Journal of Applied Botany and Food Quality 94, 124 - 131 (2021), DOI:10.5073/JABFQ.2021.094.015

[1]Division of Food and Nutrition Sciences, Ohio University, USA
[2]Fox Paw Farm, LLC., Adams County, Ohio, USA

A comparative analysis of pawpaw (*Asimina triloba*) quality and nutritional data

Robert G. Brannan[1]*, Emily E. Anderson[1], Ronald L. Powell[2], Maria N. Coyle[1]

(Submitted: February 14, 2021; Accepted: June 1, 2021)

Summary

The North American pawpaw (*Asimina triloba* [L.] Dunal) from sixteen varieties was analyzed for size, pH, °Brix, firmness, and pulp and skin color. A varietal composite was used to determine nutrient composition. Data from the current study was compared to previous literature values, and all results fit well with previous literature. The average weight of the fruits across all varieties was 194 g and ranged from 122 to 292 g, the pH of the fruits ranged from 5.4 to 6.3, the average °Brix ranged from 18.2% to 26.1%, and firmness ranged from 0.391 kg to 0.727 kg. The color of the skin and the pulp differed by variety but was well-within previously reported values. Pawpaw pulp nutritional values verified the nutritional values previously reported for pawpaw pulp from fruit harvested in Korea and will be used as the basis for inclusion of pawpaw in the USDA National Nutrient Database for Standard Reference. Several specific recommendations are made: 1) firmness of 0.2 to 0.7 kg of force can be used to describe ripe pawpaw fruit; 2) the serving size for raw pawpaw pulp is one-half cup (120 g); and 3) pawpaw pulp nutrition compares favorably to that of banana or mango.

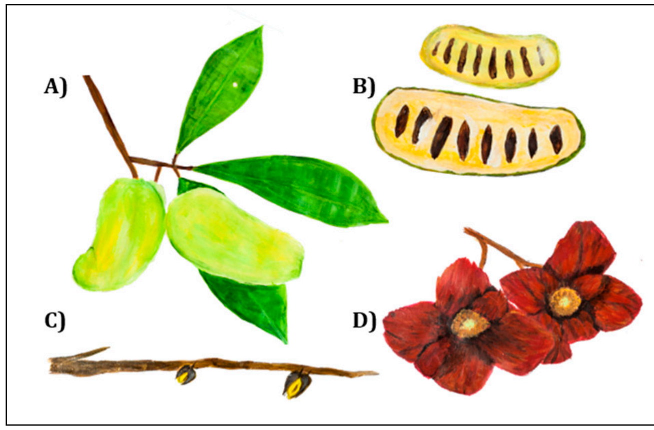

Fig. 1: Artists rendition of the parts of the pawpaw (*Asimina triloba*) plant. A) Mature fruit on the tree; B) mature fruit cut lengthwise to expose the seeds; C) branch with bud; D) blossom. (Artwork © by author M.N. Coyle)

Introduction

The North American pawpaw (*Asimina triloba* [L.] Dunal), hereafter pawpaw, is the largest edible fruit native to the United States (LAYNE, 1996). The pawpaw is in the Annonaceae family, of which 14 of the 2300 species are native to the United States (CRONQUIST, 1981), including nine species of *Asimina* (CALLAWAY, 1993). The pawpaw grows on fruit-bearing trees about 5 to 10 meters tall and often found in clusters (POMPER et al., 2003; POMPER and LAYNE, 2005). The leaves are distinctive compared to leaves of other *Asmina* species because they are long, egg-shaped, and membranous in texture (KRAL, 1960; LAYNE, 1996). The buds are dark maroon in color (POMPER and LAYNE, 2005) and the flowers are unable to self-pollinate, requiring hand pollination using a genetically different tree (BOIS, 2001; LAYNE, 1996; WILLSON and SCHEMSKE, 1980) or pollinators such as flies, beetles, and other nocturnal insects, which are unreliable for proper pollination (LAYNE, 1996; POMPER et al., 2008; WILLSON and SCHEMSKE, 1980). These pawpaw structures are shown in Fig. 1. More detailed information about the botanical characteristics of the pawpaw can be found in the literature (POMPER and LAYNE, 2005).

The fruit may grow alone or in clusters and are botanically categorized as a pulpy berry, probably an aggregate berry (JONES and LAYNE, 1997; POMPER and LAYNE, 2005). The fruit's edible flesh can range in color from creamy white to bright yellow to orange, has a custard-like texture, and has 12-20 bean-shaped seeds embedded in the pulp in two rows (LAYNE, 1996; PETERSON, 2003; POMPER and LAYNE, 2005).

The pawpaw is a climacteric fruit and ethylene and respiratory peaks are seen within three days after the fruit is harvested (ARCHBOLD and POMPER, 2003), causing the fruit to become undesirably soft and brown within 5 days of harvest at ambient temperature (GALLI et al., 2008). Refrigeration at 4 °C can delay the softening of the fruit for several weeks, but does not prevent skin browning (GALLI et al., 2008; POMPER and LAYNE, 2005).

Food quality research on the pawpaw fruit pulp appearance in the literature has been gradual, with our lab and others reporting on a variety of quality characteristics. Pulp browning and the activity of polyphenol oxidase, the enzyme responsible for pulp browning has been characterized, (BRANNAN, 2016; ZHANG et al., 2017), as has the identification of cell wall components and phytochemicals (BRANNAN et al., 2019, 2015). The utilization of pulp and seed components, especially phytochemicals and antioxidants, as potentially value-added food ingredients has been reported (BRANNAN et al., 2018; BRANNAN and SALABAK, 2009; HARRIS and BRANNAN, 2009; KOBAYASHI et al., 2008; NAM et al., 2019, 2017). Sensory quality of the pulp (BRANNAN et al., 2012; MCGRATH and KARAHADIAN, 1994) and the application of processing techniques to extend shelf life (BRANNAN et al., 2019; BRANNAN and WANG, 2017; ZHANG et al., 2017) also has been reported. The totality of research about the nutrient composition of pawpaw pulp includes two studies, one that reported nutritional information for whole pawpaws including the pawpaw skin, which is rarely consumed and often considered inedible (PETERSON et al., 1982), and a more recent study about pawpaw fruit grown in Korea (NAM et al., 2018). Many of these food quality studies sought to differentiate quality parameters by pawpaw variety (BRANNAN, 2016; BRANNAN et al., 2015; GREENAWALT et al., 2019) or pulp ripeness (HARRIS and BRANNAN, 2009; KOBAYASHI et al., 2008; NAM et al., 2019).

The objective of the present study was to investigate the quality, nutritional, and compositional characteristics of pawpaw pulp from different varieties and compare and contextualize the results to similar characteristics reported previously.

* Corresponding author

Materials and methods

Pawpaw collection and processing

Pawpaw fruit were collected from Fox Paw Farm, L.L.C. in Adams County, Ohio (38°39'N, 83°41'W, 273 m above sea level) in September 2019. Located in USDA Hardiness Zone 6, the climate for Adams County, Ohio shows average rainfall of 1133 mm, snowfall of 445 mm, 126 days of precipitation, average January temperature of -6.6 °C, and average July temperature of 29.6 °C. The farm is a rural 3.5-acre plot that contains pawpaw trees planted from 2003-2006 in three blocks. At the time of data collection, the north block contained trees in east-to-west rows with 2.5 m between trees. The east block contained rows running north-south with trees 2.5 m apart. The west block contained nine rows running north-south with 3 m between trees. In all three blocks, rows were planted 4.5 m apart. Sixteen varieties with at least four fruits from each variety were harvested for this study. The varieties were selected at the time of harvest to be sure all fruits were of similar ripeness and were harvested by hand to ensure there was no damage or bruising to the fruits being used in the analysis. The sixteen varieties were 'Estill', 'Green River Belle', 'IXL', 'KSU Atwood™', 'Lynn's Favorite', 'Mango', 'Mitchell', 'NC-1', 'Overleese', 'Pickle', 'Potomac™', 'Quakers Delight', 'SAA-Zimmerman', 'SAB Overleese', 'Shenandoah™', and 'Wabash™'. The harvested fruits were then transferred to the Food Innovation Laboratory at Ohio University on ice.

Fruit weight, size, skin and pulp color, firmness of the fruit, and pH of the pulp were recorded for each individual fruit before processing. The skin color (L*, a*, b*) was measured in three places on each fruit using a using a Konica BC-10 colorimeter (Konica Minolta Sensing Americas Inc., Ramsey, NJ), after which the hue angle was calculated according to previous work (Brannan et al., 2015). A ~25 mm circle of skin was removed in three spots on the exterior of the fruit to assess pulp color and fruit firmness on the exposed pulp. The firmness of the exposed pulp, reported as kg of force, was measured by penetrometry on the fruit situated on a solid platform with a 10-mm diameter cylindrical probe with a crosshead speed of 5 mm/s to a depth of 10 mm using a Ta-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale NY/Stable Micro Systems, Godalming, Surrey, UK).

Varietal composites for nutritional analysis were prepared according to the following scheme. One whole fruit from each of the sixteen varieties was randomly assigned into one of four groups. Pulp from each variety was not pooled before being assigned to a group, rather each individual whole fruit assigned to a group was processed by removing the skin and seeds from the pulp by hand, after which an equal weight of that pulp was used to create a composite from the one fruit of each variety in each group. Thus, the four composites were compositionally identical except that the source of the pulp from each variety was an individual fruit, not a composite of fruits from each variety. After each composite was mixed thoroughly, pulp from the composites was distributed into FoodSaver® bags, which were sealed without any attempt to exclude oxygen from the bags and held at -20 °C. A total of nine of the composite samples, two duplicates from three of the composites and three triplicates from the one remaining composite, were assigned three-digit random codes before being transported on dry ice to the laboratories for analysis.

Nutrient Analysis

Nutrient analysis was performed by Q Laboratories (Cincinnati, Ohio) except for total dietary fiber and vitamin D, which were performed by Medallion Labs (Minneapolis, Minnesota). Analysis for each analyte was performed in triplicate from each of the nine randomly-coded bags of pawpaw pulp (described above), according to standard AOAC International methods (AOAC International, 2016) except for metals (Ca, Fe, K, Na), which were quantified using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) after acid digestion of the pulp. The AOAC methods used for each nutrient are as follows: ash (AOAC 923.03), cholesterol (AOAC 994.10), lipid (AOAC 922.06), moisture (AOAC 934.06), fatty acids (monounsaturated, polyunsaturated, saturated and trans) (AOAC 996.06), total dietary fiber (AOAC 991.43), vitamin D (AOAC 2011.11).

Data Analysis

Means and standard deviations were generated for the response variables. Inferential statistics were generated to compare varieties using Analysis of Variance and means separation was achieved using Duncan's post-hoc analysis using IBM SPSS Statistics software. Significance was determined at $p<0.05$.

Results and discussion

Of the sixteen varieties of pawpaw analyzed and reported in this study, there was existing literature data for nine of the varieties, which was used for comparative analysis of the attributes for which whole fruit or pulp was not pooled, i.e. fruit size and weight, texture, °Brix, pH, and pulp and skin color. The sixteen varieties were pooled into varietal composites for nutritional analysis.

Fruit size by variety and serving size determination

Tab. 1 shows the mean weight, length, and width for each of the varieties of pawpaws used for this study. The average weight of the fruits across all varieties was 194 grams and ranged from 122 grams for variety 'Pickle' to 292 grams for variety 'KSU-Atwood'. Although there were significant differences in average fruit weight by variety ($p<0.001$), with the six heaviest varieties significantly heavier than the ten least heavy varieties (Tab. 1), post-hoc means separations did not elucidate other differences. A recent study that examined average fruit weight from all fruit of 52 varieties collected during 8 harvests from 2005 to 2012 at three sites including Fox Paw Farm, the location of fruit collected for this study, determined that fruit weight is normally distributed across all varieties and the average fruit weight by variety ranged from 72-244 g (Greenawalt et al., 2019). Results of the much smaller sample from this study fit well with those results.

Of the 9 varieties of which comparisons to previous research can be made (Tab. 1), 8 of the varieties from this study, all but 'Lynn's Favorite', weighed more and all nine varieties had larger dimensions than was reported previously and (Brannan et al., 2015) even though they came from the same location. The average weight of the fruit of the 9 varieties from the comparative study was 136 g, compared to 203 g for the same varieties from the current study. Because the intention of the current study was not to collect all fruit but rather to create composites for nutritional analysis, it is likely that larger fruit were selected.

The average fruit weights were used as a basis to determine the serving size of the pawpaw because currently there is none. After some experimentation, the Registered Dietitian on the project team (author E.E. Anderson) determined that one half cup (120 g) was an appropriate serving size. This determination was based on the knowledge that 120 g is similar to the serving size of other popular fruits and can be obtained from the pulp of one large (~240 g) or two small (~120 g) whole pawpaw fruits, assuming a 50% yield of pulp from the skin and seeds.

Fruit pH, °Brix, firmness, and color by variety

As shown in Tab. 2, the pH of the fruits from each variety ranged from 5.4 to 6.3, which categorizes pawpaw as a low acid fruit along

Tab. 1: Mean and standard error (S.E.) for size (weight, length, width) of sixteen varieties of whole pawpaws (*Asimina triloba*), nine of which can be compared directly to a previous study (Brannan et al., 2015). (Different superscript letters within a column indicate significant differences at p<0.05.)

Variety	Study	Weight (g)	S.E.	Length (cm)	S.E.	Width (cm)	S.E.
Varieties for which comparative analysis can be made							
Green River Belle	Current	187 abcde	6.2	16.6 abc	0.2	5.8 a	0.4
	Previous	152		10.5		5.7	
IXL	Current	213 bcdef	63.6	15.6 ab	3.4	8.6 bcde	0.9
	Previous	127		9.5		5.4	
KSU-Atwood	Current	292 f	22.7	18.3 bc	0.5	11.2 g	0.5
	Previous	162		11.1		5.2	
Lynn's Favorite	Current	130 ab	10.6	13.8 a	0.7	8.6 bcde	0.4
	Previous	179		11.5		5.6	
NC1	Current	217 cdef	19.5	16.3 abc	0.9	9.3 cdef	0.8
	Previous	204		10.5		6.4	
Overleese	Current	223 def	38.0	14.2 a	0.8	10.4 fg	0.7
	Previous	130		9.1		5.8	
Quaker's Delight	Current	186 abcde	22.3	16.2 abc	1.0	7.8 abc	0.2
	Previous	84		7.9		4.8	
SAA-Zimmerman	Current	247 def	28.6	19.0 c	0.7	8.3 abcd	0.5
	Previous	130		9.8		5.5	
Shenandoah	Current	133 abc	11.3	13.8 a	0.6	6.8 a	0.3
	Previous	123		8.6		5.6	
Varieties for which comparative analysis cannot be made							
Estill	Current	188 abcde	24.3	15.0 ab	1.1	9.8 ef	0.4
Mango	Current	175 abcd	17.8	14.4 a	1.1	8.0 abcd	0.3
Mitchell	Current	195 abcde	32.4	16.3 abc	1.4	9.0 bcdef	0.4
Pickle	Current	122 a	10.7	14.3 a	0.6	8.5 bcde	0.2
Potomac	Current	267 ef	34.1	15.8 abc	0.9	11.2 g	0.5
SAB Overleese	Current	197 abcde	29.1	14.8 a	0.9	9.3 def	0.4
Wabash	Current	194 abcde	25.0	15.5 ab	1.2	7.5 ab	0.6

Tab. 2: Mean and standard error (S.E.) for °Brix, firmness, and pH of sixteen varieties of whole pawpaws (*Asimina triloba*), nine of which can be compared directly to a previous study (Brannan et al., 2015) for all values except pH which can be compared to a different study (Brannan, 2016). (Different superscript letters within a column indicate significant differences at p<0.05.)

Variety	Study	°Brix	S.E.	Firmness (kg)	S.E.	Firmness (N)	S.E.	pH	S.E.
Varieties for which comparative analysis can be made									
Green River Belle	Current	21.6 defg	0.3	0.610 bc	0.083	5.17	0.74	6.1 fg	0.0
	Previous	25.1		0.419				6.8	
IXL	Current	22.6 fg	0.5	0.410 ab	0.037	4.10	0.43	5.5 ab	0.1
	Previous	22.9		0.643				6.5	
KSU-Atwood	Current	22.3 efg	0.4	0.603 abc	0.096	4.92	0.81	6.1 fg	0.7
	Previous	27.1		0.206				6.3	
Lynn's Favorite	Current	20.6 cde	0.7	0.551 abc	0.056	5.47	0.55	5.4 a	0.1
	Previous	28.0		0.232				6.2	
NC1	Current	21.2 defg	0.5	0.464 ab	0.083	4.55	0.82	5.4 a	0.1
	Previous	25.7		0.248				6.1	
Overleese	Current	20.6 cde	0.3	0.347 a	0.039	3.43	0.38	5.8 cde	0.0
	Previous	25.1		0.198				6.5	
Quaker's Delight	Current	17.1 a	0.3	0.507 abc	0.057	5.04	0.52	5.5 a	0.0
	Previous	20.9		0.499				6.5	
SAA-Zimmerman	Current	19.2 bc	0.5	0.580 abc	0.054	5.81	0.53	6.3 g	0.0
	Previous	19.9		0.551				6.5	
Shenandoah	Current	22.3 efg	0.6	0.727 c	0.172	7.24	1.68	5.8 cde	0.0
	Previous	21.2		0.432				6.7	
Varieties for which comparative analysis cannot be made									
Estill	Current	24.7 h	0.6	0.391 ab	0.048	3.94	0.45	5.8 cde	0.1
Mango	Current	18.2 abc	0.3	0.421 ab	0.075	4.18	0.78	5.6 abc	0.1
Mitchell	Current	20.4 cd	0.4	0.490 abc	0.061	4.86	0.57	5.5 ab	0.1
Pickle	Current	21.7 defg	0.2	0.391 ab	0.049	3.91	0.52	6.0 ef	0.1
Potomac	Current	21.0 def	0.7	0.623 bc	0.048	6.11	0.47	5.7 cd	0.1
SAB Overleese	Current	26.1 h	0.6	0.429 ab	0.046	4.22	0.45	5.8 cde	0.0
Wabash	Current	23.0 g	1.1	0.590 abc	0.101	5.79	0.99	5.7 cde	0.1

with such fruits as avocado, most melons, mango, papaya, and others. These values are in agreement with previously reported values (BRANNAN, 2016). Significant differences (p<0.001) for pH among varieties were found in the current study (Tab. 2) but not in the comparative study. The practical impact of the pH of pawpaw relates to the polyphenol oxidase (PPO), the enzyme responsible for skin and tissue browning. All of the varieties in this and previous studies exhibited pulp pH in the range in which pawpaw PPO has been shown to exhibit its highest activity (FANG et al., 2007), suggesting that none of these varieties would be more resistant than any other to PPO activity.

The °Brix in the whole fruits were measured using a refractometer calibrated for direct reading of percent sugar and should not be confused with the percent sugar from the composites reported later in this paper. The average °Brix of the varieties ranged from 18.2% to 26.1%, again showing good agreement with previously reported values (Tab. 2). Variation in percent sugar of pawpaw fruit likely is due to an increase in sugars during climacteric ripening, although there is no research to support this hypothesis. In this study, varieties 'Estill' and 'SAB Overleese' exhibited significantly higher °Brix values than the other 14 varieties (p<0.001).

The firmness of pawpaw is directly related to the ripeness of the fruit. There is no benchmark firmness value that defines a ripe pawpaw fruit and the current best practice for harvest is to squeeze each fruit by hand, looking for a small amount of give in the skin, an unreliable indicator. The least firm variety at the time of harvest was 'Estill' with a firmness of 0.391 kg, and the firmest variety was 'Shenandoah' with a firmness of 0.727 kg. Although there was a significant difference between these two varieties (p<0.022), post-hoc analysis did not reveal other differences of note (Tab. 2). We have shown that certain cell wall xyloglucans, pectins, and arabinogalactins degrade during refrigerated storage of pawpaw pulp (BRANNAN et al., 2019) and it is likely that compositional degradation of the cell wall causes loss of turgor during ripening and storage. Whole fruit firmness from nine varieties in the current study compares well to the firmness of fruits from similar varieties measured previously (Tab. 2). One conclusion that can be drawn from this comparison is the certainty that firmness values between 0.2 and 0.7 kg of force using the method described herein would describe ripe fruit because all of the fruits from the comparison studies were in this range and were considered ripe as determined by hand.

The CIE color (L*, a*, b*) and hue angle for the skin and pulp of the varieties sampled in this study are shown in Tab. 2 and 3, respectively. There were significant differences (p<0.001) between varieties for all of these values, however, the interpretation of these results tends to be descriptive rather than inferential because certain varieties have skin and pulp that tends to be lighter or more yellow than others. The skin color range for all of the varieties (Tab. 3) exhibited a* values (-6.0 to -14.0), b* values (37.0 to 49.3), and hue angles (99.0 to 109.1) indicating that the skin is yellow-green or green-yellow. This range of skin color by variety has led to the conclusion that skin color is not a reliable indicator of fruit ripeness (MCGRATH and KARAHADIAN, 1994). The pulp color range for all of the varieties (Tab. 4) exhibited a* values (1.0 to 11.6), b* values (32.8 to 51.2), and hue angles (76.2 to 88.3) indicating that the pulp is orange to yellow. These results are in strong agreement with previous research (Tab. 4).

Nutritional analysis of pawpaw

The proximates, vitamins, minerals, and essential and non-essential amino acids for varietal composites of pawpaw pulp from this and comparative studies (NAM et al., 2018; PETERSON et al., 1982) are

Tab. 3: Mean and standard error (S.E.) for CIE L*, a*, b* and hue angle (Hue) of the skin from sixteen varieties of whole pawpaws (*Asimina triloba*), eight of which can be compared directly to a previous study (BRANNAN et al., 2015) and variety Shenandoah to a different study (ZHANG et al., 2017). (Different superscript letters within a column indicate significant differences at p<0.05.)

Variety	Study	L*	S.E.	a*	S.E.	b*	S.E.	Hue	S.E.
Varieties for which comparative analysis can be made									
Green River Belle	Current	62.9 ce	0.8	-7.8 def	0.7	43.5 efgc	1.0	100.2 ab	1.0
	Previous	65.8		-3.1		34.2		95.1	
IXL	Current	65.4 de	0.8	-12.7 ab	0.5	49.3 h	1.0	104.5 cde	0.7
	Previous	63.4		-9.4		39.5		103.3	
KSU-Atwood	Current	59.7 ab	0.6	-12.8 ab	0.3	37.4 ab	1.2	108.9 f	0.4
	Previous	61.4		-8.6		24.6		109.2	
Lynn's Favorite	Current	59.5 ab	0.8	-12.5 ab	0.8	44.5 fg	1.2	105.7 de	1.2
	Previous	63.9		-3.8		35.8		96.1	
NC1	Current	61.8 abc	0.6	-12.6 ab	0.5	39.5 abcd	1.2	107.6 ef	0.7
	Previous	62.9		-4.8		30.2		99.0	
Overleese	Current	59.9 ab	0.7	-14.0 a	0.7	40.1 abcde	0.8	109.2 f	0.8
	Previous	65.1		-8.8		33.0		104.9	
Quaker's Delight	Current	67.4 e	0.8	-13.0 ab	0.5	45.1 fg	1.0	106.1 def	0.7
	Previous	69.3		-6.8		41.3		99.3	
SAA-Zimmerman	Current	67.7 e	0.7	-11.0 bc	0.4	41.9 cdef	1.5	104.7 cde	0.8
	Previous	65.3		-10.2		36.9		105.4	
Shenandoah	Current	60.1 ab	0.6	-11.3 bc	0.8	39.8 abcde	1.1	105.9 de	1.0
	Previous	61.8		-8.0		31.9		104.0	
Varieties for which comparative analysis cannot be made									
Estill	Current	59.3 ab	0.5	-8.0 def	0.5	37.5 ab	1.1	102.3 bc	0.9
Mango	Current	62.1 bc	0.4	-9.1 cde	0.8	38.4 abc	0.9	103.5 bcd	1.2
Mitchell	Current	64.4 cd	0.8	-8.2 def	1.4	43.2 defg	1.2	100.9 ab	13.8
Pickle	Current	64.5 cd	0.5	-6.0 f	0.7	37.0 a	0.9	99.0 a	1.0
Potomac	Current	59.8 ab	0.7	-7.6 ef	0.8	41.5 cdef	1.5	100.5 ab	1.1
SAB Overleese	Current	59.2 a	1.9	-8.1 def	1.1	41.1 bcdef	1.9	101.1 ab	12.2
Wabash	Current	65.2 de	0.7	-10.1 cd	0.9	46.2 gh	1.2	102.4 bc	1.2

Tab. 4: Mean and standard error (S.E.) for CIE L*, a*, b* and hue angle (Hue) of the pulp from sixteen varieties of whole pawpaws (Asimina triloba), eight of which can be compared directly to a previous study (BRANNAN et al., 2015) and variety Shenandoah to a different study (ZHANG et al., 2017). (Different superscript letters within a column indicate significant differences at p<0.05.)

Variety	Study	L*	S.E.	a*	S.E.	b*	S.E.	Hue	S.E.
Varieties for which comparative analysis can be made									
Green River Belle	Current	70.8 ^{bc}	3.5	7.0 ^{de}	0.3	45.6 ^{cd}	1.1	81.2 ^{cd}	0.5
	Previous	73.9		10.0		46.2		77.7	
IXL	Current	82.4 ^{g}	1.3	2.4 ^{ab}	0.3	32.8 ^{a}	1.2	85.9 ^{f}	0.4
	Previous	77.1		6.3		45.1		82.0	
KSU-Atwood	Current	78.3 ^{defg}	1.0	5.0 ^{cd}	0.5	42.6 ^{c}	1.3	83.3 ^{de}	0.5
	Previous	75.0		5.6		44.8		82.8	
Lynn's Favorite	Current	75.8 ^{cdefg}	4.1	4.5 ^{c}	1.1	36.4 ^{ab}	2.6	82.9 ^{de}	1.4
	Previous	72.6		11.1		42.9		75.4	
NC1	Current	78.2 ^{defg}	1.3	4.3 ^{bc}	0.5	37.9 ^{b}	1.6	83.5 ^{e}	0.5
	Previous	77.1		10.1		45.9		77.0	
Overleese	Current	72.5 ^{bcde}	2.1	6.5 ^{cde}	0.7	47.3 ^{cde}	1.3	82.2 ^{de}	0.7
	Previous	79.3		2.1		34.6		86.5	
Quaker's Delight	Current	82.6 ^{g}	1.0	1.0 ^{a}	0.2	32.9 ^{a}	1.2	88.3 ^{g}	0.3
	Previous	77.8		6.5		46.1		81.9	
SAA-Zimmerman	Current	80.3 ^{fg}	0.8	7.0 ^{de}	0.5	49.9 ^{de}	1.0	82.1 ^{de}	0.5
	Previous	79.8		4.4		44.2		84.3	
Shenandoah	Current	74.4 ^{bcdef}	0.8	9.3 ^{fg}	1.0	49.4 ^{de}	1.4	79.3 ^{bc}	0.8
	Previous	64.3		6.3		39.8		81.0	
Varieties for which comparative analysis cannot be made									
Estill	Current	68.4 ^{ab}	2.0	10.6 ^{gh}	0.8	51.2 ^{e}	2.9	74.3 ^{ab}	2.3
Mango	Current	75.9 ^{cdefg}	2.7	6.2 ^{cde}	1.0	44.7 ^{cd}	2.3	82.4 ^{de}	1.0
Mitchell	Current	63.0 ^{a}	2.4	11.3 ^{gh}	0.8	46.0 ^{cde}	1.7	76.3 ^{a}	0.6
Pickle	Current	71.8 ^{bcd}	1.0	11.3 ^{gh}	0.4	48.7 ^{de}	0.7	77.0 ^{a}	0.4
Potomac	Current	73.9 ^{bcdef}	1.8	11.7 ^{h}	1.0	49.6 ^{de}	1.3	76.9 ^{a}	0.8
SAB Overleese	Current	76.2 ^{cdefg}	3.2	7.4 ^{ef}	0.5	48.5 ^{de}	1.5	81.3 ^{cde}	0.6
Wabash	Current	79.4 ^{efg}	1.8	5.7 ^{cde}	1.2	36.8 ^{ab}	2.7	81.9 ^{de}	1.2

shown in Tab. 5. We were able to locate historical pawpaw nutritional information from the 1963 USDA Agriculture Handbook #8 (WATT and MERRILL, 1963), which includes information for the proximates (water, protein, fat, carbohydrate, and ash) and calories. It is unclear whether pawpaw nutritional values were listed in the database before this time. In 1982, a nutritional analysis of pawpaw pulp with skin was reported (PETERSON et al., 1982), however, many consider the skin undesirable and only consume the pulp. Nonetheless, including the nutritional information for the pulp with skin in the comparison has value for those who do consume the skin. Recently, Korean researchers published a detailed nutritional analysis of pawpaw pulp (NAM et al., 2018) but did not note the variety of pawpaw used.

The comparison in Tab. 5 revealed more similarities than differences between the composite from this study and the Korean study. Kilocalories calculated from the proximates were nearly identical (85 v 84) for the two studies. There were similarities in total lipid, ash, dietary fiber, potassium, and iron between the two studies. Nutrient analysis from the current study indicated less moisture and protein but more carbohydrates, especially glucose, vitamin C, and calcium than the Korean study.

Pawpaw nutritional quality compared to common fruits

To place the nutritional quality of the pawpaw in perspective, a weight-to-weight comparison of pawpaw nutrition information from this study to 100 g of seven common fruits (US DEPARTMENT OF AGRICULTURE, 2020) is shown in Tab. 6. On a per weight basis, pawpaw has 33-67% more lipid, 4-68% more carbohydrates, 42-69% more dietary fiber, and 16-70% more sugars than the seven other fruit. On the other hand, pawpaw has 2 to 12-fold less vitamin C than the other fruits, except apple.

Prior to this research, which establishes one-half cup (120 g) as a standard serving size for pawpaw, no standard serving size of pawpaw existed. Serving size is an important measure because the ubiquitous NUTRITION FACTS labels on food products in the U.S. are based on serving size. Tab. 7 shows a nutritional comparison of pawpaw to the same seven fruits based on serving size. One serving of the seven other fruits ranges from 118 g (banana) to 182 g (medium apple). On a per serving basis, the pawpaw nutrient composition most resembles the nutritional content provided by a banana or mango. Pawpaw is very similar in calories and carbohydrates, has similar potassium as mango, but has much less vitamin C than both fruit. Pawpaw does have more fat and fiber than banana and mango. It is an interesting coincidence that the pawpaw's closest nutritional comparisons on a per serving basis are the banana and mango because research has shown that banana and mango are the predominant flavors of pawpaw pulp (BRANNAN et al., 2012; MCGRATH and KARAHADIAN, 1994).

Benefits of up-to-date pawpaw nutritional information

It is our intention to use the information from this and the Korean study to petition the USDA for inclusion of pawpaw in the USDA's National Nutrient Database for Standard Reference. The database will be a boon for disseminating pawpaw's nutrition information to growers, the food industry, and consumers interested in learning more about the pawpaw. Up-to-date nutritional data that reflects only the edible portion of the fruit can also be used to generate NUTRITION FACTS panels for food labels. Although raw fruits and certain low volume small businesses are exempt from having the NUTRITION FACTS labels, other small businesses and/or foods for sale that make nutrient claims (e.g. "Gluten free", "Low fat", etc.) are required to have NUTRITION FACTS labeling, even if they are exempt from the

Tab. 5: Pawpaw (*Asimina triloba*) nutritional information for 100 g of pulp, one serving of pulp (1/2 cup, 120 g), and 100 g of pulp with skin. ("n.d." indicates that the nutrient was not included in the analysis. The "<" symbol indicates the nutrient was analyzed but could not be detected at or above the threshold level.)

		Pulp (without skin)				Pulp and Skin
		Current Study		NAM et al., 2018		PETERSON et al., 1982
Nutrient	Unit	100 g	1 serving	100 g	1 serving	100 g
Proximates						
Calories	KCal	85	102	84[1]	101	80
Calories	KJ	357	428	353	423	335
Moisture	g	74.5	89.4	79.1	94.9	73.2
Protein	g	0.7	0.9	1.5	1.8	1.2
Total Lipid	g	0.6	0.7	0.4	1.7	1.2
MUFA	g	0.05	0.06	0.06	0.07	n.d.
PUFA	g	<	<	0.06	0.07	n.d.
Saturated FA	g	<	<	0.05	0.06	n.d.
Trans FA	g	<	<	n.d.	n.d.	n.d.
Cholesterol	mg	<	<	n.d.	n.d.	n.d.
Ash	g	0.4	0.5	0.4	0.5	0.6
Carbohydrates (by difference)	g	23.8	28.6	18.6	22.3	18.8
Dietary Fiber	g	4.5	5.4	5.8	7.0	2.6
Total Sugars (calculated)	g	16.3	19.5	13.1	15.7	n.d.
Sucrose	g	11.4	13.7	9.3	11.2	n.d.
Glucose	g	2.7	3.2	2.1	2.5	n.d.
Fructose	g	2.2	2.6	1.7	2.0	n.d.
Lactose	g	<	<	n.d.	n.d.	n.d.
Maltose	g	<	<	n.d.	n.d.	n.d.
Vitamins						
Vitamin A	IU	n.d.	n.d.	82	98	87
Vitamin C	mg	4.9[2]	5.9	1.0	1.2	18.3
Vitamin D	IU	<	<	n.d.	n.d.	n/a
Thiamin	mg	n.d.	n.d.	n.d.	n.d.	0.01
Riboflavin	mg	n.d.	n.d.	n.d.	n.d.	0.09
Niacin	mg	n.d.	n.d.	n.d.	n.d.	1.1
Minerals						
Calcium	mg	13	16	8	10	63
Copper	mg	n.d.	n.d.	n.d.	n.d.	0.5
Iron	mg	0.2	0.2	0.3	0.4	7
Magnesium	mg	n.d.	n.d.	10	12	113
Manganese	mg	n.d.	n.d.	n.d.	n.d.	2.6
Phosphorus	mg	n.d.	n.d.	n.d.	n.d.	47
Potassium	mg	201	241	239	287	345
Sodium	mg	1.0	1.2	n.d.	n.d.	n.d.
Sulfur	mg	n.d.	n.d.	n.d.	n.d.	70
Zinc	mg	n.d.	n.d.	0.5	0.6	0.9
Essential Amino Acids						
Cystine	mg	n.d.	n.d.	n.d.	n.d.	4
Histidine	mg	n.d.	n.d.	44	53	21
Isoleucine	mg	n.d.	n.d.	13	15	70
Leucine	mg	n.d.	n.d.	38	45	81
Lysine	mg	n.d.	n.d.	30	36	60
Methionine	mg	n.d.	n.d.	n.d.	n.d.	15
Phenylalanine	mg	n.d.	n.d.	28	33	51
Threonine	mg	n.d.	n.d.	24	29	46
Tryptophan	mg	n.d.	n.d.	n.d.	n.d.	9
Valine	mg	n.d.	n.d.	24	29	58
Non-Essential Amino Acids						
Alanine	mg	n.d.	n.d.	67	81	n.d.
Aspartic Acid	mg	n.d.	n.d.	47	57	n.d.
Glutamic Acid	mg	n.d.	n.d.	58	69	n.d.
Glycine	mg	n.d.	n.d.	29	38	n.d.
Proline	mg	n.d.	n.d.	163	196	n.d.
Serine	mg	n.d.	n.d.	35	42	n.d.
Tyrosine	mg	n.d.	n.d.	16	20	25

[1]KCal calculated from proximate analysis (moisture, lipid, protein, carbohydrate)
[2]Vitamin C value was not determined in this study. It was from a previous study (HARRIS and BRANNAN, 2009).

Tab. 6: Comparison of pawpaw pulp nutritional information from this study (except where noted) to existing nutritional information for seven common fruits on a 100-gram basis.

	Pawpaw 100 g	Apple 100 g	Banana 100 g	Blueberry 100 g	Mango 100 g	Papaya 100 g	Pineapple 100 g	Strawberry 100 g
Calories (kcal)	85	52	89	57	60	43	50	32
Protein (g)	0.7	0.3	1.1	0.7	0.8	0.5	0.5	0.7
Total fat (g)	0.6	0.2	0.3	0.3	0.4	0.3	0.1	0.3
Carbohydrate (g)	23.8	13.8	22.8	14.5	15.0	10.8	13.1	7.7
Dietary Fiber (g)	4.5	2.4	2.6	2.4	1.6	1.7	1.4	2.0
Total Sugar (g)	16.3	10.4	12.2	10.0	13.7	7.8	9.8	4.9
[1]Vitamin C (mg)	4.9	4.6	8.7	9.7	36.4	60.9	47.8	58.8
Calcium (mg)	13	6	5	6	11	20	13	16
Iron (mg)	0.2	0.1	0.3	0.3	0.2	0.3	0.3	0.4
Potassium (mg)	201	107	358	77	168	182	109	153
Sodium (mg)	1	1	1	1	1	8	1	1

[1]Vitamin C value was not determined in this study. It was from a previous study (Harris and Brannan, 2009)

Tab. 7: Comparison of pawpaw nutritional information from this study (except where noted) to existing nutritional information (US Department of Agriculture, 2020) for seven common fruits per serving.

	Pawpaw 1/2 cup, pulp (120 g)	Apple 1 medium fruit (182 g)	Banana 1 medium fruit (118 g)	Blueberry 1 cup, fruit (148 g)	Mango 1 cup, pieces (165 g)	Papaya 1 cup, pieces (145 g)	Pineapple 1 cup, chunks (165 g)	Strawberry 1 cup, halves (152 g)
Calories (kcal)	102	95	105	84	99	62	83	49
Protein (g)	0.8	0.5	1.3	1.0	1.3	0.7	0.8	1.1
Total fat (g)	0.7	0.4	0.4	0.4	0.7	0.4	0.2	0.5
Carbohydrate (g)	28.6	25.1	26.9	21.5	24.8	15.7	21.6	11.7
Dietary Fiber (g)	5.4	4.4	3.1	3.6	2.6	2.5	2.3	3.0
Total Sugar (g)	19.6	18.9	14.4	14.8	22.6	11.3	16.2	7.4
[1]Vitamin C (mg)	5.9	8.4	10.3	14.4	60.1	88.3	78.9	89.4
Calcium (mg)	16	11	6	9	18	29	21	24
Iron (mg)	0.2	0.2	0.4	0.4	0.3	0.4	0.5	0.6
Potassium (mg)	241	195	422	114	277	264	180	233
Sodium (mg)	1	2	1	1	2	12	2	2

[1]Vitamin C value was not determined in this study. It was from a previous study (Harris and Brannan, 2009)

label for other reasons. Most food companies provide nutrition facts on their labels whether they are required to or not because it provides a layer of transparency for customers. As the popularity of the fruit grows, demand for up-to-date nutritional information likely will increase and the information will be beneficial for health clinicians recommending pawpaw to increase fiber intake, for example.

Conclusions

Results from this study confirm that the size, pH, °Brix, firmness, color of the skin and pulp, and nutritional information fits well with previous literature. Pawpaw pH is in the high range for PPO activity, so strategies to reduce pawpaw browning that rely on inhibition of PPO activity should take this into account. Variations in firmness of the pawpaw pulp observed in this study are likely are due to differential degradation of cell wall polysaccharides. Pawpaw skin and pulp color fall well-within the previously established values. Pawpaw pulp nutritional values compare to the values from the Korean study and will be used as the basis for inclusion of pawpaw in the USDA's National Nutrient Database for Standard Reference.

Data from this study was used as the basis for several specific recommendations: 1) firmness values between 0.2 and 0.7 kg of force using the method described herein describe ripe pawpaw fruit; 2) the serving size for raw pawpaw pulp is one-half cup (120 g); and 3) pawpaw pulp nutrition should be compared favorably to that of a banana or mango.

Acknowledgements

Funding provided by generous grants from the Northern Nut Growers Association and the National Pawpaw Foundation.

Conflict of interest

No potential conflict of interest was reported by the authors.

References

AOAC International, 2016: Official Methods of Analysis of AOAC International, 20th ed. AOAC International, Rockville, MD.

Archbold, D.D., Pomper, K.W., 2003: Ripening pawpaw fruit exhibit respiratory and ethylene climacterics. Postharvest Biol. Tech. 30, 99-103. DOI: 10.1016/S0925-5214(03)00135-2

Bois, J., 2001: Anachronistic relationships. BioScience 51, 318-320. DOI: 10.1641/0006-3568

Brannan, R.G., 2016: Polyphenol oxidase in pawpaw (*Asimina triloba* [L.] Dunal) fruit pulp from different varieties. J. Food Res. 5, 33-39. DOI: 10.5539/jfr.v5n1p33

Brannan, R.G., Faik, A., Goelz, R., Pattathil, S., 2019: Identification and analysis of cell wall glycan epitopes and polyphenol oxidase in pawpaw (*Asimina triloba* [L.] Dunal) fruit pulp as affected by high pressure processing and refrigerated storage. Food Sci. Tec. Int. 25, 711-722. DOI: 10.1177/1082013219856769

Brannan, R.G., Peters, T., Talcott, S.T., 2015: Phytochemical analysis of ten varieties of pawpaw (*Asimina triloba* [L.] Dunal) fruit pulp. Food Chem. 168, 656-661. DOI: 10.1016/j.foodchem.2014.07.018

Brannan, R.G., Peters, T.E., Black, K.J., Kukor, B.J., 2018: Valorization of underutilized North American pawpaw (*Asimina triloba*): investigation as a lipid oxidation inhibitor in turkey homogenate model system. J. Sci. Food Agr. 98, 2210-2214. DOI: 10.1002/jsfa.8706

Brannan, R.G., Salabak, D.E., 2009: Ability of methanolic seed extracts of pawpaw (*Asimina triloba*) to inhibit n-3 fatty acid oxidation initiated by peroxyl radicals and reactive oxygen, nitrogen, and sulfur. Food Chem. 114, 453-458. DOI: 10.1016/j.foodchem.2008.09.071

Brannan, R.G., Salabak, D.E., Holben, D.H., 2012: Sensory analysis of pawpaw (*Asimina triloba*) pulp puree: Consumer appraisal and descriptive lexicon. J. Food Res. 1, 179-192. DOI: 10.5539/jfr.v1n1p179

Brannan, R.G., Wang, G., 2017: Effect of frozen storage on polyphenol oxidase, antioxidant content, and color of pawpaw (*Asimina triloba* [L.] Dunal) fruit pulp. J. Food Res. 6, 93-101. DOI: 10.1016/j.lwt.2017.07.023

Callaway, M.B., 1993: Pawpaw (*Asimina triloba*): A "tropical" fruit for temperate climates. In: Janick, J., Simon, J.E. (eds.), New Crops, 505-515.

Cronquist, A., 1981: An integrated classification of flowering plants. Columbia University Press.

Fang, C., Wang, C., Xiong, Y.L., Pomper, K.W., 2007: Extraction and characterization of polyphenol oxidase in pawpaw (*Asimina triloba*) fruit. J. Food Biochem. 31, 603-620. DOI: 10.1111/j.1745-4514.2007.00133.x

Galli, F., Archbold, D.D., Pomper, K.W., 2008: Loss of ripening capacity of pawpaw fruit with extended cold storage. J. Agri. Food Chem. 56, 10683-10688. DOI: 10.1021/jf801857g

Greenawalt, L.G., Powell, R., Brannan, R.G., 2019: Comparative Analysis of Pawpaw Production Data from 2005-2012. J. Amer. Pomolog. Soc. 73, 2-11.

Harris, G.G., Brannan, R.G., 2009: A preliminary evaluation of antioxidant compounds, reducing potential, and radical scavenging of pawpaw (*Asimina triloba*) fruit pulp from different stages of ripeness. LWT-Food Sci. Tec. 42, 275-279. DOI: 10.1016/j.lwt.2008.05.006

Jones, S.C., Layne, D.R., 1997: Pawpaw description and nutritional information. KYSU Extension Bulletin.

Kobayashi, H., Wang, C., Pomper, K.W., 2008: Phenolic content and antioxidant capacity of pawpaw fruit (*Asimina triloba* L.) at different ripening stages. HortScience 43, 268-270. DOI: 10.21273/HORTSCI.43.1.268

Kral, R., 1960: A revision of Asimina and Deeringothamnus (Annonaceae). Brittonia 12, 233-278. DOI: 10.2307/2805119

Layne, D.R., 1996: The pawpaw [*Asiminia triloba* (L.) Dunal]: A new fruit crop for Kentucky and the United States. HortScience 31, 777-784. DOI: 10.21273/HORTSCI.31.5.777

McGrath, M., Karahadian, C., 1994: Evaluation of physical, chemical, and sensory properties of pawpaw fruit (*Asimina triloba*) as indicators of ripeness. J. Agr. Food Chem. 42, 968-974. DOI: 10.1021/jf00040a025

Nam, J.-S., Jang, H.-L., Rhee, Y.H., 2018: Nutritional compositions in roots, twigs, leaves, fruit pulp, and seeds from pawpaw (*Asimina triloba* [L.] Dunal) grown in Korea. J. Appl. Bot. Food Qual. 91, 47-55. DOI: 10.5073/JABFQ.2018.091.007

Nam, J.-S., Jang, H.-L., Rhee, Y.H., 2017: Antioxidant activities and phenolic compounds of several tissues of pawpaw (*Asimina triloba* [L.] Dunal) grown in Korea. J. Food Sci. 82, 1827-1833. DOI: 10.1111/1750-3841.13806

Nam, J.-S., Park, S.-Y., Oh, H.-J., Jang, H.-L., Rhee, Y.H., 2019: Phenolic profiles, antioxidant and antimicrobial activities of pawpaw pulp (*Asimina triloba* [L.] Dunal) at different ripening stages. J. Food Sci. 84, 174-182. DOI: 10.1111/1750-3841.14414

Peterson, R.N., 2003: Pawpaw variety development: A history and future prospects. HortTechnology 13, 449-454. DOI: 10.21273/HORTTECH.13.3.0449

Peterson, R.N., Cherry, J.P., Simmons, J.G., 1982: Composition of pawpaw (*Asimina triloba*) fruit. Annual Report Northern Nut Growers Association 73, 97-107.

Pomper, K.W., Crabtree, S.B., Layne, D.R., Peterson, R.N., Masabni, J., Wolfe, D., 2008: The Kentucky pawpaw regional variety trial. J. Amer. Pomolog. Soc. 62, 58-69.

Pomper, K.W., Layne, D.R., 2005: The North American pawpaw: Botany and horticulture. In: Janick, J. (ed.), Horticultural Reviews, 349-382. John Wiley & Sons, Inc., Hoboken, New Jersey.

Pomper, K.W., Layne, D.R., Peterson, R.N., Wolfe, D., 2003: The pawpaw regional variety trial: Background and early data. HortTechnology 13, 412-417. DOI: 10.21273/HORTTECH.13.3.0412

US Department of Agriculture, 2020: FoodData Central [WWW Document]. URL https://fdc.nal.usda.gov/

Watt, B., Merrill, A., 1963: Agriculture Handbook No 8: Composition of Foods – Raw, Processed, Prepared. Consumer and Food Economics Research Division United States Department of Agriculture, Washington, DC.

Willson, M.F., Schemske, D.W., 1980: Pollinator limitation, fruit production, and floral display in pawpaw (*Asimina triloba*). Bulletin of the Torrey Botanical Club 107, 401-408. DOI: 10.2307/2484160

Zhang, L., Dai, S., Brannan, R.G., 2017: Effect of high-pressure processing, browning treatments, and refrigerated storage on sensory analysis, color, and polyphenol oxidase activity in pawpaw (*Asimina triloba* L.) pulp. LWT – Food Sci. Tec. 86, 49-54. DOI: 10.1016/j.lwt.2017.07.023

ORCID
Robert G. Brannan https://orcid.org/0000-0003-0240-6373

Address of the corresponding author:
Robert G. Brannan, Division of Food and Nutrition Sciences, E170 Grover Center, Athens, OH 45701, USA
E-mail: brannan@ohio.edu