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The Influence of Rootstock and Training System on Performance of Two North American Pawpaw Cultivars

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Abstract

The pawpaw [*Asimina triloba* (L.) Dunal] is the largest tree fruit indigenous to the United States and is commercially produced on a small scale as a niche fruit crop. Pawpaws are not currently commercially propagated via cuttings, layering, or tissue culture, and clonal rootstocks are not available for pawpaw cultivars. A study was conducted to determine if establishment survival, vigor, scion precocity, and fruit yield vary by pawpaw cultivar ('Susquehanna' or 'Sunflower'), seedling rootstock source [seedlings of Sunflower, PA-Golden, Susquehanna, KSU-Atwood, and mixed seed collected from the pawpaw regional variety trial (RVT)], and pruning method (either minimal pruning or central leader training). By the sixth year of the study, there was a significant difference in survival by cultivar, 'Susquehanna' (46%) and 'Sunflower' (68%). Trees on Susquehanna and KSU-Atwood seedling rootstock had survival percentages below 60% and therefore are not recommended for use as a rootstock source. Rootstock did not significantly influence trunk cross sectional area, precocity, number of flowers, or yield. Trees with a 'Susquehanna' scion had greater fruit weight than those with a 'Sunflower' scion. Training method had a great impact, with minimally-pruned trees having greater yields per tree than central leader trained trees. However, central leader-trained trees had greater fruit weight than in minimally-pruned trees, which is desirable. Central leader trained trees were initially dwarfed, but displayed a stronger tree architecture with less breakage and facilitated orchard care of trees and weed control.

The North American pawpaw [*Asimina triloba* (L.) Dunal] is commercially produced on a small scale as a niche fruit crop in the Midwest and southeastern United States. Pawpaw is a tree-fruit native to the eastern and midwestern United States and produces the largest edible fruit native to the United States, which may reach up to 1 kg in size (Darrow, 1975; Peterson, 1991). Pawpaw fruit is mainly sold fresh at farmers markets, directly on the farm, or as part of Community Supported Agriculture (CSA) (Pomper and Layne, 2005); however, there is potential for expansion of the processing market (Archbold et al., 2003; Crabtree et al., 2014; Duffrin and Pomper, 2006; Templeton et al., 2003). Pawpaws produce a ripe fruit with soft creamy yellow-orange flesh that is high in antioxidants, vitamins, minerals, amino acids, and essential fatty acids (Kobayashi et al., 2008; Nam et al., 2019; Peterson et al., 1982). The fruit is very nutritious (Peterson et al., 1982); it has an almost tropical aroma, smooth custard-like texture, and tropical-like flavors similar to a combination of banana (*Musa* x *paradisiaca*), mango (*Mangifera indica*), and pineapple (*Ananas comosus*) (Duffrin and Pomper, 2006; Layne, 1996; Shiota, 1991). In addition to the pawpaw's utility as a fruit crop, there are natural compounds in the leaf, bark, and twig tissues that possess insecticidal and anti-cancer properties (McLaughlin, 2008).

There have been advances in pawpaw cultivars in recent years with improved fruit quality, including the cultivars: 'Shenandoah', 'Susquehanna', 'Wabash', 'KSU-Atwood', 'KSU-Benson', 'KSU-Chappell' and a number of additional selections (Greenawalt et al., 2019; Peterson, 2003; Pomper et al. 2008;

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Pomper et al, 2020). Since pawpaws are not true to type from seed, and other methods for clonal propagation such as cuttings, layering, and tissue culture have been largely unsuccessful, the propagation of pawpaw cultivars is usually via grafting and budding onto seedling rootstock (Geneve et al., 2003). Clonal rootstocks have not been developed for pawpaw cultivars; therefore, nurseries graft cultivars onto seedling rootstock from mixed sources, including locally available seed that is often of unknown origin. Great variation in scion growth and precocity is observed with seedling rootstock due to the high genetic variability among seedlings. Pawpaw rootstocks that are vigorous, have high survival, and promote precocity would be beneficial to growers. The objectives of this study were to determine if establishment survival, vigor, scion precocity, and fruit yield vary by pawpaw cultivar, seedling rootstock source, and pruning method.

Materials and Methods

In May 2003, actively growing seedlings of PA-Golden, Sunflower, Susquehanna, KSU-Atwood, and seed from the pawpaw regional variety trial (RVT) that contained 28 cultivars and advanced selections, were chip budded with single buds of 'Sunflower' and 'Susquehanna'. A factorial arrangement of treatments in a completely randomized block design was used with eight blocks, five rootstocks, two scions, and two pruning methods, with one tree of each treatment combination in each block and a total of 160 trees. In May 2004, the budded trees were field-planted into a rootstock trial at the KSU Harold R. Benson Research and Demonstration Farm in Frankfort, Kentucky. Trees were irrigated as needed with drip irrigation using two 3.78 L/h emitters per tree, and fertilized each spring with urea (46-0-0) at 28.3g of N/tree in year 1, and 85g/tree in years 2-5, and 141.5g/tree in year 6 and beyond. Glyphosate was used for weed control as needed during the growing season at the label rate. The rootstock trial included two cultivars ('Sunflower' and 'Susquehanna') on five rootstocks (PA-Golden (#1), Sunflower, Susquehanna, KSU-Atwood, and RVT) and two pruning systems (minimal pruning versus central leader). Trunk diameter, precocity, and survival were evaluated each spring after planting. Minimal pruning or central leader training, with spreading of branches at right angles and removal of competing branches to remove competition, was performed in March or early spring of each year. Additionally, the number of flowers per tree was counted visually, and trunk cross-sectional area (TCA) was measured and calculated each March. Fruit clusters were counted in July to determine the number of fruit per tree and average number of fruits per cluster. During the harvest season (late Aug. to early Sept.), 25 fruit per tree were collected and weighed to obtain fruit weights and yields, and yield efficiency (YE) and fruit set were calculated. Data were subjected to Generalized Linear Model (GLM) analysis of variance using Costat Statistical Software (CoHort Software, Monterey, CA. Data were analyzed by year and the cultivar x training method was usually not significant at the 5% level, so main effect means are presented. When the interaction was significant, the simple effect means are presented for the four treatment combinations. Rootstock means were separated with the least significant difference at the 5% level.

Results

Survival. Training method did not affect tree survival throughout the study. Survival of cultivars did not differ until 2010 when 'Susquehanna' had the greatest mortality (Fig.1A and 3A). After one season, tree survival on seedlings of Susquehanna was lower than for the other rootstocks, and by 2009, tree survival was also low on seedlings of KSU-Atwood (Fig. 2A).

TCA. In 2005, 'Sunflower' trees had greater TCA than 'Susquehanna' trees in 2005 and 2007 (Fig. 1B) and trees on 'Susquehanna' rootstock had the smallest TCA in 2005 and 2007 (Fig. 2B). TCA was not affected by

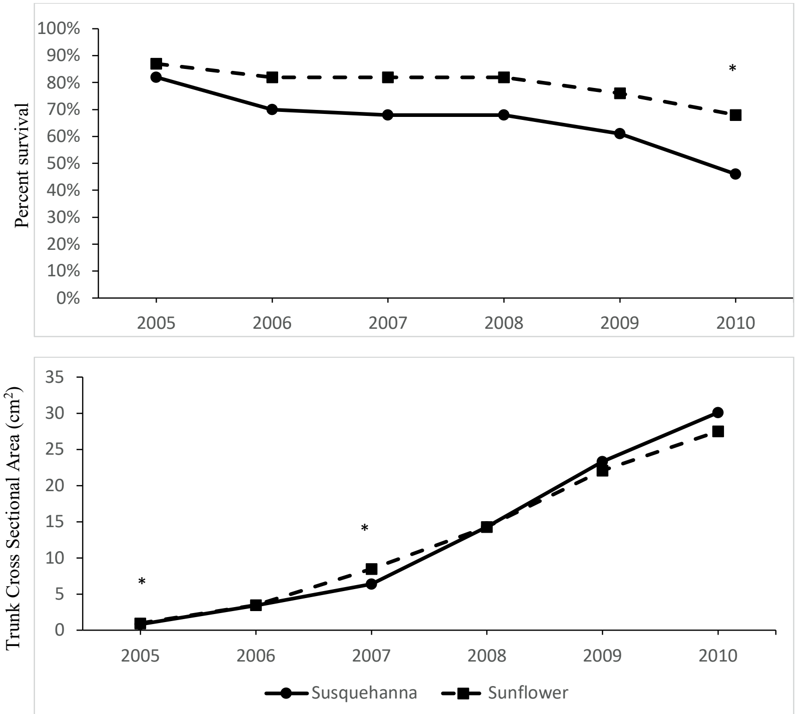

Figure 1. Survival (A) and trunk cross sectional area (cm^2) (B) in two pawpaw cultivars ('Susquehanna and 'Sunflower') grafted onto five seedling rootstocks, 2005-2010. An asterisk indicates the means are significantly different at the $P \leq 0.05$ level.

training method until 2007 when minimally pruned trees had the largest trunks for three years (Fig. 3B). The yearly increase in TCA was greatest for minimally pruned trees in 2007, 2008 and 2009, but the opposite was true in 2010 (Table 1).

Flowering. The percentage of flowering trees was greatest for 'Sunflower' from 2006 to 2008 (Fig. 4A) and for minimally pruned trees in 2006 (Fig. 6A). In general, the percentage of flowering trees was highest for trees on Susquehanna and PA-Golden seedling rootstocks and lowest for trees on KSU-Atwood seedlings (Fig. 5A). In all years, minimally pruned trees had more flower buds than central leader trees, and 'Sunflower' had more flower buds than 'Susquehanna' (data not shown). In one year (2007), trees on PA-Golden seedling rootstock had more flower buds; the remaining years there were no differences among rootstocks.

Fruit and Yield. 'Sunflower' trees had more fruit than 'Susquehanna' in 2009 (Fig 4A); however, 'Susquehanna' had higher yield and larger fruit in 2010 (Table 2). 'Susquehanna' had more fruit per cluster in 2009 and 2010 (Table 2). Yield and fruit per cluster were not affected by rootstock. In 2009, trees on Sunflower and PA-Golden seedling rootstocks had the largest fruit, whereas trees on KSU-Atwood seedlings had the smallest fruit (Table 4). Minimally pruned trees had more fruits than central leader trees in 2008 and 2010 (Fig. 6B). Minimally pruned trees had higher yield and smaller fruit than central leader trees in 2010 (Table 3). For fruit weight in 2009, the cultivar x training method was significant. For central leader training,

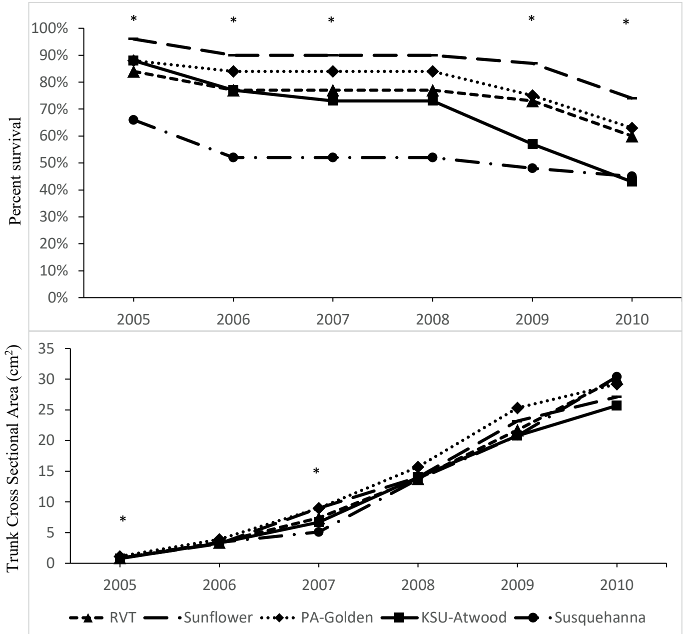

Figure 2. Tree survival (A) and trunk cross sectional area (cm^2) (B) as influenced by five seedling rootstocks grafted with two pawpaw cultivars, 2005-2010. Asterisks indicate the means are different at the $P \leq 0.05$ level, by LSD.

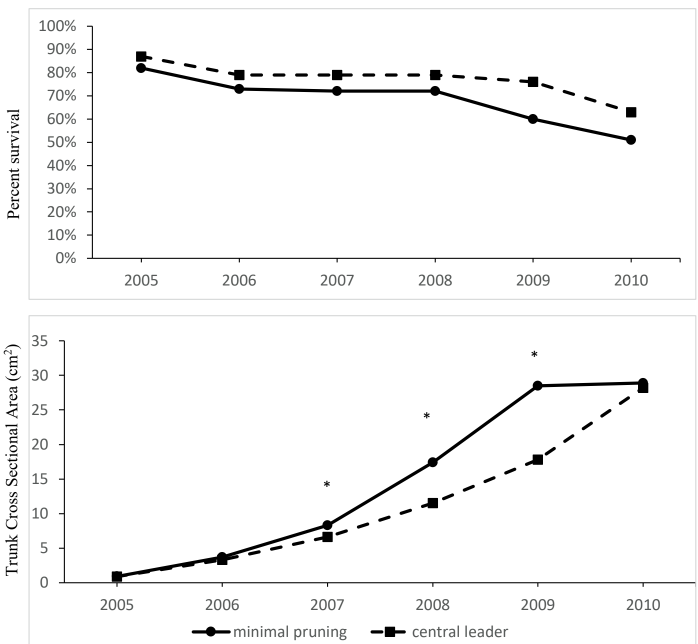

Figure 3. Tree survival (A) and trunk cross sectional area (cm^2) (B) for pawpaws pruned with two training methods (central leader and minimally pruned), 2005-2010. Asterisk indicate the means differ at the $P \leq 0.05$ level.

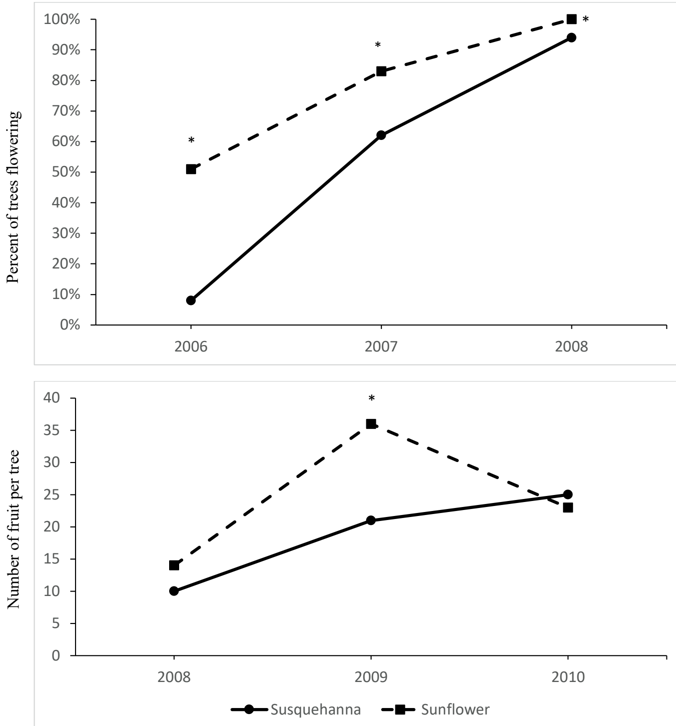

Figure 4. Percent of trees flowering (A) and number of fruit per tree (B) as influenced by two pawpaw cultivars ('Susquehanna' and 'Sunflower') averaged over five seedling rootstocks and training methods, 2005-2010. Asterisks indicate the means differ at the 5% level of signficance.

Table 1. Annual increase in trunk cross sectional area (cm^2) in pawpaws pruned with two training methods (central leader and minimally pruned), 2005-2010.

Training	2005	2006	2007	2008	2009	2010
Minimal pruning	0.53	2.7	8.21	6.33	10.37	7.50
Central leader	0.49	2.31	5.03	3.56	6.52	10.44
Significance	0.4902	0.2026	0.0000	0.0000	0.0009	0.0407

Table 2. Fruiting and yield characteristics for the pawpaw cultivars 'Susquehanna' and 'Sunflower' for 2009 and 2010.

	Fruit weight (g)		Yield (kg)		Fruit per cluster	
	2009	2010	2009	2010	2009	2010
Scion						
Susquehanna	NA	234.8	5.3	5.7	2.7	2.6
Sunflower	NA	166.4	6.9	3.7	2.1	1.9
Significance	(interaction)	0.0000	0.3646	0.0054	0.0000	0.0000

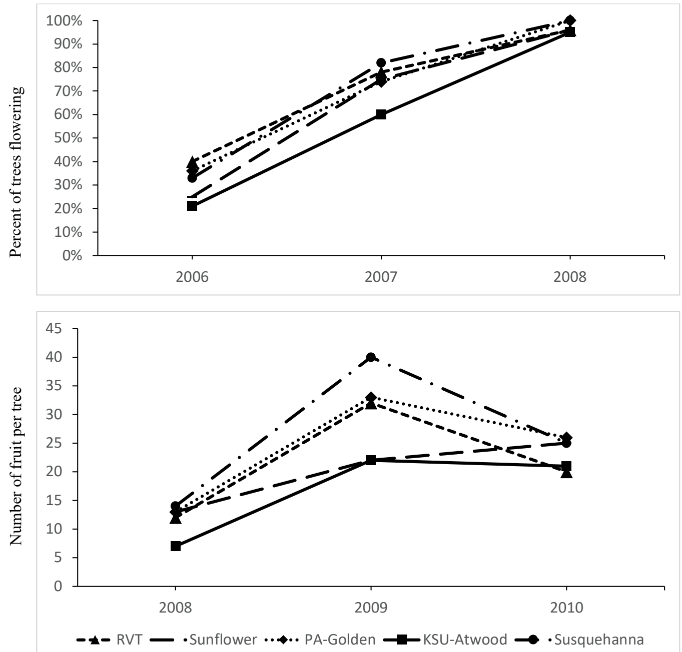

Figure 5. Percent of trees flowering (A) and number of fruit per tree (B) for five seedling rootstocks averaged over two pawpaw cultivars and two tree training methods, 2005-2010.

Table 3. Fruiting and yield characteristics for the pawpaw tree training methods of minimal pruning or central leader for 2009 and 2010.

	Fruit weight (g)		**Yield (kg)**		**Fruit per cluster**	
	2009	2010	2009	2010	2009	2010
Training						
Minimal pruning	NA	182.4	7.3	5.1	2.4	2.1
Central leader	NA	203.1	5.3	4.0	2.3	2.3
Significance	(interaction)	0.0476	0.1718	0.0197	0.6070	0.5395

Table 4. Fruiting and yield characteristics for six pawpaw seedling rootstocks for 2009 and 2010.

	Fruit weight (g)		**Yield (kg)**		**Fruit per cluster**	
Rootstock	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
RVT	218 ab[z]	187	6.3	3.4	2.3	2.3
Sunflower	226 a	196	5.1	5.0	2.4	2.2
PA-Golden	235 a	204	7.2	5.5	2.2	2.2
KSU-Atwood	176 b	179	4.0	3.7	2.2	2.0
Susquehanna	220 ab	193	8.2	4.7	2.4	2.2
Significance	0.0446	0.4399	0.2138	0.0935	0.4262	0.6433

[z]Means followed by common letters within columns do not differ at the 5% level of significance, by LSD.

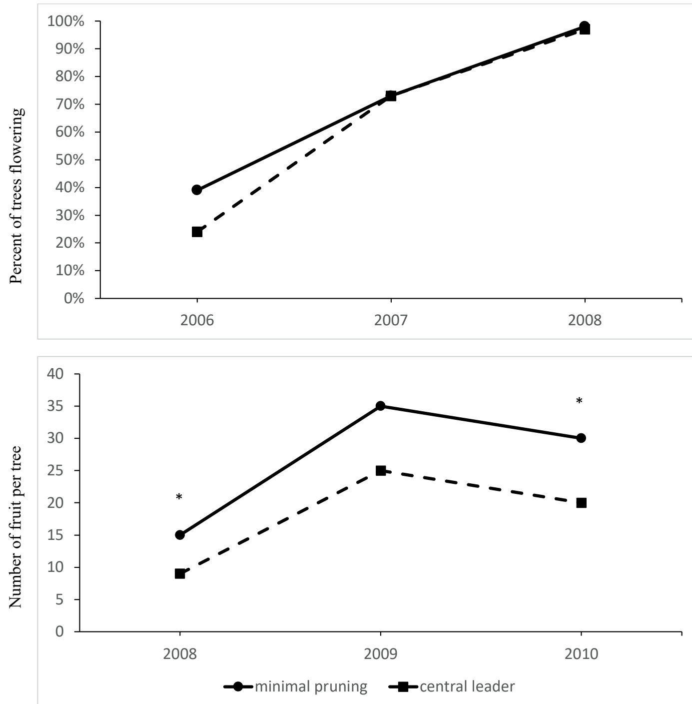

Figure 6. Percent of trees flowering (A) and number of fruit per tree (B) for pawpaw trees pruned with two training methods (central leader and minimally pruned), average over five seedling rootstocks and two cultivars, 2005-2010. Asterisk indicates that means differ at the 5% level of signficance.

'Susquehanna' trees had the largest fruit, but for minimal pruning, 'Sunflower' trees had the largest fruit (Table 5).

Discussion

Tree survival is often poor in commercial pawpaw orchards, and in the KSU orchards, for grafted and seedling trees, so these results are similar to previous observations. For some species such as chestnut, cultivars are grafted onto their own seedling rootstocks to potentially avoid genetic incompatibility (Merwin et al., 2005). This is the first study to examine the impact of pawpaw seedling rootstocks on scions. Budding onto seedlings of the same cultivar did not affect survival or growth of pawpaw scions. By the end of the study, survival differed for the two scion cultivars. Seedling rootstock derived from Susquehanna and KSU-Atwood had survival below 60% and are not recommended for use as a rootstock source. The rootstock

Table 5. Average pawpaw fruit weight as influenced by the interaction of cultivar and training method.

	Average fruit weight (g) 2009	
training	Susquehanna	Sunflower
minimal pruning	246	194
central leader	284	186

seed sources examined did not significantly influence trunk cross sectional area, precocity, number of flowers, or yield for 'Susquehanna' or 'Sunflower'. Fruit weight was greater for 'Susquehanna' than 'Sunflower' trees. After scion cultivar, the next most important factor studied was training method, with minimally pruned trees having greater yields than central leader trained trees. In previous studies, yield was similarly negatively related to pruning severity in apple (Marini et al., 1993; Schupp et al., 2017). However, fruit weight was greater in central leader trained trees than in minimally pruned trees. Apple cultivars responded similarly to different rootstocks, showing high variability in yield, survival, and TCA (Autio et al., 2001). When several peach seedling rootstocks were compared with own-rooted cuttings, they had similar tree mortality, TCA and yield (Perry et al., 2000). Various peach rootstocks were also found to influence vigor but not yield efficiency (Durner 1990). Pawpaw trees often have wind damage to branches with medium fruit loads. Central leader trained trees were initially dwarfed, but displayed a stronger tree architecture with strong scaffold limbs and less breakage. Central leader trees were also easier to care for, with higher branch levels for orchard mowing and cultivation or herbicide application for weed control.

In conclusion, trees on Susquehanna and KSU-Atwood seedling rootstock had poor survival percentages and therefore are not recommended for use as a rootstock source. Trees with a 'Susquehanna' scion had greater fruit weight than those with a 'Sunflower' scion. Training method had a great impact, with minimally-pruned trees having greater yields per tree than central leader trained trees. However, central leader-trained trees had greater fruit weight than in minimally-pruned trees, which is desirable. Central leader trained trees were initially dwarfed, but displayed a stronger tree architecture with less breakage and facilitated orchard care of trees and weed control which is desirable to growers.

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