The Pawpaw [*Asimina triloba* (L.) Dunal]: A New Fruit Crop for Kentucky and the United States

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ORIGIN AND BOTANY

The pawpaw is the largest tree fruit native to the United States (Darrow, 1975). This fruit, known commonly as the "poor man's banana," may reach up to 1 kg in weight. Pawpaws grow wild in the rich, mesic hardwood forests of 25 states in the eastern United States, ranging from northern Florida to southern Ontario (Canada) and as far west as eastern Nebraska (Kral, 1960). Pawpaws flourish in the deep, rich, fertile soils of river-bottom lands where they grow as understory trees or thicket-shrubs (Sargent, 1890). Pawpaw is the only temperate member of the Annonaceae family (Bailey, 1960), which includes several delicious tropical fruits, such as the custard apple (*Annona reticulata* L.), cherimoya (*A. cherimoya* Mill.), sweetsop or sugar apple (*A. squamosa* L.), atemoya (*A. squamosa* x *A. cherimola*), soursop (*A. muricata* L.), and biriba (*Rollinia mucosa* Baill.). In addition to the tropical annonas, there are eight other members of the *Asimina* genus that are native to the extreme southeastern states of Florida and Georgia. These include *A. incarna* (Bartr.) Exell (flag pawpaw), *A. longifolia* Kral, *A. obovata* (Willd.) Nash, *A. parviflora* (Michx.) Dunal (dwarf pawpaw), *A. pygmaea* (Bartr.) Dunal, *A. reticulata* Shuttlew. ex Chapman, *A. tetramera* Small (opossum pawpaw), and *A.* ×*nashii* Kral (Kral, 1960). The earliest documentation on pawpaws, which appeared in 1541, was from followers of the Spanish explorer Hernando De Soto, who found native peoples growing pawpaws in the Mississippi Valley (Pickering, 1879). They also used the bark for making fish nets.

PLANT DESCRIPTION

Pawpaw is a small, deciduous tree that may grow 5 to 10 m high, although the largest known tree is 230 cm in circumference (at 1.5 m height), 18 m tall, and 9 m in spread (American Forestry Association, 1990). In the forest understory, trees often exist in clumps or thickets, which may result from root suckering or seedlings developing from fruit that dropped to the ground from an original seedling tree (Gould, 1939). In sunny locations, trees typically assume a pyramidal habit, straight trunk, and lush, dark-green, long, drooping leaves (Fig. 1) that turn gold and brown during fall (Fig. 2). Leaves occur alternately, are obovate-oblong in shape, glabrous, with cuneate base, acute tip, and prominent midrib, and may be 15 to 30 cm long and 10 to 15 cm wide (Bailey, 1960). Vegetative and flower buds occur at different nodes on the stem, with flower buds being basipetal. Vegetative buds are narrow and pointed, whereas flower buds are round; both are covered with dark-brown, thick pubescence. Flowers emerge before leaves in midspring (Fig. 1). In the mid-Atlantic states and Ohio Valley, pawpaws usually flower immediately after the peak of dogwood (*Cornus florida* L.) flowering. Blossoms occur singly on previous-year's wood and may reach up to 5 cm in diameter. Individual flowers are pendant on nodding, sturdy, pubescent peduncles up to 4 cm long (Kral, 1960). Mature flowers have an outer and inner layer of three, maroon-colored, three-lobed petals (Fig. 1). Inner petals are smaller and more fleshy, with a nectary band at the base. Flowers have a globular androecium and a gynoecium composed of three to seven carpels (Kral, 1960). The actual upper limit for carpel count may be nine or higher, based on the finding of nine-fruited clusters (R.N. Peterson, The PawPaw Foundation, personal observation). Flowers are strongly protogynous and self-incompatible, and require cross-pollination (Wilson and Schemske, 1980), although some trees may be self-compatible. Pollination may be by flies (Wilson and Schemske, 1980) and beetles (Kral, 1960), which is consistent with the presentation appearance of the flower: dark, meat-colored petals and a fetid aroma. Fruit set in the wild is usually low and may be pollinator- or resource-limited (Wilson and Schemske, 1980), but under cultivation, tremendous fruit loads have been observed (R.N. Peterson, personal communication). Fruit are oblong-cylindric berries that are typically 3 to 15 cm long, 3 to 10 cm wide, and weigh 200 to 400 g. They may be borne singly or in clusters that resemble the "hands" of a banana plant (*Musa* spp.) (Figs. 1 and 2). This highly aromatic, climacteric fruit has a ripe flavor that resembles a creamy mixture of banana (*Musa* ×*paradisiaca* L.), mango (*Mangifera indica* L.), and pineapple [*Ananas comosus* (L.) Merr.] (McGrath and Karahadian, 1994). When ripe, skin ranges from green to brownish-black, and the flesh ranges from creamy white through bright yellow to shades of orange (Fig. 2). The skin should not be eaten. Shelf life of a tree-ripened fruit stored at room temperature is 2 to 3 days. With refrigeration, fruit can be held up to 3 weeks while maintaining good eating quality. Within the fruit, there are two rows of large, brown, bean-shaped, laterally compressed seeds that may be up to 3 cm long (Fig. 2). In the wild, the primary fruit consumers and seed dispersers are raccoons [*Procyon lotor* (L.) Elliot], red foxes [*Vulpes fulvus* (Desmarest) Merriam], and opossums (*Didelphis virginiana* Kerr) (among others) who eat fruit that have fallen to the ground (Peterson, 1991). Seeds contain alkaloids in the endosperm that are emetic (Vines, 1960). If chewed, seed poisons may impair mammalian digestion, but if swallowed whole, seeds may pass through the digestive tract intact.

PROPAGATION AND CULTIVATION

Seedling production

As soon as flesh is soft, collect fruit for seed. Avoid excessive fermentation of the fruit, as prolonged exposure to the fermentation products may injure and kill the seed. Seeds are easily extracted following maceration of the fruit in water and floating off of pulp [U.S. Dept. of Agriculture (USDA), 1948]. Sterilize seed by shaking them with a 10% to 20% sodium hypochlorite solution for 1 to 2 min followed by several rinses of distilled water. This step aids in reducing fungal and bacterial contamination during storage. Do not allow seeds to dry out. Once cleaned, store them refrigerated in self-closing polyethylene bags with slightly moist sphagnum (or peat) moss. Label the bags, using indelible ink, as to the seed source, extraction date, and other pertinent information for future reference. Seeds have a dormant, immature embryo and require stratification (USDA, 1948). Storage under refrigeration (5C) for 100 days is recommended to overcome embryo dormancy (USDA, 1948). Provided that desiccation and microbial contamination do not occur, seeds may be stored for several

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Fig. 1. (**clockwise from top left**) Ten-year-old pawpaw seedling trees in commercial-type orchard planting at harvest (9 Sept. 1993, Keedysville, Md.); flower blossom before dehiscence (20 Apr. 1994, Frankfort, Ky.); flower at dehiscence (mid-May 1994, Frankfort, Ky.; photo by E.A. Sugden); ovary swelling, early fruit cluster development (late May 1994, Frankfort, Ky.; photo by E.A. Sugden); cluster of eight fruit (9 Sept. 1993, Keedysville, Md); fruit on tree (photo by R. Jones).

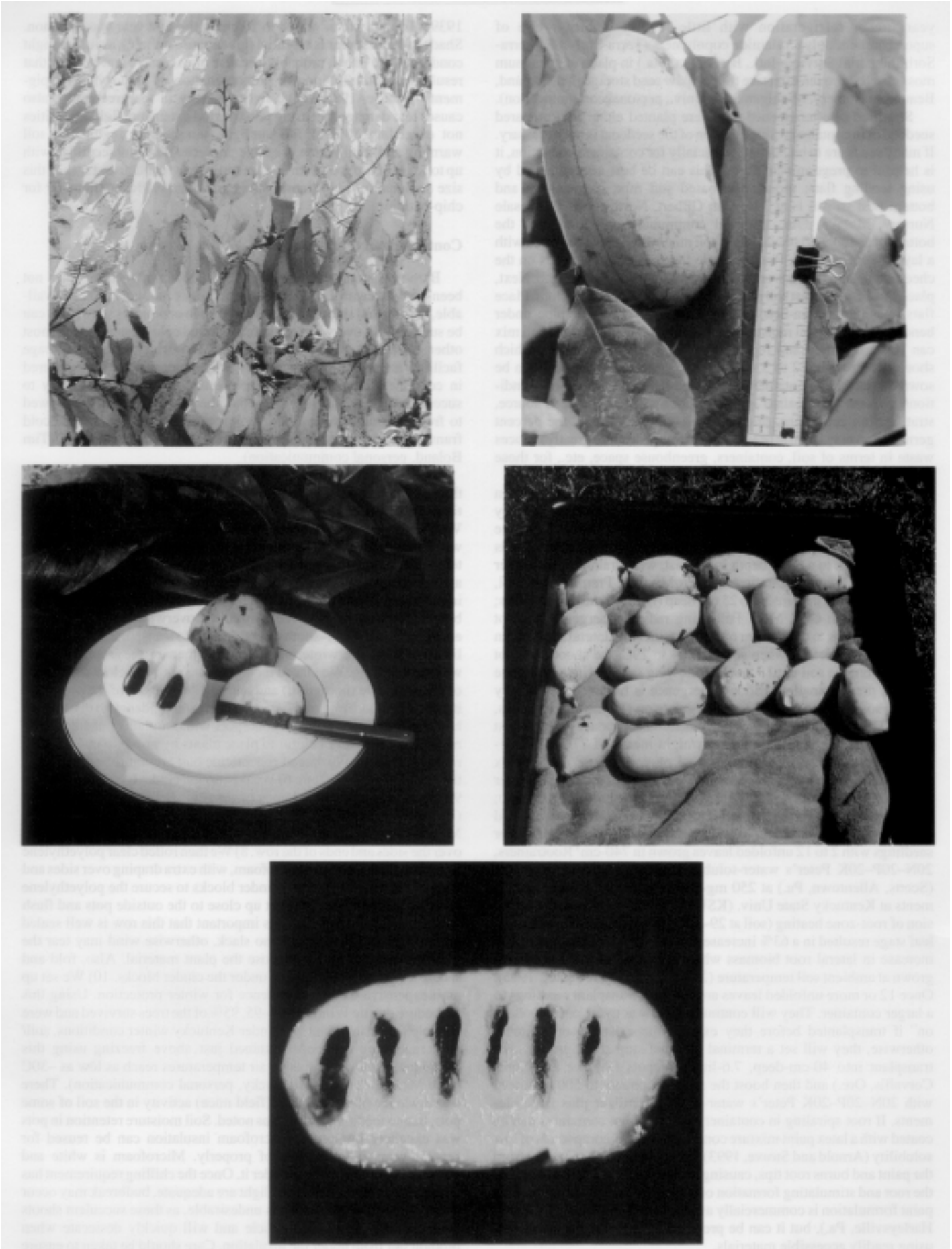

Fig. 2. (**clockwise from top left**) Fall color (October, Keedysville, Md.; photo by R.N. Peterson); single 900-g fruit (9 Sept. 1993, Keedysville, Md.); fruit immediately following harvest (9 Sept. 1993, Keedysville, Md.); longitudinal section of ripe fruit; cross section of ripe fruit (photo by R.N. Peterson).

years under refrigeration with little loss in viability. Use of superabsorbent polyacrylamide copolymers (Terra-Sorb AG; Terra-Sorb Industrial Services Intl., Bradenton, Fla.) in place of sphagnum moss also has proven effective for pawpaw seed storage (Tim Boland, Beaumont Nursery, Michigan State Univ., personal communication).

Stratified or after-ripened seeds are planted either in a prepared seedbed or in containers. Scarification of the seedcoat is not necessary. If many seeds are to be planted, especially for container production, it is helpful to pregerminate them. This can be best accomplished by using seeding flats; moist, peat-based soil mix; cheesecloth; and bottom heat so soil is at 32C (Jim Gilbert, Northwoods Wholesale Nursery, Molalla, Ore., personal communication). First, line the bottom of a seeding flat with moist soil mix, which then is covered with a layer of cheesecloth. Place a single layer of stratified seeds on the cheesecloth, and then cover it with another layer of cheesecloth. Next, place 1 to 3 cm of moist soil mix over the top layer of cheesecloth. Place flats over the bottom-heat source (heat mat, hot-water pipe under bench, etc.). Keep soil moist. The top layer of cheesecloth and soil mix can be easily lifted and replaced to check for germination, which should occur within 2 to 3 weeks. Pregerminated seeds can then be sown directly into containers (described below). Under ideal conditions, percent germination is ≈90%, but depending on seed source, stratification conditions, microbial contamination, etc., the percent germination may be 60% or less. Use of this procedure greatly reduces waste in terms of soil, containers, greenhouse space, etc., for those seeds that do not germinate.

Pawpaw seed germination is hypogeal and cotyledons remain within the seedcoat. Finneseth et al. (1996) postulated that the primary function of the cotyledons is absorption of food reserves from the ruminate endosperm for transfer to the developing seedling. Seeds should be sown to a 3-cm depth in a moist, well-drained soil or other medium that has good aeration (i.e., ProMix BX; Premier, Red Hill, Pa.) in containers that are 20 to 25 cm deep (i.e., 740-cm^3 Rootrainers; Hummert, Earth City, Mo.). Following radicle emergence, taproot growth proceeds to the bottom of the container and lateral roots begin to develop. Typically, when soil is at 24 to 29C, the shoot does not emerge from the soil until 9 weeks following sowing (including time spent in pregermination). Shoot emergence is hastened 10 days by heating soil to 29 to 32C from sowing date on (Layne and Kwantes, 1995). The optimal conditions for greenhouse production of robust seedlings include the following: day/night means of 27/24C; maximum light intensity 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux (greenhouse whitewashing recommended, especially during summer months); 16-h photoperiod (extended by high-pressure sodium lamps); fertilization 2× per week to runoff during shoot growth phase; and soil at 29 to 32C (Jones et al., 1995; Layne and Kwantes, 1995). For seedlings with 2 to 12 unfolded leaves grown in 740-cm^3 Rootrainers, 20N–20P–20K Peter's water-soluble fertilizer plus trace elements (Scotts, Allentown, Pa.) at 250 $mg \cdot liter^{-1}$ is optimal. Recent experiments at Kentucky State Univ. (KSU) have demonstrated that provision of root-zone heating (soil at 29–32C) from sowing date to the 12-leaf stage resulted in a 63% increase in total plant biomass and a 90% increase in lateral root biomass when compared to those seedlings grown at ambient soil temperature (24C) (Layne and Kwantes, 1995). Once 12 or more unfolded leaves are attained, transplant seedlings to a larger container. They will continue to grow actively once "potted-on" if transplanted before they exhaust the existing soil volume; otherwise, they will set a terminal bud and stop shoot growth. We transplant into 40-cm-deep, 7.6-liter Treepots (Stuewe and Sons, Corvallis, Ore.) and then boost the fertilization rate to 500 $mg \cdot liter^{-1}$ with 20N–20P–20K Peter's water-soluble fertilizer plus trace elements. If root spiraling in containers is a problem, containers can be coated with a latex paint mixture containing copper compounds of low solubility (Arnold and Struve, 1993). The copper leaches locally from the paint and burns root tips, causing lateral branching farther back on the root and stimulating formation of a more fibrous root system. This paint formulation is commercially available as SpinOut (E.C. Geiger, Harleysville, Pa.), but it can be prepared by the user for lower cost using readily accessible materials.

In the past, recommendations for pawpaw seedling production included growing seedlings outside, in a seedbed under shade (Gould, 1939). Top growth of only 8 to 10 cm in the first year was common. Shade in the first year is essential (greenhouse or field), as full sunlight conditions are lethal, probably because of excessive leaf heating that results in photoinhibition or photooxidation of photosynthetic pigments (Krause, 1988). High light intensity in the greenhouse also causes leaf damage. By using photoperiod extension, light intensities not exceeding 50% of full sunlight, temperature regulation, soil warming and fertilization, we have produced pawpaw seedlings with up to 1.5 m of top growth in one season in the greenhouse. Trees of this size are ideal for field transplanting and have sufficient diameter for chip-budding.

Containerized overwintering

Bare-root storage and/or shipping of pawpaw seedlings has not been very successful. Until reliable bare-root methods become available, storing and shipping trees should be in containers. Pawpaws can be successfully overwintered in refrigerated cold storage, as can most other container-grown nursery crops. If refrigerated cold-storage facilities are unavailable, pawpaws can be successfully overwintered in containers outside if adequate precautions are taken. A key to successful overwinter survival is that the root system not be allowed to freeze. Containers can be overwintered in insulated, heated cold frames provided root-zone temperature does not drop below –7C (Tim Boland, personal communication).

At KSU (USDA hardiness zone 6), we have overwintered more than 2000 trees successfully on the ground outside without an additional heat source. This was accomplished in the following manner: 1) We acclimated seedlings in the greenhouse to a dormant condition by withholding fertilization, reducing watering, lowering greenhouse temperature, and removing supplemental illumination. 2) We defoliated dormant seedlings in the greenhouse and thoroughly watered immediately before taking them outdoors in the fall. Do not prune trees before overwintering. 3) We mowed the overwintering site and oriented rows in a north–south direction. 4) We transported trees in 7.6-liter pots to the overwintering site and laid them on the ground, six pots wide and 75 long. We placed the top of one pot just below the bottom of the pot above (north of it) and laid the stem on top of the pot above it. Since the south end of the row has a greater tendency to dry out, we laid down a row of "blank" pots (pots without plants but filled with moist soil). It is very helpful to place plants by group to make spring removal easy. 5) We spread rodenticide bait around the perimeter of the row every 60 to 90 cm. 6) We positioned cinder blocks every 60 to 90 cm along the sides and ends of the row. 7) We rolled microfoam (laminated polypropylene) horticultural insulation blanket (Ametek Microfoam Div., Chaddsford, Pa.) over the pots and left extra to drape over the sides and ends of the row. 8) We then rolled clear polyethylene (0.01 mm thick) over the microfoam, with extra draping over sides and ends of the row. 9) We used cinder blocks to secure the polyethylene as the microfoam was brought up close to the outside pots and flush with the soil for a tight fit. It is important that this row is well sealed on all sides and that there is no slack, otherwise wind may tear the polyethylene and unduly expose the plant material. Also, fold and secure any extra polyethylene under the cinder blocks. 10) We set up an inexpensive electric deer fence for winter protection. Using this procedure during Winter 1994–95, 95% of the trees survived and were suitable for spring planting. Under Kentucky winter conditions, soil/air temperature can be maintained just above freezing using this technique, even when outside air temperatures reach as low as –30C (Bob McNeil, Univ. of Kentucky, personal communication). There was evidence of some rodent (field mice) activity in the soil of some pots, but no feeding damage was noted. Soil moisture retention in pots was excellent by spring. Microfoam insulation can be reused for several years if taken care of properly. Microfoam is white and transmits light to the plants under it. Once the chilling requirement has been met and temperature and light are adequate, budbreak may occur under the microfoam, which is undesirable, as these succulent shoots have a poorly developed cuticle and will quickly desiccate when brought out from under the insulation. Care should be taken to ensure that plants are brought out not only before budbreak but also after the last threat of a killing frost.

Field planting

Plant trees in the field when they are still dormant. Although trees can be planted in the fall, this is a more risky practice than spring planting. To ensure success in fall planting, the trees must be hardened-off and acclimated properly (i.e., naturally defoliated). Plant them before the first killing frost. Spring-plant a dormant tree that has had its chilling requirement fulfilled at the time of local, native pawpaw budbreak (early April in Kentucky). Planting holes should match the existing containerized root system. For 7.6-liter containers, a hand-held power auger with an 8-inch drill bit works nicely for drilling holes. Do not plant trees when soil is too dry or wet. Hole drilling in wet, clayish soils will result in glazing the hole walls, which may impede root penetration into the soil. Soil should be well drained, deep, fertile, and slightly acid (i.e., pH 5.5–7). Preplant soil tests are desirable to make necessary amendments. Plant trees such that the soil line of the pot is even with the soil line of the field. Water-in trees immediately after planting to ensure adequate root-to-soil contact. Seedlings must also receive adequate water in the year of establishment. Pawpaw trees establish and grow best when they are given shelter the first year in the field. This is accomplished by using tree shelters that are used in reforestation (i.e., 1-m TUBEX tree shelters; Treessentials Co., St. Paul). Tubes can be secured to steel reinforcing bars or pressure-treated wooden posts. Tree shelters provide several benefits in the year of establishment: 1) reduction of light intensity incident upon tree; 2) wind reduction; 3) water conservation; 4) protection from browsing animals; and 5) protection from herbicides. At least one nursery that sells container-grown pawpaw trees also sells tree shelters and strongly urges their customers to use them. This practice has significantly reduced the need to send replacement plants later (Ken Asmus, Oikos Tree Crops, Kalamazoo, Mich., personal communication). Tree tubes are not without problems, however. Mice sometimes are attracted to them as winter shelters; invariably they sever the sapling's trunk to enlarge their nests (R.N. Peterson, personal communication). Occasionally, fall acclimation of trees grown in shelters may be delayed and tip dieback from cold injury may occur. Tree shelters may not be well suited in the Deep South of the United States. They have caused excessively high temperatures that are injurious to the plant (Dean Evert, Univ. of Georgia, personal communication). If seedlings or grafted trees to be planted are 1 m or taller, tree shelters are not needed.

Weed control is necessary, especially in the establishment year. Depending on site, soil erodibility, whether tree shelters are used, etc., herbicides can be used to control weeds. At KSU we have used wood chip mulch to a 15-cm depth and have achieved good weed control and water conservation in the year of mulching. This step is labor intensive, and cost is a factor if one does not have access to free or low-cost chips. In the Deep South, mulch breaks down too readily to be practical (Dean Evert, personal communication). Another alternative is weed mats (VisPore tree mats; Treessentials Co., St. Paul). Mats are 1 m^2, 0.06 mm thick, ultraviolet-stabilized black polyethylene, with 620 heat-molded microfunnels per 10 cm^2. Weed competition is restricted from the root zone and water conservation is greatly enhanced for up to 3 years. These tree mats are designed to be used along with tree shelters to conserve water and avoid supplemental irrigation.

Granular fertilizer can be broadcast in the spring. Fertigation with liquid fertilizer can be useful if drip irrigation is installed in the orchard. If weed mats are used, run the drip line and emitters under the mats. We do not currently have recommendations for feeding field-planted trees, but we fertigate with 20N–20P–20K Peter's water-soluble fertilizer plus trace elements at 500 $mg \cdot liter^{-1}$ once in May, June, and July during the active growth phase. Fertilizer recommendations based on foliar and soil analyses need to be developed. Recommended tree spacing at present is 5.5 m between rows and 2 m apart in the row. Row orientation should be north–south.

Transplanting trees from the wild usually is unsuccessful. Young trees dug from a thicket or grove are often root suckers with few, brittle roots that have very few root hairs. Due to the poorly developed root system and frequent absence of shelter following transplanting, transplanting shock is usually severe, resulting in the death of the root sucker. Transplanting seedlings is most successful when done in the spring during budbreak. If many roots are lost during digging, prune the shoot to bring it into balance with the existing root system. Containerized seedlings transplant with high success.

Vegetative propagation

Pawpaws are easily propagated by several cloning methods, such as grafting and budding. These techniques include whip-and-tongue, cleft, bark inlay, and chip budding. Chip budding is most successful when the seedling rootstock is at least pencil thick in diameter and actively growing. Winter-collected, dormant scion budwood should have had its chilling requirement fulfilled. Do not graft flower buds onto rootstock. For storage, dip the shoot bases of the budwood in paraffin, place in a labeled polyethylene bag, and heat-seal it. Under these conditions, budwood can be stored reliably in a refrigerator for up to 3 months. Do not allow budwood to dry out, but I do not recommend wetting paper towels or adding free water to the plastic bags, as this can lead to microbial overgrowth. Larger vegetative buds have a higher success rate than smaller buds. When performing chip budding, try to match the diameter of the budwood with that of the stock plant. It is best to place buds on the smooth side of the stock between the nodes. Since vegetative buds occur oppositely and alternately on the stock and branching occurs in one plane, budding on the side perpendicular to this plane reduces confusion as to which shoot is the grafted one. I recommend wrapping the graft with Parafilm M laboratory film (American National Can, Greenwich, Conn.) strips cut to 2 × 15 cm. Parafilm M is flexible, moldable, self-sealing, and moisture resistant. When stretched, it applies adequate pressure to stimulate callus production and it maintains good humidity for union formation. We wrap buds starting one wrap above the bud, proceeding over the bud to one wrap below, and then returning back up and tying off above the bud. Within 2 weeks, buds will begin expanding and may penetrate the Parafilm M or just enlarge under it. In the latter case, Parafilm M is easily removed by using a sharp budding knife and making a shallow incision along the length of the wrap on the side opposite the bud. Take care not to damage the scion bud in the process of removing Parafilm M. Once scion growth commences, we recommend cutting back the top of the stock to 30 to 60 cm in height, leaving six or more functional lower leaves, and rubbing off all competing buds on the rootstock. This procedure will reduce apical dominance and enable the bud to grow actively while maintaining photosynthesis to supply carbohydrates and nutrients for the developing scion. We have found that cutting the stock back to just above the bud reduces scion growth. Once the scion is 30 cm long or more, remove the lower leaves on the stock and cut the stock back to a height of 20 to 25 cm above the union. Under greenhouse conditions, we also have found that leaving the stock as described above is extremely helpful because the stub of the stock projecting above the union then provides a "stake" to secure the growing scion. Some scion varieties appear to grow more horizontally from the graft union than others and using this technique ensures uniform habit and development of a strong union and vertically oriented scion. We use masking tape to tie up the scion as it grows. Once the scion becomes woody, this tape is no longer needed. Starting with a large, healthy rootstock, up to 1.5 m of scion growth can be attained in as few as 3 months under the optimal greenhouse conditions described above. Whip grafting is successful on seedling rootstock material that is as small as 3 to 4 mm in diameter, provided the scion is of similar diameter (Jim Gilbert, Northwoods Wholesale Nursery, Molalla, Ore., personal communication).

Other vegetative (clonal) propagation techniques such as root cuttings, hard and softwood cuttings, and tissue culture have met with poor or marginal success in the past by others. Current efforts here at KSU have demonstrated that winter-harvested root cuttings will sucker profusely when grown in the greenhouse with bottom heat. We have had more success with large (>2 cm in diameter) cutting pieces than smaller cuttings. We are attempting to root these cuttings and to culture nodal explants. One commercial business is attempting to root pawpaw hardwood cuttings in the greenhouse (Mike Byrne, Propagation Technologies, Lawton, Mich., personal communication). We are also conducting experiments to clonally propagate pawpaws by softwood cuttings and mound layering in the field. Hickman (1985)

successfully rooted a low percentage of pawpaw softwood cuttings. Micropropagation techniques have been developed for many Annonaceous relatives of pawpaw, indicating promise of this technology for pawpaw (Bejoy and Hariharan, 1992; Jordan, 1988; Jordan et al., 1991; Nair et al., 1983, 1984a, 1984b, 1986; Rasai et al., 1994). In attempting to micropropagate pawpaw, we have found that dormant, winter-harvested twigs that are surface-sterilized and then forced (in water) in a growth chamber provide the best source of explants (i.e., nodal cuttings) from the newly developing shoots. We currently have adventitious shoots proliferating in culture and will soon move them to a rooting medium. Embryo culture is a technique that might be used to rescue interspecific or intergeneric hybrids that would otherwise abort due to incompatibility (Pierik, 1989).

Weed and pest control

No chemicals are currently registered for commercial use on pawpaws. We use *N*-(phosphonomethyl)glycine (glyphosate; RoundUp) and 1,1´-dimethyl-4,4´-bipyridinium salts (paraquat) for maintaining a weed-free, herbicide strip down orchard rows in our research plots. We have had only minor infestations in the field of Japanese beetle (*Popillia japonica* Newman), and 1-naphthalenyl methylcarbamate (carbaryl; Sevin) is effective in treating this pest. Greenhouse pests include aphids (Family: Aphididae) and thrips (Family: Thripidae). Sevin is also effective for these pests in the greenhouse.

RATIONALE FOR DEVELOPMENT OF PAWPAW AS A NEW FRUIT CROP

The economic rationale for the development of pawpaw as a new fruit crop is very much tied to the need, in certain areas of the country, to find new high-value crops to replace old ones that are losing value. Tobacco (*Nicotiana tabacum* L.) is one example. Since 1976, the percentage of total world tobacco produced by the United States has dropped from 53% to 28% (Owens, 1994b). Significant opportunities exist for the development of alternative agricultural enterprises that could help tobacco farmers to diversify and thereby enhance their continued, long-term viability.

In Kentucky, tobacco is grown on small acreages in rural areas and tobacco sales contribute significantly to the small-farm family income. At KSU the central mission of the land-grant program is to address the needs of limited-resource (small) farmers, most of whom will be harmed by declines in tobacco production and revenue generation (Gale, 1994). One current, long-term and ongoing initiative at KSU to address the aforementioned need is the development of pawpaw as a new, commercial, tree fruit crop. Pawpaw is well adapted to all 16 tobacco-growing states in the United States, except Florida. Pawpaw cultivation in these tobacco-producing states can add diversity and has the potential to provide significant income for a portion of these states' farmers over 20 to 30 years.

COMMERCIAL POTENTIAL

Pawpaw has tremendous potential as a new fruit crop because of its 1) adaptation to existing climatic and edaphic conditions; 2) nutritional and cosmetic value of the fruit; 3) valuable natural compounds; 4) nursery wholesale and retail tree production; and 5) use as a component in residential "edible" landscapes. Pawpaw is well adapted to the 25 states to which it is native and where it already grows in the wild. It is hardy to zone 5 (–25C) and requires a minimum of 400 h annual chill units, 160 frost-free days, and 80 cm of annual precipitation, with most falling during spring and summer (Peterson, 1991). Pawpaw trees may be used for habitat restoration and biodiversification in parks, wood lots, and forests. Pawpaw is an excellent food source. It exceeds apple (*Malus domestica* Borkh.), peach [*Prunus persica* (L.) Batsch.], and grape (*Vitis* spp.) in most vitamins, minerals, amino acids, and food energy value (Peterson et al., 1982). Pawpaw fruit are best eaten fresh when fully ripe. The intense tropical flavor and aroma (Shiota, 1991) also may be useful for developing processed food products (blended fruit drinks, baby food, ice creams, etc.). The flesh purees easily and freezes nicely. Pawpaws easily substitute in equal part for banana in most recipes (Jones and Layne, 1996). Aromas may be used commercially in cosmetics and skin products (B. Hecking, perfume chemist, Mane, USA Division, Wayne, N.Y., personal communication). Pawpaw plants produce natural compounds (annonaceous acetogenins) in leaf, bark, and twig tissues that possess both highly antitumor and pesticidal properties (McLaughlin and Hui, 1993; Mikolajczak et al., 1988; Rupprecht et al., 1986; Zhao et al., 1994). Current research by Jerry McLaughlin at Purdue Univ. (personal communication) suggests that a potentially lucrative industry, based simply on production of plant biomass, could develop for production of anticancer drugs [pending Food and Drug Administration approval] and natural (botanical) pesticides. The high level of natural defense compounds in the tree make it highly resistant to insect/disease infestation (R.N. Peterson, personal observation). With proper management, organic commercial fruit production may be possible. Currently in the United States, there are more than 40 commercial nurseries selling pawpaw trees. Seedling and grafted trees in the retail nursery trade are currently selling briskly for as much as $18.50 and $26.50 a piece, respectively, vs. $3.00 to $4.00 for a 2-year-old, grafted apple tree. Currently, standing orders are in excess of 40,000 trees in the wholesale market (Jim Gilbert, personal communication). Pawpaws are ideally suited for the residential "edible" landscape due to their lush, tropical appearance; attractive growth form; size; fall color; and delicious fruit. In addition, *Asimina* spp. are suitable for butterfly gardens, as they attract the zebra swallowtail (*Eurytides marcellus* Cramer), for whom they are the exclusive larval host plant (Damman, 1986).

PUBLIC INTEREST AND HISTORY

Pawpaws have a well-established place in folklore and American history. "Where, oh where, is dear little Nellie (Sallie, etc.)? 'Way down, yonder in the pawpaw patch." This traditional American folk song and game was quite popular once and hunting for pawpaws in the woods in the fall is a cherished tradition for many rural families in the southeastern United States. In reference to the pawpaw, John Lawson said in his 1709 book, *A New Voyage to Carolina*, that they are "as sweet, as any thing can well be. They make rare Puddings of this Fruit." John Filson, an early settler, promoter, and developer of Kentucky, said in his 1784 book, *The Discovery, Settlement and Present State of Kentucke*, "the pappa-tree does not grow to a great size, is a soft wood, bears a fine fruit much like a cucumber in shape and size, and tastes sweet." Daniel Boone and Mark Twain were reported to have been pawpaw fans. In their journal entry on 18 Sept. 1806, Lewis and Clark recorded how pawpaws helped save them from starvation, "our party entirely out of provisions subsisting on poppaws. We divided the buiskit which amounted to nearly one buiskit per man, this in addition to the poppaws is to last us down to the Settlement's which is 150 miles. The party appear perfectly contented and tell us that they can live very well on poppaws". John James Audubon painted the yellow-billed cuckoo on a native pawpaw tree (ca. 1827). During the famous Hatfield–McCoy feud along the Kentucky–West Virginia border, on 9 Aug. 1882, three sons of Randolph McCoy (clan leader) were tied to pawpaw bushes and executed by the rival Hatfield family (Owens, 1994a). Several American towns, townships, creeks, and rivers were named after the pawpaw during the 19th century.

Several national organizations have had a long-standing interest in pawpaws, including the Northern Nut Growers Association, the North American Fruit Explorers, and the California Rare Fruit Growers, Inc. In 1988, R. Neal Peterson founded The PawPaw Foundation (PPF) as a nonprofit organization "dedicated to research and development of *Asimina triloba* as a new fruit crop for American farmers and consumers." Currently, PPF has almost 300 members. PPF, under the leadership of Peterson, has been active in collecting, evaluating, and preserving germplasm; breeding pawpaws; distributing fruit; selling seed; interacting with research scientists; and educating the public. PPF receives hundreds of letters each year requesting information about pawpaws. PPF also publishes a semi-annual newsletter, "From The

PawPaw Patch." Here at KSU, I have received more than 700 inquiries (phone calls, letters, e-mail) in the last 6 months alone from people across the United States seeking information about pawpaws and the availability of fruit, trees, and seeds. Many of these people have shared wonderful reminiscences of this fruit. Others express great enthusiasm and excitement upon learning that someone is *finally* taking an academic interest in pawpaws. One recent caller wanted to know where he could get a semi-truck load of fruit to market in downtown Los Angeles! The affection pawpaw "enthusiasts" have for this historically neglected and uniquely American native fruit is quite remarkable. Public interest has been fueled by high-profile articles in several newspapers, including *The Wall Street Journal*, *USA Today*, *Baltimore Sun*, *Detroit Free Press*, *Lafayette Journal and Courier*, *Lexington Herald Leader*, *Frankfort State Journal*, and *Windsor Star*. Recent features also have been published in popular magazines, including *American Horticulturist* (Feb. 1995), *Country America* (Sept. 1995), and *The Fruit Gardener* (May/June and July/August 1996). I was interviewed on 5 Dec. 1995 about pawpaws by Noah Adams on National Public Radio's daily program "All Things Considered."

Whether curiosity, folklore, the exotic nature of the fruit and tree, or genuine commercial interest, pawpaws are beginning to gain considerable attention across the United States. This national attention is a mixed blessing. It is great exposure for promoting pawpaw's commercial development, but we are at the infancy stage in terms of academic research and industry development (fruit production, processing, marketing, etc.) and we have only limited information for those who seek more. Scientifically based recommendations, which are a prerequisite for industry development, take many years of research to develop.

PAWPAW RESEARCH AT KENTUCKY STATE UNIV.

KSU has had a comprehensive research program since 1990 directed toward developing pawpaw as a new commercial tree fruit crop for Kentucky and the United States (Callaway, 1992). In Kentucky, alternative and potentially high-value cash crops, such as pawpaw, are being investigated for their production feasibility to help farmers diversify agricultural production away from tobacco. A significant obstacle in the development of any new crop is the dearth of scientific information available on how the crop grows and how best to grow the crop. In the case of pawpaw, scientifically based recommendations for commercial tree production did not exist. Much initial work by others involved adopting techniques/technologies used for other tree fruit crops, educated "best guesses," and trial and error. We have already made considerable progress toward production of robust, healthy trees in the greenhouse (Jones et al., 1995; Layne and Kwantes, 1995). Ongoing research projects at KSU include 1) determining factors that affect seed germination and seedling growth and development; 2) developing cultural recommendations for greenhouse and orchard production; 3) long-term evaluation of promising pawpaw clones and hybrids; 4) determining heritabilities for commercially important traits; and 5) characterizing the morphological and molecular variation in a diverse germplasm collection (Huang and Layne, 1996). Future efforts also will include developing techniques to 1) clonally mass-propagate desirable plants; 2) preserve diverse and promising germplasm; and 3) provide easy access to germplasm and information about germplasm, research findings, commercial recommendations, etc., to interested parties via an on-line database accessible through a World Wide Web Home Page on the Internet. These latter three objectives will be addressed by a newly funded FY95 USDA–1890 Institution Capacity Building Grant entitled "A Centralized Research Support System for *Asimina* Germplasm and Information," which establishes research partnerships among the KSU Community Research Service, KSU Cooperative Extension Service, USDA [Agricultural Research Service (ARS)–National Clonal Germplasm Repository (NCGR) (Corvallis, Ore.), National Agricultural Library and Germplasm Resource Information Network (GRIN) (Beltsville, Md.), and the Forest Service (Rhinelander, Wis.)], the Univ. of Kentucky, Stetson Univ. (DeLand, Fla.), PPF, and a private collector/breeder.

GERMPLASM

In 1994 KSU was approved by the USDA–ARS–NCGR system to serve as the national repository for *Asimina* spp. germplasm in the United States (as a satellite of the NCGR in Corvallis, Ore.). The current collection of germplasm consists of trees planted in orchards and growing in greenhouses, and seeds in refrigerated storage. Four orchards at KSU contain ≈2800 trees. These trees include grafted pawpaw varieties and seedlings from more than 70 distinct geographical regions of 17 states, including Arkansas, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maryland, Mississippi, Missouri, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, Tennessee, Virginia, and West Virginia. Trees range in age from 2 to 4 years. None of the trees are fruiting yet, although several flowered for the first time during Spring 1995. Also planted are *A. parviflora* seedlings and intra- and interspecific hybrid seedlings, including *A. triloba* x *A. triloba*, *A. obovata* x *A. triloba*, *A. reticulata* x *A. triloba*, and *A. parviflora* x *A. triloba*. In Fall 1995, a Regional Variety Trial (RVT) orchard (described below) was planted. In Spring 1996, 800 intraspecific hybrids of the PPF's advanced selections (cooperative research project with R.N. Peterson) were also field-planted. This is the largest collection of *Asimina* spp. germplasm in the world. We also are growing several potted specimens of the southern *Asimina* species, *A. longifolia* and *A. tetramera* (an endangered species), in the greenhouse. Several thousand pawpaw seeds of diverse origin as well as seed from tropical species, including *Rollinia mucosa* (Bail.), *Annona squamosa* x *Annona cherimola* (atemoya), and *Annona squamosa*, are held in cold storage. Germplasm evaluation and selection will be an ongoing, high-priority area of the KSU pawpaw research program.

PAWPAW REGIONAL VARIETY TRIAL

In 1993, PPF and KSU embarked on a joint venture to test within pawpaw's native range many of the commercially available, named pawpaw cultivars and PPF's advanced selections (Layne and Peterson, 1996). Orchards for RVT were planted in 16 different locations from Fall 1995 through Fall 1996 and consisted of 300 trees each. At each RVT site, eight replicate trees of each of the 28 grafted scion varieties will be tested in a randomized complete block design. Named cultivars that are secured for testing include: 'Middletown', 'Mitchell', 'NC-1', 'Overleese', 'PA-Golden', 'Sunflower', 'Taylor', 'Taytwo', 'Wells', and 'Wilson'. The other 18 clones to be evaluated originated in PPF orchards at the Univ. of Maryland experiment stations at Wye, Md., and Keedysville, Md. Seedling trees from local native sources were planted around the perimeter as a buffer against edge effects and to allow comparisons with local germplasm.

Identical orchards will be planted at the following institutions and locations: Univ. of Arkansas, Fayetteville; Purdue Univ., West Lafayette, Ind.; Iowa State Univ., Crawfordsville; Kentucky State Univ., Frankfort; Univ. of Kentucky, Princeton; Louisiana State Univ., Calhoun; Univ. of Maryland, Keedysville; Univ. of Nebraska, Lincoln; Cornell Univ., Ithaca; North Carolina State Univ., Raleigh; Ohio State Univ., Piketon; Oregon State Univ., Corvallis—outside of native range; Clemson Univ., Clemson, S.C.; and the Univ. of Tennessee, Knoxville. An orchard of nonidentical design was planted at Florida State Univ., Tallahassee. Additional sites in Connecticut and Chile are being contemplated. The Institute of Forestry, Chinese Academy of Forestry, Beijing, will be the international site.

Orchard performance to be examined at each RVT site will include climatic factors, culture, pests, growth, flowering, yield, and fruit characteristics. Trees will be evaluated for several years for yield, year-to-year consistency, regional suitability, etc. At the end of several fruiting seasons, regional recommendations will be made. Each site will serve as a regional demonstration for growers and nursery operators, and will serve public education/extension purposes. Once trees begin fruiting, annual RVT cooperator meetings will rotate from site to site for research updates and plot evaluations/tours.

FIRST INTERNATIONAL PAWPAW CONFERENCE

The first International Pawpaw Conference hosted by PPF was held 9–11 Sept. 1994 at the Western Maryland Research and Education Center (WMREC), Keedysville. There are some 700 open-pollinated, 12-year-old, bearing pawpaw trees at WMREC. Several cultivars and advanced PPF selections to be planted in the RVT were available for harvest and taste evaluation during this conference. Those in attendance included research scientists, nursery operators, horticulturists, amateur naturalists, a perfume chemist, and several freelance writers. Several presentations were made regarding pawpaw research in nutrition, reproductive biology, germination/container culture, early growth enhancement, transplanting techniques, and anticancer drug development. In addition, workshops were held on evaluating fruit, taste testing, cleaning seed, and grafting/budding techniques. Participants also were treated to a presentation and taste evaluation comparing many of the tropical Annonaceous relatives of pawpaw. A second international conference will be held at KSU in Sept. 1997.

CONCLUSIONS

Considerable efforts are currently underway at KSU and Purdue Univ. (and others will soon be implemented at several academic institutions through RVT cooperation) to overcome the horticultural limitations to developing pawpaw as a new commercial fruit crop. In addition to the aforementioned research, several additional areas will also require concerted attention: 1) developing postharvest techniques to maximize shelf life and maintain quality of fresh fruit; 2) developing processed pawpaw food products; 3) developing commercial/retail markets and promotion/public education strategies; 4) developing commercially feasible techniques for a renewable pawpaw biomass production system; and 5) developing an understanding of pollination biology and strategy to ensure adequate fruit production. As these and other questions are addressed and answered, pawpaw will almost certainly become a profitable fruit crop to grow in the United States and it may gain popularity similar to kiwifruit [*Actinidia deliciosa* (A. Chev.) C.F. Liang et Ferguson] in the future.

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