Journal of the American Pomological Society 64(4): 234-240 2010

Within-Cluster Hand-Thinning Increases Fruit Weight in North American Pawpaw [*Asimina triloba* (L.) Dunal]

S. B. Crabtree[1], K. W. Pomper[2] and J. D. Lowe[1]

Abstract

Pawpaw [*Asimina triloba* (L.) Dunal] is a tree fruit native to the Eastern United States with increasing popularity as a high-value niche crop. Two undesirable characteristics of pawpaw are great variation in fruit size and short shelf-life, caused in part by a small tear in the skin created when fruit are harvested from the cluster, allowing pathogens to enter the fruit. Within-cluster thinning of pawpaw to one fruit could increase fruit size and improve shelf-life by allowing the peduncle to be cut at harvest, maintaining an intact epidermis. The objectives of this study were to determine if hand thinning of multi-fruit clusters to one fruit could be accomplished without causing abortion of the remaining fruit and to determine if within-cluster thinning would increase average fruit size. In a preliminary experiment with seedling trees in 2004, hand thinning of clusters to a single fruit did not lead to cluster abortion or greater drop rates than unthinned clusters. Mature trees of four pawpaw cultivars were utilized in a fruit thinning study in 2006 and 2008. Trees were hand thinned in early-June, and fruit were harvested from mid-August through late-September. Fruit from hand-thinned trees weighed significantly more than those from control trees (47% and 23% greater weight in 2006 and 2008, respectively). Crop density, yield efficiency, and fruit number per tree tended to be or were significantly higher for unthinned trees. Number of clusters per tree, trunk cross-sectional area, yield, and the percent cluster drop and fruit drop, were not significantly different for thinned and unthinned trees. In pawpaw, as in other tree fruits, fruit thinning increases fruit size by reducing competition among and within clusters.

The pawpaw [*Asimina triloba* (L.) Dunal] is a tree fruit native to the eastern United States with increasing interest as a high-value niche crop among small, limited resource and organic farmers (19, 20). Pawpaw can be grown successfully in USDA plant hardiness zones 5 (minimum of -29°C) through 8 (minimum of -7°C) (12). This tree produces the largest edible fruit native to the United States and may reach up to 1 kg in size (5). The pawpaw fruit has both fresh market and processing potential, with an intense flavor that resembles a combination of banana, mango, and pineapple (7). Local delicacies made from the fruit include pawpaw ice cream, compote, jam, and wine.

Pawpaw flowers are strongly protogynous and are believed to be self-incompatible (25), although some cultivars, such as 'Sunflower', may be self-fruitful. Pollination is by flies (Diptera) and beetles (Nitidulidae), and possibly other nocturnal insects (9, 12). The pawpaw fruit is a berry and clusters of 1 to 13 fruit can develop from an individual flower (6). The fruit are oblong-cylindrical, typically 3 to 15 cm long, 3 to 10 cm wide and weigh from 100 to 1000 g. In the fruit, there are two rows of seeds (12 to 20 seeds) that are brown, bean shaped, and up to 3 cm long.

Fruit are hand harvested when they have already begun ripening and have lost some firmness. A common practice to determine maturity is to touch each fruit to determine if it is ready to harvest; ripe softening pawpaw fruit yield to slight pressure, as ripe peaches do, and can be picked easily with a gentle tug. This is labor intensive and may result in slight bruising injury, perhaps leading to off-flavors (17). Fruit can be harvested over several weeks, reflecting an extended bloom period of several weeks that occurs in

[1] Co-Investigator of Horticulture, Atwood Research Facility, Kentucky State University, Frankfort, KY 40601-2355
[2] Principal Investigator of Horticulture and Curator, USDA National Clonal Germplasm Repository for *Asimina* species, Atwood Research Facility, Kentucky State University, Frankfort, KY 40601-2355. To whom reprint requests should be addressed.

pawpaw (18). Pawpaw fruit soften rapidly at room temperature after harvest. McGrath and Karahadian (14) and Layne (13) indicated a 2-to-3-day shelf life, although fruit that are just beginning to soften have a 5-to-7-day shelf life (1) at room temperature. However, pawpaw fruit that have just begun to ripen can be stored for 1 month at 4°C with little change in fruit firmness; fruit then ripen upon removal to ambient temperature (2).

Two undesirable characteristics of pawpaw fruit are great variation in fruit size (10–900 g, with most fruit from 100–200 g, unpublished data) and short shelf-life. The rapid perishability of ripe pawpaw fruit can be hastened in part by a small tear in the skin created at harvest when fruit are torn away from the cluster, which can allow entry of pathogens (unpublished data). It is desirable for growers to produce large, consistently sized fruit to obtain a premium price and decrease time spent sorting fruit. Within-cluster thinning of pawpaw to one fruit could increase fruit size and improve shelf-life by allowing the peduncle of the fruit to be cut at harvest, maintaining an intact epidermis and eliminating a possible entry point for pathogens.

The elimination of part of the potential production by thinning flowers or fruit of peach (4, 10, 11, 15) apple (8, 21), and pear (23) fruit crops is a common technique to increase fruit size, improve quality, and reduce limb breakage. Fruit thinning is often used in tree fruit crops with a heavy fruit set, in very young trees, older trees, trees low in vigor, and injured trees. The timing of thinning is important; thinning during or soon after bloom increases final fruit size (3, 4, 22), compared to late thinning on trees (16).

There are several methods of fruit thinning, including hand, mechanical, or chemical (4, 10, 23). Hand thinning is simply removing individual fruit by hand. Hand thinning fruit is very time- and labor-intensive, but allows selective removal of smaller fruit and more control over fruit spacing. Mechanical thinning can involve the use of high pressure water jets, brushes, sticks, and shakers. This is less labor intensive but can require special equipment, depending on the method used, and does not allow much control over which fruit are removed. Chemical thinning involves the application of certain chemicals that cause fruit drop. Chemicals that can be used to thin tree fruits include naphthaleneacetic acid (NAA), dinitro-o-cresylate (DNOC), ethephon, and carbaryl (24). Fruit thinning has not been previously examined in pawpaw. The objectives of this study were to determine if hand thinning of multi-fruit clusters to one fruit could be accomplished without causing abortion of the remaining fruit in the thinned cluster, and to determine if average fruit size would be increased in several commercially available cultivars by within cluster thinning.

Materials and Methods

Preliminary experiment. Four seedling pawpaw trees, A3-7, A4-5, A5-2, and A5-12, which had been established for 13 years at the Kentucky State University Research Farm in Frankfort, Kentucky were used in the study. Trees were planted at a distance of 2.4 m between trees and 5.5 m between rows in a Lowell silt loam soil (pH 6.9) and were fertilized each year in late winter with ammonium nitrate (34-0-0) at the rate of 2 oz of N per tree. To determine if hand thinning of multi-fruit clusters to one fruit could be accomplished without causing abortion of the remaining fruit, 15 clusters each for control and hand thinning treatments were chosen that were similar in fruit size and appearance on each tree. Each individual tree served as an experimental unit, and treatments were applied in a completely randomized design. All clusters were on individual branches. The number of fruit in each cluster was counted prior to treatment on May 12, 2004. The number of control and thinned clusters retained and the number of fruit in each cluster were recorded on May 20, June 11, and July 27, 2004. The average number of fruit per cluster and number of fruit retained in each treatment were subjected to GLM analysis of variance and Least Significant Difference (LSD) means separation,

using the statistical program Costat (CoHort Software, Monterey, Calif.). Treatment means were separated based on a significance level of $P < 0.05$. Data were normally distributed and no transformation was required.

Cultivar thinning experiment. Eight trees each of the pawpaw cultivars PA-Golden, NC-1, Mitchell, and Overleese were planted with 2.4 m between trees and 5.5 m between rows in a randomized design in April, 2000 at the Kentucky State University Research and Demonstration Farm in Frankfort, KY. Trees were planted in a Lowell silt loam soil (pH 6.9) and were fertilized each year in late winter with ammonium nitrate (34-0-0) at the rate of 2 oz of N per tree. In 2006 and 2008, the cultivars began flowering in mid-April and continued flowering until mid-May. Data were not collected in 2007 due to a spring freeze event that destroyed all pawpaw flowers on the selections. Trunk diameter was measured at 30 cm above the soil surface in March of each year. In 2006, at least three replicate trees per treatment/cultivar combination were utilized and in 2008 at least two replicate trees per treatment/cultivar combination were examined using a completely randomized design. Trees were thinned on June 8, 2006 and June 6, 2008, prior to June drop, and when a majority of the fruit on the trees were approximately 1.5 cm in length. Treatments were no thinning (control) or hand-thinning all clusters on the tree to one fruit per cluster. Fruit counts were conducted prior to thinning. Fruit in a cluster were gently pinched or broken off, leaving one fruit per cluster. Cluster counts were performed on all trees in the thinning study in early August. Fruit were harvested three times a week, on Monday, Wednesday, and Friday, from mid August through late September, and harvest data were recorded. Twenty-five fruit per tree were collected and weighed to obtain average fruit weights for each treatment and variety. Data for trunk cross-sectional area, number of fruit per tree, fruit weight, cumulative yield, cumulative yield efficiency, and crop density were subjected to GLM analysis of variance and Least Significant Difference (LSD) means separation, using the statistical program Costat (CoHort Software, Monterey, Calif.). Treatment means were separated based on a significance level of $P < 0.05$.

Results and Discussion

In 2004, a preliminary experiment was conducted to determine if hand thinning the multi-fruit clusters to one fruit could be accomplished without causing abortion of the remaining fruit. The length and number of fruit per cluster were similar in the four pawpaw seedling trees before thinning began on May 12, 2004 (Table 1). Pawpaw clusters and fruit within a cluster exhibited a June drop period (Tables 1 and 2). There was a decline in the number of fruit per cluster in control clusters during the experiment. Although there was genotypic variation in the number of clusters dropped during the experiment, about half of

Table 1. Length and number of fruit per cluster in four pawpaw seedling trees before and after thinning on May 12, 2004.[z]

	Fruit length on May 12, 2004 (cm)		Number of fruit per cluster					
			12-May		11-Jun		27-Jul	
Selection	Control	To be thinned	Control	To be thinned	Control	Thinned	Control	Thinned
A5-2	0.8 c	1.2 c	5.8 a	5.7	2.5 b	1	1.7 bc	1
A4-5	1.5 b	1.5 bc	5.8a	5.4	4.6 a	1	4.8 a	1
A5-12	1.9 a	1.9 a	4.2 b	5.1	2.6 b	1	2.9 b	1
A3-7	1.8 a	1.8 ab	6.2 a	6.1	2.1 b	1	1.6 c	1
P-value	0.0001***	0.0032**	0.0005***	0.2347	0.0001***	--	0.0001***	--

[z] Fifteen similar clusters were selected for control or hand thinning on each seedling selection.

Table 2. The percentage of clusters remaining in four pawpaw seedling trees after hand thinning on May 12, 2004.

Date	Treatment[z]	Selection 3-7	4-5	5-12	5-2
20-May	Control	93	100	93	33
	Thinned	87	73	80	33
	P-value	0.5182	0.1161	0.3739	0.9989
11-Jun	Control	80	87	87	20
	Thinned	80	73	73	27
	P-value	0.9784	0.4216	0.4216	0.8149
27-Jul	Control	60	87	73	20
	Thinned	53	73	60	27
	P-value	0.8512	0.4216	0.6702	0.8149

[z] Three replicate blocks of five clusters each were selected for control or hand thinning on each seedling selection.

both control and thinned clusters remained on the seedling selections at the end of the experiment.

In 2006, cultivar and thinning main effects were significant, but there was no significant interaction between the main effects. Fruit weight and number of fruit per tree were similar in the pawpaw cultivars examined, although there was a trend for smaller fruit in 'Mitchell' (Table 3). The cultivar 'PA-Golden' had a significantly larger number of clusters per tree than 'Overleese' or 'PA-Golden.' Trunk cross-sectional area, yield, cumulative yield efficiency, and crop density were similar for all cultivars (Table 3). All cultivars displayed a June drop, losing between 11% and 39% of the clusters between the early June and August counting periods (data not reported). The percent cluster drop and fruit drop were similar in all cultivars. Fruit weight was 47% higher in thinned trees (Table 4). There was a strong trend for the number of fruit per tree to be lower (50%) for thinned trees. Crop density was also higher for unthinned trees. The number of clusters per tree, trunk cross-sectional area, yield, yield efficiency, percent cluster drop, and percent fruit drop, were similar for thinned and unthinned trees.

In 2008, cultivar and thinning main effects were significant (Table 5). Fruit weight depended on cultivar; however, the number of fruit per tree, number of clusters, trunk cross-sectional area, yield, yield efficiency, and crop density were similar for all cultivars. Fruit weight was 23% higher and there was a strong trend for the number of fruit per tree to be lower for thinned trees. Yield efficiency and crop density were lower for thinned trees. The number of clusters per tree, trunk cross-sectional area, and yield were similar for thinned and unthinned trees (Table 6).

Hand thinning of peach, pear, and apple fruit is common technique to increase fruit size, improve quality, and reduce limb breakage (4, 8, 11, 15, 21, 23). Damage to the developing cluster in pawpaw as a result of hand-thinning did not cause fruit abortion. However, there was a natural fruit drop in both thinned and unthinned trees during the late spring and early summer. Hand-thinning pawpaw fruit to one fruit per cluster significantly increased fruit size in both 2006 and 2008. Therefore, within cluster thinning increased pawpaw final fruit size, and yields were similar to unthinned trees. The timing of thinning is important for increasing final fruit size in other tree fruits (3, 4, 22). Earlier thinning than attempted in this study in pawpaw could result in greater gains in final fruit size. The total number of fruit that can be supported based on TCA and pawpaw

Table 3. Vegetative, fruit, and yield characteristics for four thinned and unthinned pawpaw cultivars in production in 2006 at the Kentucky State University Research and Demonstration Farm.

Cultivar	Fruit weight (g)[z]	No. of fruit/tree	No. of clusters/tree	Trunk-cross sect. area (TCA, cm^2)	Yield (kg)	Yield efficiency (kg/cm^2)	Crop density (# $fruit/cm^2$)	Cluster drop (%)	Fruit drop (%)
Mitchell	73	144	89 ab	47.1	9.6	0.27	4.0	13.9	21.1
NC-1	128	79	49 b	39.7	9.8	0.25	2.1	18.2	19.7
Overleese	117	68	40 b	33.0	7.9	0.24	2.2	39.3	45.7
PA-Golden	108	130	100 a	41.9	13.3	0.34	3.1	11.0	18.1
P-value	0.0604	0.1299	0.0341 *	0.6117	0.3216	0.5055	0.1078	0.5919	0.5624

[z]Average fruit weights were determined by weighing 25 randomly selected fruit per tree.

Table 4. Vegetative, fruit, and yield characteristics for hand thinned and unthinned pawpaw cultivars in production in 2006 at the Kentucky State University Research and Demonstration Farm.

Treatment	Fruit weight (g)[z]	No. of fruit/tree	No. of clusters/tree	Trunk-cross sect. area (TCA, cm^2)	Yield (kg)	Yield efficiency (kg/cm^2)	Crop density (# $fruit/cm^2$)	Cluster drop (%)	Fruit drop (%)
Unthinned	88	129	62	36.5	11	0.32	3.7	23.5	34.4
Thinned	129	86	86	45.2	10.3	0.25	2	14.0	14.0
P-value	0.0048*	0.0518	0.3235	0.1834	0.5288	0.1287	0.0014**	0.0511	0.0974

[z]Average fruit weights were determined by weighing 25 randomly selected fruit per tree.

cultivar has not been determined; therefore reducing the total number of clusters per tree could also result in increased final fruit size.

Larger fruit are more appealing to the consumer and could command a premium price in the marketplace for fresh-market fruit. Hand-thinning of pawpaw fruit is labor intensive, but could ultimately increase profits for growers. Before recommending hand-thinning to growers as a method of increasing fruit size, marketing studies on willingness to pay for different sizes of pawpaw fruit would be beneficial to determine if the labor costs of hand thinning pawpaw fruit would be offset by increased profits.

Pawpaw, like many other tree fruits, benefits from fruit thinning to reduce competition among clusters or fruit within clusters in order to increase final fruit size. Fruit size increased by up to 50% by hand thinning pawpaw clusters to one fruit without reducing total yield. This may also eliminate wounding at harvest, extending the shelf life of the fruit; and could also increase profits for growers selling larger fruit.

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Table 5. Vegetative, fruit, and yield characteristics for four pawpaw cultivars in production in 2008 at the Kentucky State University Research and Demonstration Farm.

Cultivar	Fruit weight (g)[z]	No. of fruit/tree	No. of clusters	Truck cross-sect. area (TCA, cm^2)	Yield (kg)	Yield efficiency (kg/cm^2)	Crop density (# fruit/cm^2)
Mitchell	81 c	76	49	59.7	5.1	0.09	1.4
NC-1	155 ab	51	24	53.6	7.9	0.15	0.9
Overleese	191 a	51	28	44.4	8.8	0.22	1.3
PA-Golden	128 b	86	58	47.9	10.4	0.22	1.9
P-value	0.0071 **	0.5157	0.2262	0.4450	0.4403	0.2425	0.4082

[z]Average fruit weights were determined by weighing 25 randomly selected fruit per tree.

Table 6. Vegetative, fruit, and yield characteristics for hand thinned and unthinned cultivars in production in 2008 at the Kentucky State University Research and Demonstration Farm.

Treatment	Fruit weight (g)[z]	No. of fruit/tree	No. of clusters	Truck cross-sect. area (TCA, cm^2)	Yield (kg)	Yield efficiency (kg/cm^2)	Crop density (# fruit/cm^2)
Unthinned	118 b	99	45	51.8	11.5	0.24 a	2.1 a
Thinned	145 a	44	44	50.9	5.7	0.11 b	0.8 b
P-value	0.0494 *	0.0583	0.7322	0.9946	0.0839	0.0432 *	0.0422 *

[z]Average fruit weights were determined by weighing 25 randomly selected fruit per tree.

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CALL FOR WILDER SILVER MEDAL NOMINATIONS

The Wilder Committee of the American Pomological Society (APS) invites nominations for the 2011 Wilder Silver Medal Award. All active members of APS are eligible to submit nominations. The award was established in 1873 in honor of Marshall P. Wilder, the founder and first president of APS. The award consists of a beautifully engraved medal which is presented to the recipient at the annual meeting of APS, held during the American Society for Horticultural Science annual meeting.

The Wilder Medal is presented to individuals or organizations that have rendered outstanding service to horticulture in the area of pomology. Special consideration is given to work relating to the origination and introduction of meritorious fruit cultivars. Individuals associated with either commercial concerns or professional organizations will be considered if their introductions are truly superior and have been widely planted. Significant contributions to the science and practice of pomology other than through fruit breeding will also be considered. Such contributions may relate to any important area of fruit production such as rootstock development and evaluation, anatomical and morphological studies, or noteworthy publications in any of the above subjects. Information about the award, past recipients, etc. can be found on the APS web site at http://americanpomological.org/wilder1.html.

To obtain nomination guidelines, please contact committee chairperson:
Dr. Douglas Archbold, Department of Horticulture, University of Kentucky
Phone: 859-257-3352; fax: 859-257-2589; e-mail: darchbol@uky.edu

Nominations must be submitted by May 2, 2011.