carrots grown in CA. WA and WI are the largest producers of carrots for processing. Nation-wide expansion of small-scale local vegetable markets has increased carrot production, and this trend contributes to the growing organic market share of the US production, estimated at 14%. Conventional and organic growers, processers, and seed industry breeders and their marker lab scientists were surveyed in 2014 and convened in 2015 to identify top traits deemed important for improving productivity, expanding product development, and strengthening economic viability. Based on this stakeholder input, this project addresses the critical needs of the carrot industry, to identify novel sources of genes for carrot improvement in future carrot breeding. We are identifying genes for improved resistance to diseases and pests, reliable crop production and tolerance to environmental stress, and enhanced consumer quality. To complement this gene discovery, we are developing a carrot database to provide breeders and other researchers with a platform to deliver information for carrot breeders to tap into the breadth of carrot genetic diversity; and establish a science-based foundation for long-term carrot improvement. Nutritional profiles and consumer attitudes toward carrots are being developed, the economic value of new breeding traits is being measured, and students are being educated. These new gene sources will be used in future breeding efforts to develop crop germplasm that requires less pesticide use and increased farm value; novel, high-value carrot products; and improved flavor and nutritional value for consumers. Long-term impacts are expected to increase crop consumption, benefit the environment and human health, and develop crop improvement strategies applicable to other crops.

Project Objectives and Annual Progress:

1 Phenotype diverse carrot germplasm and breeding stocks to discover and describe previously uncharacterized variation for important traits. Variation in key traits identified by stakeholders was phenotyped in a carrot germplasm collection that includes 694 diverse open-pollinated carrots from the USDA-NPGS and 70 public inbreds, referred to as the "PI collection".

Screening to identify M. incognita nematode resistant entries was completed and several lines were confirmed to be resistant to M. javanica, M. arenaria and M. hapla. At the cavity spot (Pythium violoae and P. sulcatum) field nursery site established at WSU in 2019, a subset of 57 PI lines was evaluated, of which 2 had less severe cavity spot symptoms than Purple Haze, the resistant check, and 4 had symptoms more severe than Purple Haze but less severe than Propeel, the next

more resistant commercial cultivar. In WI, ~39 PIs were confirmed to have superior Alternaria leaf blight resistance. Bolting was evaluated in summer and winter crops where ~30% of PIs bolted at time of harvest, with high concordance between lines across locations and years. Inheritance is complex with epistasis and genotype x environment interaction. Drought tolerance field and greenhouse phenotype data collected at UCRiverside were analyzed and prepared for GWAS, and a subset of most tolerant lines was increased for continue testing. Three years of data have been taken on early establishment, height, and final stand establishment on the PI collection in WI. An association analysis has been conducted and a manuscript has been prepared. Mapping populations were created and F2 families were phenotyped for linkage mapping of stand establishment. Four years of data on the PI collection has been taken on harsh flavor and sweetness, carotenoids, anthocyanins, total dissolved solids, sugars, ionomic profile, and root shape. Data for all traits are being used for GWAS analysis. The carotenoid study has been published, the total dissolved solids has been published in thesis form and the others are in preparation for publication.
2 - Develop an expanded carrot genomic database for breeders to catalogue genomic and phenotypic variation and track genes underlying important traits: We developed an improved genome assembly, gene annotation of carrot DH1. The new assembly v3, covers 440 Mb, all assembled into 9 chromosomes, with a contig N50 >6Mb. Compared with the previous assembly (v2), the v3 assembly include about 11% (54 Mb) new sequences, >21% (>100 Mb) extra sequence anchored to chromosome level, representing >189 fold increase in contig N50. In total, 36,216 genes were predicted, with >4,000 new gene models as compared to the previous gene prediction. Also, initiated efforts to sequence the genome of a white and dark purple genotypes using PacBio HiFi technology. Data from several QTL, transcriptome, gene annotation and functional analysis studies targeting anthocyanin genetics and genes in carrot, and anchored all these QTLs and genes to the v2 and v3 genomes. These allowed identification of novel candidate genes controlling carotenoids, anthocyanin biosynthesis in carrot root and petiole, and genes associated with carrot domestication and improvement.
3 - Initiate development and evaluation of breeding pools from diverse germplasm and breeding stocks, and detailed quality analysis: Roots with elite nematode, Alternaria and cavity spot resistance, drought tolerance, low-bolting incidence, large tops, vigorous stand establishment, excellent flavor, improved nutritional value and unique color were advanced to develop breeding pools. To advance studies on bioefficacy evaluation of carrot nutritional quality, two gerbil and one chicken nutrition evaluation studies were completed. Carrot was found to be effective in improving animal nutrition in these studies.
4 - Evaluate the economic impacts of new carrot traits on grower practices and costs, and consumer decisions: Large U.S. surveys (about 400,000 consumer responses) of self-reported carrot buyers were conducted to estimate expressed willingness to pay for carrot traits from 2019 to 20210. Specifically, we compared expressed willingness to pay for organic baby carrots, conventional baby carrots, organic full-sized carrots, and conventional full-sized carrots. Consumers' median willingness to pay is about $0.7 per pound for the organic trait. The results are robust across multiple surveys conducted from 2019 to 2021. The results document that consumers are willing to pay for observable and claimed trait differences when selecting carrot products. The willingness to pay for traits did not differ across rounds of the survey from before the pandemic and as the pandemic evolved.

What opportunities for training and professional development has the project provided?

Activities included grow-out of diverse carrot breeding stocks which are being distributed to stakeholders and general public contacts for project promotion and as educational materials. Stakeholder training for database use was initiated through communication with stakeholders seeking information on project results and discussions virtually at grower meetings.
As part of the education activities, undergraduate students, graduate students and post-doctorates were trained in vegetable breeding, crop and seed production, disease protection and diagnosis, drought tolerance, stand establishment and bolting, genomic analysis and database development and econometrics of food demand as they participate in research projects critical to the project achieving the research goals. We also presented practical economic findings to undergraduate and graduate classes.
FARM SMART Carrot Activities during the project included field production of colored carrots, field tours, and extensive exposure to elementary high school and college students, and members of the general public visiting and touring the Desert Research and Extension Center (DREC) near El Centro, CA. These activities included:
Year 1 2016/2017 FARM SMART Carrot Activities, September 2016: California Ag in the Classroom Conference, Sacramento, CA. Led a carrot themed "Taste of California" table at the annual Ag in the Classroom conference dinner; introducing California educators from across the state to the colored carrot research taking place at the University of California, Desert Research and Extension Center. The dinner included a display on colored carrots, information on current research from Dr. Simon, information on the history of carrots, packets of carrot seeds to take back to their classrooms, colored carrot tastings, and lesson plan development specifically related to the research. Lesson plans included an emphasis on carrots and carrot diversity, and health benefits of disease-preventive pigments that give plants their distinctive colors. Participants left with a better understanding of the history of carrots and methods to incorporate carrots into their varying grade levels and educational institutions. Conference attendance was over 300 educators.
In January-February, 2017: FARM SMART Winter Visitor Program - Provided field tours to close to 1000 participants from across the United States and Canada and included hands-on activities such as carrot harvesting, carrot recipe demonstration,

and carrot sampling. FARM SMART was able to introduce the research and history of the colored carrots, offer harvesting of colored and traditional carrots, and provide nutritional values of the different colored carrots. Participants were also introduced to carrot harvesting methods and carrot production facts for Imperial County and California.
In March-April, 2017: FARM SMART K-12 Field Trips - Provided carrot education through outreach to over 7500 participants in our K-12 field trip program. Students who attended a FARM SMART program from March to April had the opportunity to learn what carrots need to grow, the history of colored carrots, the nutritional value, as well as an opportunity to harvest their own traditional and organic carrots. Teachers were also given resources to further enrich their lesson plans to include carrots.
In April-May, 2017: Imperial Valley College Ag Students - Provided carrot research information and introduced colored carrots to over 30 visiting community college agriculture students. Students had the opportunity to harvest traditional and colored carrots from the FARM SMART garden and experiment with colored carrot recipes.
Year 2 FARM SMART Carrot Activities continued those initiated in year 1 of the project including field production of colored carrots, field tours, and extensive exposure to elementary high school and college students, and members of the general public visiting and touring the Desert Research and Extension Center near El Centro, CA.
Year 3 FARM SMART Carrot Activities continued those initiated in years 1-2 of the project including field production of colored carrots, field tours, and extensive exposure to elementary high school and college students, and members of the general public visiting and touring the Desert Research and Extension Center near El Centro, CA.
Year 4 FARM SMART Carrot Activities continued those initiated in previous years of the project including field production of colored carrots, field tours, and extensive exposure to elementary high school and college students, and members of the general public visiting and touring the Desert Research and Extension Center near El Centro, CA.
In addition to these activities at DREC, a short Carrot Research Video is being developed. Since the coronavirus (COVID-19) pandemic and quarantine began, it has been important to add more video content to the program of services offered to local educators, students and our community. Tracking of video content access has indicate the ability to reach a wider audience and reach beyond the local community. In a remote world, video allows us to meet, to educated and to provide services. The recorded short video gives an overview of colored carrot research at Desert REC. The video is still in the editing stage, but includes viewing the variety of colored carrots, observing the harvest, and sorting process of colored carrots for research and gives nutritional content information. Distribution of the short video includes social media sites, DREC website and linked to Farm Smart newsletter. We expect to distribute this video digitally to local teachers as well as show the video during field tours where we cover carrot research at Desert REC.
In Davis, CA, the project allowed Student Farm undergraduate interns, volunteers and student employees to participate in carrot production in Student Farm Market Garden and Ecological Garden teaching areas. This numbers 50-60 students each academic quarter. Students involved in our undergraduate courses PLS 193 and PLS 49 also learn about how carrots are grown and have the opportunity to harvest and consume fresh product. This numbers roughly 25-30 students per quarter. In addition during spring quarter we hosted 2000 school children and roughly 200 chaperones on this site before COVID curtailed student visits. Roughly half of those students and their chaperones learn about and/or harvest and eat carrots during their educational activities.

How have the results been disseminated to communities of interest?

Educational events and conference presentations included:

First PAG Workshop on Apiaceae; January, 2020:

- Simon, P.W. S.L. Ellison, D.Senalik. 2020. Trait Identification and Genomic Database Development for Carrot (Daucus carota) Improvement. XXVII Plant & Animal Genome, January 13, 2020, San Diego, California, USA.
- Iorizzo, M., H. Bostan, S.L. Ellison, D. Senalik, P.W. Simon. J.Curaba. 2020. Improved Hybrid de novo Genome Assembly, Gene Prediction and Annotation of Carrot (Daucus carota). XXVII Plant & Animal Genome, January 13, 2020, San Diego, California, USA.
- S.L. Ellison, Simon, P.W., D. Senalik. 2020. Genome-Wide Association Analysis of Carotenoids in Carrot. XXVII Plant & Animal Genome, January 13, 2020, San Diego, California, USA
- Van Deynze, A.. Hill, TA, Garcia-Llanos, A., Roberts, P., Mathews, W. Ellison, S., Senalik, D., Loarca, J. and Simon, P. 2020. Characterization of the Tendency for Bolting among Carrot Germplasm Accessions. XXVII Plant & Animal Genome, January 13, 2020, San Diego, California, USA.
- Macko-Podgorni, A., K. Stelmach, K. Kwolek, D. Grzebelus. 2020. Abundance and Insertional Polymorphism of Carrot Mites and Demography of Daucus carota. XXVII Plant & Animal Genome, January 13, 2020, San Diego, California, USA.

2nd Apiaceae Workshop at PAG Jan. 17, 2022, San Diego, California, USA

- Iorizzo, M. et al. Development of a genetic framework to regulate anthocyanin accumulation in carrot for improving its application in the food colorant industry

- Coe, K. et al. The influence of the Or gene on carotenoid accumulation in orange carrots
- Macko-Podgorni, A. et al. Diverse and Mobile - Eccdna-Based Identification of Carrot Low-Copy LTR Retrotransposons Active in Callus Cultures
- Meyer, C. et al. An efficient system for producing transgene-free gene edited carrot plants
- Brainard, S. et al. Dissecting the genetic basis of root shape in carrot with digital imaging
- Van Deynze, A. Genomic analysis of bolting in carrot

Other educational events and conference presentations throughout the duration of the project:

- March 19, 2017, SCRI Advisory Panel meeting, Bakersfield, CA
- March 20, 2017, SCRI poster and oral presentations, International Carrot Conference, Bakersfield, CA
- August 30, 2017, SCRI PD meeting, Traverse City, MI
- January 13-17, 2018, poster presentation at Plant and Animal Genome Meeting, San Diego
- June 11, 2018, oral presentation (S. Tanumihardjo), FASEB Retinoids Conference, Steamboat Springs, CO
- June 19, 2018, oral presentation (S. Tanumihardjo), Gordon Research Conference on Carotenoids, Newry, ME
- July 31 - August 3, 2018, poster presentation (P. Simon) at ASHS, Washington, DC
- August 21-23 2018, poster and oral presentation (M. Iorizzo) oral presentation of population structure and potential core collection strategies (S. Ellison), poster (P. Simon) International Carrot Conference, Madison WI.
- September 20, 2018, oral presentations at International Apiaceae Meeting (P. Simon, M. Iorizzo, S. Ellison), September 19-22, 2018, Krakow, Poland
- January 12-16, 2019, poster presentation (K. Coe) at Plant and Animal Genome Meeting, San Diego
- February 18, 2019, Dept. Genetics Seminar series, (M. Iorizzo) NCSU Raleigh, NC
- March 12, 2019, oral presentations (P Roberts; P Simon; L. DuToit), California Carrot Symposium, Bakersfield, CA; hosted by California Fresh Carrot Advisory Board for carrot researchers, producers and processors.
- June 3-6, 2019, oral presentation (P. Simon) at CROPS, Huntsville, AL
- June 11, 2019, oral presentation (H. Bostan) at PHHI Seminar Series, RCCC-NCRC Kannapolis, NC
- July 22-25, 2019, oral presentation (P. Simon) at ASHS, Las Vegas, NV
- Van Deynze, A. 2020. Seed Biotechnology Center update. California Seed Association annual meeting. March 6, 2020, Carlsbad, CA.
- Nov. 20-21, 2019, oral presentation (L. du Toit). Carrot cavity spot. Pacific Northwest Vegetable Assoc. Annual Convention & Trade Show, Kennewick, WA. (200 people)
- February 24, 2020, oral presentation (H. Lee; R. Goldstein; D. A. Sumner), at UC Davis, CA; a seminar for undergraduates
- August 10, 2020, oral presentation (H. Lee; R. Goldstein; D. A. Sumner), 2020 Virtual Meeting, Agricultural & Applied Economics Association.
- February 18, 2021, Demand for Food Attributes during COVID-19: Evidence from a Large Sample of US Carrot Buyers. Agricultural Economics Workshop. Agricultural and Resource Economics, University of California, Davis, CA
- August 20-21, 2021, Demand for Organic, Convenience Foods: A Large Online Survey from U.S. Carrot Buyers during COVID-19. the 10th Congress of the Asian Association of Environmental and Resource Economics, Asian Association of Environmental and Resource Economics, Seoul, South Korea
- August 2021, oral presentation (Loarca, Jenyne) on "Identifying Phenotype and Genetic Markers in Diverse Carrot Germplasm (Daucus carota subsp. sativus) To Deliver Improved Stand Establishment to Growers". Invited Speaker, Midwest Population Genetics Conference, UW Madison
- September 2021, oral presentation (Loarca, Jenyne) on "Leveraging a Carrot Diversity Panel: Identification of Phenotypes and Genetic Markers to Deliver Improved Stand Establishment to Growers". Invited Speaker, JF Crow Institute Seminar Series, UW Madison
- October 2021 oral presentation (Loarca, Jenyne) on "Genome-Wide Association Analysis with a Carrot Diversity Panel". Plant Genetics Undergraduate Course, University of California Davis
- December 2021, oral presentation (Loarca, Jenyne) on "Why Genetic Diversity Matters in Science - A Case Study with 700 Carrot Cultivars" Participatory Learning And Teaching Organization (PLATO): UW Madison Division of Continuing Studie.
- March 20-21, 2021, oral presentation (L.J. duToit) Screening carrot germplasm for resistance to cavity spot and bacterial blight. Research presentation update at Carrot Research Symposium, CA Fresh Carrot Advisory Board, virtual because of COVID-19. (59 people)

Stakeholder events included:

- March 19, 2017, SCRI Advisory Panel meeting, Bakersfield, CA

- March 20. 2018, SCRI Advisory Panel meeting, Bakersfield, CA
- Feb. 27- March 1, 2019, carrot harvest, PI collection demonstration and breeding pool development and March 5, hybrid trials (P. Simon, M. Colley, J. Sidhu, A. Van Deynze) at Desert Research and Extension Center, El Centro, CA

- March 12, 2019, SCRI Advisory Panel meeting, Bakersfield, CA
- October 8, 2019, carrot harvest and nematode evaluation (P. Roberts, P. Simon) at University of California Kearney Agricultural Center, Parlier, CA
- Various dates, in vitro cavity spot inoculation protocol evaluation (L. du Toit) at Washington State University Mount Vernon, WA; carrot phenotyping for carotenoids, flavor, root shape and top size; breeding pool development (P. Simon, S. Ellison) at the USDA, ARS Department of Horticulture, University of Wisconsin, Madison, WI
- March 4 - 13, 2020, carrot harvest, PI collection evaluation and breeding pool development; and March 10 hybrid trials (P. Simon, M. Colley, J. Sidhu) at Desert Research and Extension Center, El Centro, CA

- January to March 2020, FARM SMART delivered carrot info/curriculum and harvested carrots (876 participants including kids, youth and adults). We also reached 15 teachers with carrot information and seed distribution.
- January, 2021 - Stakeholder advisory panel zoom meetings were held to report project progress and seek input
- March 22, 2021, oral presentations (P Roberts; P Simon; L. DuToit), California Carrot Symposium (Virtual), Bakersfield, CA; hosted by California Fresh Carrot Advisory Board for carrot researchers, producers and processors.
- October, 2021 - A survey was sent to stakeholders to gather additional input from them on current and future project direction including input on traits, databases, and approaches for delivering data and germplasm to stakeholders

What do you plan to do during the next reporting period to accomplish the goals?

{Nothing to report}

Participants

Actual FTE's for this Reporting Period

Role	Non-Students or faculty	Students with Staffing Roles			Computed Total by Role
		Undergraduate	Graduate	Post-Doctorate	
Scientist	4.1	1.9	5.2	4.2	15.399999999999999
Professional	1.4	0	0.2	0	1.5999999999999999
Technical	3.2	10.1	0	0	13.3
Administrative	0	0	0	0.3	0.3
Other	0	0	0	0	0
Computed Total	8.7	12.0	5.4	4.5	30.5999999999999989

Student Count by Classification of Instructional Programs (CIP) Code

Undergraduate	Graduate	Post-Doctorate	CIP Code
5	2	2	26.08 Genetics.
4	1	1	01.11 Plant Sciences.
3	3	2	26.12 Biotechnology.

Target Audience

The audience for the web site being developed for this project includes all members of the scientific and breeding communities interested in phenotypic information important for crop production and improvement. Results are shared with

stakeholders at international, national, regional and local grower and industry meetings and at field days. Carrot is a crop that the general public is familiar with, so to better communicate with the general public, approx. 40 selected diverse carrots were grown and managed annually by undergraduate students at land grant universities including those in California, North Carolina, Washington and Wisconsin. This diversity garden approach is being the basis of interactive science outreach programs for K-12 students, undergraduate students, educational, and consumer groups in those states focusing on breeding, genetic diversity and nutrition. These diverse carrots are available to any field-based STEM and agricultural education institution. The FARM SMART program at the University of California Desert Research and Extension Center developed an agricultural literacy component that incorporates agriculture (in particular an expanded awareness of carrots and other vegetables) in presentations to school (K-12) and community (adult) outreach programs in carrot nutrition and production.

Markers and sequence information for traits phenotyped are available to stakeholders through conferences, web-accessible databases, and publications. Genomic tools were demonstrated at workshops including hands-on training with presentations/webinars/videos developed to demonstrate approaches to marker discovery and marker assisted selection for breeders. The process of discovering plants with desirable carrot phenotypes was described to the scientific and breeding communities in publications, webinars, and at meetings to instruct them on critical aspects of both the phenotype screening process as well as best procedures to utilize breeding pools developed by this project, and to initiate the development of breeding pools on their own. On-farm testing was used to engage growers in participating in the evaluation of breeding pools, and for them to provide critical feedback to project scientists about the on-farm level performance of early-generation breeding stocks. Quality assessments of breeding pools by chefs and consumers also both inform those stakeholders about germplasm under development from this project, as well as provide feedback to project scientists about the progress achieved by this project in carrot improvement at the consumer level. Nutritional quality evaluations were presented at horticulture, nutritional science, and grower meetings and in scientific and popular publications. Student and general public outreach staff and scientists involved in the project receive and dispense information from on-farm and consumer stakeholder testing. Information on economic impacts of carrot traits is being presented at agricultural economics and agribusiness meetings and in scientific publications. Cost and return results and consumer demand results were presented to industry stakeholders in reports, websites and other media based tools. Issues briefs and short information bulletins are developed to inform carrot industry stakeholders on important opportunities about new varieties, and the general public were extensively used this information.

Products

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2018	YES

Citation

Shelby L. Ellison, Claire H. Luby, Keo E. Corak, Kevin M. Coe, Douglas Senalik, Massimo Iorizzo, Irwin L. Goldman, Philipp W. Simon and Julie C. Dawson
GENETICS Early online October 23, 2018; https://doi.org/10.1534/genetics.118.301299

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2018	YES

Citation

Iorizzo M., Cavagnaro P.F., Bostan H., Zhao Y., Zhang J. and Simon PW. 2018. A cluster of MYB transcription factors regulates anthocyanin biosynthesis in carrot (Daucus carota L.) root and petiole. Frontier in Plant Science, 9:1927

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	YES

Citation

Titcomb, T., M. Kaeppler, J. Shannon, P.W. Simon, and S. Tanumihardjo. 2019. Carrot leaves maintain liver vitamin A concentrations in Mongolian gerbils regardless of the alpha- to beta-carotene ratio when beta-carotene equivalents are equalized. J. Nutrit. 149:951-958.

Accession No. 1009938 **Project No.**

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	YES

Citation

Titcomb T.J., M.S. Kaeppler, M.E. Cook, P.W. Simon, S.A. Tanumihardjo. 2019.Carrot leaves improve color and xanthophyll content of egg yolk in laying hens but are not as effective as commercially available marigold fortificant. Poult. Sci.; doi: 10.3382/ps/pez257.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	YES

Citation

Sheftel , J., M. Sowa, L. Mourao, L.T. Zoué, C.R. Davis, P.W. Simon, and S.A. Tanumihardjo. 2019. Total adipose retinol concentrations are correlated with total liver retinol concentrations in male Mongolian gerbils, but only partially explained by chylomicron deposition assessed with total ?-retinol. Curr. Dev. Nutr. 3:nzy096.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	YES

Citation

Bannoud F., Ellison S., Paolinelli M., Horejsi T., Senalik D., Fanzone M., Iorizzo M., Simon P. (2019) Dissecting the genetic control of root and leaf tissue-specific anthocyanin pigmentation in carrot (Daucus carota L.) Theor Appl Genet 132: 2485

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Simon P.W., Geoffriau E., Ellison S., Iorizzo M. 2019. Carrot Carotenoid Genetics and Genomics. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Ellison, S. 2019. Carrot Domestication. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Iorizzo M., Ellison S., Pottorff M., Cavagnaro P.F. 2019. Carrot Molecular Genetics and Mapping. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Cavagnaro P.F., and Iorizzo M. 2019. Carrot Anthocyanin Diversity, Genetics and Genomics. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Accession No. 1009938 **Project No.**

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Iorizzo M., Macko-Podgórni A., Senalik D., Van Deynze A., and Simon P.W. 2019. The Carrot Nuclear Genome and Comparative Analysis. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Type	Status	Year Published	NIFA Support Acknowledged
Book Chapters	Published	2019	NO

Citation

Bostan H., Senalik D., Simon PW, and Iorizzo M. 2019. Carrot Genetics, Omics and Breeding Toolbox. In: Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Type	Status	Year Published	NIFA Support Acknowledged
Books	Published	2019	NO

Citation

Simon P., Iorizzo M., Grzebelus D., Baranski R. (eds) The Carrot Genome. Compendium of Plant Genomes. Springer International Publishing.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2020	YES

Citation

Iorizzo M., Curaba J., Pottorff M., Ferruzzi G.M., Simon. P. and Cavagnaro P. 2020. Carrot anthocyanins genetics and genomics: status and perspectives to improve its application for the food colorant industry. Genes, 11: 906

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2020	YES

Citation

Curaba J., Bostan H., Cavagnaro P., Senalik D., Mengist M.F., Zhao Y., Simon P. and M. Iorizzo. 2020. Identification of an SCPL gene Controlling Anthocyanin Acylation in Carrot (Daucus carota L.) Root. Frontiers in Plant Science, 10:1770

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	NO

Citation

Iorizzo M., M. Pottorff, H. Bostan, S.L. Ellison, P.F. Cavagnaro, D. Senalik, D.M. Spooner and P.W. Simon. 2019. Recent advance in carrot genomics. ISHS Acta Horticulturae 1264: Proceedings of the II International Symposium on Carrot and Other Apiaceae. 10.17660/ActaHortic.2019.1264.9

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2019	NO

Citation

Cavagnaro P.F., F. Bannoud, M. Iorizzo, D. Senalik, S.L. Ellison and P.W. Simon. 2019. Carrot anthocyanins: nutrition, diversity and genetics. ISHS Acta Horticulturae 1264: International Symposium on Carrot and Other Apiaceae. 10.17660/ActaHortic.2019.1264.11

Accession No. 1009938 **Project No.**

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2020	YES

Citation

Sowa, M., L. Mourao, J. Sheftel, M. Kaeppler, G. Simons, C. Davis, P.W. Simon, S. Tanumihardjo. Overlapping Vitamin A Interventions with Provitamin A Carotenoids and Preformed Vitamin A Fortificant Cause High Liver Retinol Stores in Male Mongolian Gerbils. Journal of Nutrition 150: 2912–2923. 2020. https://doi.org/10.1093/jn/nxaa142

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2020	NO

Citation

du Toit, L., and Derie, M. 2020. Spot-on research. Establishing a carrot cavity spot nursery at Washington State University. Carrot Country, Spring 2020:4-9.

Type	Status	Year Published	NIFA Support Acknowledged
Theses/Dissertations	Published	2020	YES

Citation

Su Liu, 2020. Improved Hybrid de novo Genome Assembly, Resistance Gene Prediction and Annotation of Carrot (Daucus carota). MS thesis. North Carolina State University, Raleigh.

Type	Status	Year Published	NIFA Support Acknowledged
Theses/Dissertations	Published	2020	YES

Citation

Coe. Kevin. 2020. Genetic analysis of domestication and carotenoid accumulation in carrot (Daucus carota L.) and the polyploidization of switchgrass (Panicum virgatum L.). Ph.D thesis. University of Wisconsin-Madison

Type	Status	Year Published	NIFA Support Acknowledged
Theses/Dissertations	Published	2020	YES

Citation

Yildiz, Gunay. 2020. Genome Wide Association Analysis of Free Sugars in the Storage Roots of a Diverse Collection of Carrot (Daucus carota L.). MS thesis. University of Wisconsin-Madison.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2021	YES

Citation

Bannoud F., Carvajal S., Ellison S., D. Senalik, Talquenca S.G., Iorizzo M., Simon P. and P.F. Cavagnaro. 2021. Genetic and transcription profile analysis of tissue-specific anthocyanin pigmentation in carrot root phloem. Genes 2021, 12, 1464.

Type	Status	Year Published	NIFA Support Acknowledged
Conference Papers and	Published	2021	YES

Citation

Iorizzo M., Mengit M.F., Bostan H., Curaba J., M. Pottorff. From genome to genes and DNA markers to improve agronomic performance and quality of fruit and vegetables crops. Genetyka Aplikacyjna Ro?lin XXI, September 22-24, 2021, Warsaw, Poland

Accession No. 1009938 **Project No.**

Type	Status	Year Published	NIFA Support Acknowledged
Conference Papers and	Published	2021	YES

Citation

Iorizzo M. Development of a genetic framework to improve the efficiency of bioactive stability and delivery from carrot and blueberry. Webinar: Current status of Phyomediomics and Nutriomics. Organized by the Korean Academy of Science and Technology (KAST), December 15, 2020.

Type	Status	Year Published	NIFA Support Acknowledged
Conference Papers and	Published	2021	YES

Citation

Sumner, Daniel A. 2021. "Impact of COVID-19 and the Lockdowns on Labor-Intensive Produce Markets, with Implication for Hired Farm Labor" Choices. Quarter 3. Available online: https://www.choicesmagazine.org/choices-magazine/theme-articles/agricultural-market-response-to-covid-19/impact-of-covid-19-and-the-lockdowns-on-labor-intensive-produce-markets-with-implication-for-hired-farm-labor

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2021	YES

Citation

Coe, K., S. Ellison, D. Senalik, J. Dawson, P.W. Simon. The influence of the Or and Carotene Hydroxylase genes on carotenoid accumulation in orange carrots [Daucus carota (L.)]. Theor. Applied Genet. 134: 3351-62. 2021. DOI: 10.1007/s00122-021-03901-3

Type	Status	Year Published	NIFA Support Acknowledged
Theses/Dissertations	Published	2021	YES

Citation

Loarca, Jenyne. 2021. Identifying Phenotypes and Markers in Diverse Cultivated Carrot Germplasm (Daucus carota) to Deliver Improved Stand Establishment to Growers. PhD thesis. University of Wisconsin-Madison.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2022	YES

Citation

Rolling WR, Senalik D, Iorizzo M, Ellison S, Van Deynze A, Simon PW. CarrotOmics: a genetics and comparative genomics database for carrot (Daucus carota). Database (Oxford). 2022 Sep 7; 2022:baac079. doi: 10.1093/database/baac079. PMID: 36069936; PMCID: PMC9450951.

Other Products

Accession No. 1009938	**Project No.**

Product Type

New Germplasm

Description

Products include well-tested germplasm bearing multiple genetic sources of genes for carrot improvement, well-tested screening methods to evaluate traits, and new data for GRIN, making carrot one of the best characterized germplasm collections; information for breeders to identify PI sources of genes for important traits; seed samples of preliminarily-tested germplasm bearing multiple genetic sources of genes for critical traits are developed and will be made available.

Product Type

Databases

Description

CarrotOmics, a carrot database will be published and released early in 2022, cataloging genomic and phenotypic information including a new genome assembly and annotation to improve the quality of subsequent association analysis and functional studies of important loci in this project. Robust genomic datasets are included. This is among the most extensive database for any crop germplasm collection, including extensive phenotypic data to complement genomic data, and tools to analyze both.

Product Type

Other

Description

Economic analysis will provide the public with updated Current Cost and Returns Studies for carrots.

Changes/Problems

Some data collection and outreach activities were delayed or omitted due to COVID restrictions.