

NC STATE UNIVERSITY

NCCC-212 2020 Report

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1. List your research and extension projects under the official NCCC-212 objectives, emphasizing collaborative projects with other researchers.

Objective 1 - Develop improved small fruit germplasm through cooperative breeding and evaluation programs:

Blackberry and Raspberry:

Rubus GWAS/BSH study, Multi institution phenotyping project initiated with Univ. Ark, Cornell, USDA-ARS Corvallis, BC Berry, Plant Science Inc (Watsonville) and Pairwise Plants (Durham NC) in 2019/2020. In spring and summer of 2020, . 5 cultivars were planted at each location and will be phenotyped over the next 2 years. Phenotyping has begun at most locations. New graduate student, Katie Sheehan-Lust (NCSU) will be using this project for her MS research. In addition, Pairwise plants, has developed five scaffold or pseudomolecule genome assemblies, generation genomic resequencing data for approximately 500 (?) public lines, and shared genomic resequencing data on all public lines and associated phenotype measurements in a publicly accessible database.

Blueberry:

Characterized fruit quality traits in blueberry germplasm (Massimo Iorizzo in collaboration with Food Scientists and NCGR-OR). Extensive variation for all fruit traits (pH, TA, Brix/TSS, fruit size, anthocyanins, phenolic acids, flavanols, flavonols) evaluated in a Diversity Panel (DP) was detected. Broad sense heritability of the traits estimated in 100 tetraploid accessions, ranged from 20 to 90%, with most traits revealing moderate to high broad sense heritability ($H^2 > 40\%$), suggesting that strong genetic factors control these traits. TSS was positively and significantly correlated with most of the anthocyanins, flavanols, and phenolic aids and pH was positively associated with acylated anthocyanins. Fruit size can be estimated as a proxy of fruit weight or volume and vice versa, and it was negatively correlated with content of most of phytochemicals. However, size-independent variation for anthocyanin content and profile exists in the tetraploid accessions and can be explored to identify other factors such as genes related to the biosynthetic pathway that control this trait (Molla et al., 2020a, Farneti et al., 2020).

Establishing a community based project to advance fruit quality studies in blueberry and cranberry. (Massimo Iorizzo, Penelope Perkins-Veazie and Mary

Ann Lila from NCSU in collaboration with 17 blueberry and cranberry scientists). Secured a multimillion dollar (>6.4M) project, VacCAP, funded by USDA-NIFA (SCRI program) to develop marker assisted selection (MAS) capacity in *Vaccinium* breeding programs, to enable breeders to select and pyramid fruit characteristics (FCs) that positively contribute to fruit quality and market value. The project involves a multidisciplinary team of 20 scientists, from 13 US institutions including universities, USDA and two international institutions from New Zealand and Italy. Specific objectives are to: (1) establish a cost effective genotyping platform to expand marker-trait association analysis (MTA) in *Vaccinium*, exploiting the shared ancestry of *Vaccinium* crops; (2) identify DNA markers linked to fruit characteristics (FCs) and elucidate how and which fruit characteristics affect fruit quality, relative to consumer preferences, decay during mechanical harvest, processing and distribution; (3) develop DNA assays to implement MAS in core *Vaccinium* core breeding programs with a common focus on fruit quality traits; (4) enlarge market potential, and increase consumption of *Vaccinium* fruits by using socio-economic knowledge of consumer preferences to inform breeding; and (5) enhance sustainability of cultivar development by transferring MAS technologies to public and private U.S. Target fruit characteristics for blueberry include texture, size, scar diameter, volatile and non-volatile chemical composition. Fruit quality analysis will include, sensory analysis, shelf-life, bruising. The project began on Sept 1, 2019. During year 1 NCSU team performed phenotyping FCs in Northern Highbush material.

Ashrafi Blueberry Breeding and Genetics lab: Hamid Ashrafi, Jessica Spencer, Lauren Redpath, Rishi Aryal

Season overview: A cool Nov-Dec 2019 followed by unseasonal warmth in 2020 meant patchy flowering and unusual ripening behavior. The last hard frost in February took out Star, an early low-chill but everything else cropped ahead of normal time, with highbush season ending in late June and rabbiteye starting around the same time. A lot of intermittent heavy rains starting mid- season meant a lot of split and soft fruit and poor quality. Covid-19 prevented some analyses usually conducted indoors by multiple people, but overall the season proceeded normally.

Blueberry breeding efforts: The past 5 years have been rebuilding our traditional breeding program after faculty retirements left gap years.

Activity by Year	2015	2016	2017	2018	2019	2020
Crosses made	53	50	46	47	58	65
Seedlings transplanted to field		3700	4020	8000	9000	(8000)
Selections made	42	1	12	77	108	140
Cultivars & Selections put into Yield Trial	97	69	0	56	93	(80)
Selections Advanced			2	17	29	2
Cultivars & Selections put into Machine Harvest Trial			5		17	41
Selections put with growers/cooperators	2				2	(?)

An estimated 5,000 seedlings from 60 populations will be planted at the end of 2020, along with a high density plot with leftover seedlings from 2019 and/or 2020 modeled after University of Florida.

Selections are made mainly for commercial purposes, with selected bushes being scored on yield, firmness, scar, and flavor. Selections are cloned and put into yield trials of 4 plant plots in duplicate. A minimum of 2 bushes are harvested by hand. Total yield is recorded, and if possible, cup weight with count of good/tear/split/green, flavor, and firmness and size using Firmtech2. Selections are advanced based on these scores. 4-6 bushes of advanced selections are harvested and scored the same in following years but are also evaluated for soluble solids, titratable acids, pH, and storage-ability. Advanced selections are cloned via cuttings and tissue culture for on-site machine harvest trials (2 reps of 10 plants) and co-operator evaluation. After 2 years of yield trial data, we are at a point where we can begin more cooperator trials.

NC3104 has been disclosed with the NC State Office of Research Commercialization (ORC) and it is in process of patent processing. It is a sibling of New Hanover and very similar except without the stem-tears. It is a large, firm berry with good flavor, and blooms and ripens a few days after New Hanover and has a slightly darker color.

Efforts are disseminated in January at the NC Blueberry Council annual conference.

Cooperative efforts- After a few setbacks, we were able to send Michael Dossett in British Columbia, Canada softwood cuttings of Reveille x Arlen population of ~300 that have been central to marker studies at NCSU. We will likely need to repeat the process depending on survivability.

Blueberry Genetic Marker Development and Association Mapping

As part of AFRI project that was funded in 2019, entitled “ Developing An Economic Standardized Genotyping Tool to Enhance Blueberry Breeding Programs” , PhD student Lauren Redpath, and research associate Rishi Aryal in collaboration with USDA-ARS scientists Dr. Nahla Bassil and her team at National Clonal Germplasm Repository and Dr. Amanda Haulse-Kemp team are working on a diversity panel of advanced selections and cultivars where native species have been hybridized into their pedigrees for trait introgression. As a part of this study 150 individuals at the Sandhills research station in Jackson Springs, NC and 76 individuals at the National Clonal Germplasm Repository were selected and phenotyped over the summers of 2019 and 2020 with 2 to 3 harvests per individual and clonal replication. Phenotyping included bloom time, fruit ripening duration and ting, as well as fruit skin color spectrum analysis, firmness, weight, size, area, anthocyanin content, puncturability, soluble solid and acid content determination, titratable acidity. Analysis confirmed that there were significant differences between successive harvests. Within a harvest there were significant differences between individuals for each of the measure traits; these results are anticipated in a diversity panel. Phenotypic measurements were highly correlated over the years of study ($R^2 > 0.55$).

These phenotypic measurements are in the process of being associated with genotypic markers in a genome wide association study (GWAS). Sequence capture strategy via Tecan (Allegro) Targeted Genotyping) was used to capture 60,000 SNP makers in the gene space of blueberry. The markers were developed as part of the AFRI project as well

as a previous project by sequencing of ~54 blueberry accessions from 8 sections and 28 species. For the sequencing capture data, we used two pipelines for variant calling of 251 individuals including the individuals in the phenotyping population and select parents. We initially called 14.5 M variant positions with both Freebayes and an in-house pipeline, further filtering for previously established Allegro probes, we established 30,000 variant positions for further investigation. These probes have been used in STRUCTURE analysis, wherein patterns of introgressed species clustering has been detected, and GWASpoly for association analysis. Pseudo molecule development and scaffolding is underway to establish linkage groups and present a more accurate representation of association between variant and phenotype.

Grape:

Muscadine anthocyanin grape profile shifted to more malvidin by using *V. popenoi* in crosses. Jim Ballington, Terry Bland, Guoying Ma, North Carolina State University. Malvidin is considered a more shelf stable anthocyanin pigment than the delphinidin most commonly found in muscadine grapes and products. Malvidin can be increased by using Fennels 3-way in crosses with *V. rotundifolia*. Ballington and Bland tested *V. popenoi* (DVIT 2970) as a parent to increase malvidin in *V. rotundifolia*. Fruit of 5 seedlings were screened for anthocyanin profiles for 2 years. Total anthocyanin content was high, at 1500-5900 mg/100g, and percent malvidin in the total anthocyanin content was increased from 10% to 50-80%.

Strawberry:

Genome Wide Association Studies in an Octoploid Strawberry Biparental Population Discover QTLs for Hemibiotrophic and Necrotrophic Infection Resistance to *Colletotrichum acutatum* and *C. gloeosporioides*. Chacon, J.G., Olukolu, B., Iorrizo, M., Louws, F.J. & Fernandez, G. This study goals were to discover QTLs for the genetic resistance to the necrotrophic and hemibiotrophic stages of anthracnose diseases in octoploid strawberry. Using the new OmSeq platform, we found: 1. SNP's on multiple dosages in octoploid strawberry, 2. QTLs were discovered for resistance to anthracnose necrotrophic and HB infections. 3. Specific SNPs and subgenomic location determined (data not shown). Selection markers for future work. Linkage map and further exploration of QTL analysis underway.

Strawberry breeding. Fernandez, G, R. Schiavone, G. Chacon. Fruit from seedlings, selections and replicated trials were ripening during Covid-19 lockdown. Only one person allowed in the field for the first month. Limited data collected. However 5000 seedlings were evaluated and 122 new selections made. Focus of the program overall is on improving firmness, flavor, disease resistance and yield. 'Rocco' and 'Liz' doing well in the midwest. 'Rocco' replacing 'Sweet Charlie' as early season cultivar. 'Liz' is not good at producing runners and will be in low supply due to this trait.

Evaluation of composition, sugars, organic acid, and pigments in strawberry selections. Perkins-Veazie, Penelope and Gina Fernandez, NC State University

Cultivar evaluation and numbered breeding line evaluation in collaboration with Lassen Canyon and Cottle Farms. M. Hoffmann. Evaluation of yield and fruit quality

characteristics in an on-farm field trial. (partly funded by the NC Strawberry Association).

Impacts: ‘Rocco’ is gaining popularity in midwest states. Growers are replacing ‘Sweet Charlie’ with ‘Rocco’. Estimated production for 2021 will be between 1.0 and 1.5 M plants.

Virtual Strawberry Field Day: more than 50 participants

Objective 2 - Develop practices for small fruit production tailored for climatic and market needs of growers.

Blackberry and Raspberry:

Managing vigor of blackberry with prohexadione calcium: Effects on vegetative and reproductive development. Gina Fernandez, Tom Kon, Penny Perkins-Veazie and Karen Blaedow. Primocane growth management of blackberry by commercial growers relies on summer pruning/tipping primocanes at multiple heights throughout the growing season. However, tipping is a labor intensive and expensive process (~\$600 per acre) that increases risk of cane blight infection. We investigated use of a plant growth regulator, prohexadione calcium (P-Ca), as an alternative primocane growth management strategy of blackberry. No treatments imposed in 2020 and no new data collected. Kon et al. received Specialty Crop Grant to support this work in 2021.

Survey of single and double cropped primocane fruiting blackberries at 2 on-farm locations. Objective was to assess seasonal nutrient status in single and double cropping primocane fruiting cultivars. We found: 1). Sufficiency survey levels do not follow those of floricanes fruiting types, 2) most differences are evident between single and double cropped plants, 3) early season is not a good time for leaf sampling in double cropping systems, 4) June is stable for N and K, and 5) cultivars are different (so may need different recommendations). Fernandez, Hicks, Blaedow, Shires, Speer, McNicoll, and Gumpertz.

Pest Management Strategic Plan (PMSP) for Blackberry in Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. Gina Fernandez, Karen Blaedow, Hannah Burrack, Sara Villani, Katie Jennings, Wayne Mitchem, Danesha Seth-Carley, Daniel Tregeagle, Roger Batts, Rocco Schiavone, Katie Lohff, Phil Hatfield, Ryan Adams, North Carolina State University, Elizabeth Cieniewicz, Clemson University, Elina Coneva, Edgar Vinson, Arlie Powell, Auburn University, Katheryn Fontenot, Louisiana State University, David Lockwood, University of Tennessee, Amanda McWhirt, University of Arkansas, Rebecca Melanson, Mississippi State University, Jonathan Oliver, University of Georgia, Doug Pfeiffer, Jayesh Samtani, Virginia Polytechnic Institute & State University (Virginia Tech), Guido Schnabel, Clemson University, Ash Sial, University of Georgia, Eric T. Stafne, Mississippi State University. In January 2020, thirty-one University Extension Specialists, IR-4 field research director and growers from the southern US met in Savannah, GA to develop this Pest Management Strategic Plan (PMSP) for blackberries. This PMSP is targeted for the states of Alabama, Arkansas, Georgia,

Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. These states are all members of the Southern Region Small Fruit Consortium.

Impacts: PMSP: Although blackberries are native to the southern region, and have been harvested for centuries, a significant commercial industry has developed in the past decade, valued between \$100,000,000 and \$250,000,000 (Tregeagle estimate). With the growth in commercial production, a number of challenges have emerged that can limit the productivity of this crop. The goal of this workshop was to develop a comprehensive list of pests (insect/mite, pathogen/nematode, weeds, and vertebrate/wildlife) and the known biological, chemical and cultural current control mechanisms for the pests. The attendees of the meeting developed lists of regulatory and research priorities in the following categories, cultural, insects/mites, weeds and diseases. Grower input was essential and with their help and guidance, we feel this report represents the current challenges and needs of the southern blackberry industry. The report will be submitted (and posted?) in December 2020. Sponsored by Southern IPM Center.

Blueberry:

Postharvest shelf life changes in blueberry cultivars Cooperators: Penelope Perkins-Veazie, Massimo Iorizzo, NCSU

Shelf Life: Cuticular Wax Bloom of Blueberry Fruit: An Innovated Edible Coating for Enhancing Quality and Shelf-life. Hamid Ashrafi, Mahnaz Kargar. North Carolina State University.

In summer 2020, we harvested ripe fruits of six different blueberry cultivars and accessions. The samples were stored in the walking cooler at 4°C to study the shelf life. Fruits of each cultivar/accession separated into two groups: with bloom, and without bloom (polished with cloth). Three replicates were considered for each group and 10 to 30 fruits were designated to each replication depending on the size of the fruits. Replicates were weighed every 10 days to investigate the weight loss during storage. They also were checked for rot and fungal deterioration during this time. The preliminary results show that the polished fruits had more weight loss compared to the unpolished ones which proves the role of bloom in water preservation and weight loss prevention. In addition, the number of rotted fruits observed in polished samples was higher than the samples with intact bloom.

Grape:

Shelf Life of seedless and seeded muscadine grapes. M. Hoffmann and P. Perkins-Veazie. This work is supported by a NC New and Emerging Crops grant. Seedless muscadines have been introduced to the fresh market but little is known about their shelf life relative to seeded varieties. Evaluations are currently underway to follow changes in firmness, mold, browning during 0 to 42 days storage at 3 C.

Optimal pruning and flower removal studies on seedless muscadine cultivars. M. Hoffmann, E. Volk and P. Perkins-Veazie. Little is known about production and management of newly introduced muscadine cultivars. With different growth and flowering habits, pruning, trellising and management practices need to be explored

especially for the ever-bearing cultivar Razzmatazz. Evaluations are currently underway (ongoing, funded by the NCDA&CS NEC Program).

Grape Trunk Disease Management in NC. M. Hoffmann, E. Volk and S. Villani. Assessment of organisms involved in NC, development of best management practices and spray programs for NC, development of molecular assays for the PDIC, development of extension resources. (starting December 2020; funded by NC Grape and Wine Council; NCDA&CS Speciality Crop Grant).

Grapevine virus survey and development of testing service through the MPRU and PDIC. M. Hoffmann, C. Almeyda, W. Talton, M. AlRwahnih, M. Sudarshana, M. Nita, E. Volk: Ongoing, partly funded through the NC Grape and Wine Council.

Evaluation of seasonal differences in nutrient content of muscadine tissue samples
M. Hoffmann, T. Rana (MHS thesis).

Impacts: Development of Grapevine Virus-Testing Service for North Carolina Growers in collaboration with PDIC; Securement of a trunk-disease management and identification block grant for North Carolina (\$100,000). Several grape webinars on management, diseases, U-pick operations, reached more than 100 people; Agent training on grape cultural and pest management strategies in NC. Development of a muscadine production guide for the Southeast; COVID-19 related outreach: more than 6,000 views in April and May alone on NCSU grape portal;

Strawberry:

Impact of stolon removal rates on daughter plant production of ever-bearing strawberry cultivars. M. Hoffmann, R. Hernández, G. Fernandez, X. Shi: Rates of propagation could be manipulated by harvesting intervals under CE conditions. We were able to produce more than 100 daughter plants per mother plant in 64 days. Manuscript submitted (MS Thesis)

Impact of NO₃ - NH₄ ratio on flower production and daughter plant production in ever-bearing strawberry cultivars. M. Hoffmann, B. Jackson, X. Shi: Higher ratios of NH₄ had suppressing effect on flower production. Manuscript in preparation (MS Thesis)

Steam in combination with AITC as non-chemical alternative to MBM. Hoffmann, S. Fennimore. Steam in combination with AITC had higher weed and pathogen control efficacy than any of the stand-alone treatments. Manuscript published.

Evaluation of weed and pathogen control efficacy of integrated methods (Steam, AITC, heat releasing substances) over different steam time exposure. M. Hoffmann, J. Neal, S. Fennimore, E Volk: Evaluating the efficacy of integrated management methods in Y1-2 and integrating results into nursery field steam applications, using state-of-the art soil steam technology in Y 3. (ongoing, funded by NASGA and USDA-NIFA MB Trans); (MS Thesis)

Impact of pre-plant fertilizer Nitrogen rates on Nitrogen movement in soil, plant establishment and strawberry production. M. Hoffmann, B. Jackson, A Woodley, M. Schroeder-Moreno, A. Lay: ongoing, partly funded by ICL and NC Strawberry Assoc.; (MS Thesis)

Impacts: Development of a collaborative multi-state SCRI project on optimizing strawberry plant propagation, with the long-term aim to create tools for clean strawberry plant production; Development of integrated soil disinfection methods with steam, collaborative effort with UC Davis (\$500,000 USDA Methyl Bromide Transition; \$110,000 to NC State). Two virtual strawberry field days and a virtual strawberry pre-plant meeting, in total more than 150 participants. Agent training on strawberry cultural and pest management strategies in NC in December. COVID-19 related outreach: more than 20,000 views in April and May alone on NCSU strawberry portal;

Objective 3 - Explore the association between fruit constituents and human health impacts

Blueberry:

Characterized bioactive bio-accessibility in blueberry germplasm (Massimo Iorizzo in collaboration with Food Scientists and NCGR-OR). A high-throughput in vitro digestion model was developed and implemented for the first time to evaluate phenolic bioaccessibility in blueberry. Moderate genetic heritability for absolute and relative bioaccessibility was estimated for several phenolics. Acylated anthocyanin had significantly higher relative bioaccessibility. Relative and absolute bioaccessibility can be measured and used as phenotypic traits to improve delivery of phenolics in new blueberry cultivars (Molla et al., 2020b).

**2. How have the results been disseminated to communities of interest?
What do you plan to do during the next reporting period to accomplish the goals?**

Blackberry and raspberry: Results/discussion of the PCa and GWAS/Pairwise experiment were shared at the SE Regional Fruit and Vegetable Conference in Savannah GA in January and at the NARBA meeting in St. Louis in March.

Blueberry: Results are published along with a seminar at the annual NC Blueberry Council meeting in January.

Grape: Muscadine: Anthocyanin results from crosses of *V. popenoi* and *V. rotundifolia* were presented at the 2020 ASHS conference and the abstract will be published on line in December 2020.

Results for all fruit are disseminated through the NC Fruit Extension Team (<https://ncfet.cals.ncsu.edu/>), list-servs, webinars and online grower meeting, and the grape extension portal: <https://grapes.ces.ncsu.edu/>

Strawberries: Results are disseminated through the NC Fruit Extension Team

(<https://ncfet.cals.ncsu.edu/>), list-servs, webinars and online grower meeting, and the strawberry extension portal: <https://strawberries.ces.ncsu.edu/>
Strawberry GWAS-Antracnose study was presented at the NAPB meeting, virtually.

3. Include any data, germplasm/cultivar descriptions, research results, etc. that you would like to discuss at the meeting. Please keep this brief, highlighting no more than three discussion points within 500 words. Additional information (data tables, abstracts, etc...) can be included in an appendix.

4. List retrievable or archived publications arising from your collaborative research projects including journal articles, book chapters, review articles, theses, proceedings, and extension publications. Please use ASHS style.

- Fernandez, G., Pattison, J., Perkins-Veazie, P., Ballington, J. R., Clevinger, E., Schiavone, R., Gu, S., Samtani, J., Vinson, E., McWhirt, A., & Chacón, J. (2020). 'Liz' and 'Rocco' Strawberries, *HortScience horts*, 55(4), 597-600. Retrieved Jun 24, 2020, from <https://journals.ashs.org/hortsci/view/journals/hortsci/55/4/article-p597.xml>
- Bradish, C.M., J. M. Bushakra , L. R. Robbins , E. Karaadac, S. Teo, J. L. Willard, P. Perkins-Veazie, J. Lee, J. C. Scheerens, C.A. Weber , M. Dossett , N. V. Bassil, C. E. Finn and G. E. Fernandez. 2020. Standardized Phenotyping in Black Raspberry. *Amer. Pom. Soc.* 74 (1): 2-17
- Jacobs, R.L., T. B. Adhikari, J. Pattison, G. C. Yench, G. E. Fernandez, and F. J. Louws. 2019. Assessing Rate-Reducing Foliar Resistance to Anthracnose Crown Rot and Fruit Rot in Strawberry. *Plant Disease*, Vol. 104, No. 2:, 398-407. <https://apsjournals.apsnet.org/doi/10.1094/PDIS-04-19-0687-RE?ai=rs&ui=1z2&af=T>
- Chacon Jimenez, Jose Guillermo (2019-12-13). [Strawberry Studies: Screening of Germplasm and Identification of Quantitative Trait Loci for Necrotrophic and Hemibiotrophic Resistance to Anthracnose Diseases, and Validation of a Set of SSR Fingerprinting Markers.](#)
- Chacon, J.G.1, Olukolu, B., Iorizzo, M., Louws, F.J. & Fernandez, G. Genome Wide Association Studies in an Octoploid Strawberry Biparental Population Discover QTLs for Hemibiotrophic and Necrotrophic Infection Resistance to *Colletotrichum acutatum* and *C. gloeosporioides*. NAPB annual meeting. Aug 2020.
- Mengist M.F., Grace M.H, Xiong J., Kay C.D., Bassil N., Hummer K., Ferruzzi M., Lila M.A. and M. Iorizzo (2020). Diversity in metabolites and fruit quality traits in blueberry enables ploidy and species differentiation and establishes a strategy for bioactive genetic studies. *Frontiers in Plant Science*, 11:370. <https://doi.org/10.3389/fpls.2020.00370>
- Farneti B., Emanuelli F., Giongo L., Toivonen P., Iorizzo M., Folta K.M. and C.E. Finn. 2020. Editorial: Interdisciplinary Approaches to Improve Quality of Soft Fruit Berries" to be considered for publication in *Frontiers in Plant Science*,

- section Crop and Product Physiology. *Frontiers in Plant Science*, 11:592222. <https://doi.org/10.3389/fpls.2020.592222>
- Mengist M.F., Burtch H., Debelo H., Pottorff M., Bostan H., Nunn C., Corbin S., Kay C.D., Bassil N., Hummer K., Lila M.A., Ferruzzi M. and M. Iorizzo. 2020. Diversity of phenolic bioaccessibility in blueberry germplasm: towards the development of a genetic framework to improve the efficiency of bioactive delivery. *Scientific Report*, 10, 17311. <https://doi.org/10.1038/s41598-020-74280-w>
 - Iorizzo M, Lila MA, Perkins-Veazie P, Pottorff M, Finn C, Vorsa N, Edger P, Bassil N, Munoz P, Zalapa J, Gallardo KR, Atucha A, Main D, Giongo L, Li C, Polashock J, Sims C, Canales E, DeVetter L, Chagne D, Espley R and Coe M. VacciniumCAP, a community-based project to develop advanced genetic tools to improve fruit quality in blueberry and cranberry. XXVII Plant & Animal Genome, January 11-15, 2020, San Diego, California, USA.
 - Perkins-Veazie, P., Trandel, M. A., Fernandez, G. A Rapid Method for Estimating Titratable Acidity in Tomato and Small Fruits . 2019. ASHS Conference Proceedings, 54: S212 (abstract). <https://journals.ashs.org/hortsci/view/journals/hortsci/54/9S/hortsci.54.issue-9S.xml>
 - Hoffmann, M., Talton, W., Nita, M., Jones, T., Al Rwahnih, M., Sudarshana, M.R. and Almeyda, C. 2019. First Report of Grapevine Red Blotch Virus, the causal agent of Grapevine Red Blotch Disease in *Vitis vinifera* in North Carolina. *Plant Disease*. <https://apsjournals.apsnet.org/doi/full/10.1094/PDIS-07-19-1539-PDN>
 - Hoffmann, M., Ajwa, H.A., Westerdahl, B.B., Koike, S.T., Stanghellini, M., Wilen, C. and Fennimore, S.A. 2020. Multi-tactic pre-plant soil fumigation with Allyl Isothiocyanate (AITC) in cut-flower and strawberry. *HortTechnology* 30(2):251-258.
 - Kim, D.S., Hoffmann, M., Kim, S., Scholler, B.A. and Fennimore, S.A. 2020. Integration of steam with allyl-isothiocyanate for soil disinfestation. *HortScience* 55(6):920-925.
 - Hoffmann, M., Talton, W., Nita, M., Jones, T., Al Rwahnih, M., Sudarshana, M.R. and Almeyda, C. 2020. First report of grapevine leafroll-associated virus 3 (GLRaV-3) in *Vitis vinifera* in North Carolina. *J. Plant Pathol* (accepted).
 - Shi, X., Hernández, R. and Hoffmann, M. 2020. Timing of stolon removal alters daughter plant production and quality in the long-day strawberry (*Fragaria x ananassa*) cultivar 'Albion'. *HortScience* (submitted).
 - Michuda, A., Goodhue, R.E., Hoffmann, M. and Fennimore, S.A. 2020. Predicting net returns of organic and conventional strawberry following soil disinfestation with steam or steam plus additives. *Agronomy* (submitted).
 - Master Thesis: Impact of Stolon Removal Intervals and Nitrogen Source Ratios on Propagation of Long-day Strawberries (*Fragaria x ananassa* 'Albion') in Soil-less Greenhouse and Controlled Environment Systems - Xiaonan Shi, 2020, NCSU (Advisor: Mark Hoffmann)
 - Hoffmann, M., Volk, E., and Peres, N.. 2020. Hurricane Preparation and Recovery Guide for North Carolina Strawberry Plasticulture Producers. In:

- McNulty, Steven; Gavazzi, Michael; Matchett, Karin, eds. Hurricane preparation and recovery in the Southeastern United States. Gen. Tech. Rep. SRS-xxx. Asheville, NC: USDA Forest Service, Southern Research Station.
- Hoffmann, M., Conner, P., Brannen, P., Burrack, H., Mitchem, W., Cline, B., Perkins-Veazie, P. and Poling, B. 2020. Muscadine production guide for the Southeast (Hoffmann, Hickey, Burrack (eds)) 36pp.
<https://content.ces.ncsu.edu/muscadine-grape-production-guide>

APPENDIX

Utilizing *Vitis popenoei* to successfully increase the malvidin content of muscadine grape

Perkins-Veazie, P., T. Bland, G. Ma, J. Ballington

Muscadine grapes (*Vitis rotundifolia*) grow exceptionally well in the southeastern US. Fruit anthocyanin pigments in *V. rotundifolia* contain primarily diglucoside forms of delphinidin and cyanidin, with little acylation of pigments. In contrast, *V. vinifera* grapes primarily have monoglucoside forms of anthocyanins, mostly with acylation. Ideal wine and juice stability is thought to be obtained by use of grapes high in malvidin-3-glucoside, malvidin-3,5-diglucoside, or high in malvidin anthocyanins with acylation. For many years, breeding efforts have been made to increase and alter the anthocyanin profile in muscadine grapes. *Vitis munsoniana* is a subtropical relative of *V. rotundifolia* and *V. popenoei* is a tropical relative. All three of these species were successfully used to generate Fennels 3-Way hybrid (25, 25, and 50% *V. rotundifolia*, *V. munsoniana* and *V. popenoei*, respectively). Crosses with Fennels 3-Way hybrid have been used in the University of Georgia breeding program to double the total anthocyanin content and increase malvidin-3,5-diglucoside content up to 60%. In North Carolina, crosses were made between DVIT 2970, a *V. popenoei* selection containing 74% of total anthocyanin as malvidin-3,5-diglucoside, and a *V. munsoniana* x *V. rotundifolia* selection, FL 17:66, that is high in total anthocyanin content (>4,000 mg/100 g dry weight). Fruit from five of the seedlings from this cross were collected in 2018 and 2019 and anthocyanin profiles of freeze-dried peels determined using HPLC. One DVIT 2970 x 17:66 selection, CH 19:25-31, was found to be high in total anthocyanin (4100-6900 mg/100 g dry weight) and with over 76-79% of this as malvidin-3,5- diglucoside in both years. Percent malvidin-3,5-diglucoside among the five seedlings ranged from 50 to 79 of total pigments and total anthocyanin from 1500 to 6900 mg/100 g. These results indicate that *V. popenoei* can be used to shift anthocyanin profiles in muscadine grape to a high malvidin percentage without loss of total anthocyanin.