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Food and Environment
*Agricultural Experiment Station*

# Fruit and Vegetable
## 2019 ANNUAL RESEARCH REPORT

**Agricultural Experiment Station** | Kentucky Tobacco Research and Development Center | Veterinary Diagnostic Laboratory | Division of Regulatory Services | Research and Education Center
Robinson Forest | Robinson Center for Appalachian Resource Sustainability | University of Kentucky Superfund Research Center | Equine Programs

# 2019 Fruit and Vegetable Crops Research Report

*Edited by John Snyder, Chris Smigell, and John Strang*


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## Important Note to Readers
The majority of research reports in this volume do not include treatments with experimental pesticides. It should be understood that any experimental pesticide must first be labeled for the crop in question before it can be used by growers, regardless of how it might have been used in research trials. The most recent product label is the final authority concerning application rates, precautions, harvest intervals, and other relevant information. Contact your county's Cooperative Extension office if you need assistance in interpreting pesticide labels.

This is a progress report and may not reflect exactly the final outcome of ongoing projects. Please do not reproduce project reports for distribution without permission of the authors.

**Cover:** Fresh market cabbage grown at the University of Kentucky College of Agriculture, Food and Environment's Horticultural Research Farm in Lexington, Kentucky.

**Photographer:** Steve Patton




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# Contents

# The 2019 Fruit and Vegetable Crops Research Program

*John Strang, Horticulture*

Fruit and vegetable production continues to show sustained growth in Kentucky. As the industry grows around a diverse collection of marketing tactics (wholesale, farmer markets, CSAs, and direct to restaurants) as well as various production systems, there continues to be a need for applied practical information to support the industry. The 2019 Fruit and Vegetable Crops research report includes results for eleven projects. One blackberry demonstration plot was conducted in Boone County and high tunnel hybrid tomato and colored cauliflower demonstration plots were conducted in McCracken County. Research was conducted by faculty and staff from the Horticulture Department in the University of Kentucky College of Agriculture, Food and Environment. Faculty and staff of Kentucky State University also contributed to this report.

Variety trials included in this year's publication include Primocane-fruiting blackberries, matted-row strawberries, black rot-resistant cabbage, and high-tunnel beets. Additional research trials include natural enemy predators associated with blackberries bordered by native perennial plants or pasture, the effect of container and substrate composition on the productivity and growth of 'Duke' highbush blueberry, rootstock effects on apple tree growth and yield, glucosinolates content of turnips grown in sewage sludge-amended soil, vitamin C, reducing sugars and total phenolic contents of three cultivars of onion grown under field conditions, results of selection for high yield and zingiberene content of interspecific hybrid tomatoes grown in the open field, and recovery of spider mite resistance in advanced generations of interspecific hybrid tomatoes. Evaluation of varieties is a continuing necessity and allows us to provide the most up to date information in communications with vegetable growers. The vegetable variety trial results are the basis for updating the recommendations in our Vegetable Production Guide for Commercial Growers (ID-36). These updates are not based solely on one season's data or location. It is necessary to trial varieties in multiple seasons and if at all possible, multiple locations. We may also collaborate with researchers in surrounding states such as Ohio, Indiana, and Tennessee to discuss results of variety trials they have conducted. The results presented in this publication often reflect a single year of data at a limited number of locations. Although some varieties perform well across Kentucky year after year, others may not. Following are some helpful guidelines for interpreting the results of fruit and vegetable variety trials.

## Our Yields vs. Your Yields

Yields reported in variety trial results are extrapolated from small plots. Depending on the crop, individual plots range from 1 to 200 plants. Our yields are calculated by multiplying the yields in these small plots by correction factors to estimate per-acre yield. For example, if you can plant 4,200 tomato plants per acre (assuming 18" within row spacing) and our trials only have 10 plants per plot, we must multiply our average plot yields by a factor of 420 to calculate per-acre yields. Thus, small errors can be greatly amplified. Due to the availability of labor, research plots may be harvested more often than would be economically possible. Keep this in mind when reviewing the research papers in this publication.

## Statistics

Often yield or quality data will be presented in tables followed by a series of letters (a, ab, bc, etc.). These letters indicate whether the yields of the varieties are statistically different. Two varieties may have average yields that are numerically different, but statistically are the same. For example, if tomato variety 1 has an average yield of 2,000 boxes per acre, and variety 2 yields 2,300 boxes per acre, one would assume that variety 2 had a greater yield. However, just because the two varieties had different average yields does not mean that they are statistically or significantly different. In the tomato example, variety 1 may have consisted of four plots with yields of 1,800; 1,900; 2,200; and 2,100 boxes per acre. The average yield would then be 2,000 boxes per acre. Tomato variety 2 may have had four plots with yields of 1,700; 2,500; 2,800; and 2,200 boxes per acre. The four plots together would average 2,300 boxes per acre. The tomato varieties have plots with yield averages that overlap, and therefore would not be considered statistically different, even though the average per acre yields for the two varieties appear to be quite different. This example also demonstrates variability. Good varieties are those that not only yield well but have little variation. Tomato variety 2 may have had yields similar to variety 1 but also much greater variation. Therefore, all other things being equal, tomato variety 1 may be a better choice due to less variation in the field.

Statistical significance is shown in tables by the letters that follow a given number. For example, when two varieties have yields followed by completely different letters, they are significantly different; however, if they share even one letter, statistically they are no different. Thus a variety with a yield that is followed by the letters "bcd" would be no different than a variety followed by the letters "cdef," because the letters "c" and "d" are shared by the two varieties. Yield data followed by the letters "abc" would be different from yield data followed by "efg."

When determining statistical significance, we typically use a P value of 0.05. In this case, P stands for probability. If two varieties are said to be different at $P < 0.05$, then at least 95 percent of the time those varieties will be different. If the P value is 0.01, then 99 percent of the time those varieties will be different. Different P values can be used, but typically $P < 0.05$ is considered standard practice for agricultural research.

This approach may be confusing, but without statistics our results wouldn't be useful. Using statistics ensures that we can make more accurate recommendations for farmers in Kentucky.

# Yield and Berry Weight of Three Primocane-fruiting Blackberry Selections Grown Organically at Kentucky State University

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## Introduction

In Kentucky, over 670 farms grow berry crops, including 368 farms that grow blackberries, which are valued at over $2,600,000 annually (Census of Agriculture, 2012). Blackberries are native to Kentucky and Kentucky's climate is well-suited for blackberry production. Two cane types exist within brambles: primocanes (or first-year canes), which are usually vegetative, and floricanes, which are the same canes that flower and produce fruit the next growing season. Primocane-fruiting blackberries, also known as fall-fruiting and ever-bearing blackberries, have the potential to produce two crops per year: a normal summer crop on the floricane and a later crop on the current season's primocanes. Primocanes flower and fruit from mid-summer until frost, depending on temperature, plant health, and the location in which they are grown. Growers can reduce pruning costs by mowing canes in late winter/early spring to obtain a primocane crop only; this also provides control for anthracnose, cane blight, and red-necked cane borer without pesticides. Relying only on a primocane crop also avoids potential winter injury of floricanes. However, late-ripening blackberries are more prone to spotted wing Drosophila infestations so growers who are marketing the berries will need to maintain a pest-control program.

The first commercially available primocane-fruiting blackberry varieties, 'Prime-Jim®' and 'Prime-Jan®', were released by the University of Arkansas in 2004 (Clark et al., 2005). 'Black Magic™' is a thorny, primocane-fruiting selection suited for home growers and on-farm sales (Clark et al., 2014). 'Prime-Ark®45', released in 2009 for commercial use, has improved heat tolerance and shipping traits compared to previous selections (Clark and Perkins-Veazie, 2011). 'Prime-Ark® Freedom' was the first thornless primocane-fruiting blackberry and produces large fruit, but displays inferior shipping traits compared to 'Prime-Ark® 45' (Clark, 2014). 'Prime-Ark® Traveler', also a thornless primocane-fruiting selection, has improved storage and shipping characteristics compared to 'Prime-Ark® Freedom' and is recommended for commercial production (Clark and Salgado, 2016). In the fall of 2017, APF-205T was released as 'Stark® Black Gem®'. APF-268 is an advanced selection from the University of Arkansas breeding program. It is a primocane-fruiting blackberry that is not thornless, but has a reduced number of thorns compared to other thorny primocane-fruiting cultivars.

Summer temperatures above 85°F can greatly reduce fruit set, size, and quality on primocanes, which results in substantial reductions in yield and fruit quality (Clark et al., 2005; Stanton et al., 2007). The objective of this study was to determine if 'Prime-Ark® Traveler' is superior to 'Stark® Black Gem®' and the advanced selection APF-268 in terms of yield and fruit quality under Kentucky growing conditions. Here we report results from the variety trial in its first and second years of fruit production.

**Table 1.** 2018-19 yields and berry weights for 'Prime-Ark® Traveler', 'Stark® Black Gem®', and APF-268 at the Kentucky State University Harold R. Benson Research and Demonstration Farm, Frankfort, KY.

| Selection | 2018 | | 2019 | |
|---|---|---|---|---|
| | Fruit Weight (g) | Yield (lb/acre) | Fruit Weight (g) | Yield (lb/acre) |
| 'Stark® Black Gem®' | 4.24 a[1] | 860 a | 2.87 a | 279 a |
| 'Prime-Ark® Traveler' | 3.26 b | 757 a | 2.15 b | 206 a |
| APF-268 | 4.36 a | 961 a | 3.14 a | 475 a |

[1] Numbers in a column followed by the same letter are not significantly different (least significant difference P = 0.05)

## Materials and Methods

In May 2016, a primocane-bearing blackberry variety trial was planted at the KSU Research and Demonstration Farm on certified organic land. The planting contained the selections 'Prime-Ark® Traveler', 'Stark® Black Gem®', and APF-268, which are all primocane-fruiting selections from the University of Arkansas. Plants were arranged in a completely randomized design, with four replicate plots each containing five plants of 'Prime-Ark® Traveler', 'Stark® Black Gem®', or APF-268 (total of 20 plants of each selection) in 10-foot plots with a plant spacing of 2 feet. This trial was managed using organic practices following the National Organic Program standards. A combination of cultivation, hand weeding, and straw mulch was used for weed control. Drip irrigation was used as needed. Plots were fertilized with NatureSafe 10-2-8 fertilizer (Griffin Industries LLC, Cold Spring, KY) at 100 lbs of N per acre. Primocanes were tipped on all selections at one meter beginning in early June to promote lateral branching and flowering. Ripe fruit were harvested twice per week from early July through mid-October. Analysis of variance and least significant difference means separation were performed using CoStat Statistical Software (CoHort Software, Monterey, CA).

## Results and Discussion

Fruit were harvested from early July until mid-October. A floricane crop was produced in 2019; however, due to cold temperatures during the winter of 2017-2018, only a primocane crop was produced in 2018. The results presented in this report are for primocane crops for 2018 and 2019. Growing conditions in 2018 and 2019 were hot; daily high temperature was above 85°F for 59 out of 122 days from June through September in 2018 and 83 out of 122 days in 2019. The average high for July was 84.7°F in 2018 and 87.4°F in 2019. July, August, and September all had average highs of above 85°F in 2019. The high temperatures likely reduced fruit set, size, and quality on primocanes, especially in 2019.

In 2018, fruit size varied significantly; 'Stark® Black Gem®' and APF-268 had a larger fruit size (4.24 g and 4.36 g) versus 'Prime-Ark® Traveler' (3.26 g; Table 1). In 2019, a similar trend for the selections was seen in fruit size. APF-268 and 'Stark® Black Gem®' had significantly larger fruit sizes (3.14 g and 2.87 g) compared to 'Prime-Ark® Traveler' (2.15 g; Table 1). There was no significant difference in yield in 2018 or 2019, but there was a trend for APF-268 to have a higher yield both years. Primocane yields in 2019 were approximately half of what they were in 2018, likely due to the extreme temperatures present in the summer of 2019.

The University of Arkansas Blackberry Breeding Program recommends that commercial producers plant 'Prime-Ark® Traveler' due to its superior shipping and storage qualities. Due to softer fruit, 'Stark® Black Gem®' is recommended for pick-your-own (also called U-pick) and on-farm sales as well as for home gardens. Year-to-year yield characteristics will need to be evaluated further; however, the data to date suggests that 'Stark® Black Gem®' has large fruit, yields well in Kentucky, and should be considered by growers interested in producing primocane-fruiting blackberries for markets with little to no shipping.

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# Natural Enemy Predators Associated with Blackberries Bordered by Native Perennial Plants or Pasture

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## Introduction

The spotted-wing Drosophila (SWD), *Drosophila suzukii*, is native to Asia and a pest of soft skinned fruit, including strawberries, blueberries, raspberries, and blackberries. SWD was first discovered in central California in 2008 and in Kentucky in 2012. Females oviposit their eggs inside undamaged fruit. Once inside, the eggs and larvae are protected by the fruit, therefore implementing management strategies is difficult.

Insect predators and parasitoids consume pollen and nectar in addition to prey or when prey is unavailable. The consumption of pollen and nectar can increase the longevity and fecundity of natural enemies (Irvin et al. 1999; Lee & Heimpel 2008). Conservation biological control (CBC) utilizes native perennial plants and grasses next to or within an agricultural crop to attract natural enemies. The availability of flowering resources can be essential to natural enemy efficacy in biological control of pest insects (van Rijn and Sabelis 2005). Plants also provide microclimates, in the form of moderated temperatures, which offer shelter for these natural enemies (Fiedler and Landis 2007.) The objective of this study was to determine if native perennial plants increased the number and diversity of natural enemy predators in blackberries.

## Materials and Methods

Research was conducted at Kentucky State University's Harold R. Benson Research and Demonstration Farm in Franklin County, Kentucky. Eight blackberry plots measuring 25 m long x 12 m wide (0.03 ha) were planted with two rows of 'Prime Ark Traveler' blackberries in 2016. Each blackberry row was divided into five 3.7 m sections with 1.2 m breaks between sections. Blackberries were planted using 6 m row spacing and 0.6-m plant spacing. Each plot was bordered on its length by either native perennial plants or pasture. The native perennial borders were planted with 14 species of flowering plants and 5 grasses. Pasture borders were a mixture of grasses, clover, and broad leaf weeds. Native perennial plants included thimbleweed, *Anemone virginiana*; smooth blue aster, *Aster laevis*; New England aster, *Aster novae-anglica*; purple coneflower, *Echinacea purpurea*; rattlesnake master, *Erygium yuccifolium*; Joe Pye weed, *Eupatorium fistulosum*; common boneset, *Eupatorium perfoliatum*; blue lobelia, *Lobelia siphilitica*; bee balm, *Monarda fistulosa*; foxglove beardtongue, *Penstemon digitalis*; hairy beardtongue, *Penstemon hirsutus*; slender mountain mint, *Pycantheum tennuifolium*; greyheaded coneflower, *Ratibida pinnata*; stiff goldenrod, *Solidago rigida*; big bluestem, *Andropogon* *gerardii*; side-oats grama, *Bouteloua curtipendula*; prairie switchgrass, *Panicum virgatum*; little bluestem, *Schizacharium scoparium*; and prairie dropseed, *Sporobolus heterolepis*. Native perennial border rows were planted in 2011. Stiff goldenrod; Joe Pye weed; and smooth blue aster, were added in 2017.

This was a randomized block design replicating each treatment four times. All plots were separated by 75 m. Natural enemies were caught and quantified using 15-cm x 15-cm yellow sticky traps from July through November 2016, June through November 2017, and June through October 2018. In 2016, four yellow sticky traps were deployed equidistant from each other and from the ends of each border row. In 2017 and 2018, five sticky traps were deployed equidistant from each other and from the ends of each border row, and in the center of each blackberry section. Sticky traps were changed weekly in 2016 and 2017. In 2018, sticky traps were deployed every other week and collected after one week. Traps were placed in one-gallon plastic bags, labeled, transported to the laboratory, and stored in a freezer or boxes for natural enemy predator identification and quantification. A maximum of ten ripening or ripe blackberries were harvested from each section weekly in 2017 and biweekly in 2018. If there were not ten blackberries in a section, we harvested what fruit was available. Berries were placed in labeled quart freezer bags and taken to the laboratory. To determine if SWD larvae were present in the blackberries, berries were gently pressed inside the labeled bags using a thumb and index finger to separate drupelets. In 2017, a float method was performed using a brown sugar and water solution (Dreves, et al. 2014) and pouring the berries into dark blue or black bowls and then counting the number of larvae that float to the top of the solution. This method was used on fresh berries when larvae were alive. Blackberries in later harvests were frozen and identified in the 2017/2018 winter using a salt and water solution and method developed utilizing a reusable polyester mesh coffee filter and 23-gauge metal hardware mesh (Van Timmeren et al. 2017). Berries were again gently pressed. Two cups of salt solution were poured into each quart bag and allowed to sit for at least one hour. Berries could also sit in the salt solution for three to four days in the refrigerator. A plastic quart container was used as a base to hold the poured-off solution. The coffee filter was placed inside the top portion of the quart container. The bottoms of two clear plastic 18 oz. cups were cut out and the cups were placed inside the quart container. Two plastic cups were used so that the cups would be more stable. A metal hardware mesh was formed to fit inside the top of the plastic cups. Contents of the quart bag were then poured over the hardware mesh so that the mesh held the berries, the coffee filter held the larvae and the quart container held the remaining solution. Larvae were counted using a binocular dissecting microscope. Data were analyzed using ANOVA and Fisher's Protected LSD procedures using CoStat Statistical Software (CoHort Software 2006.)

## Results and Discussion

The beneficial insect species caught during this study were: pink lady beetles, *Coleomegilla maculata*; multicolored Asian lady beetles, *Harmonia axyridis* (Pallas); spotless lady beetles, *Cycloneda sanguinea*; seven spotted lady beetles, *Coccinella septempunctata;* mildew-eating lady beetles, *Psyllobora parvinotata*; orange-spotted lady beetles, *Brachiacantha ursina*; minute pirate bugs (MPB; *Orius* spp.); syrphid flies, Syrphidae; and big-eyed bugs, *Geocoris*. MPB followed by the multicolored Asian lady beetles were the most abundant natural enemies found in 2017 and 2018.

In both 2017 and 2018, the number of MPB in the blackberries bordered by pasture was higher than in blackberries bordered by native perennial plants, but the differences were not significant (Figures 1 and 2). The number of multicolored Asian lady beetles was greater in blackberries bordered by pasture in 2017, yet in 2018 the numbers were higher in blackberries bordered by native perennial plants.

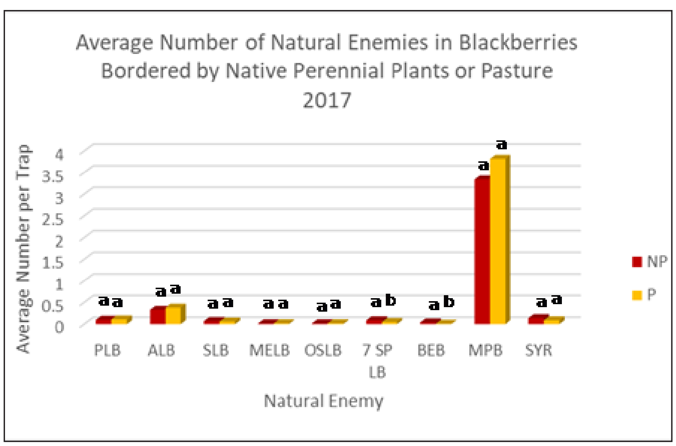


**Figure 1.** Average number of natural enemies per trap. 2017. NP=native perennial plants; P=pasture. PLB=pink lady beetle; ALB=multicolored Asian lady beetle; SLB=spotless lady beetle; MELB=mildew eating lady beetle; OSLB=orange spotted lady beetle; 7 SP LB=seven spotted lady beetle; BEB=big-eyed bug; MPB=minute pirate bug; SYR=syrphid flies.

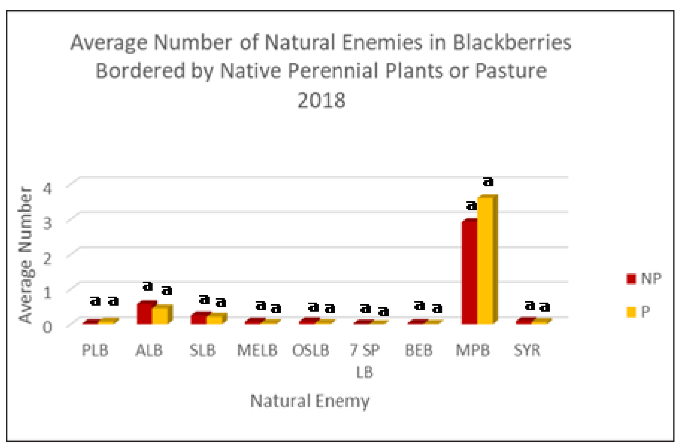


**Figure 2.** Average number of natural enemies per trap. 2018. NP=native perennial plants; P=pasture. PLB=pink lady beetle; ALB=multicolored Asian lady beetle; SLB=spotless lady beetle; MELB=mildew eating lady beetle; OSLB=orange spotted lady beetle; 7 SP LB=seven spotted lady beetle; BEB=big-eyed bug; MPB=minute pirate bug; SYR=syrphid flies.

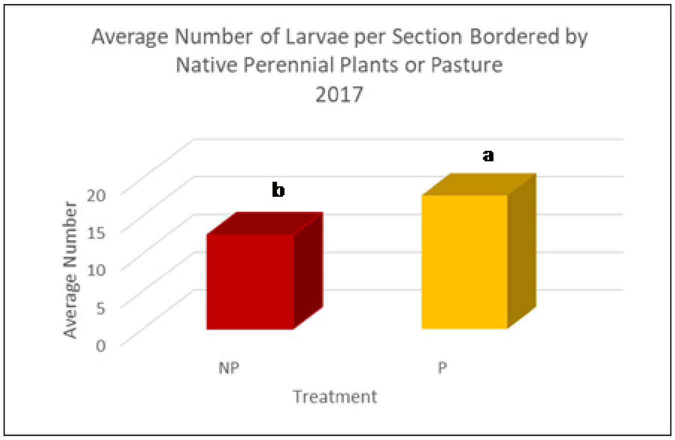


**Figure 3.** Average number of larvae per blackberry section. 2017. NP=native perennial plants; P=pasture.

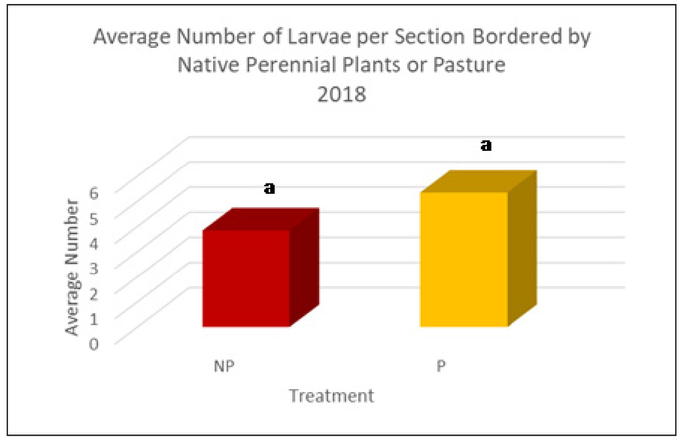


**Figure 4.** Average number of larvae per blackberry section. 2018. NP=native perennial plants; P=pasture.

Although the number per trap was low, in 2017, there were significantly more seven spotted lady beetles and big-eyed bugs in blackberries bordered by native perennial plants than in blackberries bordered by pasture (Figure 1). There was also a slight trend of more spotless lady beetles and syrphid flies in blackberries bordered by native perennial plants. Pink lady beetles and multicolored Asian lady beetles showed a slight trend in being greater in number in blackberries bordered by pasture.

In 2018, there were no significant differences in the numbers of natural enemies in either the blackberries bordered by native perennial plants or pasture (Figure 2). The numbers of multicolored Asian lady beetles, spotless lady beetles, mildew eating lady beetles, orange spotted lady beetles, seven spotted lady beetles, big-eyed bugs, and syrphid flies were slightly greater in blackberries bordered by native perennial plants than in blackberries bordered by pasture. In contrast, pink lady beetles were slightly more abundant in blackberries bordered by pasture.

There were significantly more SWD larvae found in blackberries bordered by pasture than in blackberries bordered by native perennial plants in 2017 (Figure 3). In 2018, there were also more SWD larvae in blackberries bordered by pasture although there was not a significant difference (Figure 4). This is a positive finding; however, the numbers were still too numerous in the blackberries bordered by native perennial plants, as consumers would prefer to see zero larvae in their fruit. Larvae from berries collected in September and October 2018 must still be quantified.

There are more sticky traps collected in the rows of blackberries to be identified and quantified from 2018 as well as all of the collection dates for the border rows. Because of this, data from the 2016 and 2017 border rows were not included in this report.

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# Effect of Container and Substrate Composition on the Productivity and Growth of 'Duke' Highbush Blueberry

*Daniel Becker, Dwight Wolfe, Winston Dunwell, and Ginny Travis, Horticulture*

## Introduction

The highbush blueberry (*Vaccinium corymbosum* L.) is noted for its health benefits, encouraging increased consumer demand. Excellent sales potential exists in local markets, but exacting soil requirements limit suitable production sites. Blueberries require acidic soils with a pH of 4.5 to 5.2, and high organic matter (Strang, et. al., 2003). Leaf chlorosis and weakened growth due to iron deficiency is increasingly common when soil pH moves above 5.3. Soils for blueberries must be well drained. When grown in high pH and wet, poorly drained soils, blueberries are highly susceptible to phytophthora root rot, a devastating fungal disease that can destroy entire plantings. Without significant site preparation such as building raised beds and often extensive soil amendments which can exceed $7,000/acre during establishment, few sites in Kentucky will meet the requirements necessary for sustained productivity and long-term profitability (Ernst, 2019).

Often the best sites are located great distances from desirable markets, reducing on-farm direct to customer sales and increasing transportation costs to farmers markets. Increased market distance also limits the size and long-term viability of a small farm operation. Grown on sites with good market potential, but poor suitability, blueberries often fail to thrive, leading either to abandonment of the project or further expenses of up-keep without a requisite increase in returns. By growing blueberries in containers there is potential for growers to successfully diversify their operations, adding much needed capital, without the need for an optimum growing site.

This study was initiated in order to evaluate the adaptability of the highbush blueberry to perennial container production. It is important to note the ongoing and intended multi-year nature of this trial. Blueberry fruit production in above-ground containers is untested in Kentucky, research and experience is also limited in other regions. Treatment results are expected to adjust over time, so that future outcomes may be radically different than those reported.

## Materials and Methods

'Duke' blueberries received as one-year bare-root nursery plants were grown in 2017 with automatic irrigation in seven-gallon plastic containers filled with ⅜" average particle size pine bark fines substrate. Osmocote PLUS 15-9-12 (12-14 months at 70°F) was top-dressed at 156 g/container in May. Cropping was prevented this year and the following by hand-stripping of blooms. In April 2018, 54 of the healthiest plants were transplanted into 25-gallon containers. Treatments consist of two container types, solid black plastic or Smart pot® black fabric filled with either of three substrate mixes, 100% pine bark fines, 100% Pro-Moss® sphagnum peat moss, or 50/50% peat moss/pine bark. Plants were set onto a gravel bed 4 feet apart in three rows spaced 14 feet apart, with each row being a replication of 18 plants. Plots consist of three plants of each container and substrate combination in a randomized complete block design.

Annual fertilizer consisted of 267 g/container of Osmocote PLUS split into three, 89 g applications every six weeks in mid-April, late May, and early July. Automatic irrigation operated for one-minute durations, twice a day at 10:00 am and 2:00 pm, supplying 1.3 gal. of water through two 9.8 gal./hr. MIL Irrigation® emitters set on stakes located 6-inches from the base of the plant on each side. The irrigation system was manually shut-off during extended periods of heavy rainfall and turned-on for an additional 10-minute run/week when little or no rainfall occurred, as needed. In December, the plants were moved close together in a block, the outside perimeter pots wrapped with frost covers, and the whole covered with three layers of 3 oz/sq. yd. winter blankets to provide freeze protection.

The majority of data collected focuses primarily on yield characteristics. A harvest pass was performed once per week. Ripe fruit collected during each pass were summed at the end of the season to determine the total yield/plant; fruit weight from each pass was divided by the total yield per plant to get a percentage of the total. A random 50-berry subsample was collected and weighed during the second harvest. Plant height and width were measured in mid-September to verify canopy volume. The data was statistically analyzed using SAS v.9.4 (SAS Institute, Cary, NC) and subjected to analysis of variance (ANOVA) and separating means using Duncan's Multiple Range Test LSD ($P \leq 0.05$).

## Results and Discussion

Apart from February, when an excess of 6.31 inches of rain fell for the month, January to June 2019 had near normal rainfall and average temperatures. Some increased disease incidence did occur, primarily botryosphaeria stem blight (*Botryosphaeria dothidea*) and Phomopsis twig blight (*Phomopsis vaccinii*) but was generally minor. Overall plant health was good coming out of winter. Lows of 9.3 and 9.5°F on the mornings of January 30 and 31 from a polar vortex did not cause any noticeable winter injury. A 25.7°F freeze on April 1 did not affect cropping potential as the floral development was still in the tight cluster phase. Harvest passes occurred on June 7, 14 and 21, a 14-day duration from start to finish. Yield characteristics and canopy volume are shown in Table 1; the treatments are ranked based on mean yield/plant.

Harvest yield was significantly affected by treatment. Plants in plastic containers with peat moss substrate were more productive than either pine bark or the 50/50% mix. Harvest yield of plants grown in the fabric containers were generally lower

**Table 1.** 2019 blueberry container and substrate composition trial results at UKREC, Princeton, KY.

| Container | Substrate | Yield/ plant (oz)[1] | | Wt. 50 berries (oz)[2] | | Percent Yield of Harvest | | | | | | Canopy volume (cu ft)[3] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1st wk. | | 2nd wk. | | 3rd wk. | | | |
| Plastic | Peat moss | 112.1 | a | 2.7 | a | 40.4 | b | 42.8 | ab | 16.8 | ab | 16.3 | a |
| Plastic | Pine bark | 99.5 | ab | 2.6 | a | 39.8 | b | 43.8 | a | 16.3 | ab | 12.6 | b |
| Fabric | Pine bark | 89.2 | bc | 2.7 | a | 52.2 | a | 38.2 | ab | 9.6 | b | 14.3 | ab |
| Plastic | 50/50 pine bark/peat moss mix | 84.7 | bc | 2.6 | a | 38.6 | b | 40.0 | ab | 21.3 | a | 13.0 | ab |
| Fabric | 50/50 pine bark/peat moss mix | 77.0 | bc | 2.7 | a | 45.0 | ab | 43.3 | a | 11.7 | b | 11.7 | b |
| Fabric | Peat moss | 73.9 | c | 2.7 | a | 42.4 | b | 37.2 | b | 11.6 | b | 11.6 | b |

1 Means within columns followed by the same letter are not significantly different (Duncan's Multiple Range Test LSD, $P \leq 0.05$).
2 Weight of 50 berry sample collected during the 2nd harvest week.
3 Canopy volume calculated as the volume of a cylinder based on its height and the square of its radius, which is half of the width ($V = \pi^* r^2 {}^* h$).

than other treatments except for those grown on pine bark substrate which was greater, but not significantly different from those in plastic with a 50/50% substrate mix. Plants in fabric containers with peat moss substrate had the lowest yields. Treatment did not affect berry size when collected during the second harvest.

Plants grown on the pine bark substrate had a greater proportion of their total yield collected during the first and second harvests within the cloth and plastic containers, respectively. The percentage harvested from the cloth and 50/50% container-substrate treatment was similarly advanced during the second harvest. In contrast, the amount of fruit picked from the plastic and 50%/50% container-substrate mix was more evenly distributed, resulting in a greater amount harvested during the final week.

Similar to yield, plants grown in plastic containers and a peat moss substrate generally developed the largest canopies. Comparatively, canopy sizes and yields were lowest in the cloth-peat moss and 50/50% mix container-substrate treatments. Except for the plastic/pine bark treatment combination which produced the second greatest yield on the third smallest mean plant sizes, there is a clear relationship between canopy volume and yield; i.e. larger canopies produce greater yields.

Productivity and growth differences between treatments may be a result of container and substrate water retention influences. Conventional plastic containers are non-porous except for the drainage holes located on the bottom surface. Substrates will retain moisture over longer periods in plastic containers compared to fabric which has porous walls and a greater evaporative surface area. Peat moss has a higher water holding capacity compared to pine bark and requires longer to dry once fully wetted. However, when dehydrated, peat moss will repel water and is difficult to rehydrate uniformly. All treatments were irrigated similarly in duration with a focus on preventing waterlogging to avoid phytophthora root rot infection. It is likely that the irrigation program resulted in some treatments, namely those in the fabric containers being underwatered to varying degrees. This might explain the dramatic yield and canopy volume differences noted between the container types holding the straight peat most substrate.

## Acknowledgements

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# Evaluation of Strawberry Varieties as Matted Rows

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Strawberries are popular with Kentucky consumers and acreage is dispersed across the state with concentrations closer to larger cities. There are approximately 200 acres of strawberries grown in the state and about 130 of these use the matted row system as opposed to the annual plasticulture system. The matted row cultural system involves less capital outlay and grower risk. This study evaluated newer strawberry varieties planted in the matted row system at the University of Kentucky Horticultural Research Farm in Lexington. This is the second year, or first fruiting year, of this study.

## Materials and Methods

Thirteen dormant, bare-rooted strawberry varieties were planted on 13 April, 2018. Allstar, Chandler, Earliglow, and Jewel were included as standards. All plants were dipped into Viterra® Agri-gel™ (Nepera Chemical Company, Inc.) prior to planting to enhance water retention and plant survival. Each plot was a 10 ft long single row and consisted of six plants set 2 feet apart in the row with 4 feet between rows. Plots were replicated four times in a randomized block design. Fifty pounds of nitrogen per acre as 34-0-0 which was a mixture of ammonium sulfate and urea was tilled into the soil prior to planting.

Insect, disease and weed control were conducted in accordance with the Midwest Fruit Pest Management Guide (ID-232). No fungicides or insecticides were applied in 2018. Chateau pre-emergence herbicide was applied over the top of the dormant plants five days after transplanting and Devrinol was applied 28 August 2018 for pre-emergence weed control. Rows were narrowed to 14 inches on 31 August to keep plots separated and strawberry plants that rooted in row middles after this were manually removed. The field was mulched with wheat straw on 21 November, 2018 for winter protection. Chateau was again applied 28 February 2019. Captan and Pristine were applied two times each during bloom in 2019. No insecticides were applied in 2019. Plants were drip irrigated as needed.

Ten-foot sections in each plot were harvested in the spring of 2019. Yield, fruit size, flavor, and appearance data were collected. Plant vigor was rated on 16 May 2019.

Data are shown for the 2019 harvest season. Twenty berries were weighed for each variety at each harvest to determine average berry weight. Berry flavor was assessed by two individuals, four times and fruit firmness and attractiveness were assessed twice for each variety and replication.

On 9 May replicates were assessed for leaf spot (*Mycosphaerella fragariae*) disease. Eight entire (trifoliate) leaves were randomly sampled from each replicate. The number of leaf spot lesions on each leaf were counted, and the percent of leaf area showing disease symptoms surrounding the lesions was estimated. On 18 June replicates were assessed for leaf spot, angular leaf spot (*Xanthomonas fragariae*), and leaf blight (*Phomopsis obscurans*), following the same protocol used in the 9 May assessment.

## Results and Discussion

Both the 2018 and 2019 springs were cool and rainy, so plant establishment and early growth in 2018 and yield and berry size in 2019 were generally good. However, these weather condition in 2019 likely reduced berry flavor. There were no late spring frosts in 2019 that would have reduced yields.

**Table 1.** Strawberry yield, fruit characteristics and harvest mid-point, 2019.

| Variety | Yield (lbs/A)[1] | | Avg. wt. 20 berries[2] (lb) | Attractiveness[3] (1-5) | Firmness (1-5)[4] | Flavor (1-5)[5] | Harvest midpoint[6] (date) | Plant vigor (1-5)[7] |
|---|---|---|---|---|---|---|---|---|
| Honeoye | 23100 | a | .39 | 4.2 | 3.7 | 3.6 | 27 May | 4.8 |
| Allstar | 21800 | ab | .46 | 3.9 | 4.7 | 4.0 | 29 May | 4.3 |
| Galletta | 21500 | ab | .45 | 4.5 | 4.1 | 3.7 | 25 May | 4.8 |
| AC Wendy | 20500 | ab | .52 | 4.1 | 3.7 | 3.8 | 25 May | 4.1 |
| Sonata | 20400 | ab | .41 | 4.1 | 3.5 | 4.0 | 31 May | 3.9 |
| Yambu | 18900 | ab | .57 | 4.2 | 3.7 | 3.7 | 26 May | 3.5 |
| Jewel | 17700 | b | .49 | 4.0 | 3.8 | 3.8 | 31 May | 4.3 |
| Flavorfest | 17200 | b | .58 | 4.1 | 4.0 | 4.1 | 30 May | 4.1 |
| Earliglow | 16900 | b | .35 | 4.2 | 3.7 | 4.3 | 23 May | 4.5 |
| AC Valley Sunset | 12500 | c | .68 | 3.8 | 3.8 | 4.2 | 08 Jun | 3.7 |
| Archer | 11100 | c | .71 | 3.7 | 3.8 | 4.0 | 29 May | 2.3 |
| Rutgers Scarlet | 11000 | c | .50 | 4.1 | 4.1 | 4.1 | 31 May | 3.6 |
| Chandler | 9400 | c | .40 | 3.7 | 3.5 | 3.6 | 01 Jun | 3.4 |

[1] Numbers followed by the same letter are not significantly different (Duncan Multiple Range Test LSD P≤0.05).
[2] Based on 20 berries weighed at each harvest.
[3] Attractiveness: 1 = poor; 5 = excellent.
[4] Firmness: 1 = soft; 5 = very firm.
[5] Flavor based on four evaluations by two individuals: 1 = poor; 5 = excellent.
[6] Date on which half of the berries were harvested, based on total yield weight.
[7] Plant vigor and row fill rating 16 May, 2019: 1=poor vigor and row fill; 5= excellent.

Honeoye, Allstar, Galletta, AC Wendy, Sonata and Yambu had the highest yields (Table 1). Earliglow, AC Valley Sunset, Flavorfest, Rutgers Scarlet, Allstar, Sonata and Archer were rated as having the best tasting fruit. Average berry weight tended to be highest for Archer and AC Valley Sunset and lowest for Earliglow, Honeoye, Chandler and Sonata. Galletta, Honeoye, Yambu and Earliglow rated very high for attractiveness, while Archer, Chandler, AC Valley Sunset and Allstar rated lower. Allstar, Galletta and Rutgers Scarlet rated very high for berry firmness while Chandler and Sonata fruit were softer. Plant vigor and row fill rated on 16 May 2019 was excellent for Honeoye, Galletta, Earliglow, Allstar and Jewel. However, Archer plant vigor was lower and rows were not adequately filled with plants to produce a full crop.

A minimal fungicide spray program was used to provide a means to evaluate plant and fruit disease susceptibility. Plant evaluations on 9 May and 18 June 2019 showed that Allstar, Galletta, Sonata, Jewel, Earliglow, Flavorfest, AC Valley Sunset and Chandler had low leaf spot incidence and severity ratings, while Honeoye and Yambu had higher ratings (Table 2). Phomopsis leaf blight evaluations did not show any statistical differences in leaf disease severity. However, Allstar and AC Wendy tended to have a lower incidence of this disease. Angular leaf spot is a bacterial disease and all varieties showed some symptoms. Yambu stood out as tending to have some of the lowest incidence of this disease, while Archer, Honeoye, Allstar, AC Wendy and Flavorfest tended to have higher incidences. Honeoye had a significantly higher severity rating for angular leaf spot than any other varieties in the trial.

Taking into account all the traits rated in this study and realizing that there is no perfect variety, the best performing early-maturing varieties in this trial were **Galletta** followed closely by **AC Wendy**. Galletta yielded well and fruit were firm, very attractive and shiny, although fruit flavor was not quite where we would like to see it. It had excellent plant vigor and a very low leaf spot rating. AC Wendy had a similar yield, and tended to have slightly larger, slightly better tasting fruit than Galletta, though less attractive and less firm. Leaf spot and Phomopsis leaf blight were minimal although it tended to have a little more angular leaf spot than Galletta.

The best performing midseason varieties were **Allstar** and **Flavorfest**. Both yielded well and had excellent plant vigor. Fruit were medium in size and had excellent flavor and both had low leaf spot and Phomopsis leaf blight ratings. Allstar tended to have firmer fruit than Flavorfest.

**AC Valley Sunset** was the best performing late season variety. It had a lower yield than most of the other varieties. However, the yields and fruit quality of earlier- and later-maturing varieties are often limited by the genetics of the crop. AC Valley Sunset fruit were very large, tasted very good, but were slightly softer and less attractive because the berries did not hold up well due to rain during harvest. Leaf spot ratings were low to moderate, while Phomopsis leaf blight incidence and severity were higher in comparison with other varieties in the trial.

Honeoye had one of the highest yields and was rated to have very attractive fruit, but berry size and flavor received low ratings. It had some of the highest susceptibility ratings for leaf spot, Phomopsis leaf blight and angular leaf spot. Earliglow was included in the trial as a flavor standard and performed well, however its rapid drop-off in size after the first couple harvests has resulted in a substantial reduction in Ealiglow acreage in Kentucky. Chandler, one of the main varieties used in plasticulture production in Kentucky, performed poorly in this study. Its leaves were slightly chlorotic throughout the season and a field pH measurement following harvest showed a soil pH of 7.4 suggesting an iron deficiency caused the chlorosis. Chandler may be less adapted to a higher soil pH. Sulfur was applied to the plot at renovation to lower the pH for next year.

**Table 2.** Estimated incidence and severity of foliar leaf spot, phomopsis leaf blight and angular leaf spot, 2019.

| | Leaf spot, 9 May[1] | | Leaf spot, 18 June[1] | | Leaf blight, 18 June[2] | | Angular leaf spot, 18 June[3] | |
|---|---|---|---|---|---|---|---|---|
| Variety | Incidence[4,5] | Severity[6] | Incidence | Severity | Incidence | Severity | Incidence | Severity |
| Honeoye | 3.0 b | 1.3 a | 17.6 a | 3.6 b | 2.5 ab | 7.6 | 13.2 a | 6.3 a |
| Allstar | 0 c | 0 b | 0.2 b | 0.2 c | 0.5 b | 2.9 | 12.8 a | 2.0 b |
| Galletta | 0.4 c | 0.3 b | 0.3 b | 0.2 c | 1.5 ab | 7.5 | 7.0 abc | 1.4 b |
| AC Wendy | 0.7 c | 0.3 b | 7.8 b | 1.1 bc | 0.6 b | 3.4 | 10.3 ab | 2.3 b |
| Sonata | 0.1 c | 0.1 b | 1.5 b | 0.5 c | 1.9 ab | 6.4 | 3.7 bc | 1.3 b |
| Yambu | 5.2 a | 1.3 a | 25.6 a | 8.0 a | 1.5 ab | 9.5 | 1.9 c | 0.9 b |
| Jewel | 0.3 c | 0.2 b | 2.5 b | 0.3 c | 2.7 a | 9.1 | 6.5 abc | 2.2 b |
| Flavorfest | 0.1 c | 0 b | 0.1 b | 0.1 c | 1.4 ab | 9.6 | 10.1 ab | 2.9 b |
| Earliglow | 0.4 c | 0.2 b | 1.1 b | 0.4 c | 1.1 ab | 7.4 | 9.9 abc | 1.9 b |
| AC Valley Sunset | 0.7 c | 0.2 b | 1.1 b | 0.2 c | 2.8 a | 9.4 | 5.9 abc | 1.1 b |
| Archer | 0.5 c | 0.3 a | 0.5 b | 0.2 c | 2.3 ab | 7.2 | 14.0 a | 3.3 b |
| Rutgers Scarlet | 1.9 bc | 0.8 ab | 3.9 b | 0.7 c | 1.0 ab | 5.0 | 6.8 abc | 1.9 b |
| Chandler | 0.1 c | 0.1 b | 0.5 b | 0.2 c | 1.2 ab | 8.2 | 7.6 abc | 1.9 b |

1 Leaf spot caused by *Mycosphaerella fragariae*.
2 Phomopsis leaf blight caused by *Phomopsis obscurans*.
3 Angular leaf spot caused by *Xanthomonas fragariae*.
4 Number of leaf lesions on a trifoliate leaf, averaged from 8 leaves per replicate.
5 Means within same column followed by the same letter are not significantly different (Duncan's Multiple Range Test $P \leq 0.05$).
6 Percent of leaf area showing infection symptoms on the same leaves used to determine disease incidence.

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# Rootstock Effects on Apple Tree Growth and Yield

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## Introduction

Although apple and peach are the principal tree fruits grown in Kentucky, the hot and humid summers and heavy clay soils make their production more difficult here than in some neighboring tree fruit producing regions and can lead to high disease and insect pressure in Kentucky orchards. Despite these challenges, orchards can offer high per-acre income and are suitable for rolling hills and upland soils.

Identification of improved rootstocks and cultivars is fundamental for advancing the Kentucky tree fruit industry. For this reason, Kentucky cooperates with researchers from 29 other states in the United States, three Canadian provinces, Mexico, and Chile in the Cooperative Regional NC-140 Project entitled, "Improving Economic and Environmental Sustainability in Tree Fruit Production through Changes in Rootstock Use." The NC-140 trials are critical to Kentucky growers, allowing access to and testing of new rootstocks from around the world (Table 1). The detailed and objective evaluations allow growers to select the most appropriate rootstocks for Kentucky.

## Materials and Methods

Grafts of known cultivars on the various rootstocks were produced by nurseries on the West Coast and distributed to cooperators. Kentucky's NC-140 rootstock plantings are located at UK Research and Education Center (UKREC) at Princeton, KY. They are:

- **The 2010 apple rootstock trial bitter pit evaluation.** The 2010 apple rootstock trial consisted of thirty-one different rootstocks with 'Aztec Fuji' as the scion cultivar (Table 1). These were compared in a randomized complete block experimental design in four blocks with one to three trees per rootstock per block. The trees were planted in March, 2010, on a 6 by 15-foot spacing, and trained to the tall spindle system. Other details and a final summary of this trial have been reported previously (Wolfe, 2018; Wolfe et al., 2018). From this trial one tree from each replication (where available) was selected from each of the rootstocks (listed in Table 2) for a follow-up study to evaluate the influence of rootstock on the incidence of bitter pit. A 50-fruit sample

**Table 1.** Rootstocks in the 2010 apple rootstock trial with 'Aztec Fuji' as the scion cultivar.

| Rootstock | Clone status | Breeding Program—Location |
|---|---|---|
| B.9 | named | Budagovsky—Michurinsk State Agrarian University, Michurinsk, Tambov Region, Russia |
| B.10 | | |
| B.7-3-150 | not released | |
| B.7-20-21 | | |
| B.64-194 | | |
| B.67-5-32 | | |
| B.70-6-8 | | |
| B.70-20-20 | | |
| B.71-7-22 | | |
| G.11 | named | Cornell-Geneva—New York State Agricultural Experiment Station |
| G.41 N (stool bed produced) | | |
| G.41 TC (tissue culture produced) | | |
| G.202 N (stool bed produced) | | |
| G.202 TC (tissue culture) produced) | | |
| G.214 (formerly CG.4214) | | |
| G.814 (formerly CG.4814) | | |
| G.222 (formerly CG.5222) | | |
| G.935 N (stool bed produced) | | |
| G.935 TC (tissue culture produced) | | |
| CG.2034 | not released | |
| CG.3001 | | |
| CG.4003 | | |
| CG.4004 | | |
| CG.4013 | | |
| CG.5087 | | |
| Supp.3 | named | Pillnitz—Institut fur Obstforschaung, Dresden-Pillnitz, Germany |
| PiAu.9-90 | not released | |
| PiAu.51-11 | | |
| M.9 NAKBT337 | named | NAKB clone of M.9— NAKB, Netherlands |
| M.9 Pajam2 | named | CTIFL clone of M.9— CTIFL, France |
| M.26 EMLA | named | E. Malling clone of M.26— East Malling Res. Station, Kent, England |

[1] For more information on Geneva rootstocks, see: http://www.ctl.cornell.edu/plants/GENEVA-Apple-Rootstocks-Comparison-Chart.pdf.

**Table 2.** 2018-2019 results for the 2010 NC-140 apple rootstock trial bitter pit evaluation, Princeton, KY.

| Rootstock[1] | Initial Number of Trees | 2018 TCSA (sq.in.) | Flesh Firmness (lbs.)[3] | Brix (%)[3] | Bitter Pit at 2018 Harvest (%) | Bitter Pit after storage[3] (%) | Bitter Pit at 2019 Harvest (%) |
|---|---|---|---|---|---|---|---|
| M.26 EMLA | 4 | 18.2 | 13.8 | 15.5 | 0.60 | 1.18 | 0.50 |
| G.222 (G.5222) | 4 | 13.4 | 13.6 | 15.3 | 0.70 | 1.35 | 0.00 |
| M.9 Pajam2 | 2 | 12.9 | 14.2 | 15.2 | 0.70 | 1.20 | 0.00 |
| CG.3001 | 3 | 12.7 | 13.6 | 15.3 | 0.67 | 1.33 | 2.00 |
| G.202 N | 4 | 12.6 | 14.0 | 15.1 | 0.45 | 1.03 | 1.00 |
| G.935 N | 4 | 12.3 | 14.3 | 15.5 | 0.85 | 1.40 | 0.50 |
| G.814 (G.4814) | 4 | 11.5 | 13.7 | 15.0 | 1.00 | 1.23 | 2.50 |
| CG.4004 | 4 | 10.6 | 14.5 | 15.5 | 0.53 | 0.98 | 0.00 |
| G.11 | 4 | 10.4 | 13.9 | 15.4 | 1.25 | 1.78 | 1.00 |
| CG.5087 | 2 | 10.3 | 14.3 | 16.3 | 0.90 | 1.35 | 0.00 |
| G.214 (G.4214) | 3 | 9.8 | 13.9 | 16.0 | 0.70 | 1.13 | 0.00 |
| M.9 NAKBT337 | 3 | 9.7 | 13.7 | 15.7 | 0.93 | 1.30 | 0.67 |
| Supp.3 | 1 | 9.6 | 14.1 | 15.1 | 1.10 | 3.10 | . |
| B.10 | 4 | 8.8 | 14.0 | 15.9 | 1.08 | 1.93 | 0.50 |
| G.41 N | 3 | 7.2 | 13.8 | 14.9 | 1.23 | 1.53 | 1.33 |
| CG.4003 | 4 | 6.6 | 13.8 | 15.8 | 0.55 | 1.18 | 1.50 |
| CG.2034 | 1 | 5.1 | 14.8 | 15.3 | 1.80 | 3.60 | 6.00 |
| B.9 | 4 | 3.7 | 15.0 | 15.3 | 1.23 | 2.25 | 1.50 |
| Means | NA | 10.6 | 14.0 | 15.4 | 0.86 | 1.46 | 0.96 |
| LSD (5%)[2] | NA | 4.1 | 1.24 | 1.2 | 1.11 | 1.32 | 2.01 |

1 Arranged in descending order of the fall trunk cross-sectional area (TCSA) for each rootstock.
2 Least significant difference (LSD) at the 5% probability level. Differences between two numbers within a column that are less than the LSD value are not significantly different.
3 From fruit stored for 90 days after harvest in a cooler at 40ºF.

was collected at harvest from each of these trees, evaluated for the presence of bitter pit, and then stored in a cooler for approximately 90 days at about 40° F. The fruit from each sample were then reevaluated for flesh firmness and the presence of bitter pit, and Brix readings were recorded from a subsample of 10 fruits from each 50-fruit sample.

- **The 2019 apple rootstock trial.** A new apple rootstock trial was planted April 11, 2019, at the UKREC orchard, Princeton, KY. The trial consists of 'Buckeye Gala' as the scion grafted onto seven different rootstocks. These are: M.9 NAKBT-337, M.26 EMLA, G.41, G.814, and G.969, B.10, and one New Zealand rootstock (NZ.2) that is purported to have M.9 vigor, high yield efficiency, and tolerance to aphids and fire blight (possibly immune). Three trees of each rootstock were planted in each row (replication) in a randomized complete block design and trained to the tall spindle system. In order to eliminate the effect of more vigorous stocks competing with the less vigorous ones, only the center tree of each of the three-tree subplots will be evaluated. Thus, the confounding effect due to different rootstock sizes adjacent to one another will be eliminated in this trial. For 2019, only tree height and trunk circumference 20 cm above the graft union were measured. Trunk cross-sectional area was calculated from the trunk circumference. All data was analyzed using SAS v.9.4 (SAS Institute).

**Table 3.** 2019 results for the 2019 NC-140 apple rootstock trial, Princeton, KY.

| Rootstock[1] | Number of Data Trees | TCSA (sq.in.) | Height (ft.) |
|---|---|---|---|
| G.814 | 5 | 1.28 | 9.9 |
| M.26 EMLA | 5 | 1.27 | 9.3 |
| G.969 | 5 | 1.25 | 10.1 |
| NZ.2 | 5 | 1.21 | 9.5 |
| B.10 | 5 | 1.13 | 8.5 |
| G.41 | 5 | 1.13 | 9.1 |
| M.9 NAKBT337 | 5 | 1.02 | 8.4 |
| Means | NA | 1.19 | 9.3 |
| LSD (5%)[2] | NA | 0.13 | 0.7 |

1 Arranged in descending order of the fall trunk cross-sectional area (TCSA) for each rootstock.
2 Least significant difference (LSD) at P≤5%. Differences between two numbers within a column that are less than the LSD value are not significantly different.

## Results and Discussion

- **The 2010 apple rootstock trial bitter pit evaluation.** For the 2018 apple harvest, and the subsequent evaluation after 90 days in cold storage, neither flesh firmness nor Brix were significantly different among rootstocks. Nor were there any differences in percentage of fruit showing bitter pit at harvest or after being in cold storage for 90 days (Table 2). For 2019, 6% of the fruit sampled from trees on CG.2034 had bitter pit. This result was significantly more than that of all of the other rootstocks. The results for fruit sampled from the 2019 harvest that are in cold storage for three months, (flesh firmness, Brix reading, and incidence of bitter pit) will not be available until early in 2020. Bitter pit has been shown to be related to calcium levels in the fruit, and calcium levels in fruit are influenced by rootstock (Autio et al., 1991). Caution in prematurely interpreting these results is warranted as there was only one tree available for sampling on Supp.3 and CG.2034.

- **The 2019 apple rootstock trial.** For 2019, trunk cross-sectional area at 20 cm above the graft union, and tree height were both statistically different among the seven rootstocks (Table 3). G.814, M.26 EMLA, G.969, and IFO #2 were the largest trees in terms of TCSA, and were not significantly different from each other. Trees on G.969 were significantly taller than all of the others except for those on G.814 and IFO #2. The expected vigor of these rootstocks as a percent of standard was approximately 35% for M.9 NAKBT-337, IFO#2, G.41, and B. 10, 40% for G.814, 45% for M.26 EMLA, and 65% for G.969. Currently, the plan is for this trial to be evaluated for the next 10 years.

The results from both the bitter pit study and the 2019 apple rootstock trial are preliminary and future data from this work will be needed to come to any final conclusions.

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# Spring Black Rot-resistant Cabbage Cultivar Evaluation

*Chris Smigell, John Strang and John Snyder, Horticulture*

## Introduction

Fourteen green fresh market cabbage cultivars were evaluated in a replicated trial to evaluate their performance in Central Kentucky. This trial was conducted to evaluate cultivars with black rot tolerance as this can be a problem in Kentucky.

## Materials and Methods

Varieties were seeded on 12 February into 72-cell plastic plug trays filled with ProMix BX general growing medium (Premier Horticulture, Inc.) at the UK Horticulture Research Farm in Lexington. Greenhouse-grown transplants were set into the field in bare soil on 5 April, 12 inches apart in single rows with 36 inches between rows. Varieties were replicated four times in a randomized, complete block design. Each plot (replicate) row was 10 feet long and contained 11 plants. Prior to planting, Devrinol (3.3 lb/A) herbicide was tilled into the soil and Goal (1.5 pt/A) herbicide was applied to the soil surface.

Fifty pounds per acre of nitrogen, phosphorus and potassium were applied as 19-19-19, prior to planting, and tilled in. Approximately one cup per plant of starter solution (3 lb Miller Sol-U-Gro 12-48-8 in 50 gallons of water) was applied at transplanting. The plot was drip-irrigated and fertigated weekly with 2 lb of nitrogen per acre (using calcium nitrate) beginning on 15 May for a total of five fertigations and 10 lb of nitrogen per acre. Badge SC (1pt/A) was applied one time early in the season for disease control. Coragen insecticide (6 fl oz/A) was applied 21 May through the drip lines, and Danitol (10 oz/A), and Dipel (1.5 pt/A mixed with Scanner spreader/sticker at 5oz/A) were sprayed for insect control.

All heads were harvested when firm and were evaluated for total marketable yield based on weight and head number and cull number. Harvesting began on 10 June, and continued on a roughly weekly basis through 15 July. One head from each of four replications was evaluated for head firmness (by feel), raw taste, head roundness/flatness, internal and external appearance, and interior color by two horticulture department personnel and was measured for its head and core sizes (lengths and widths). Sugar content was measured as °Brix using a handheld refractometer (American Optical model 10431, Deerfield, IL).

## Results and Discussion

The growing season was cool, wet and ideal for cabbage production. In spite of frequent rains, very few heads of any cultivar split. Bacterial soft rot and *Sclerotinia* stem rot did show up in a couple of cultivars and reduced yields. Harvest and head measurement data are shown in Table 1 and flavor and appearance ratings, and field plant ratings are in Table 2. Varieties are ranked based on total marketable yield in both tables. For most farm market producers, marketable yield is not the primary consideration for selecting a variety. Desired head size, appearance and quality are more important, so the following recommendations are based mainly on these characteristics, and a low cull percentage. All cultivars in the trial were similar in head firmness, interior and exterior color, and most had round heads, with Bravo and Taurus having slightly flattened heads.

#### *Early season cultivars (65-69 day maturity)*

Lucky Ball was the best early cultivar with a 65-day catalogue maturity date. It was consistently tender, sweet to slightly sweet, had little to no sulfur aftertaste and a low percentage of culled heads. Its 3.6 lb head was one of the smallest of the cultivars evaluated and it is well suited for retail markets where a small head is desirable. Conqueror was another good early cultivar with a listed 65-day maturity date, although in the taste evaluation it seemed less sweet than Lucky Ball, and had some sulfur aftertaste. It had medium-sized heads and the fourth-highest yield of all cultivars in the trial. It was the first to be completely harvested, and had one of the narrower harvest windows, which would make it attractive for wholesale producers. Both Lucky Ball and Conqueror ranked highly for plant uniformity in the field.

#### *Mid-season cultivars (70-84 day maturity)*

Bronco was the best mid-season cultivar. It ranked highly for taste, was tender, juicy, and had little to no sulfur aftertaste. It was also one of the highest yielders, and had a medium-sized, round head. Its core was one of the larger ones measured. It also had a narrow harvest window, good uniformity in the field, and is described in a seed catalog as a good shipper. Bronco would be a good choice for fresh-market and wholesale producers. Botran had the highest yield in the trial, because of its large-sized, round head. It ranked highly for attractiveness and taste, with little or no sulfur aftertaste. Bravo, the standard in trial, was another good yielder with a large, slightly flattened head and a small core. It had some sulfur aftertaste, but was considered tender and juicy. Thunderhead did not yield as well as the above cultivars, but had the smallest core of any cultivar evaluated. It had the smallest head length measurements of any cultivar in the trial, but was small- to mid-sized at four pounds. It had a high °Brix and was mild-tasting with some sulfur aftertaste. It had the widest harvest window of any cultivar in the trial, which may work well for growers looking for a steady supply of a small- to medium-sized, mid-season cultivar.

#### *Late-season cultivars (90-110 day maturity)*

These cultivars, Superstar, Capture, Tekila and Taurus tended to be dry and chewy, and left a burning sensation after chewing. Some showed tip-burn. These characteristics were consistent with cabbage grown in high temperatures. These cultivars also tended to be the lowest yielders. Superstar, an 85-day maturing cultivar, was an exception, being the fifth-

**Table 1.** Yields, head counts and head measurements, 2019.

| Variety | Seed Source | Days to Harvest[1] | Total Marketable Yield (lb/A)[2] | | Heads (No/A) | Avg. Head Wt (lb) | Cull Wt (%)[3] | Head Length (in) | Head Width (in) | Core Length (in) | Core Width (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Botran | SW | 84 | 47400 | a | 9150 | 5.2 | 2.6 | 6.6 | 7.6 | 3.2 | 1.4 |
| Bravo | HO | 85 | 43300 | ab | 9150 | 4.7 | 1.0 | 6.9 | 8.0 | 2.9 | 1.3 |
| Bronco | SW | 80 | 39400 | abc | 9150 | 4.3 | 1.3 | 7.1 | 6.9 | 3.1 | 1.6 |
| Conqueror | SW | 65 | 38700 | abc | 9150 | 4.2 | 3.9 | 6.9 | 7.8 | 3.0 | 1.5 |
| Superstar | SW | 85 | 38200 | abc | 8930 | 4.3 | 4.5 | 6.8 | 7.3 | 2.2 | 2.0 |
| Taurus | SI | 100-110 | 37300 | abcd | 7620 | 5.0 | 9.8 | 6.6 | 7.7 | 3.6 | 1.5 |
| Blue Dynasty | ST | 75 | 36500 | abcd | 9150 | 4.0 | 2.0 | 6.9 | 7.4 | 2.7 | 1.4 |
| Thunderhead | ST | 82 | 36000 | bcd | 8930 | 4.0 | 3.0 | 5.9 | 7.1 | 2.4 | 1.2 |
| Capture | SW | 85 | 34500 | bcd | 7620 | 4.5 | 12.6 | 6.6 | 7.3 | 2.6 | 1.3 |
| Blue Vantage | ST | 76-80 | 33300 | bcd | 8930 | 3.8 | 5.7 | 6.6 | 7.5 | 2.8 | 1.4 |
| Lucky Ball | SI | 65 | 32200 | bcd | 8710 | 3.6 | 2.3 | 6.9 | 7.4 | 2.8 | 1.5 |
| Tekila | ST | 90 | 29400 | cd | 8060 | 3.5 | 3.1 | 6.7 | 6.7 | 2.9 | 1.7 |
| Bobcat | HO | 80 | 29400 | cd | 8280 | 3.5 | 4.6 | 6.2 | 6.8 | 2.6 | 1.4 |
| Early Thunder | ST | 74 | 26600 | d | 8280 | 3.2 | 6.7 | 6.1 | 6.7 | 2.7 | 1.4 |

1 Listed in seed catalogs.
2 Yields followed by the same letter are not significantly different (Waller-Duncan Test, LSD $P \leq 0.05$).
3 Percent of the weight of all harvested heads.

**Table 2.** Head evaluation ratings and comments, 2019.

| Variety | External Appearance (1-5)[1] | Internal Appearance (1-5)[1] | Head Shape (1-3)[2] | Taste Raw (1-5)[1] | Sugar Content (°brix)[3] | Uniformity in Field[4] | Plant Size[5] | Comments and Disease Resistance[6] |
|---|---|---|---|---|---|---|---|---|
| Botran | 4.7 | 4.6 | 2.0 | 4.7 | 5.3 | 3.9 | 3 | Mid-season; slightly sweet, juicy, little/no sulfur taste, variable tenderness; HR: Y, BR |
| Bravo | 4.6 | 4.6 | 1.4 | 4.4 | 5.4 | 4.0 | 3 | Mid-season, long harvest period; tender, juicy, slight sulfur taste; HR: Y, IR: BR, TB |
| Bronco | 4.4 | 4.5 | 2.0 | 4.7 | 5.8 | 4.3 | 2 | Mid-season; short harvest period, juicy, tender, slightly sweet, little/no sulfur taste, lg core; R: Y, TB, TT, IR: BR |
| Conqueror | 4.5 | 4.9 | 2.0 | 4.5 | 5.8 | 4.6 | 2 | Very early, mild taste; HR: Y, IR: BR |
| Superstar | 4.6 | 4.6 | 1.9 | 4.6 | 6.3 | 4.2 | 2.5 | Late harvest, slightly sweet, little/no sulfur taste, hard; HR: Y, IR: BR |
| Taurus | 4.7 | 4.0 | 1.5 | 4.2 | 5.1 | 4.4 | 3 | Late harvest, some tip burn, little/no sulfur taste, lg core; R: Y, IR: BR |
| Blue Dynasty | 4.7 | 4.6 | 2.0 | 4.4 | 6.0 | 4.0 | 2.6 | Early harvest, little/no sulfur taste; R: BR, Y, TB |
| Thunderhead | 4.7 | 4.6 | 1.6 | 4.5 | 6.1 | 3.9 | 2 | Mid-season; very wide harvest window, very mild, slightly sweet, tender, small core; R: BR, IR: Y |
| Capture | 4.6 | 4.3 | 1.6 | 3.9 | 6.3 | 4.1 | 3 | Late harvest, little/no sulfur taste, small core; HR: Y, IR: BR |
| Blue Vantage | 4.6 | 4.2 | 1.6 | 4.4 | 5.5 | 4.1 | 2 | Early, wide harvest window, variable tenderness, little/no sulfur taste; R: BR, TB, BS, Y |
| Lucky Ball | 4.1 | 4.3 | 2.0 | 4.5 | 5.6 | 4.3 | 1 | Early, wide harvest window, tender, slightly sweet, little/no sulfur taste R: BR |
| Tekila | 4.4 | 4.6 | 2.3 | 4.3 | 6.2 | 4.3 | 2.3 | Late, very short harvest window, slightly sweet, not tender, variable sulfur taste, lg core, some tip burn; R: BR,CR |
| Bobcat | 4.5 | 4.6 | 1.9 | 4.3 | 5.4 | 3.7 | 2 | Early-mid, wide harvest window, tender, little/no sulfur taste; R: Y, BR, BS, TB |
| Early Thunder | 4.4 | 4.6 | 1.9 | 4.4 | 5.3 | 3.8 | 2 | Early, wide harvest window, little/no sulfur taste, slight/not sweet; IR: BR,Y |

1 1=poor; 5=excellent.
2 1=flattened; 2= round; 3=pointy.
3 Refractometer measurement of soluble solids (primarily sugars) in cabbage juice sample.
4 Uniformity of heads' size and maturity in field: 1=not uniform; 5=very uniform.
5 Relative size of plants compared to other cultivars: 1=small; 3=large.
6 Disease resistances from seed catalogs: HR=highly resistant; R=resistant; IR=intermediate resistance; BR=black rot; BS=black speck; CR=club root; TB=tip burn; TT=thrip tolerant; Y=Fusarium yellows.

highest yielder in the trial, had a high °Brix, and ranked highly for taste. It had medium to large, round heads. Superstar may be a good cultivar to extend the cabbage market into summer.

Although black rot was not encountered in this trial, these varieties would be good choices to guard against possible infection. Where growers have a history of black rot in their fields the highly resistant cultivars would be recommended.

## Acknowledgments

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# High Tunnel Table Beet Cultivar Trial

*Rachel Rudolph, Horticulture*

## Introduction

Beet (*Beta vulgaris*) is an herbaceous biennial crop that is grown as an annual. It forms its root and leafy foliage in the first year. It is a relatively fast-growing cool season vegetable crop that is generally considered easy to grow. The green leafy portion of the crop can be susceptible to insect pressure and certain foliar diseases. Little to no infrastructure is required for successful beet production. Average yields for fresh market beet production range between 8 to 10 tons per acre (Swiader and Ware, 2002). Beet may be a quick and simple crop to produce in an unheated high tunnel prior to planting tomato in March or April. However, not all cultivars are suited for extreme cold temperatures that can be experienced on cloudy days in a high tunnel in the winter months. The highest quality beet crop occurs at temperatures between 55 to 70°F (Swiader and Ware, 2002). Additionally, certain cultivars may be appropriate for smaller, direct-to-consumer markets, but may not produce roots uniform enough for larger markets, such as wholesale. The objectives of this trial were to evaluate cultivars not previously evaluated in Kentucky and assess appropriate cultivars for cold-season high tunnel production that may serve as a quick crop prior to planting a more intensive and valuable crop like tomato.

**Table 1.** Cultivar characteristics.

| Cultivar[1] | Days to maturity[2] | Description |
|---|---|---|
| Avalanche | 45 | White skin and flesh; vigorous tops and large, round roots |
| Boro | 51 | Deep red, very round, strong foliage |
| Bresko | N/A | Deep purplish red |
| Chioggia | 60 | Pink skins, pink and white flesh; foliage is green with pink-striped stems |
| Detroit Dark Red | 65 | Deep red skin and flesh |
| Red Ace | 53 | Bright red flesh; strong tops with red-veins |
| Red Cloud | 53 | Dark red, very round, high sugar content |
| Touchstone Gold | 60 | Orange skin, yellow flesh; leaves and petioles are green |
| Boldor | 55 | Orange skin, light yellow flesh; strong tops; comparable to Touchstone Gold |

1 All seeds were donated by Seedway with the exception of 'Boldor' which was purchased from Johnny's Selected Seeds.

2 Refers to average number of days from seeding to harvest according to the seed packet.

## Materials and Methods

Nine cultivars of beets were direct-seeded in a high tunnel (30 x 96 ft) on 8 Feb. 2019 at the University of Kentucky Horticultural Research Farm in Lexington. The cultivars were 'Avalanche,' 'Boro,' 'Bresko,' 'Chioggia,' 'Detroit Dark Red,' 'Red Ace,' 'Red Cloud,' 'Touchstone Gold,' and 'Boldor' (Table 1). The trial was arranged as a randomized complete block design with five replications of the nine cultivars. Treatment plots were 6 ft long and 3 ft wide with three rows 1 ft apart. The crop was direct-seeded into recently tilled Maury silt loam soil with 2-inch spacing between each seed. The buffer space between each treatment plot within the same row was 2 ft.

Fertilizer was incorporated prior to seeding at 50 lb of N per acre (33.06 lb of Nature Safe® 10N-0P-8K). Drip irrigation tape with 4-inch emitter spacing was installed after seeding and was placed directly adjacent to each row of beet seeds. Plant irrigation was maintained as needed based on soil moisture which was approximately one hour every three days. Plants were maintained in a conventional high tunnel, but no pesticide applications were necessary throughout the production cycle. Plots were weeded as needed. Beet seedlings were not thinned. Due to poor germination, one plot of 'Boro' and one plot of 'Bresko' were reseeded on 2 April.

All cultivars were harvested on 11 May 2019. Beet roots were harvested from the middle 2 ft of each row in each treatment replication. We determined a beet root to be mature enough for harvest if it was at least 1.5 inches in diameter. Marketable and unmarketable beets were sorted based on USDA grading recommendations (USDA, 2016). Both marketable and unmarketable beets were counted, roots and tops were trimmed, and then roots were weighed immediately after harvest. Data were subjected to an analysis of variance (ANOVA) test using Statistical Analysis System (SAS) statistical software (Version 9.4; SAS Institute Inc.). Tukey was used to separate means when ANOVA tests were significant. Alpha was set at 0.05 for all data.

## Results and Discussion

None of the beets cultivars were harvested within their reported days to maturity and were not harvested in time to plant a high tunnel tomato crop in March or April. The 2019 winter season did have low temperatures, with the lowest temperature in Lexington of 9.7 °F occurring on 5 March. Some of the colder temperatures most likely caused the delayed growth and maturity of the beets which delayed harvest. For the month of February, the average high temperature was 50.4 °F and the average low temperature was 33 °F (Kentucky Mesonet, 2019). The month of March was similar with the average high of 51.3 °F and the average low of 33 °F (Kentucky Mesonet, 2019). These temperatures may seem mild, but the optimum air temperature for growth for beet is 60-65 °F, with the minimum air temperature of 40 °F (Maynard and Hochmuth, 2007). The optimum range of soil temperatures for beet is 50-85 °F, with a minimum of 40 °F. Calendar days to maturity can be unreliable because it does not take the fluctuations of temperature into account. Growing degree days (GDD), also called heat units, is the accumulation of both temperature and time. Each crop requires a certain amount of heat to develop and mature. GDDs are the units used to calculate the amount of heat accumulated over time (University of California IPM, 2016). Utilizing GDDs to predict when a crop will be harvested will be more accurate and reliable for growers.

'Red Cloud,' 'Avalanche,' and 'Boro' performed consistently well in both count and weight. 'Red Cloud' had the highest marketable yield and was significantly higher than 'Chioggia,' 'Red Ace,' 'Touchstone Gold,' and 'Boldor' (Table 2). 'Red Cloud' had a higher mean marketable count than all other cultivars with the exception of 'Avalanche' and 'Boro.' The two golden beet cultivars with orange skin and yellow flesh, 'Touchstone Gold' and 'Boldor,' had lower yields and counts, but were only significantly less than 'Red Cloud' (Table 2). Overall, 'Red Ace' had the lowest marketable yield and count. 'Detroit Dark Red' had the highest total unmarketable yield and the highest mean unmarketable yield per plot. However, it was only significantly higher than 'Bresko' (Table 3). 'Red Ace' had the highest mean unmarketable count with an average of 38.6 unmarketable beet roots per plot. It was significantly higher than 'Bresko' which had an average of 9.2 unmarketable beet roots per plot and the lowest mean unmarketable count per plot (Table 3).

'Red Cloud,' 'Avalanche,' and 'Boro' would be appropriate for larger-scale commercial high tunnel production in Kentucky. These three cultivars produced uniform roots and had attractive, healthy tops, making them more appropriate for either wholesale fresh markets or direct-to-consumer markets. 'Boro' and 'Red Cloud' are fairly standard in color, which may not attract customers in direct-to-consumer markets. 'Avalanche,' however, would be considered unusual with white skin and white inner flesh.

**Table 2.** Marketable yield and weights

| Cultivar | Total marketable yield (lb)[1] | Total marketable count | Mean marketable yield/plot (lb)[2] | | Mean marketable count/plot | | Mean marketable fruit wt (lb)[4] | |
|---|---|---|---|---|---|---|---|---|
| Avalanche | 38.05 | 107 | 7.61 | abc[3] | 21.4 | ab | 0.36 | b |
| Boro | 45.40 | 115 | 9.08 | ab | 23.0 | ab | 0.39 | b |
| Bresko | 43.25 | 95 | 8.65 | abc | 19.0 | b | 0.46 | a |
| Chioggia | 30.40 | 89 | 6.08 | bc | 17.8 | b | 0.34 | a |
| Detroit Dark Red | 34.75 | 75 | 6.95 | abc | 15.0 | b | 0.46 | b |
| Red Ace | 25.20 | 74 | 5.04 | c | 14.8 | b | 0.34 | b |
| Red Cloud | 49.75 | 144 | 9.95 | a | 28.8 | a | 0.35 | b |
| Touchstone Gold | 29.70 | 78 | 5.94 | bc | 15.6 | b | 0.38 | |
| Boldor | 26.75 | 78 | 5.35 | c | 15.6 | b | 0.34 | |

[1] Total marketable yield represents the yield from all treatment plots harvested from five reps which equals 60 $ft^2$.
[2] All plots were 18 $ft^2$, but only 12 $ft^2$ were harvested.
[3] Values within the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$.
[4] Calculated by dividing the total marketable yield by the total marketable root count.

**Table 3.** Unmarketable yield and weights

| Cultivar | Total unmarketable yield (lb)[1] | Total unmarketable count | Mean unmarketable yield/plot (lb)[2] | | Mean unmarketable count/plot | |
|---|---|---|---|---|---|---|
| Avalanche | 21.65 | 174 | 4.33 | ab[3] | 34.8 | a |
| Boro | 12.15 | 104 | 2.43 | ab | 20.8 | ab |
| Bresko | 5.85 | 46 | 1.17 | b | 9.2 | b |
| Chioggia | 16.00 | 132 | 3.2 | ab | 26.4 | a |
| Detroit Dark Red | 24.95 | 182 | 4.99 | a | 36.4 | a |
| Red Ace | 18.50 | 193 | 3.7 | ab | 38.6 | a |
| Red Cloud | 9.10 | 91 | 1.82 | ab | 18.2 | ab |
| Touchstone Gold | 15.95 | 145 | 3.19 | ab | 29 | a |
| Boldor | 13.15 | 126 | 2.63 | ab | 25.2 | ab |

[1] Total unmarketable yield represents the yield from all treatment plots harvested from five reps which equals 60 $ft^2$.
[2] All plots were 18 $ft^2$, but only 12 $ft^2$ were harvested.
[3] Values within the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$.

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# Glucosinolates Content of Turnips Grown in Sewage Sludge-amended Soil

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## Introduction

Bio-fumigation is the integration of dry or fresh *Brassica* vegetable plant residues into the soil where they release isothiocyanates (ITCs) upon hydrolysis of plant glucosinolates (GSLs) as the residues decompose. ITCs, the most effective product of GSLs hydrolysis, are toxic to many soil-borne pests. GSLs, natural S-glycosides, are secondary metabolites present in Brassicaceae vegetables (cabbage, radish, mustard, kale, collard, cauliflower, broccoli, horseradish, turnip, oilseed rape, etc.). GSLs have become an important consideration in developing new crop varieties because they possess antioxidant, bioherbicidal, fungicidal, and anti-carcinogenic properties (Merillon and Ramawat 2017).

The bioactive mechanism in the Brassicaceae family is the GSLs-myrosinase chemical defense system (Fig. 1). The GSLs and myrosinase components are located in two separate compartments in the plant cells that when combined release large amounts of defensive chemicals. ITCs can be used as alternative pest control agents to replace metam sodium, a commonly used fungicide. The main objective of this investigation was to assess variation in total GSLs concentration among turnip plants grown under seven soil management practices for potential use of turnip crude extracts in plant protection.

## Materials and Methods

The study was conducted at the University of Kentucky Horticultural Research Farm, Lexington, KY in a randomized, complete-block design replicated three times. We investigated the impact of seven soil treatments on the concentration of GSLs in field-grown turnip (*Brassica rapa* var. Purple Top White Globe) roots and shoots. The soil treatments were: sewage sludge, horse manure, chicken manure, vermicompost (worm castings), commercial inorganic fertilizer (NPK 19-19-19), commercial organic fertilizer (Nature Safe NPK 10-2-8), and native bare soil as a control. Each amendment was roto-tilled into the top six inches (15 cm) of soil in an amount that would add an additional 5% nitrogen (N) to the native soil (Table 1). Table 1 explains the amount of each soil amendment added to native soil to obtain 5% nitrogen. GSLs, separated by adsorption on a diethyl amino-ethyl ether ion exchange resin, were quantified by measurement of enzymatically released glucose upon hydrolysis of GSLs by myrosinase (thioglucosidase) (Fig. 1).

An inexpensive and accurate method developed by Antonious (2019) was used for extraction, separation and quantification of GSLs in turnip roots and shoots. GSLs were extracted with boiling methanol to inhibit endogenous myrosinase (the enzyme that hydrolyzes GSLs). The crude extracts were vacuum-filtered to remove the methanol and the remaining extracts were filtered through 10 mL disposable pipette tips that contained celite powder to obtain purified aqueous extracts. GSLs were separated by adsorption on a diethyl-amino ethyl ether) ion exchange resin and quantified based on measurement of enzymatically released glucose.

## Results and Discussion

The overall GSLs concentrations in turnip plants grown in sewage sludge-amended soil were 5399 and 544 µM (micro moles)/g in turnip shoot and root fresh tissue, respectively, indicating 10 times more GSLs concentration in the shoots compared to the roots on a fresh-weight basis. This is a 112% increase in GSLs concentration compared to plants grown in no-mulch bare soil (Table 2). This increase in GSLs could play a significant role in controlling soil-borne diseases in conventional and organic agriculture rather than using synthetic soil fumigants. Plants grown in commercial inorganic fertilizer (NPK 19-19-19) produced a total GSLs concentration similar to sewage sludge-amended soil. This high GSLs level has the potential to suppress fungal growth, aiding in soil borne fungal disease reduction in agricultural fields infested with soil-borne

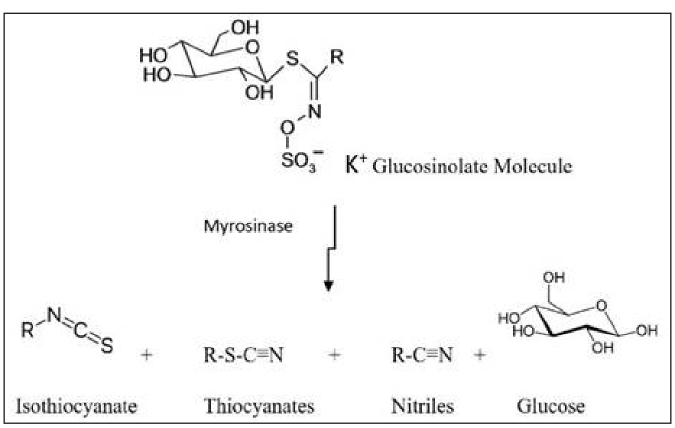


**Fig. 1** Chemical reaction of glucosinolates (GSLs) and degradation products liberated upon hydrolysis of GSLs molecules.

**Table 1.** Percentages of nitrogen, phosphorus, and potassium in soil amendments and amounts of nitrogen added to native soil in the study, Fayette County, KY.

| Soil Amendment | Nitrogen (% N) | Phosphorus (% P) | Potassium (% K) |
|---|---|---|---|
| Sewage Sludge | 5.00 | 3.00 | 0.00 |
| Chicken Manure | 1.10 | 0.80 | 0.50 |
| Horse Manure | 0.70 | 0.30 | 0.60 |
| Vermicompost | 1.50 | 0.75 | 1.50 |
| Organic Fertilizer | 10.00 | 2.00 | 8.00 |
| Inorganic Fertilizer | 20.00 | 20.00 | 20.00 |
| **Amounts of Soil Amendments added in lbs./ Acre** | | | |
| Sewage Sludge | 2000 | 1200 | 0 |
| Chicken Manure | 5900 | 4300 | 2700 |
| Horse Manure | 14300 | 6100 | 12200 |
| Vermicompost | 8300 | 4200 | 8300 |
| Organic Fertilizer | 1000 | 200 | 800 |
| Inorganic Fertilizer | 500 | 500 | 500 |

disease-causing fungi. Brassicaceae plants can be grown easily in Kentucky and used for soil-borne disease control either by spreading plant dry powder on the field or by tilling plants into the soil as a green manure. The release of ITC from GSL molecules could be aided by selecting varieties of *Brassica* with high GSLs content, increasing plant tissue cellular disruption to release more GSLs, and by supplying enough soil moisture to enable GSLs breakdown and release of the breakdown products. *Brassica* crops used as green manures have been associated with reductions in soilborne pests and pathogens including *Rhizoctonia solani*, and *Sclerotinia sclerotiorum*, two of the most destructive soilborne pathogens in crop production (Handisenim et al. 2017).

**Table 2.** Total glucosinolates concentrations in turnip expressed as µmoles $g^{-1}$ fresh plant tissue.

| Soil Treatment | Glucosinolates, µMoles/g Fresh Tissue | | | | | |
|---|---|---|---|---|---|---|
| | Shoot | | Root | | Total | |
| Sewage Sludge | 5398 ± 666 | a | 544 ± 77 | a | 5943 ± 649 | a |
| Chicken Manure | 3519 ± 1078 | ab | 609 ± 69 | a | 4128 ± 1010 | ab |
| Horse Manure | 3886 ± 1140 | ab | 454 ± 74 | a | 4340 ± 1149 | ab |
| Vermicompost | 3798 ± 876 | ab | 435 ± 82 | a | 4233 ± 800 | ab |
| Organic Fertilizer | 4066 ± 1404 | ab | 403 ± 55 | a | 4469 ± 1450 | ab |
| Inorganic Fertilizer | 4824 ± 238 | ab | 476 ± 107 | a | 5299 ± 169 | a |
| No Mulch Bare Soil | 2540 ± 479 | b | 160 ± 78 | b | 2700 ± 504 | b |

[1] Each value in the table is an average of three replicates ± standard error. Values accompanied by a different letter in each column are significantly different ($P < 0.05$).

## Acknowledgments

This investigation was supported by an Evans-Allen grant from the United States Department of Agriculture, National Institute of Food and Agriculture (USDA/NIFA) under Agreement # KYX-10-18-65P Accession # 1017900 to Kentucky State University.

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# Enzyme Activity in the Rhizosphere of Tomato Soil After Animal Waste Application

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## Introduction

Soil quality is dependent on soil biology. Soil microorganisms play an energetic part in soil fertility and crop production through enzymatic activity, critical for organic matter decomposition and nutrient cycling. The mineralization of organic matter is carried out by microorganisms and involves a wide range of metabolic processes in the soil. Positive correlations between the activity of soil enzymes and nutrient mineralization have been reported in agricultural soils (Shi 2011). Soil amendments such as animal manures contribute to soil fertility. However, trace metals in native soil and soil amendments may inhibit soil enzyme activity and therefore reduce soil quality and fertility. Using bioindicators as monitoring tools to assess soil health and potential impact of soil amendments has been recommended (Antonious 2018; 2016). Soil enzymes' activity in the rhizosphere (the soil area that surrounds the plant root surface) are bioindicators of soil biological status.

Urease enzyme (urea amidohydrolase, EC 3.5.1.5) breaks down urea fertilizers into ammonia and carbon dioxide (Fig. 1A). Invertase is the enzyme that splits sucrose (common table sugar) into glucose and fructose (Fig. 1B). Urease and invertase are important in soil for releasing simple carbon and nitrogen molecules used by soil microorganisms for their growth. Phosphatases break down organic phosphate esters to orthophosphate (Fig. 1C), which plants are able to take up. The study of soil enzymes' activities is important since they indicate the potential of a soil to carry out specific biochemical reactions for maintaining soil quality and fertility.

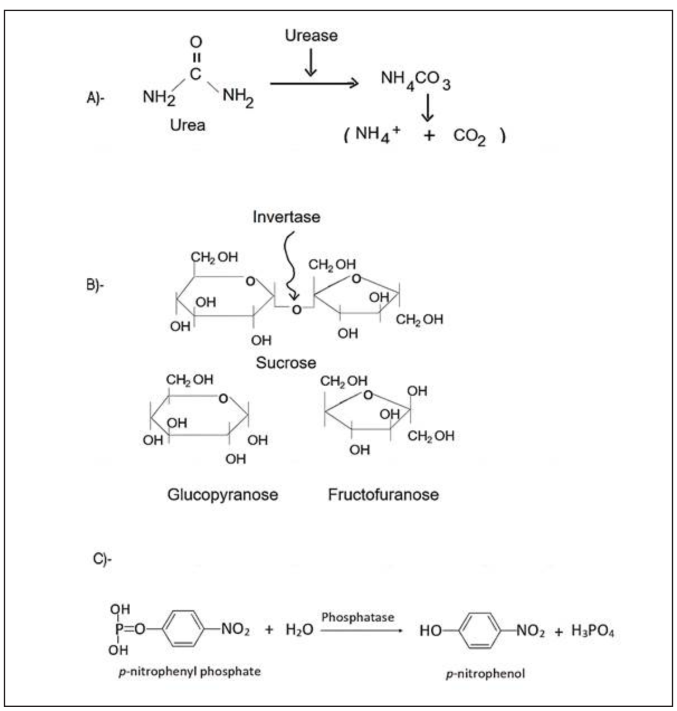


**Fig. 1** Soil enzymatic reactions and hydrolysis products of urease (A), invertase (B), and phosphatase (C).

Recycling animal manures as fertilizer would reduce synthetic fertilizer use and provide low-cost fertilizers to limited-resource farmers. Studies have indicated that biochar (a product of burning wood by pyrolysis) soil amendments could increase plant nutrient availability, soil cation exchange capacity (CEC), soil organic matter, soil microbial activity (Haipeng et al., 2017). Biochar use has gained attention, due to its potential for climate change mitigation and improvement of soil properties like CEC, nutrient and water retention, and positive influences on soil microbial communities and crop yields (Ferreira et al., 2017).

The main objective of this investigation was to assess the impact of mixing agricultural soil with animal manures (sewage sludge, chicken manure, horse manure, and vermicompost (worm castings) and biochar on soil urease, invertase, acid and alkaline phosphatase activity.

## Materials and Methods

A field experiment at the University of Kentucky Horticulture Research Farm in Lexington, KY, was established in a randomized, complete block design. Each plot was 4 × 10 feet and the entire study area contained 42 plots (3 replicates × 14 treatments). Plants were grown in rows six feet apart and 18 inches apart in the row. When the plants reached 13 inches high, a string trellis was installed, with stakes between every other plant. The soil treatments were: a control of untreated soil and no mulch (NM), sewage sludge (SS - Metropolitan Sewer District, Louisville, KY), horse manure (HM - Kentucky Horse Park, Lexington, KY), chicken manure (CM - Department of Animal and Food Sciences, University of Kentucky), vermicompost (worm castings) (Vermi - Worm Power (Montpelier, VT), organic fertilizer (Nature Safe 10:2:8), and inorganic fertilizer (Southern States 19:19:19). These seven treatments were duplicated, but also was mixed with 10% (w/w) biochar (Bio - Wakefield Agricultural Carbon, Columbia, MO) to make total of 14 treatments. All soil amendments were applied at 5% nitrogen (N) on dry weight basis to eliminate variations among soil treatments due to N content (Antonious 2018).

Soil amendments were added to native topsoil, and rototilled to a depth of six inches. Sixty-day old seedlings of 'Marglobe' tomato were planted in raised beds of freshly tilled soil covered with black plastic and watered using drip irrigation beneath the plastic. Weeding and other agricultural operations were carried out regularly as needed. The plants were sprayed with the insecticide esfenvalerate (Asana XL) three times at seven-day intervals at a rate of 5.5 oz/A to control Japanese- and Colorado potato beetles.

Three soil samples were collected from the rhizosphere (the soil area that surrounds the plant root surface) around tomato plants to a depth of six inches. Samples were collected using a one-inch diameter core sampler (Clements Associates, Newton, IA) equipped with plastic liner tubes to maintain soil samples' integrity. Soil samples were air-dried at room temperature, passed through a 2 mm sieve, and kept in plastic bags at 40 $^{O}$F up to 24 h before use.

Determination of soil urease activity was as described by Tabatabi and Bremner (1972). Invertase activity was measured by the method of Balasubramanian et al. (1970). Acid and alkaline phosphatase activities were determined by the method of Tabatabai and Bremner (1969). All enzyme activity data were statistically analyzed using analysis of variance (ANOVA) and the means were compared using Duncan's multiple range test (SAS Institute, 2016).

## Results and Discussion

Our results revealed significant differences in soil urease, invertase, and acid phosphatase activities before, and 4 months after amending soil. Urease activity was increased by 2.2 times in HM-amended soil and about 3.4 times in CM-amended soil 4 months after the amendments were added to the soil (Fig. 2). Similarly, significant rises in urease activity were found after adding SS, CMBio, SSBio, and VermiBio to native soil and to all other soil treatments, even in the no-mulch bare soil control (NM). There is evidence that urease activity in soils can increase by the addition of organic materials (Garcia et al., 2000). Soil urease activity also was significantly higher ($P < 0.05$) in vermicompost mixed with soil 4 months after treatment compared to before treatment. Biochar added to HM, SS, CM, vermicompost, inorganic and organic fertilizers, and even the no-mulch bare soil control (NM) increased soil urease activity 4 months after biochar addition.

Invertase activity increased significantly 4 months after addition of all amendments to the tomato soil (Fig. 3). Therefore, the increases in soil urease and invertase activities could be attributable to the nutrients in the soil amendments. Tomato roots also secrete these enzymes and can be expected to secrete greater quantities of them as the plants enlarge. There were few differences among soil amendments in acid phosphatase activity before and after soil amendments application (Fig. 4). No significant differences in alkaline phosphatase activity among soil amendments were found before and 4 months after addition of amendments (Fig. 5). Some compounds in animal manures and native soil act as enzyme inhibitors. Berezhetsky et al. (2008) indicated that the common metals' inhibition of immobilized phosphatase is as follows: $Cd^{2+}$ >

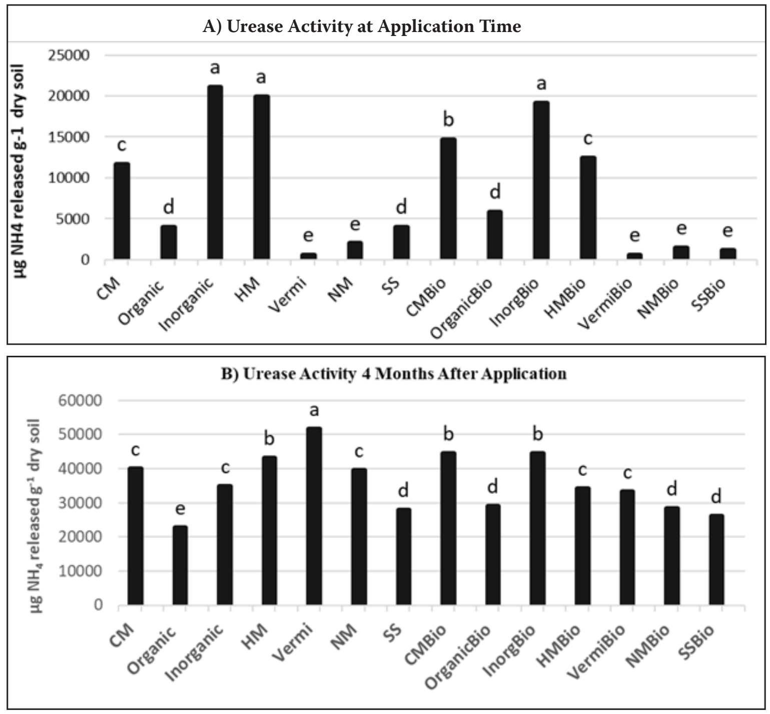


**Fig. 2** Impact of soil amended with organic, inorganic fertilizers, or animal manures mixed with biochar or no-biochar on soil urease activity in the rhizosphere of field-grown tomato before (A) and after (B) treatment. Statistical comparisons were carried out among soil treatments. Bars accompanied by different letter(s), within or between bar graphs A and B indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

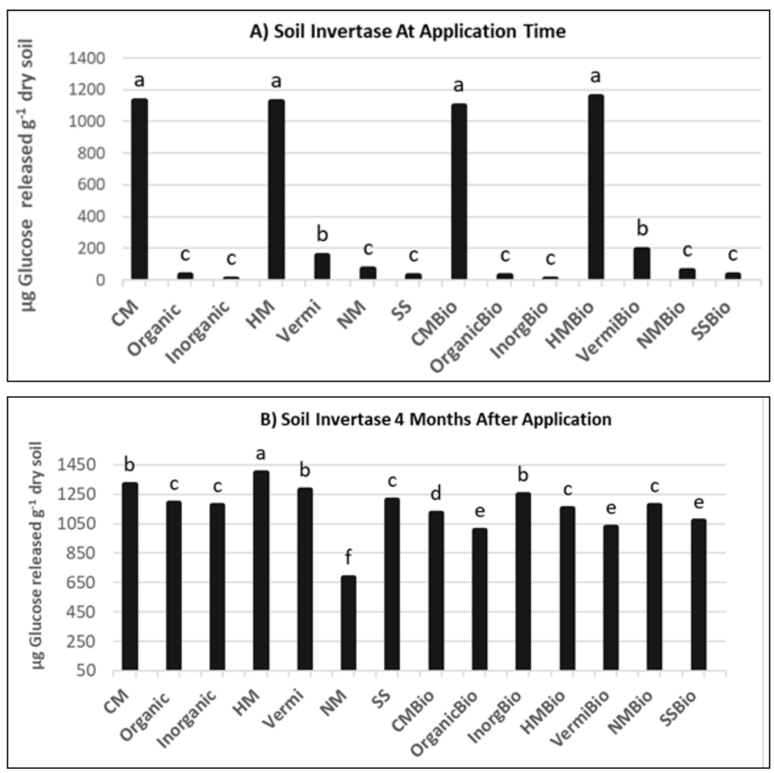


**Fig. 3** Impact of soil amended with organic, inorganic fertilizers, or animal manures mixed with biochar or no-biochar on soil invertase activity in the rhizosphere of field-grown tomato before (A) and after (B) treatment. Statistical comparisons were carried out among soil treatments. Bars accompanied by different letter(s) within or between bar graphs A and B indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

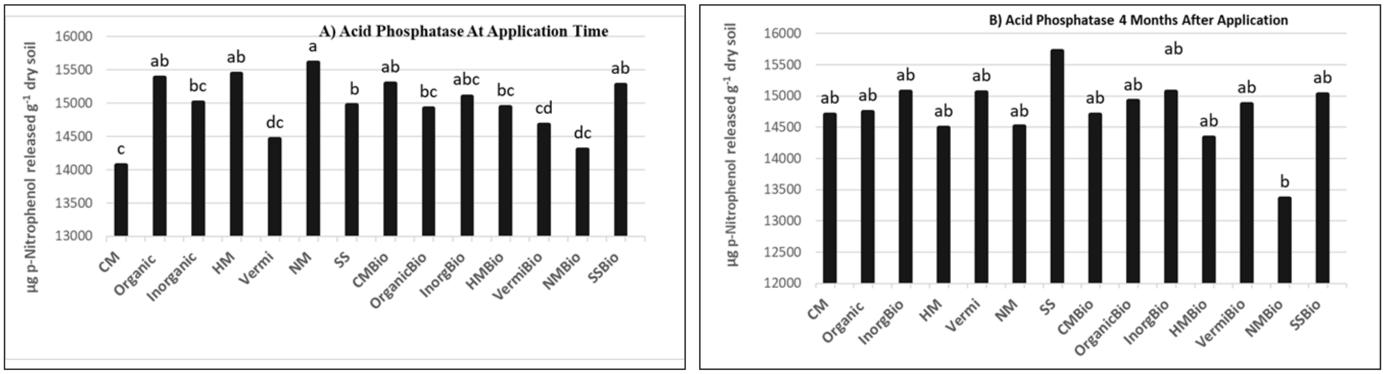


**Fig. 4** Impact of soil amended with organic, inorganic fertilizers, or animal manures mixed with biochar or no-biochar on soil acid phosphatase activity in the rhizosphere of field-grown tomato before (A) and after (B) treatment. Statistical comparisons were carried out among soil treatments. Bars accompanied by different letter(s) within or between bar graphs A and B indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

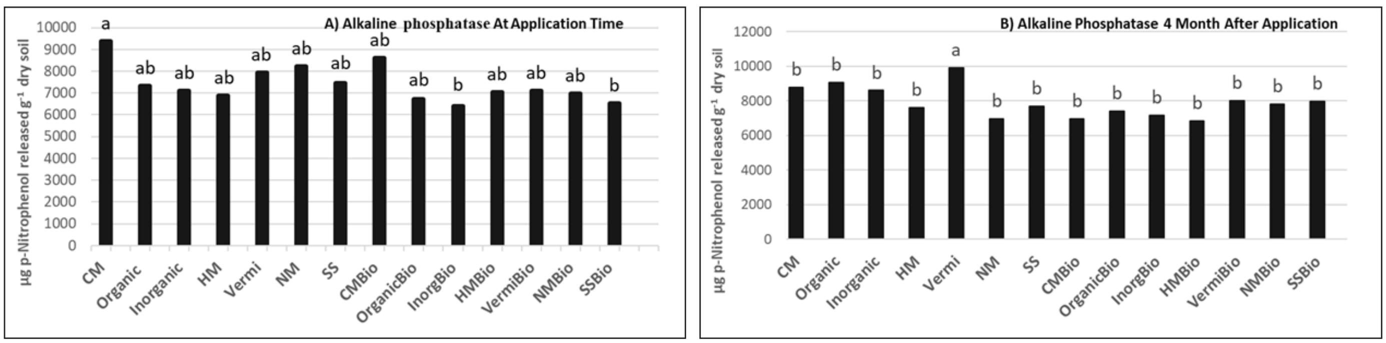


**Fig. 5** Impact of soil amended with organic, inorganic fertilizers, or animal manures mixed with biochar or no-biochar on soil alkaline phosphatase activity in the rhizosphere of field-grown tomato before (A) and after (B) treatment. Statistical comparisons were carried out among soil treatments. Bars accompanied by different letter(s) within or between bar graphs A and B indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

$Co^{2+} > Zn^{2+} > Ni^{2+} > Pb^{2+}$. Trace elements-contaminated soils inhibit soil enzyme activities (Tyler et al. 1989) mainly due to direct interactions between trace elements and enzyme molecules, or substrates of enzymes forming substrate complexes.

Many microorganisms multiply and others decrease in population, due to trace metal contamination, which results in shifts in the quality and functionality of soils. Little information is available on the changes in the release of enzymes by plants or microorganisms exposed to trace elements, hormones, and antibiotics in human and animal manures. More studies are needed on the effect of trace metals, hormones, and antibiotics in contaminated soils on soil microorganisms, the enzymes they produce, and the hydrolase activity in the rhizosphere of growing plants.

## Acknowledgments

The authors thank Steven Diver and his farm crew for maintaining the field plots. The study was funded by a grant # KYX-10-18-P65 Accession # 1017900 from the United States Department of Agriculture, National Institute of Food and Agriculture (USDA/NIFA) to Kentucky State University.

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# Results of Selection for High Yield and Zingiberene Content of Interspecific Hybrid Tomatoes Grown in the Open Field

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## Introduction

Worldwide, tomato is the second most significant vegetable crop, next to potato. World production today amounts to around 200 million tons on 12 million acres (FAOSTAT 2017). In modern breeding programs genetic variation available in wild tomato relatives has often been the source of characteristics used to breed for enhanced yield, fruit quality, disease and insect resistance (Rick and Chetelat 1995). Yield is a genetically complex character and genetic selection for yield requires tremendous attention by the breeder. An increase in yield and quality of self-pollinated crops such as tomato is usually accomplished by choosing those genotypes that have the desired combination of phenotypic characters (de Souza, Melo et al. 2012). It is extremely important to understand the extent of genetic diversity available to improve the yields of tomatoes (Bhattarai, Louws et al. 2016). Due to ease of application, morphological features have often been utilized to estimate genetic diversity (Fufa, Baenziger et al. 2005).

The sesquiterpene hydrocarbon, 7-epizingiberene, is a semi-volatile compound naturally synthesized by plants of *Solanum habrochaites*, a wild relative of cultivated tomato. 7-epizingiberene is one of the main anti-insect chemicals present in its leaf trichomes (Snyder, Guo et al. 1993, Antonious and Kochhar 2003, Antonious and Snyder 2006). Tomato breeders around the world are attempting to introgress high levels of 7-epizingiberene from wild tomatoes into cultivated types. Their intent in doing so is to improve insect resistance of tomato because 7-epizingiberene has been associated with resistance to arthropods such as spider mites, aphids, and whiteflies (Weston and Snyder 1990, Aragão, Dantas et al. 2000, Maluf, Campos et al. 2001, Freitas, Maluf et al. 2002, Gonçalves, Maluf et al. 2006, Bleeker, Diergaarde et al. 2011). Since 7-epizingeberene is an oil, the tomato plant expends a great deal of energy to synthesize it, and because of this, there may be a negative association between yield and production of 7-epizingeberene. Also, yield in interspecific hybrids may be reduced due to genic incompatibilities, often referred to as Bateson-Dobzhansky-Muller interactions. This research is the first report of yields for interspecific hybrid tomatoes having high concentrations of 7-epizingeberene.

## Materials and Methods

The experiment took place in 2019 at the Horticulture Research Farm, Lexington, KY. Each experimental plot consisted of four tomato plants spaced two feet apart within the row, and rows were set on seven-foot centers in raised beds with trickle irrigation and black plastic mulch. The statistical design was a randomized complete block design that included 13 interspecific hybrid breeding lines and two F1 hybrid tomato cultivars in each of three blocks. The cultivars evaluated were 'BHN589' and 'Red Deuce.' All 13 breeding lines were BC3F7 generation lines obtained from crossing between a wild tomato relative, S. *habrochaites* (LA2329) and 'Zaofen 2,' a pink-fruited determinate variety released in 1962. The BC3F7 lines had been selected for high yield and for high zingiberene production and eight were chosen from the D90 family and five from the

F22 family. On 9 April, seeds were soaked in 50% sodium hypochlorite for 30 minutes and were then were directly sown into 72-cell flats containing Fort Light compost-based potting soil (Vermont Compost Co., Montpelier, VT). Transplanting occurred on 10 May. Transplant and field production cultural methods were followed in accordance with ID-36 'http://www2.ca.uky.edu/agcomm/pubs/id/id36/id36.pdf

Harvest began on 21 July and plants were harvested weekly for four weeks. Harvested tomatoes were weighed and counted.

## Determination of 7-epizingiberene in Plant Leaves

The center ⅓ portion of one leaflet from the third or fourth leaf positions on each of the four plants in a plot was placed into a 20 ml vial and then 2 ml of n-hexane containing 20 µL/L of n-tetradecane as internal standard was added. Vials were vortexed for 30 seconds. Subsequently the 7-epizingiberene content of the extract was determined by gas chromatography and area of the extracted leaflets was determined by image analysis. Results were expressed as µg of 7-epizingiberene/$cm^2$ of leaflet.

## Statistical Analysis

All data were analyzed using the GLM procedure of SAS version 9.4 statistical software 'SAS Institute, Inc., Cary, NC' (Der and Everitt 2015). Means were compared using the LSMeans option or using Duncan's multiple range test, as appropriate. In order to evaluate the relationship between yield and 7-epizingiberene content in the interspecific hybrids, the Pearson correlation coefficient was determined for these two variables.

## Results and Discussion

Analysis of variance revealed significant differences among families for yield, number of fruits per plant and average fruit weight. Fruit number per plant was significantly higher in interspecific lines compared to the tomato cultivars, 'Red Deuce' and 'BHN589'. For the interspecific hybrid lines the highest number of fruit was for line SF89, which produced 80 fruit/plant, while the lowest number was for SF37 which produced 46 fruit/plant The cultivar 'Red Deuce' produced 34 fruit/plant and 'BHN589' produced 45 fruit/plant (Figure 1). Total fruit weight on average, was 25.11±1.45 lbs. per plants for the cultivars compared with 15.18±0.58 lbs. per plant for the interspecific hybrid lines (Figure 2). Fruit from the interspecific hybrids were much smaller, 0.24±0.01 lb./fruit, compared to the very large fruit produced on the hybrid cultivars, 0.68±0.02 lb./fruit (Figure 3).

The 7-epizingiberene content did not differ among lines within an interspecific hybrid family and but did differ significantly between the two interspecific hybrid families (Figure 4). For the F22 family the average 7-epizingibiberene content was 45 µg/$cm^2$ and was 26 µg/$cm^2$ for the D90 family whereas there was no 7-epizingiberene detected in the tomato cultivars.

We also investigated the relationship between 7-epizingeberene content and yield for the interspecific hybrids. There was a significant negative association, r = -0.75 between average plant yield and 7-epizingeberene content, indicating that as 7-epizingeberene content increased, yield tended to decline. These results indicated that production of high levels of 7-epizingiberene may be associated with a yield penalty.

This experiment provides a snapshot of field performance of an inbred population, an F7 resulting from seven successive self-pollinations of a relatively advanced interspecific backcross generation, a BC3. Yields were adequate, equal to or greater than that normally observed on recurrent parent 'Zaofen 2.' Despite the breeding and selection challenges that can occur in interspecific hybrid development, we were successful

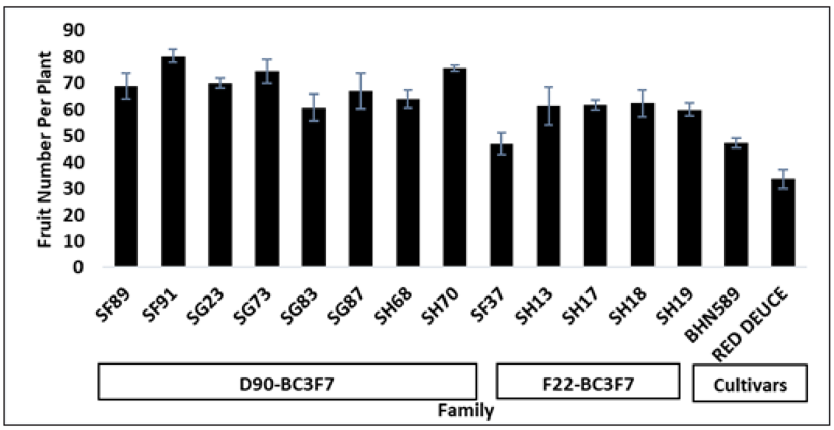


**Figure 1.** Average fruit number/plant of two F1 hybrid tomato cultivars ('BHN589', and 'Red Deuce'), and thirteen BC3F7 interspecific hybrid lines (SF37, SF89, SF91, SG23, SG73, SG83, SG87, SH13, SH17, SH18, SH19, SH68, and SH70 obtained from the D90 and F22 families (*S. habrochaites* X *S. lyco-persicum*).

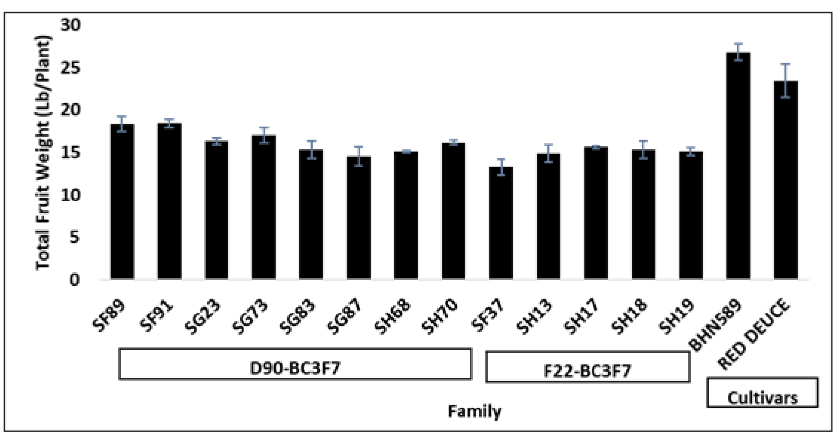


**Figure 2.** Total fruit weight (lb./ Plant) of two F1 hybrid tomato cultivars ('BHN589' and 'Red Deuce'), and thirteen BC3F7 interspecific hybrid lines (SF37, SF89, SF91, SG23, SG73, SG83, SG87, SH13, SH17, SH18, SH19, SH68, and SH70) obtained from the D90 and F22 families (*S. habrochaites* X *S. ly-copersicum*).

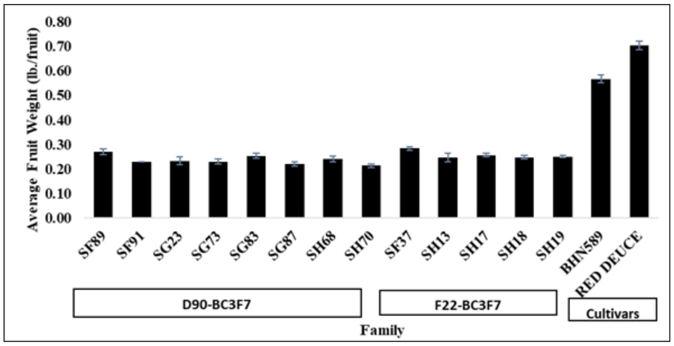


**Figure 3.** Average fruit weight (lb./fruit) for two F1 hybrid tomato cultivars ('BHN589', and 'Red Deuce'), and thirteen BC3F7 interspecific hybrid families (SF37, SF89, SF91, SG23, SG73, SG83, SG87, SH13, SH17, SH18, SH19, SH68, and SH70) obtained from the D90 and F22 families (*S. habrochaites* X *S. ly-copersicum*).

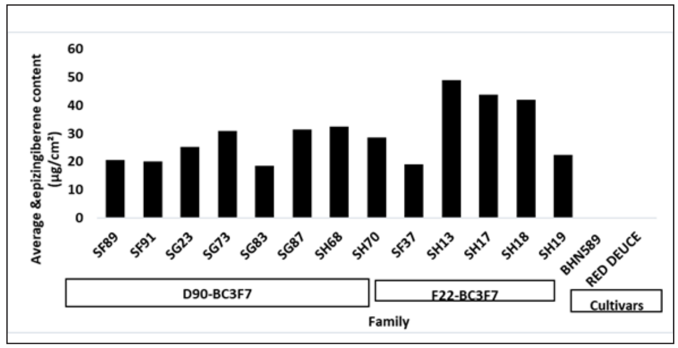


**Figure 4.** 7-epizingiberene content (µg/cm² of leaf) of two F1 Hybrid tomato cultivars ('BHN589' and 'Red Deuce'), and thirteen BC3F7 interspecific hybrid families (SF37, SF89, SF91, SG23, SG73, SG83, SG87, SH13, SH17, SH18, SH19, SH68, and SH70 obtained from the D90 and F22 families (*S. habrochaites* X *S. lycopersicum*) No zingiberene was detected in the tomato cultivars.

in breeding interspecific hybrids having high yield similar to their recurrent parent and 7-epizingeberene production similar that in the wild donor parent.

## Conclusion

The current study revealed that the fruit number per plant in interspecific hybrid families was higher than that in the tested tomato cultivars while total yield per plant was higher in cultivars than that in interspecific hybrids. Average weight of fruit per plant was negatively correlated with 7-epizingeberene content, suggesting a need for future investigation of the true relationship between 7-epizingiberene production and yield. These initial results suggest that it may be possible to breed tomatoes with both high yield and sufficient 7-epizingebrene contents in their leaves, which could perhaps lead to improvement in plant pest resistance and yield.

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# Recovery of Spider Mite Resistance in Advanced Generations of Interspecific Hybrid Tomatoes

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## Introduction

Cultivated tomato plants are extremely susceptible to the two-spotted spider mite, *Tetranychus urticae* Koch. Infestations are more likely and often are more damaging when tomatoes are grown in protected environments like high tunnels and greenhouses. Certain wild relatives of tomato are extremely resistant to spider mites and selection for pest resistance is usually an important step to achieve successful genetic resistance transfer from wild relatives into cultivated tomato genotypes. To breed for spider mite resistance in tomato, we have used a wild relative of tomato, *Solanum habrochaites* LA2329, as a male parent that is highly resistant to spider mites. Its resistance has been attributed to the presence of a high density of type IV and type VI trichomes (leaf surface glands) and to production of zingiberene, a 15-carbon oil produced by leaf trichomes. The main goal of this research was to verify the transfer of spider mite resistance from the wild parent to a cultivated tomato. The effects of trichome densities and leaf zingiberene concentrations on spider mite deterrence/repellency were also evaluated in this research.

This research was conducted as part of Ammar al-Bayati's Ph.D. dissertation, and is under consideration for publication. As such, data tables are not included in this report, but can be found in his dissertation:

Al-Bayati, A.S., 2019. Breeding for Tomato Resistance to Spider Mite *Tetranychus urticae* Koch (Acari: Tetranychidae). Ph.D. Dissertation, University of Kentucky.

## Materials and Methods

Backcross hybrids were made by crossing between the wild tomato LA2329 and the cultivated tomato 'Zaofen 2.' Nine backcross hybrids ($BC_3F_3$ and $BC_3F_4$), chosen for whole leaf bioassay, and seven hybrids ($BC_3F_2$), chosen for thumbtack bioassays, were used to verify transfer of spider mite resistance to these hybrids. In the thumbtack assay, mites were put on the head of a thumbtack that was inserted through a test leaflet. The thumbtacks and mites were then photographed every 15 minutes, and the number of mites remaining on the thumbtacks was counted and the distance the mites travelled was determined by image analysis. For the whole-leaf bioassay, leaf samples were examined under a stereo microscope to determine location of spider mites, degree of webbing, feeding damage and number of eggs.

## Results and Discussion

Mite responses on some of the hybrids tested by the whole leaf bioassay were similar to those on the resistant wild donor parent LA2329, as indicated by number of leaflet surfaces infested by mites, degree of mite webbing and feeding damage. Egg densities on four backcross hybrids were similar to that on the resistant parent. These results confirm transfer of resistance from the wild donor to some of the hybrids.

In the thumbtack bioassay, several backcross hybrids performed similarly to the wild donor parent, displaying shorter distances traveled on the leaves after 15 and 30 minutes. Multiple regression analysis showed that the type IV trichome density was the most important factor in mite deterrence or repellency, and zingiberene content was a secondary factor across most time durations. Therefore, results confirmed the transfer of mite repellency from the wild resistant parent into advanced backcross hybrids.

In conclusion, most of the hybrids showed significant adverse impact on spider mite behavior and/or biology in whole leaf- and thumbtack bioassays, confirming transfer of resistance. Also the tomato hybrids that showed resistance to spider mites may be a potential source of resistance to other insect pests.

## Appendix A
# Sources of Vegetable Seeds

The abbreviations used in this appendix correspond to those listed after the variety names in tables of individual trial reports.

AAS ................ All America Selection Trials, 1311 Butterfield Road, Suite 310, Downers Grove, IL 60515 https://all-americaselections.org

AC.................. Abbott and Cobb Inc., Box 307, Feasterville, PA 19047 www.abbottcobb.com

AT.................. American Takii Inc., 301 Natividad Road, Salinas, CA 93906 www.takii.com

BHN................ BHN Seed, Division of Gargiulo Inc., 16750 Bonita Beach Rd., Bonita Springs, FL 34135 www.bhnseed.com

BBS................ Baer's Best Seed, 154 Green St., Reading, MA 01867 www.baersbest.com

BC.................. Baker Creek Heirloom Seeds, 2278 Baker Creek Rd., Mansfield, OH 65704 www.rareseeds.com

BK.................. Bakker Brothers of Idaho Inc., P.O. Box 1964, Twin Falls, ID 83303 www.bakkerbrothers.nl

BL.................. Burrell Seed Growers, P.O. Box 150, Rocky Ford, CO 81067 https://burrellseeds.us

BU.................. W. Atlee Burpee & Co., P.O. Box 6929, Philadelphia, PA 19132 www.burpee.com

BZ.................. Bejo Zaden B.V., 1722 ZG Noordscharwoude, P.O. Box 9, The Netherlands https://www.bejo.com

CA.................. Castle VegTech Inc., 190 Mast St., Morgan Hill, CA 95037 https://seedquest.com

CF.................. Cliftons Seed Co., 2586 NC 43 West, Faison, NC 28341 https://www.cliftonseed.com

CH.................. Alf Christianson, P.O. Box 98, Mt. Vernon, WA 98273 (360) 336-9727

CL.................. Clause Home Garden, 100 Breen Road, San Juan Bautista, CA 95045 www.clausehomegarden.com

CR.................. Crookham Co., P.O. Box 520, Caldwell, ID 83605 https://www.crookham.com

D.................... Daehnfeldt Inc., P.O. Box 947, Albany, OR 97321 https://seedquest.com

DR.................. DeRuiter Seeds Inc., P.O. Box 20228, Columbus, OH 43320 www.deruiterseeds.com

EV.................. Evergreen Seeds, P.O. Box 2036 Sunnyvale, CA 94087 http://evergreenseeds.com/

EX.................. Express Seed, 300 Artino Drive, Oberlin, OH 44074 https://www.expressseed.com

EZ.................. ENZA Zaden, P.O. Box 7, 1600 AA, Enkhuisen, The Netherlands 02280-15844 https://www.enzazaden.com/us/

FED................ Fedco Seed Co., P.P. Box 520 Waterville, ME, 04903 www.fedcoseeds.com

FM.................. Ferry-Morse Seed Co., P.O. Box 4938, Modesto, CA 95352 https://ferrymorse.com

GB.................. Green Barn Seed, 18855 Park Ave., Deephaven, MN 55391 http://greenbarngardens.com/

GO.................. Goldsmith Seeds Inc., 2280 Hecker Pass Highway, P.O. Box 1349, Gilroy, CA 95020 www.voeksinc.com/goldsmith-seeds/

GU.................. Gurney's Seed and Nursery Co., P.O. Box 4178, Greendale, IN 47025 www.gurneys.com

HI................... High Mark Seeds, 5313 Woodrow Ln, Hahira, GA 31632 www.highmarkseed.com

HL/HOL......... Hollar & Co. Inc., P.O. Box 106, Rocky Ford, CO 81067 www.hollarseeds.com

H/HR............. Harris Moran Seed Co., 3670 Buffalo Rd., Rochester, NY 14624, Ph: (716) 442-0424 https://www.hmclause.com

HMS............... High Mowing Organic Seeds, 76 Quarry Rd., Walcott, VT 05680 www.highmowingseeds.com

HN.................. HungNong Seed America Inc., 3065 Pacheco Pass Hwy., Gilroy, CA 95020

HO.................. Holmes Seed Co., 2125-46th St., N.W., Canton, OH 44709 www.holmesseed.com

HR.................. Harris Seeds, 60 Saginaw Dr., P.O. Box 22960, Rochester, NY 14692 www.harrisseeds.com

HS.................. Heirloom Seeds, P O Box 245, W. Elizabeth PA 15088-0245 412-384-0852

HZ.................. Hazera Seed, Ltd., P.O.B. 1565, Haifa, Israel https://www.hazera.com

JU................... J. W. Jung Seed Co., 335 High St., Randolf, WI 53957 www.jungseed.com

JS/JSS........... Johnny's Selected Seeds, Foss Hill Road, Albion, MA 04910-9731 www.johnnyseeds.com

KS.................. Krummrey & Sons Inc., P.O. 158, Stockbridge, MI 49285 517-851-7550

KU.................. Known-You Seed Co., Ltd. https://knownyouseed.com/

KTS................ Kitazawa Seed Co., PO Box 13220 Oakland, CA 94661-3220 www.kitazawaseed.com

LI.................... Liberty Seed, P.O. Box 806, New Philadelphia, OH 44663 https://libertyseeds.com

MB.................. Malmborg's Inc., 5120 N. Lilac Dr., Brooklyn Center, MN 55429 www.malmborgsinc.com

MKS............... Mikado Seed Growers Co. Ltd. en.mikadokyowa.com/about-us-en/

MR.................. Martin Rispins & Son Inc., 3332 Ridge Rd., P.O. Box 5, Lansing, IL 60438 rispensseeds.com

MWS.............. Midwestern Seed Growers, 10559 Lackman Road, Lenexa, KS 66219 www.midwesternbioag.com

NE.................. Neuman Seed Co., 202 E. Main St., P.O. Box 1530, El Centro, CA 92244 619-337-3100

NU/NH.......... Nunhems (see Canners Seed Corp.) http://nunhems.us/

NS.................. New England Seed Co., 3580 Main St., Hartford, CT 06120 https://www.neseed.com

NZ.................. Nickerson-Zwaan, P.O. Box 19, 2990 AA Barendrecht, The Netherlands www.rijkzwaan.com

ON.................. Osbourne Seed Co., 2428 Old Hwy 99 South Rd Mt Vernon, WA 98273 www.osborneseed.com

OUT............... Outstanding Seed Co., 354 Center Grange Rd, Monaca PA 15061 https://outstandingseed.com

OLS................ L.L. Olds Seed Co., P.O. Box 7790, Madison, WI 53707 www.oldsgardenseed.com

OR.................. Orsetti Seed Co., P.O. Box 2350, Hollister, CA 95024 www.orsettiseeds.com

P..................... Pacific Seed Production Co., P.O. Box 947, Albany, OR 97321 www.pacificseed.com

PA/PK............ Park Seed Co., 1 Parkton Ave., Greenwood, SC 29647-0002 www.ParkSeed.com

PARA............. Paragon Seed Inc., P.O. Box 1906, Salinas CA, 93091 831-753-2100

PG.................. The Pepper Gal, P.O. Box 23006, Ft. Lauderdale, FL 33307-3006 www.peppergal.com

PL.................. Pure Line Seeds Inc., Box 8866, Moscow, ID https://purelineseed.com

PAN................ Pan American Seed Company, P.O. Box 438, West Chicago, IL 60185 www.panamseed.com

PT.................. Pinetree Garden Seeds, P.O. Box 300, New Gloucester, ME 04260 www.superseeds.com

RM................. Reimer Seed Co., PO Box 236, Mt. Holly, NC 28120 www.reimerseeds.com

RG ...... Rogers Seed Co., P.O. Box 4727, Boise, ID 83711-4727 928 783 7204

RI/RSP ...... Rispens Seeds Inc., 3332 Ridge Rd., P.O. Box 5, Lansing, IL 60438 rispensseeds.com

RS ...... Royal Sluis, 1293 Harkins Road, Salinas, CA 93901 www.sluisgarden.com

RU ...... Rupp Seeds Inc., 17919 Co. Rd. B, Wauseon, OH 43567 www.ruppseeds.com

SM ...... Seminis Inc., 2700 Camino del Sol, Oxnard, CA 93030-7967 www.seminis.com

SE ...... Southern Exposure Seed Exchange, P.O. Box 460 Mineral, VA 23117 www.southernexposure.com

SHUM ...... Shumway Seed Co., 334 W. Stroud St. Randolph, WI 53956 www.rhshumway.com

SI/SG ...... Siegers Seed Co., 8265 Felch St., Zeeland, MI 49464-9503 www.siegers.com

SK ...... Sakata Seed America Inc., P.O. Box 880, Morgan Hill, CA 95038 www.sakata.com

SN ...... Snow Seed Co., 21855 Rosehart Way, Salinas, CA 93980 dev.snowseedcompany.com

SOC ...... Seeds of Change, Santa Fe, NM www.seedsofchange.com

SST ...... Southern States, 6606 W. Broad St., Richmond, VA 23230 www.southernstates.com/farm-store/

ST ...... Stokes Seeds Inc., 737 Main St., Box 548, Buffalo, NY 14240 www.stokeseeds.com

SU/SS ...... Sunseeds, 18640 Sutter Blvd., P.O. Box 2078, Morgan Hill, CA 95038 https://vitakraftsunseed.com

SV ...... Seed Savers Exchange, 3094 North Winn Rd., Decorah, IA 52101 www.seedsavers.org

SW ...... Seedway Inc., 1225 Zeager Rd., Elizabethtown, PA 17022 www.seedway.com

SY ...... Syngenta AG, 600 N Armstrong Place (83704), Box 4188, Boise, ID 83711 www.syngenta.com

TR ...... Territorial Seed Company, Box 158, Cottage Grove, OR 97424 www.territorialseed.com

TGS ...... Tomato Growers Supply Co., P.O. Box 2237, Ft. Myers, FL 33902 www.tomatogrowers.com

TT ...... Totally Tomatoes, P.O. Box 1626, Augusta, GA 30903 www.totallytomato.com

TW ...... Twilley Seeds Co. Inc., P.O. Box 65, Trevose, PA 19047 www.twilleyseed.com

UA ...... US Agriseeds, San Luis Obispo, CA 93401 www.voloagri.com

UG ...... United Genetics, 8000 Fairview Road, Hollister, CA 95023 unitedgenetics.com

US ...... US Seedless, 12812 Westbrook Dr., Fairfax, VA 22030 usseedless.com

VE ...... Vesey's Seed Limited, York, Prince Edward Island, Canada www.veseys.com

VL ...... Vilmorin Inc., 6104 Yorkshire Ter., Bethesda, MD 20814 www.shamrockseed.com

VS ...... Vaughans Seed Co., 5300 Katrine Ave., Downers Grove, IL 60515-4095 www.vaughans.com/

WI ...... Willhite Seed Co., P.O. Box 23, Poolville, TX 76076 www.willhiteseed.com

WP ...... Wood Prairie Farms, 49 Kinney Road, Bridgewater, ME 04735 www.woodprairie.com

ZR ...... Zeraim Seed Growers Co. Ltd., P.O. Box 103, Gedera 70 700, Israel www.zeraim.com/en

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