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RIPENING AND POSTRIPENING OF ASIMINA (*ASIMINA TRILOBA* L. DUNAL) FRUITS (REVIEW)

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Abstract

Pawpaw or Northern banana (Asimina triloba L. Dunal), is part of the Annonaceae family, although it is a temperate fruit tree species. The pawpaw fruit is an exciting new food option for people looking for new, balanced food choices. One hundred grams of pawpaw pulp delivers 80 calories and contains 1.2 g of proteins and 1.2 g of total fat. Studies have shown that during ripening, loss of firmness is extremely rapid. This trait may be the biggest obstacle to developing a broader market, as handling without injury is difficult. Cold storage of pawpaw seems limited to four weeks at 4°C. Cold storage for longer than four weeks caused cold injury symptoms such as black discoloration, rapid loss of firmness, impaired respiration, tissue acidification, decreased antioxidant content, reduced volatile ester production, and development of off-flavor volatile compounds. This paper aims to review pawpaw ripening and postripening characteristics under local conditions.

***Key words**: firmness, cold storage, cold injury, paw-paw.*

INTRODUCTION

Pawpaw or Northern banana (*Asimina triloba* L. Dunal), is part of the Annonaceae family, although it is a temperate fruit tree species.

The pawpaw fruit is an exciting new food option for people looking for new, balanced food choices.

This paper aims to review pawpaw ripening and post-ripening characteristics under local conditions.

RESULTS AND DISCUSSIONS

Asimina or paw-paw has a specific profile regarding nutritional values.

One hundred grams of pawpaw pulp delivers 80 calories and contains 1.2 g of proteins and 1.2 g of total fat. At the same time, 18.8 carbohydrates, 2.6 dietary fiber, 1g vitamin A, 30.5 vitamin C, 0.8 mg/100 g fw) thiamin, 6 mg/100 g fw riboflavin, 6.5 mg/1000 g fw niacin. For the minerals, in 100 g fw, there were 9.9 g K, 7.9 g Ca, 5.9 g P, and 35.9 g. Mg, 56 g Fe, 6.7 g Zn, 22.2 g Cu, and 74.3 g Mn (Paw-paw, 2023).

The fat composition of pawpaw fruit consists mainly of unsaturated fatty acids such as palmitoleic (5.8-10.2%), oleic (23.2-42.0%), linoleic (8.0-12.0%), and linolenic (14.0-24.4%) (Peterson, 1982).

For the essential amino acids, in 100 g fw, there were 21 g histidine, 70 g isoleucine, 81 g leucine, 60 g lysine, and 51 g phenylalanine (Paw-paw, 2023).

Despite the rancidity problem, pawpaw-derived products as carbohydrate-based, fat-reducing agents in baked food formulations have been studied (Wiese & Duffrin, 2003).

More research suggested that pawpaw fruit pulp had the potential to be added to various consumer goods to add increased nutritional benefits or flavor enhancement (Brannan et al., 2012).

Pawpaw fruits are fragrant and nutritious, with a unique aroma and flavors like a combination of banana, mango, and pineapple (Duffrin & Pumper, 2006).

Literature data consider pawpaw pulp as a good source of polyphenols (ranging from 22.13 to 37.36 mg GAE per g) and apples, oranges, grapes, and strawberries (Brindza, 2019).

In particular, the predominant polyphenolic compounds were three phenolic acids, protocatechuic acid hexoxide, p-coumaroyl hexoxide, and 5-O-p-coumaroylquinic acid, and flavanols, particularly (−)-epicatechin, B-type procyanidin dimers and trimers (Brannan et al., 2015).

There has been interest in the pawpaw because of its tropical scent and flavors, leading to its niche use. Recent research has shown the pawpaw to have a fermented yeasty smell, with many of the natural scents coming from alcohol or alcohol derivatives (Goodrich et al., 2006).

Volatile methyl esters increase as the fruit matures. As the pawpaw ripens, fruity aroma, sweet aroma, melon-like aroma, and fermented aroma intensities increase, and cut-grass (green) intensity decreases (McGrath & Karahadian, 1994).

However, flavor and aroma vary among pawpaw varieties, with some fruits displaying complex flavor profiles that have not been described. Pawpaw fruit ripening is characterized by increased soluble solids concentration (up to 20%), flesh softening, increased volatile production, and, in some genotypes, a decline in green color intensity (McGrath & Karahadian, 1994).

Determining the levels of phytochemicals in pawpaw may benefit attempts to commercialize the fruit. Two studies have reported levels of antioxidant compounds in pawpaw pulp. One group reported that phenolic content and antioxidant capacity in fruit from two pawpaw cultivars tended to decrease with ripening (Kobayashi et al., 2008).

The amount of total phenolics in pawpaw pulp was not affected by the level of ripeness. However, the level of total flavonoids was 40% higher in underripe pawpaw than ripe, which was 12% higher than in overripe pulp. The level of total phenolics reported in pawpaw (9.2 μmol gallic acid equivalents per gram fresh fruit) was similar to several commercially important *Annonaceous* fruits, including soursop/guanábana/graviola (Harris & Brannan, 2009).

The preliminary analyses indicated that firmness declined due to the action of at least four enzymes: polygalacturonase, cellulase, pectin methylesterase, and endo-ß-man-nanase (Koslanund, 2003).

Pawpaw fruit has traditionally been harvested from native plant stands and small orchards for immediate sale and consumption. Other than the decline in fruit firmness, there are no. Obvious indicators of fruit ripening. This lack of a good harvest index is also a problem with the related cherimoya (Merodio & De la Plaza, 1997).

The fruits on a single tree do not ripen within proximity in time to one another. An extended harvest period of two weeks or more from a tree is not uncommon. The protracted harvest may be partly due to the staggered spring bloom period, up to two weeks or more. Each fruit cluster develops from an individual flower, and fruit within a cluster often ripen at different times. Cultivar variation in harvest date also exists, with early to late season cultivars ripening over 4 to 6 weeks. Currently, multiple harvests from one tree are conducted to obtain high-quality fruit. Because a decline in firmness is the main indicator of ripening, this requires repeated visits to and touching individual fruit, which is very laborious. A once-over harvest from a tree is not feasible (Miller, 1989).

Since pawpaw exhibits an ethylene climacteric, it too may be susceptible to ethylene treatment to induce ripening and treatments to affect ethylene production or action. It was found that fruit harvested immature did not ripen, even if treated with ethephon at 1000 mg•L^{-1}, but using commercially available growth regulators to manipulate pawpaw ripening warrants further study. Postharvest application of 1-methylcyclopropene, an ethylene action inhibitor, has recently been used to successfully slow the ripening of climacteric species and may help do the same with pawpaw (Fan et al., 1999).

Although germplasm selection and breeding have led to more pawpaw cultivars, two main obstacles to market interest development, the fruit's rapid postharvest perishability and the absence of harvest synchronization within and among trees, have not yet been overcome.

Once riped, pawpaw fruit is marketable for only 3-4 days when held at room temperature (Archbold & Pomper, 2003).

When fully ripe, the fruit must be handled with care since its thin skin and highly soft pulp expose it to bruises and other physical damages

(Peterson, 1991; Archbold et al., 2003; Archbold & Pomper, 2003)
Pawpaws fail to complete the ripening process if harvested too early (Archbold, personal communication).
Ripe pawpaw fruit could be cold stored at 4°C for 4 weeks with minor changes in fruit quality (Archbold et al., 2003; Archbold & Pomper, 2003).
Like other climacteric fruits, pawpaw ripening is characterized by increased ethylene production and respiratory activity (Archbold & Pomper, 2003; Koslanund et al., 2005). Single peaks of each were generally detected three days after harvest.
Mean ethylene on a fresh weight basis were 4.7 and 7.6 μg $kg^{-1}h^{-1}$, and mean respiratory (CO_2 production) maxima on a fresh weight basis were 220 and 239 $mg \cdot kg^{-1} \cdot h^{-1}$ in 1999 and 2001 harvests, respectively.
Ethylene and respiration peak values in pawpaw were similar to those reported for sugar apple and cherimoya. However, ethylene values were significantly lower and respiration values significantly higher than the values reported in other climacteric fruits such as apple, which at harvest produces 10-100 μg $C_2H_4 \cdot kg^{-1} \cdot h^{-1}$ and 5-10 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ (Kader, 2002).

Figure 1. Unripe pawpaw fruits (source: own data)

Harvested fruits are still living organs; hence, even though detached from the plant, they continue to exchange gas with and lose water to the environment.
Since the connection with the mother plant has been cut, the respiratory substrate and water losses that occur cause permanent changes in fruit composition (Burdon, 1997).
Many preharvest and postharvest factors, such as genetics, cultural practices, maturity at harvest, and postharvest handling techniques, influence the composition and quality of fruit by the time it reaches the consumer (Archbold et al., 2003).

Figure 2. Ripe pawpaw fruits (source: own data)

Cold storage delayed the ripening of fruit and significantly delayed firmness loss. However, firmness declined rapidly upon removal from cold storage, accompanied by a rise in ethylene production and respiration.
Like cherimoya (Merodio & De La Plaza, 1997), cold-stored pawpaw fruit exhibited a higher ethylene maximum than fruit ripened after harvest (Archbold et al., 2003).
Preliminary observations indicated that more extended storage periods resulted in external and internal black discoloration of the fruit (Koslanund, 2003), possibly symptoms of cold injury similar to other *Annonaceae* like cherimoya (Martinez-Tellez & Lafuente, 1997).

Figure 3. Harvested fruit (source: own data)

In the research of Galli (2007), fruit were cold stored at 4°C for 0 (harvest) 2, 4, 6, or 8 weeks. Measurements for ethylene production were collected daily for three days after beginning bench ripening and were expressed as μg C_2H_4/kg fw/h. Respiration was determined and expressed as mg CO_2/kg fw/h.

The highest ethylene production was recorded two weeks after harvesting by the Middletown variety (7.00 μg C_2H_4/kg fw/h). Only PA Golden and Taytwo fruits stayed mold–free until the end of the eight weeks of cold storage.

'9-58' and Middletown fruits were the firmest (32 N and 27 N, respectively) in 2004, and Taytwo and Middletown fruit were the firmest (28 N and 26 N, respectively) in 2005.

After two weeks of cold storage, the overall number of fruits with firmness higher than 15 N decreased from 71% (at harvest) to 19%.

Taytow recorded the highest amounts of glucose and sucrose in the 8th week and the most significant amount of starch when the fruit was unripe.

Taytwo pawpaw fruit pH significantly increased with ripening after harvest and 4 or 6 weeks of cold storage. After eight weeks of cold storage, the fruit pH had significantly decreased.

Headspace volatile profile composition of pawpaw cultivars at harvest was determined. At harvest, when fruit was considered in the early ripening stage, Wilson produced a significantly higher amount of total volatile compounds, 10-fold or more, than the other cultivars similar to one another.

During bench ripening, the rise in volatile production was principally linked to an increased emission of hexanoate and octanoate esters for Taytwo. The concentration of hexanoates increased by more than 700-fold during ripening. The major volatiles detected were (following retention time) ethyl alcohol (EA), ethyl acetate (EAC), ethyl butanoate (EB), methyl hexanoate (MH), ethyl hexanoate (EH), methyl octanoate (MO), octanoic acid (OA), ethyl octanoate (EO), ethyl decanoate (ED), ethyl propionate (EP), hexanoic acid (HA), methyl butanoate (MB).

Regarding enzyme activity, in the Taytwo cultivar, AAT activity was detected at an early ripening stage. ADH activity in Taytwo fruit was almost 50- and 3 times lower than ADH activity measured in apples and tomatoes at harvest, respectively.

LOX activity at harvest was comparable to that reported for apples and strawberries. As with the ADH activity above, the variability of the LOX data was high.

Alcohol acyltransferase (AAT), alcohol dehydrogenase (ADH), and lipoxygenase (LOX) activity of Taytwo fruit at 4 and 72 h after harvest or after 2, 4, 6, or 8 weeks of cold storage were determined. Enzyme activities were expressed as mU/mg protein.

The highest total glutathione and GSH concentrations were measured in fruit bench ripened for 72 h after harvest and after 2 and 4 weeks of cold storage.

Content of total glutathione, oxidized glutathione (GSSG), reduced glutathione (GSH), and glutathione reductase (GR) activity in Taytwo cultivar one week before commercial harvest (unripe), at harvest, and after 2, 4, 6 and 8 weeks of cold storage was also determined. Measurements were collected after 4 and 72 h of bench ripening.

The ascorbate content of Taytwo fruit at harvest was similar to that reported in other research. The highest total ascorbate concentration was in fruit at harvest. Values had significantly dropped by two weeks of cold storage, and there were significant declining trends over storage time when measured at 4 or 72 h. However, bench ripening did not affect total ascorbate.

As for total antioxidant activity during storage and ripening, no differences were found among values one week before commercial harvest (unripe), at harvest, or after 2, 4, 6, or 8 weeks of cold storage, irrespective of 4 or 72 hours of bench ripening. Even though cold storage did not affect total antioxidant content, phenolic concentration varied with storage length.

Carotenoid content varied among pawpaw cultivars. Wilson cultivar had the highest carotenoid content, and '8-20' had the lowest. Fruit of carotenoid-rich cultivars had the most intense pulp color, and carotenoid-poor cultivars had moderate pulp color.

PA Golden cultivar was used to investigate the possible modification of carotenoid content during cold storage. Carotenoid content at harvest was significantly higher than in unripe fruit, but no differences were observed between fruit at the beginning and the end of bench ripening.

Brannan (2015) conducted a study and determined the PPO activity of five pawpaw cultivars. Significant Polyphenol oxidase activity was observed in Sun Flower > Green River Belle > Susquehanna ≥ Wild ≥ Sue. All cultivars exhibited pulp pH in the range of 5.9-6.3. Previous research has shown that pawpaw pH exhibits maximum activity at pH 7.0, while pH 6-7 range values exhibit high activity (Fang et al., 2007; Brannan, 2015). In addition to having the lowest PPO activity, variety Sue had the lowest sugar content (15%) compared to the other varieties. However, there was no clear trend concerning sugar content and PPO activity in the other varieties (Brannan, 2015).

In another study, GRB was the only variety in common with both of the varieties analyzed in each of the two phases of this study. The pH values of the varieties ranged from 6.1 to 6.8, which is in the high range of pawpaw PPO activity. The PPO activity of GRB was in good agreement between the two phases of the current research, exhibiting PPO activity (ΔABS/min/g protein) of 5.31 and 5.36. PPO activity among the 12 variations showed that six varieties (T2, RG, NC1, OL, RAP, and GRB) exhibited PPO activity statistically higher than QD and LF. The other four varieties (SAAZ, SHEN, ATW, IXL) exhibited PPO activity that was not significantly different from each other or QD and LF. However, they were significantly lower than T2, RG, and NCl (Brannan, 2015).

The antioxidant activity of *Asimina triloba* genotypes evaluated by the DPPH method ranged from 2.84 (AzT-01) to 7.04 mg TEAC. g^{-1} (AzT-04). The variation coefficient (31.77%) in all the genotypes tested confirmed the degree of mean variability of parameters. The antioxidant activity evaluated by the molybdenum-reducing antioxidant power varied from 97.25 (AzT-06) to 275.41 mg TEAC.g^{-1} (AzT-03). The degree of mean variability of parameters was confirmed by the variation coefficient (35.07%) in tested genotypes (Brindza et al., 2019).

The total polyphenol content in *Asimina triloba* genotypes ranged from 22.13 (AzT-05) to 37.36 mg GAE.g^{-1} (AzT-02). The variation coefficient (16.87%) confirmed the high variability of the parameter. The differences between the present and previously conducted studies may be attributable to the plant's geographical origin as well as the different methods of extraction. The flavonoid content varied from 15.10 (AzT-05) to 32.02 mg.g^{-1} QE (AzT-02). The variation coefficient (25.39%) supported this parameter's observations of high variability. The total phenolic acid content was found to vary significantly among the various *Asimina triloba* genotypes, possibly due to their different botanical and regional origins. The mean total phenolic acid of the studied fruit genotypes was 25.16 mg.g-1 CAE, with the highest phenolic acid recorded by genotype AzT-02 at 32.02 mg. g^{-1} CAE, indicating its superior antioxidant potential. The variation coefficient (25.39%) supported this parameter's observations of high variability (Brindza et al., 2019).

The analysis of the ripening behavior of 10 different pawpaw cultivars (1-7-2, 8-20, 9-58, Middletown, PA Golden, Shenandoah, Taytwo, Taylor**,** Wells, and Wilson) over two seasons showed that all genotypes ripened similarly after harvest. For fruit held for up to three days at room temperature, CO_2 production ranged from 48 to 174 mg CO_2/kg fw/h, ethylene production ranged from 0.2 to 2.7 µg C_2H_4/kg fw/h, and firmness decreased by 30-50%. In both harvest years, ethylene and CO_2 peaks were generally detected within 48 hours from harvest. No differences in the cold storage response were found among the different genotypes. After cold storage, ethylene production ranged from none detected to 28 µg C_2H_4/kg/h, respiration ranged from 0 to 214 mg CO_2/kg fw/h, and firmness declined as the storage period increased (Galli, 2007).

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