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2023 Fruit and Vegetable Crops Research Report

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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: Pawpaw tree at Kentucky State University's Harold R. Benson Research and Demonstration Farm in Frankfort, KY, on Sept. 20, 2022.

Photographer: Jonathan Palmer
Kentucky State University Land Grant Program

The 2022-2023 Fruit and Vegetable Crops Research Program

Rachel Rudolph, Horticulture

This report is a bit different from previous reports in that it represents two years' worth of work. It is also smaller than the reports of previous years. In 2021, a tornado destroyed much of our research center in Princeton, KY, and in 2022, a flood destroyed much of our research center in Quicksand, KY. Although both locations are rebuilding as quickly as they can, research trials have been hindered. We hope to have more trials and more reports in the future. Research was conducted by University of Kentucky faculty, staff, and students from the Department of Horticulture, as well as faculty and staff of Kentucky State University.

Evaluation of varieties is a continuing necessity and allows us to provide current information to growers across the state about the production and performance of various crops. The results are the basis for updating the recommendations in several of our production guides, which are updated every few years. We may also collaborate with researchers in surrounding states such as Ohio, Indiana, and Tennessee to discuss results of similar 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 plants or varieties perform well across Kentucky year after year, others may not. Below are guidelines for interpreting the results of our projects.

Our Yields vs. Your Yields

Yields reported in variety trial results are often extrapolated from small plots. Depending on the crop, individual plots range from one to 200 plants. Sometimes our yields are reported as is, and at other times, they are calculated by multiplying the yields in these small plots by correction factors to estimate per-acre yield. For example, if 4,200 tomato plants can be planted per acre (assuming in-row spacing of 18 in) 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 for larger plots or entire acreages. 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 the same. For example, if tomato variety 1 has an average yield of 2000 boxes per acre, and tomato variety 2 yields 2300 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 1800, 1900, 2200, and 2100 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 1700, 2500, 2800, and 2200 boxes per acre. The four plots together would average 2300 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 also yield consistently. Tomato variety 2 may have had yields similar to variety 1, but it also had much greater variation. Therefore, all other things being equal, tomato variety 1 may be a better choice due to less variable yield 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 $P \leq 0.05$, 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 $P \leq 0.05$ is considered standard practice for agricultural research. This approach may be confusing, but without statistics, our results would not be useful. Using statistics ensures that we can make more accurate recommendations for growers.

Rootstock Effects on Apple Tree Growth and Yield

Dwight Wolfe, Daniel Becker, Ginny Travis, and Brent Arnoldussen, Horticulture, University of Kentucky

Introduction

Although apples and peaches are the principal tree fruits grown in Kentucky, the hot and humid summers and heavy clay soils in some areas of the state make their production more difficult than in some neighboring tree fruit-producing regions. Hot, humid summers and warm winters 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. The detailed and objective evaluations allow growers to select the most appropriate rootstocks for Kentucky.

Materials and Methods

The Kentucky 2019 NC-140 rootstock planting is located at the UK Research and Education Center (UKREC) in Princeton, KY. It was planted 11 Apr 2019, at the UKREC orchard and consists of 'Buckeye Gala' as the scion grafted onto seven different rootstocks (Table 1). One of the rootstocks is a proprietary rootstock from The New Zealand Institute for Plant Food and Research, Ltd., that has neither been named nor released but has been designated by the NC-140 group as 'NZ.2' for the purpose of this trial only. This rootstock is purported to have 'Malling 9' ('M.9') vigor, high yield efficiency, and tolerance to aphids and fire blight (possibly immune).

Three trees of each rootstock trial were planted in each row (replication) in a randomized complete block design and trained to the tall spindle system with a 3-ft spacing between trees and a 13.5-ft spacing between rows. 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 is evaluated. Thus, the confounding effect due to different rootstock sizes adjacent to one another is eliminated in this trial. Trunk circumference 30 cm above the graft union, tree height, and tree width (average of across-row width and within-row width) are measured each fall during the life of the trial (Wolfe 2022; Wolfe et al. 2019; Wolfe et al. 2020; Wolfe et al. 2021). Trunk cross-sectional area (TCSA) is calculated from the trunk circumference. Trees were first harvested during the 2020 season in late August and annually thereafter. All data are analyzed using SAS v.9.4 (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The 2023 growing season was particularly active with tornadoes and windy conditions in western Kentucky. Three data trees—one on 'Geneva 814' ('G.814'), one on 'Geneva 41' ('G.41'), and one on 'Malling 26' ('M.26')—in the 2019 NC-140 rootstock trial broke at the graft union during one of these storms. However, this did not result in statistically significant differences in tree mortality among the seven rootstocks (Table 2).

Tree height, average tree width, and number of root suckers per tree were also not significantly different among the seven rootstocks, but significant differences were observed for trunk cross-sectional area (TCSA) 30 cm above the graft union (Table 2). 'G.814' and 'Geneva 969' ('G.969') were the largest trees in terms of TCSA and were significantly different from 'Budagovsky 10' ('B.10'), 'Malling 9 NAKBT337' ('M.9 NAKBT337'), and 'G.41,' which were the smallest trees in terms of TCSA. 'Malling 26 EMLA' ('M.26 EMLA') was not significantly different from the largest trees. To date, 'NZ.2' in Kentucky has been at least as vigorous as 'M.26,' in contrast to the purported 'M.9' vigor suggested earlier.

The average weight of a single fruit (fruit size), yield (weight of all fruit/tree) in 2023, and yield efficiency (yield in 2023 per TCSA) did not vary significantly among the seven rootstocks (Table 3). Yield in years 2020 through 2022 and average yield per tree per year for the years 2020 through 2023 did vary significantly among the seven rootstocks. The highest average yearly yield was for trees on 'NZ.2,' at 17.8 lb/tree, and the lowest was for trees on 'M.9 NAKBT337' at 11.1 lb/tree. The yield on any rootstock varied from year to year, as did the rootstock with the highest yield for any particular year. The yield was highest for trees on 'G.41' in 2020, 'NZ.2' in 2021, 'G.969' in 2022, and the trend was toward 'G.814' in

Table 1. Rootstocks in the 2019 apple rootstock trial with 'Buckeye Gala' as the scion cultivar, located at University of Kentucky Research and Education Center, Princeton, KY.

Rootstock	Clone status	Origin	Location of program
Budagovsky 10	named	Michurinsk University	Michurinsk University, Michurinsk, Tambov Region, Russia
Geneva 41	named	Cornell-USDA [z]	New York State Agricultural Experiment Station, Geneva, New York
Geneva 814	named	Cornell-USDA	
Geneva 969	named	Cornell-USDA	
NZ.2	not released	The Institute for Plant & Food Research	The Institute for Plant & Food Research, Auckland, New Zealand
Malling 9 NAKBT337	named	NAKB virus free sub-clone of M.9	NAKB, Roelofarendsveen, The Netherlands
Malling 26 EMLA	named	East Malling virus free sub-clone of M.26	East Malling Research Station, Kent, England

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

Table 2. Mortality and growth of trees in 2023 for the NC-140 apple rootstock trial planted in 2019 in Princeton, KY.

Rootstock [z]	Number of data trees at planting	Mortality (% alive)	Fall TCSA (in^2)	Tree height (ft)	Average width (ft)	Number of root suckers
Geneva 814	5	80.0	4.43 a	12.6	6.2	2.0
Geneva 969	5	100.0	3.94 a	12.8	5.7	1.2
NZ.2	5	100.0	3.80 ab	12.8	5.9	0.8
Malling 26 EMLA	5	80.0	3.63 ab	12.1	5.2	0.0
Malling 9 NAKBT337	5	100.0	2.97 bc	12.4	5.7	0.8
Geneva 41	5	80.0	2.80 c	12.4	5.3	0.3
Budagovsky 10	5	100.0	2.77 c	11.5	4.9	0.0
Means	NA[x]	91.4	3.44	12.5	5.6	0.7
LSD (5%) [y]	NA	NS	0.93	NS	NS	NS

[z] Arranged in descending order of the 2023 fall trunk cross-sectional area (TCSA) for each rootstock.
[y] Least significant difference (LSD) at $P \leq 5\%$. Values within a column followed by the same letter are not significantly different. "NS" indicates that differences were not significant in the analysis of variance at $P \leq 5\%$.
[x] "NA" indicates not applicable.

Table 3. Yield and fruit size for trees in the NC-140 apple rootstock trial planted in 2019 in Princeton, KY.

Rootstock [z]	Average fruit size in 2023 (oz/fruit)	2020 yield (lb/tree)	2021 yield (lb/tree)	2022 yield (lb/tree)	2023 yield (lb/tree)	Average annual yield (2020-23) (lb/tree)	2023 yield efficiency (lb/in^2 of TCSA)
Geneva 814	6.2	6.6 b	19.7 b	3.1 b	29.1	15.0 ab	7.1
Geneva 969	6.0	8.3 ab	23.1 ab	8.2 a	26.1	16.4 a	7.0
NZ.2	6.9	8.2 ab	31.7 a	5.1 ab	26.0	17.8 a	7.1
Malling 26 EMLA	6.1	8.5 ab	21.3 b	7.4 a	21.2	15.1 ab	7.5
Malling 9 NAKBT337	6.2	5.0 b	14.5 b	3.1 b	21.6	11.1 b	7.3
Geneva 41	6.8	13.9 a	18.8 b	5.4 ab	19.5	14.7 ab	8.0
Budagovsky 10	6.2	8.3 ab	14.9 b	6.2 ab	17.8	11.8 b	7.2
Means	6.4	8.4	20.6	5.6	23.6	14.6	7.3
LSD (5%) [y]	NS	6.0	9.4	3.4	NS	4.3	NS

[z] Arranged in descending order of the 2023 fall trunk cross-sectional area (TCSA) for each rootstock.
[y] Least significant difference (LSD) at $P \leq 5\%$. Values within a column followed by the same letter are not significantly different. "NS" indicates that differences were not significant in the analysis of variance at $P \leq 5\%$.

2023. Yield efficiency for 2023 was highest for trees on 'G.41,' but it was not significantly more yield efficient than any of the other rootstocks in this trial. Yield efficiency is a measure of the amount of fruit that a tree produces relative to the amount of vegetative growth it has. This measurement is more useful during the first few years of production but becomes less relevant as trees in high-density plantings fill their allotted space (NC-140 group communication).

This was the fourth year that these trees were fruited and the fifth season of this trial. NC-140 trials have typically been evaluated over a 10-year period before results are summarized and recommendations made. However, NC-140 cooperators may decide to shorten or lengthen the period of a trial based on the benefit of obtaining further information versus the cost of collecting more data.

In spring 2023, a new NC-140 planting was initiated in Lexington, KY, with the cider apple cultivar 'Porter's Perfection' as the scion. This planting contains seven rootstocks from the Cornell Geneva rootstock breeding program: 'Geneva 41' ('G.41'), 'Geneva 11' ('G.11'), 'Geneva 210' ('G.210'), 'Geneva 202' ('G.202'), 'Geneva 213' ('G.213'), 'Geneva 969' ('G.969'), and 'Geneva 890' ('G.890'). Further discussion of this trial will not be reported here but in future publications.

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Planting Date and the Effect on Pawpaw (*Asimina triloba*) Seedling Growth and Survival

Jeremiah D. Lowe, Sheri B. Crabtree, Jacob Vincent, Kirk W. Pomper, and Anju Chaudhary, Kentucky State University Land Grant Program

The North American pawpaw (*Asimina triloba*) is a tree fruit native to the eastern United States that is increasing in small-scale commercial production across the United States and internationally and has an enthusiastic base of home growers (Pomper and Layne 2005). Pawpaw is unique in that it is a temperate tree, but the fruit have a tropical flavor resembling a combination of mango (*Mangifera indica*), pineapple (*Ananas comosus*), and banana (*Musa ×paradisiaca*), giving it potential to be a high-value crop or a useful addition in edible landscaping and butterfly gardens (Layne 1996; Pomper et al. 1999).

Establishment of field-planted pawpaws can be difficult and survival low due to a variety of factors, including small tree size, transplant shock, intolerance of root damage, summer heat and drought conditions after planting, and failure to acclimate seedlings properly from shade to sun prior to planting. Pawpaw seedlings develop a strong taproot that can be easily damaged during field digging for transplanting (Layne 1996). Due to this, methods for the container production of pawpaws have been developed, and current recommendations are for pawpaw trees to be planted in late spring using container-produced stock (Jones et al. 1998; Pomper et al. 2003). However, spring in Kentucky is typically wet, and it is often June before soils are dry enough for planting, resulting in air temperatures that are much higher than optimal for pawpaw transplanting. In the orchards at Kentucky State University, June-planted trees often display a mortality rate over 30%, even with frequent irrigation (Jeremy Lowe, personal observation) . Despite the recommendation to plant in late spring, some growers have reported success with planting pawpaws in late fall. In order to provide growers with better recommendations, an experiment was designed and implemented to look at growth and survival of pawpaw seedlings planted at three different times of year: late fall, early spring, and early summer.

Materials and Methods

A randomized block design orchard was planted at the Kentucky State University H.R. Benson Research and Demonstration Farm in Frankfort, KY. Two-year-old container-grown pawpaw seedlings at least 60 cm in height were planted on three different dates: early November 2020, late March 2021, and mid-June 2021. The planting contains three blocks,

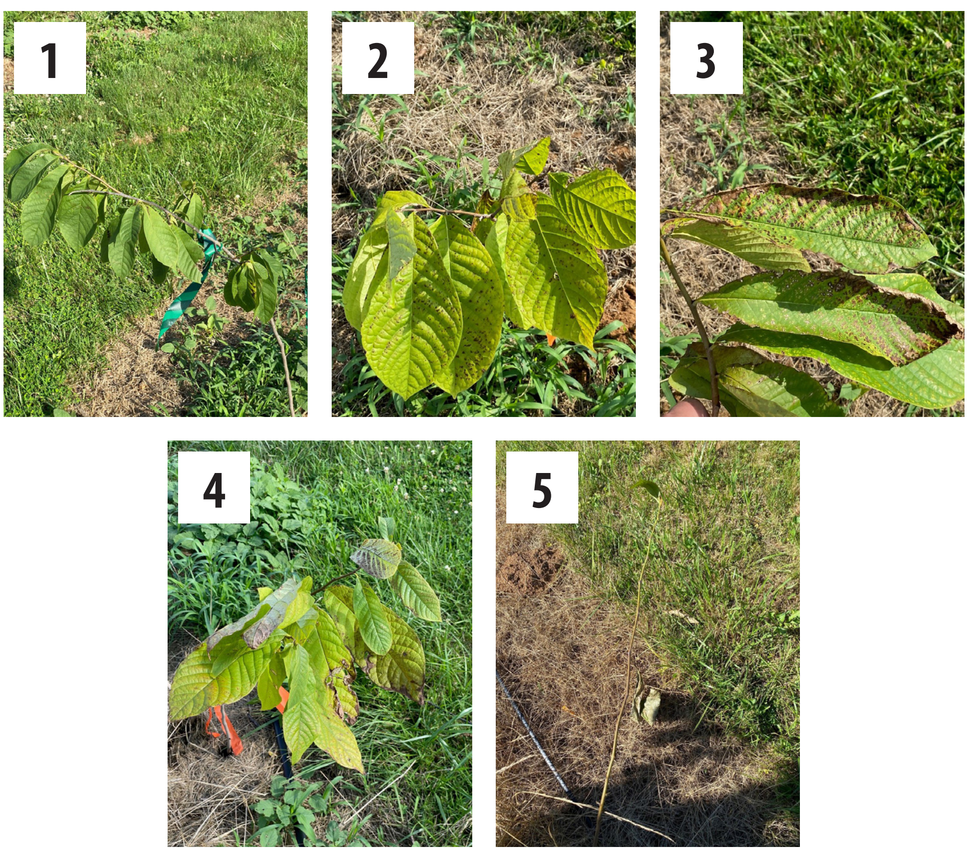

Figure 1. Scaled rating examples of pawpaw seedling transplant shock: 1) no chlorosis or sunburn, 2) mild chlorosis and sunburn, 3) moderate chlorosis and sunburn, 4) severe chlorosis and sunburn, and 5) complete defoliation.

Table 1. Survival in March 2022, average transplant shock rating, and average trunk diameter for pawpaw seedlings planted at three different times of year in Frankfort, KY.

Month planted	Survival (%)	Shock rating[y]	Diameter (mm)
November 2020	100 a[z]	1 a	8.92 a
March 2021	100 a	1 a	8.86 a
June 2021	73 b	3.4 b	6.43 b
***P*-value**	0.0039	0.0000	0.0000

[z] Values followed by the same letter within a column are not significantly different (least significant difference $P \leq 0.05$).

[y] The shock rating is on a scale from 1 to 5. See examples in Figure 1.

with each block containing five trees of each planting date, for a total of 15 trees per planting date. In July 2021, trees were evaluated for signs of transplant shock (chlorosis, sunburn, or fallen leaves) on a scale of 1 (no shock) to 5 (severe shock with complete defoliation) (Figure 1). In March 2022, survival and trunk diameters were recorded at a height of 30 cm. Data were analyzed using CoStat Statistical software (CoHort Software, Monterey, CA), and subjected to analysis of variance and least significant difference (LSD) means separation. Treatment means were separated based on a significance level of $P \leq 0.05$.

Results and Discussion

Both the November- and March-planted trees were dormant at the time they were planted, while the June-planted trees were actively growing when removed from the greenhouse to be planted. This resulted in the June-planted trees displaying an average transplant shock rating of 3.4, compared to a rating of 1 for the November- and March-planted trees (Figure 1; Table 1). November- and March-planted trees had a significantly higher survival rate than June-planted trees. All of the November- and March-planted trees were alive in March 2022, whereas only 73% of the June-planted trees were still alive (Table 1). Additionally, June-planted trees had significantly smaller trunk diameters, averaging 6.4 mm, compared to November- and March-planted trees that had trunk diameters averaging nearly 9 mm (Table 1). The November-planted trees experienced several severe winter weather events in late 2020 and early 2021, including several ice storms and a low temperature of -16 °C (3.2 °F). Despite this, the November-planted trees displayed similar survival, growth, and transplant shock to the March-planted trees, which were both significantly better than the June-planted trees. While data will continue to be collected in subsequent years, current data indicate that planting pawpaws in the fall or early spring can be recommended to growers, while planting in June or later in Central Kentucky should be avoided.

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Consumer Preference of Kentucky State University Advanced Selection Pawpaws Compared to Commercially Available Cultivars

Sheri B. Crabtree, Kirk W. Pomper, and Jeremiah D. Lowe, Kentucky State University Land Grant Program

Introduction

The North American pawpaw (*Asimina triloba*) is the largest edible tree fruit native to North America (Pomper and Layne 2005). Pawpaw fruit have a predominantly banana-mango flavor, with undertones of pineapple, coconut, melon, vanilla, and caramel apparent in different genotypes. Wild fruit have variable—often poor—quality, and many older pawpaw cultivars from the 1960s and earlier also have mediocre to poor fruit size, yields, and flavor. Since the 1990s, there has been a resurgence in interest in pawpaw, and breeding work has been done by individuals such as Neal Peterson (Peterson Pawpaws, Harpers Ferry, WV; Peterson 2003). Kentucky State University (KSU) is designated as the USDA National Clonal Germplasm Repository satellite site for spp. and possesses a large, genetically diverse collection of both wild collected material and commercially available cultivars.

One of the goals of KSU's pawpaw research program is breeding and evaluating new improved cultivars for commercial release. KSU has released three pawpaw cultivars, 'KSU-Atwood,' 'KSU-Benson,' and 'KSU-Chappell,' which have excellent flavor, fruit size, yield, and vigor, and they are sold by nurseries across the United States and Europe. We are continuing to breed and evaluate additional advanced selections for potential cultivar release. The objective of this study was to determine consumer preference for pawpaw advanced selections from KSU's breeding program compared to commercially available cultivars.

Materials and Methods

Two pawpaw fruit tastings were held in September 2022. The first tasting was held at a pawpaw workshop in Boone County, KY, on 8 Sep 2022, and the second at KSU's Third Thursday Thing Sustainable Agriculture Workshop in Frankfort, KY, on 5 Sep 2022. At the Boone County tasting, KSU advanced selections G4-25, G9-109, G9-111, Hi7-1, and NRVT3-10 were tasted by participants (n = 57) alongside commercially available cultivars 'KSU-Atwood,' 'KSU-Benson,' 'KSU-Chappell,' 'Sunflower,' 'Susquehanna,' 'Tallahatchie,' and 'Mango,' and an additional selection from a southern Indiana grower not yet commercially available, 'Ralph's Whopper.' At the Frankfort tasting, KSU advanced selections G4-25, G9-109, Hi7-1, and NRVT3-4 were tasted by participants (n = 63) alongside commercially available cultivars 'KSU-Atwood,' 'KSU-Benson,' 'KSU-Chappell,' 'Sunflower,' 'Susquehanna,' and 'Tallahatchie.'

Background of Advanced Selections

G4-25 is a selection discovered in KSU's germplasm repository orchard, and is a seedling sent to us from a volunteer in Tompkins County, NY. G9-109 and G9-111 are both crosses of PawPaw Foundation advanced selections 11-13 x 1-23. Hi7-1 is an open-pollinated seedling from mixed seed obtained from the 1998 Frankfort pawpaw regional variety trial. NRVT3-4 and NRVT3-10 are open-pollinated seedlings from a mixed seed lot of 'Sunflower' and 'Susquehanna.'

For the tastings, fruit were cut into slices to be sampled by participants and evaluated on a scale of 1 (poor) to 5 (excellent) for the qualities of flavor, appearance, and texture. Data were analyzed using CoStat Statistical software (CoHort Software, Monterey, CA), and subjected to analysis of variance and least significant difference (LSD) means separation. Treatment means were separated based on a significance level of ≤ 0.05.

Table 1. Five pawpaw advanced selections and eight cultivars ranked in a fruit tasting by participants at a pawpaw workshop and tasting held in Boone County, KY, in 2022. Rankings were on a scale of 1 (poor) to 5 (excellent) on the basis of flavor, appearance, and texture.

Variety	Flavor	Appearance	Texture
G4-25	3.92 a[z]	3.95 ab	3.75 abcd
G9-109	3.29 bcd	3.44 cde	3.24 d
G9-111	3.62 ab	3.57 bcde	3.53 cd
Hi7-1	2.91 de	3.33 e	3.37 d
NRVT3-10	3.29 bcd	3.52 cde	3.40 d
KSU-Atwood	3.54 abc	3.73 abcd	3.58 cd
KSU-Benson	2.69 e	3.92 ab	3.64 bcd
KSU-Chappell	3.73 a	3.83 abc	3.83 abc
Mango	3.54 abc	3.58 bcde	3.29 d
Ralph's Whopper	3.70 ab	3.92 ab	4.02 ab
Sunflower	2.81 de	3.38 de	3.33 d
Susquehanna	3.82 a	4.00 a	4.08 a
Tallahatchie	2.91 de	3.67 abcde	3.38 d
Significance	0.0000	0.0014	0.0001

[z] Values followed by the same letter within a column are not significantly different (least significant difference $P \leq 0.05$).

Table 2. Mean score of flavor, texture, and appearance combined of pawpaw fruits rated on a scale of 1 (poor) to 5 (excellent) by fruit-tasting participants at a tasting event held in Boone County, KY, in 2022.

Overall ranking	Variety	Mean score of flavor, texture, and appearance[z]
1	Susquehanna	3.97
2	Ralph's Whopper	3.88
3	G4-25	3.87
4	KSU-Chappell	3.80
5	KSU-Atwood	3.61
6	G9-111	3.57
7	Mango	3.47
8	KSU-Benson	3.42
9	R3T10	3.40
10	G9-109	3.32
11	Tallahatchie	3.32
12	Hi7-1	3.20
13	Sunflower	3.17

[z] Mean score values that appear to be the same in this table are the result of rounding and do not reflect equal ranking.

Table 3. Four pawpaw advanced selections and six cultivars ranked in a fruit tasting by participants at a pawpaw tasting held in Frankfort, KY, in 2022. Rankings were on a scale of 1 (poor) to 5 (excellent) on the basis of flavor, appearance, and texture.

Variety	Flavor	Appearance	Texture
G4-25	3.98 a[z]	4.22 a	4.03 abc
G9-109	3.26 b	3.76 c	3.52 d
Hi7-1	4.05 a	4.19 a	4.23 a
NRVT3-4	4.13 a	4.08 ab	4.12 ab
KSU-Atwood	4.06 a	3.83 bc	3.85 bc
KSU-Benson	3.57 b	4.17 a	3.89 bc
KSU-Chappell	4.00 a	4.13 a	3.95 abc
Sunflower	3.50 b	3.75 c	3.76 cd
Susquehanna	4.12 a	4.18 a	4.10 ab
Tallahatchie	3.43 b	3.56 c	3.46 d
Significance	0.0000	0.0000	0.0000

[z] Values followed by the same letter within a column are not significantly different (least significant difference $P \leq 0.05$).

Table 4. Mean score of flavor, texture, and appearance combined of pawpaw fruits rated on a scale of 1 (poor) to 5 (excellent) by fruit-tasting participants at tasting held in Frankfort, KY, in 2022.

Overall ranking	Variety	Mean score of flavor, texture, and appearance
1	Hi7-1	4.16
2	Susquehanna	4.13
3	NRVT3-4	4.11
4	G4-25	4.07
5	KSU-Chappell	4.03
6	KSU-Atwood	3.91
7	KSU-Benson	3.88
8	Sunflower	3.67
9	G9-109	3.51
10	Tallahatchie	3.48

Results and Discussion

Boone County, KY

KSU advanced selections G4-25 and G9-111 were rated significantly higher on flavor than commercially available varieties 'Tallahatchie,' 'Sunflower,' and 'KSU-Benson.' G4-25 was rated as having a superior appearance to 'Sunflower.' G4-25 was also the most highly rated KSU advanced selection based on texture (Table 1). Mean scores of flavor, appearance, and texture were combined for a general overall score. 'Susquehanna' ranked the highest, followed by 'Ralph's Whopper,' G4-25, 'KSU-Chappell,' and 'KSU-Atwood' (Table 2).

Frankfort, KY

KSU advanced selections G4-25, Hi7-1, and NRVT3-4 were rated significantly higher on flavor than commercially available varieties 'KSU-Benson,' 'Sunflower,' and 'Tallahatchie.' G4-25 and Hi7-1 were rated as having a superior appearance to 'KSU-Atwood,' 'Sunflower,' or 'Tallahatchie.' Hi7-1 and NRVT3-4 were rated as having a better texture than 'Sunflower' and 'Tallahatchie' (Table 3). Mean scores of flavor, appearance, and texture were combined for a general overall score. Hi7-1 ranked the highest, followed by 'Susquehanna,' NRVT3-4, G4-25, and 'KSU-Chappell' (Table 4). Most KSU advanced selections compared favorably to current commercially available cultivars, with the exception of G9-109 and NRVT3-10, which were rated low by participants in these tastings. Hi7-1 was rated much more highly by participants at the tasting in Frankfort than in Boone County. This may be because Hi7-1 is generally a later-ripening selection (mid-September). Fruit may have been slightly underripe or prematurely ripe, with flavors and sugars not fully developed, at the Boone County tasting on 8 Sep, despite efforts to only sample perfectly ripe fruit. Ratings overall were higher at the tasting held in Frankfort, which could be due to several factors, such as participants being more familiar with pawpaws or the tasting being held in mid-September during peak harvest.

Overall, Hi7-1, NRVT3-4, G4-25, and G9-111 were rated highly by participants compared to several commercially available cultivars. These advanced selections will continue to be trialed and evaluated for vigor, disease resistance, fruit size, and yield in addition to consumer preference, to be considered for future cultivar release by KSU's pawpaw breeding program.

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Mustard Cover Crop Planting Date and Variety Trial

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Introduction

Plants in the Brassicaceae family include rapeseed (*Brassica napus* or *Brassica rapa*), mustard (*Brassica juncea* or *Sinapis alba*), radish (*Raphanus sativus*), bok choy (*Brassica rapa* var. *Chinensis*), and broccoli (*Brassica oleracea* var. *italica*), among others (Clark 2007). All Brassicaceae crops contain various levels of compounds called glucosinolates, which influence the bitter and spicy taste characteristic (Clark 2007). Certain mustard crops have been bred with higher glucosinolate content to be used as cover crops with the potential to act as biofumigants (Kirkegaard et al. 1999). Biofumigants are living biological agents that release naturally occurring chemicals into the soil to manage soilborne pests and pathogens (Rudolph and Pfeufer 2021). Currently, several traditional fumigants have been or are being phased out of use because of the potential dangers to the health of farm workers and community members and the potential environmental effects. One such example of this is an effective fumigant called methyl bromide, which was used throughout the twentieth century and was classified as a Class I controlled substance in 1992 by the Parties of the Montreal Protocol (Sande et al. 2011). Biofumigant cover crops have the potential to be alternatives for chemical fumigants, while also potentially increasing soil health and quality (Kirkegaard et al. 1999). They may also provide similar benefits as regular cover crops, such as increasing soil organic matter, preventing nutrient loss, improving soil porosity, and preventing wind or water erosion (Clark 2007; Quinn et al. 2019).

To our knowledge there is no information available to Kentucky growers regarding the cultivar performance and recommended planting dates of mustard cover crops for Kentucky. Publications from other states can provide a guideline for Kentucky, but because of climatic differences, they remain only a rough estimate. For example, Michigan State University recommends that fall plantings should be made before mid-August to balance long day photosensitivity and biomass production (Snapp et al. 2006). Lansing, MI, (lat. 42.78°, long. -84.59°) has an annual average air temperature that falls between 39.2 °F and 57.9 °F and is in hardiness zone 5b (NOAA 2021; USDA 2012). The University of Massachusetts Amherst recommends that mustards be seeded in late August (Campbell-Nelson et al. 2015). Amherst, MA, (lat. 42.38°, long. -72.52°) has an annual average air temperature that falls between 37.1 °F and 59.3 °F and is in hardiness zone 5b (NOAA 2021; USDA 2012). Dale Gies, a Washington potato, wheat, and seed farmer, plants his mustard-arugula cover crop around 10 Aug (Yorgey et al. 2017). Moses Lake, WA, (lat. 47.13°, long. -119.28°) has an annual average air temperature that falls between 40.5 °F and 62.4 °F and is in hardiness zone 6b (NOAA 2021; USDA 2012). In comparison, Lexington, KY, (lat. 38.04°, long. -84.46°) has an average annual temperature that falls between 46.4 °F and 66.4 °F and is in hardiness zone 6b (NOAA 2021; USDA 2012). By comparing six mustard varieties planted in early, mid-, and late August, this trial was intended to provide information to Kentucky growers on when and how to use mustard cover crops. Mustard cultivars were evaluated within and across planting dates based on biomass production.

Materials and Methods

'Pacific Gold,' 'White Gold,' Trifecta Power Blend™ (comprised of 'Kodiak,' 'White Gold' and 'Pacific Gold,' by Mighty Mustard®, Spokane, WA; L.A. Hearne Company, King City, CA), 'Caliente 199' mustard blend, 'Caliente Rojo,' and 'Nemat' arugula (*Eruca vesicaria*; Biosustainable Solutions, Moses Lake, WA) were the six cultivars evaluated. The trial was arranged in a randomized complete block design with four replicates of each cultivar in plots measuring 4 × 20 ft. Plots were seeded with a drop spreader at a rate of approximately 20 lb/acre. Each plot had a 6-ft buffer from the edges of the field, within the same row, and between rows. Buffers were cultivated twice in the growing season to reduce weed pressure. A soil sample was collected from all three planting-date plots (Table 1).

The planting dates were approximately two weeks apart and included 5 Aug (early), 19 Aug (middle), and 30 Aug (late). Precipitation increased by 1 inch between consecutive planting dates (Table 2). Average temperature values decreased by 3 to 4 °F between the early and middle planting dates and by approximately 10 °F between the middle and late planting dates.

Biomass collection occurred when approximately 70% of the mustard crops were flowering. These dates included 24 Sep (early), 19 Oct (middle), and 23 Nov (late). Two 1-ft^2 sections were collected from the middle of all plots (approximately 10 ft from each end). Plants were cut at soil level and weeds were separated out. The two 1-ft^2 samples from each plot were

Table 1. Pre-plant soil analysis from three fields where Brassicaceae cover crops were seeded in Lexington, KY, in 2021.

Planting date	Soil pH	Phosphorus (lb/acre)	Potassium (lb/acre)	Calcium (lb/acre)	Magnesium (lb/acre)	Zinc (lb/acre)
5 Aug	6.65	113	454	3624	461	2.7
19 Aug	6.76	109	498	3653	402	2.9
30 Aug	6.8	153	683	3849	428	3.4

Table 2. Precipitation and average temperature values that occurred between seeding and Brassicaceae cover crop biomass collection during three planting dates in Lexington, KY, in 2021.

Planting date	Harvest date	Total precipitation (inches)	Average maximum temperature (°F)	Average minimum temperature (°F)	Average temperature (°F)
5 Aug	24 Sep	9	80.9	65	73
19 Aug	19 Oct	10	78	61	69.5
30 Aug	23 Nov	11	68.4	51	59.6

combined, placed in paper bags and oven dried at 60 °C for approximately 7 to 10 d. Dried biomass weights were then recorded. The mean biomass for each Brassicaceae cover crop was collected and analyzed using the Tukey-Kramer method to test for differences.

Results and Discussion

Early, middle, and late planting plots all had significant differences in mean biomass production (Table 3). Trifecta Power Blend™ had significantly higher biomass production compared to all other treatments during the early planting date. The lowest biomass production was from 'Nemat' arugula, and it was significantly lower than all other cover crops except for 'Caliente 199' (Table 3). There were fewer significant differences in biomass production in the middle planting date. Trifecta Power Blend™ had the highest biomass production, but it was only significantly higher than 'Caliente Rojo' and 'Nemat' arugula (Table 3). In the late planting date, Trifecta Power Blend™ had the highest biomass, followed closely by 'White Gold' and 'Pacific Gold'. 'Caliente 199' and 'Nemat' arugula produced significantly less biomass than all other cover crops during this time period.

The biomass production of each cultivar was compared across the three planting dates. All cover crops besides 'Caliente 199' showed significant differences between the early and middle plantings (Table 3). The early planting had much lower mean biomass production than the other two planting dates (Table 3). The early planting date received less precipitation throughout the growing season and higher average temperatures than later plantings. Seedlings experienced more severe weed competition, which likely resulted in uneven emergence and poor stand (Figure 1). 'Nemat' arugula was particularly susceptible to weed pressure, with two of the four plots in the early planting completely overtaken by weeds.

All crops showed significant biomass differences between the early and late plantings (Table 3). Cover crops grown in the late planting date had significantly higher biomass production compared to those grown in the early planting date. Increased heat stress during the early planting date could have accelerated the plant reproductive stage, which may explain why plants in the early plots flowered quickly and produced less biomass (Figure 2). The harvest date for the early planting was 11 d earlier than the middle planting and 35 d earlier than the late planting. Harvest was dependent on flowering, so earlier flowering would reduce the vegetative period needed to accumulate biomass and would reduce planting yields. Despite the higher biomass production in the late planting, 70% flowering was not observed, because the photoperiod was not long enough to trigger flowering. 'Nemat' arugula did not flower in any of the plantings. The lack of flowering would most likely lower biofumigation efficacy if a grower were using these cover crops for biofumigation purposes.

There were no significant differences in biomass production between the middle and late plantings for any of the Brassicaceae cover crops (Table 3). Between the middle and late plantings, the mean biomass across all the varieties except Trifecta Power Blend™ and 'Caliente 199' increased. This change was not enough to be significant, however. A later harvest put the late planting at risk of frost damage (Figure 3). There were multiple mild freezes that occurred while waiting for the plants to flower. Vegetative growth in the late planting began to stagnate approximately three weeks before harvest, when temperatures dropped and the photoperiod became shorter. The cover crops continued to acquire biomass until harvest, but at a slower pace. Cover crops were eventually harvested out of concern for a major frost kill, despite not reaching 70% flowering.

The mean biomass for each planting was scaled up to give an example of the possible biomass that could be produced if grown on a larger scale (Table 4). The amount of biomass produced by cover crops is a direct contributor to soil organic matter. Once biomass is tilled under, that biomass is decomposed and contributes to soil organic matter. It is difficult to give a prescriptive answer for growers seeking to quantify the nutrient benefits and potential organic matter of growing cover crops. Table 3.4 in *Building Soils for Better Crops* provides estimates that can be used as a reference (Magdoff and van Es 2021). Another excellent resource for estimating benefits is the Oregon State University Extension Service Organic Fertilizer and Cover Crop Calculator. This is an Excel-based worksheet that can forecast the quantity of plant-available nitrogen when given certain

Table 3. Dry biomass for each Brassicaceae cover crop seeded in Lexington, KY, in Aug 2021.

Treatment	Average biomass (lb/ft^2)[z]								
	5 Aug			19 Aug			30 Aug		
Caliente 199	0.045	cd[y]	A[x]	0.127	ab	AB	0.086	b	B
Caliente Rojo	0.071	cb	A	0.107	b	B	0.141	a	B
Nemat arugula	0.023	d	A	0.069	b	B	0.088	b	B
Pacific Gold	0.071	cb	A	0.143	ab	B	0.148	a	B
Trifecta Power Blend™	0.104	a	A	0.196	a	B	0.163	a	B
White Gold	0.076	b	A	0.143	ab	B	0.154	a	B

[z] Means were created by compiling the biomass for each plot of a cover crop selection within a given planting date.
[y] Values within the same column followed by the same lowercase letter(s) are not significantly different at $P \leq 0.05$.
[x] Values within the same row followed by the same capital letter(s) are not significantly different at $P \leq 0.05$.

Table 4. Estimated dry biomass for scaled-up Brassicaceae cover crop production based on the dry biomass produced in 2021.

	Average estimated biomass (lb/acre)		
Treatment	5 Aug	19 Aug	30 Aug
Caliente 199	1980.68	5521.92	3721.29
Caliente Rojo	3061.06	4681.62	6122.12
Nemat arugula	1020.35	3001.04	3841.33
Pacific Gold	3061.06	6242.17	7082.45
Trifecta Power Blend™	4501.56	8522.96	7202.49
White Gold	3301.15	6242.17	6722.33

organic inputs such as compost, cover crop residues, and fresh organic material (Sullivan et al. 2019).

Conclusion

Among the six Brassicaceae cover crop selections evaluated, Trifecta Power Blend™ consistently performed the best in terms of flowering and accumulating biomass. Other varieties with similar performance were 'White Gold' and 'Pacific Gold.' 'Caliente 199' and 'Caliente Rojo' were in the mid-level biomass producers. 'Nemat' arugula consistently underperformed and struggled to establish itself in Lexington, KY.

Both the early and middle plantings matured to the point of 70% flowering, the point at which glucosinolate production is highest without a chance of accidental seed rain. Biomass increased between the middle and late plantings, but not enough to be significant. Whether growing Brassicaceae cover crops for biomass production or biofumigant potential, we recommend planting during mid-August. A mid-August planting takes advantage of the increased precipitation and cooler weather while avoiding the shortened photoperiod and risk of frost that postponing seeding would bring.

Figure 1. Variation in first planting. Comparison between 'Pacific Gold' (left) and 'Nemat' arugula (right) in the first planting, one week before harvest. The 'Pacific Gold' is flowering and about to go to seed, but the abundance of weeds in the 'Nemat' arugula plot choked out the mustard.
Photo by Maya Horvath, University of Kentucky

Figure 2. Blooming mustard. Blooms from the middle planting, one week before harvest.
Photo by Rachel Rudolph, University of Kentucky

Figure 3. Frost and insect damage on foliage. Frost damage seen after temperatures dropped below 19 °F. Insect damage occurred earlier in the season from flea beetles.
Photo by Maya Horvath, University of Kentucky

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