The Papaya Special

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Red-fleshed Sunrise Papaya, a favorite of Molokai farmers due to its good yields, striking red-orange flesh, and superior sweetness.

Papaya is a tropical crop adapted to a narrow range of temperatures found ideally in the tropics. It can be grown in the warmer subtropics as an annual crop. Hawaii is at the northern edge of the tropics with a climate moderated by dominant northeast trade winds that create cooler weather than normally experienced in the tropics.

In the warmer summer months, temperatures can be as high as 90^{o} F, occasionally above 100^{o} F with either very low or high humidity similar to the more tropical areas.

Papaya is native to the lowlands of Central America from South Mexico to Nicaragua. It is a volunteer crop in forests where it's often the first to become established when there's a break in the canopy.

Papaya's abundance of seed and long seed viability allowed this crop to be carried to all corners of the tropical world. In these areas, farmers and gardeners selected superior plants for their specific needs and conditions.

Papaya arrived in Hawaii in the early 1800s from the Marquesas, and botanist Don Francisco de Marin is credited with its introduction.

Hawaii Papaya Cultivars

The most important commercial papaya variety is the smaller pear-shaped 'Solo' type, introduced to Hawaii from the Caribbean in the early 1900's. Early introductions included the larger watermelon-type papaya still found in Hawaii.

Today, the Hawaiian 'Solo' papaya reigns supreme, and is called 'Solo' because it's small enough for one person to consume at one sitting, breakfast, lunch, dinner, or anytime, and not because the tree is short and 'so-low'.

Hawaii Solo varieties include Kapoho, Waimanalo Low-Bearing (X-77), Sunrise, and Sunset. Other solo varieties grown in rural communities can still be found, but are rapidly disappearing due to the presence of

Papaya Ringspot Virus (PRSV), a debilitating virus that can wipe out a papaya crop and is found pan-tropically.

Genetically-modified (GM) varieties developed to resist Papaya Ringspot Virus (PRSV), include Rainbow and Sun-up. Additional regional varieties have been derived from GM pioneers, including Kahuku Sweet, and Laie Gold.

Molokai Sunrise

On Molokai, in the absence of PRSV, the Sunrise variety is grown almost exclusively, both for subsistence and commercial production. Most of the commercial crop on Molokai is grown organically and sold through organic markets such as Whole Foods, shipped out-of-state, and on-line.

Ripe Molokai Sunrise papaya ready to eat.

The red-fleshed Sunrise is a cross between **Line 9**, an orange-red flesh Solo variety with good plant characteristics but low sugar content, and **Kariya Solo**, a good standard-type growers strain from Oahu with yellow flesh and high fruit quality.

Sunrise was developed by Dr. Richard Hamilton and Dr. Phil Ito of UH Hawaii Institute for Tropical Agriculture and Human Resources (HITAHR), and released in the mid-1960s. In production areas with high light intensity, sugar levels as total soluble solids (TSS) can reach 16, considered high for papaya. Total soluble solids, sugar content, or Brix is a measure of sweetness.

A sister line of Sunrise Solo is Sunset, a firmer fruit than Sunrise due to a different ripening pattern resulting in a longer post-harvest shelf life. Under Molokai conditions, Sunset has a tendency to produce a crowded fruit column with more than one fruit a peduncle or stem.

This variety holds potential for expanded production and export of papaya because of its longer post-harvest shelf life. Seed selection to reduce column crowding could move this variety ahead of Sunrise as the preferred red-fleshed export variety.

The Kauai Experience

Sunrise Solo has been grown commercially in the Moloa'a area on Kauai since the early 1970's. Farmers have selected seeds for their specific needs and conditions for over two decades. Moloa'a soil is similar to the soils of Ho'olehua on Molokai, i.e. red pineapple soils known as Oxisols.

Seed improvement priorities for Kauai growers have included uniformity of fruit size and shape, low bearing height and fruit set, fruit flesh color and high TSS. Trees selected should also have little or no summer 'skips' or flower drop due to high temperatures and low soil moisture conditions. Short leaf stem lengths allow for closer in-line spacing between trees resulting in higher density plantings. If leaves overlap, photosynthetic efficiency is decreased in the shaded leaves.

When growth is optimal, farmers have had to thin fruits because of fruit overcrowding. Multiple fruiting at one node can be a measure of plant health but can lead to flattened fruit that are not suitable for

marketing. Softer fruit has been an indication of plant stress, including nutritional imbalance or deficiencies, and poor cultural management practices.

Young hermaphrodite fruits of Sunrise with its characteristic pear shape.

Root-knot nematodes, *Meloidogyne incognita* and *Meloidogyne javanica,* can be a major limiting factor in papaya production, especially on pineapple soils. Root galls from nematode feeding result in decreased nutrient uptake and water stress, no matter what nutrients are available in the soil or amount of water given.

Organic remedies include application of large amounts of organic matter and also utilizing nematode-resistant cover crops as a rotation prior to planting papaya to break the nematode growth cycles. However, even in low concentrations at the start of the crop season, nematode populations can explode, seriously affecting crop output.

Hurricanes Iwa in 1982, and Iniki ten years later in 1992 resulted of major devastation to the Moloa'a papaya crop. Wet conditions after the hurricanes spawned the proliferation of ***Phythophthora infestans***, a serious fungal disease that ravaged crops, and farmers never fully recovered even into the late 1990's. Today, small pockets of Sunrise papaya are still grown on Kauai, but not to the scale found prior to the two hurricanes.

Where's the Seed?

Planting seeds from a papaya purchased in a local store can be dicey unless you're buying it on Molokai since you know the seed will be the Sunrise variety. On Molokai, we share seeds with each other or just save seeds from a good papaya. The UH CTAHR Seed Store is a good source of papaya seed, with many varieties available.

Climatic Conditions

When identifying a good location to plant papaya, the first rule of thumb is finding a lowland location from sea level to 500 feet elevation, although some production is found at higher elevations.

Papaya is a shade-avoiding species, and thrives is sunny open areas within an adaptable temperature range. Areas with minimum cloud cover are ideal for this crop. Competing interests for these kinds of conditions in the lowland for housing still leaves a few areas available in the state for this crop, including South Kauai, Maui's Central Plains, and Hoolehua on Molokai.

The optimum growing temperature is between 70 to 88^{o} F. Less than optimum temperatures will affect the sexual orientation of flowers and pollination. A minimum humidity of 66% is required for optimal growth, since lower humidity can adversely affect flower development as well.

Rainfall of about 1 inch per week is sufficient for good growth. In lower rainfall conditions, supplemental irrigation is required. Drought causes rapid shedding of new flowers and older leaves, and poor fruit set.

At maturity, there's an average of 15 leaves per tree. In Hawaii, papaya leaves are produced at the rate of 2.4 leaves per week in the cool season and 3.0 leaves in the warm season.

Crazy Papaya Sex

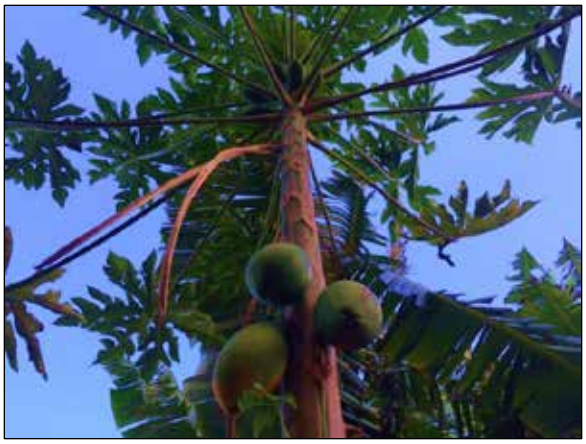
Of all the major tropical fruit crops, papaya is probably the most complicated when it comes to the sex of flowers and also sex of the trees. There are five basic types of papaya flowers, including male, female, and three types of hermaphrodites or male and female flowers in the same flower.

Three tree sex types are male, female, and hermaphrodite with eight possible flower combinations. Many of these flowers can change their sexual orientation with changes in temperature, including both high and low temperatures affecting sex in different ways.

The greatest variation occurs with hermaphrodite flowers. Flowers are very temperature sensitive, with a limited range of adaptability in Hawaii. Extremely high temperatures can cause the shedding of female flowers or rendering hermaphrodite flowers functionally male with poorly developed female parts.

With the lack of both sexes present, cross-pollination doesn't occur, and flowers will drop off the tree and create gaps in fruit set, referred to as '***skips'. Skips*** occurring during summer months can affect winter fruit availability, and the ability to deliver a consistent supply to markets.

Environmental conditions triggering changes in sex type of flowers occurs a month or more before effects are seen. Temperatures above 85^{o} F can rapidly decrease the net photosynthetic rate.



An extreme case of 'skips' in a volunteer hermaphrodite tree resulting from a combination of water and nutrient stress in addition to high summer temperatures.

Carpellody

At the other end of temperature effects is carpellody or catfacing. This disorder occurs when initially hermaphroditic fruits resemble misshapen female fruits. In this case, the male part of hermaphroditic flowers fuse with female parts, and can be pollinated by pollen from other trees. The fruits that developed are misshapen and normally not suitable for marketing. This disorder is caused by a combination of factors starting with low temperatures and further aggravated by high moisture and nitrogen.

Temperatures of less than 63^{o} F can result in 100% carpellodic fruits. This tendency also varies between and within cultivars. Varieties such as Sunrise have been screened for carpellody and selected away from this disorder.

Seed Selection

Selecting superior trees for seed saving is a critical step in ongoing crop improvement to select away from characteristics causing abscission or flower drop (summer sterility). In selecting key individual trees for seed

increase, selections should be evaluated for occurrence of stamen carpellody in winter and again during warm periods for female sterility. Trees that show no carpellody in winter may show a high incidence of female sterility in summer, or the opposite.

The author with the red-fleshed Taiwanese papaya Red 14, including female (L) and pentandria hermaphrodite (R) trees. In Taiwan, these are served in restaurants in 3 inch squares similar to brownies. Note different degrees of'skips' on trees.

Seed selections should be conducted in less than ideal conditions when trees show their true sexual orientation, including both extreme cold and hot conditions. Seeds gathered from hermaphrodite flowers will breed true-to-type, and self-pollination in papaya does not appear to result in any loss of vigor.

There's some research indicating that in subtropical conditions, dioecious trees with male and female on different trees are better able to withstand less than ideal growing conditions, both hot and cold conditions than hermaphrodite trees, and you see this is other areas of the world such as Taiwan and India.

However, in Hawaii, the market demands uniform hermaphrodite fruits and drives production, so female fruits cannot be sold in commercial markets.

Multiple Fruit Set

As previously mentioned, hermaphrodite trees have a propensity to hold multiple fruits on a peduncle or at one leaf node. It's common for the terminal flower to set while lateral flowers will drop off, but under favorable growing conditions with healthy plants, one or two laterals may be set and persist for 2-3 weeks or remain to produce undersized fruits that crowd the fruit column.

Crowding creates fruit compaction and misshapen fruit, affecting the grade-out of fruits, leading to a considerable percentage of culls. Fruit thinning is practiced, but can be costly and labor intensive. The degree of compaction is affected by peduncle length; with a longer peduncle, more fruits can be held. Multiple fruiting can be a function of variety and the environment, but is also strongly influenced by soil fertility.

Peduncles must be long enough to prevent overcrowding which produce misshapen, 'pancake-like', flat fruit. Sunset has a tendency to hold on to more fruits compared to Sunrise, and could be related to nutrient efficiency of the cultivar.

Annual fruit set depends upon the length of the female sterility period in hot weather. When there's an extended period of hotter than usual weather, skips can continue for a while, even over a month. When this happens, it will adversely affect the overall fruit set and fruit count of that tree over the

entire crop season. Again, seed selection under adverse weather conditions is important and should be on-going.

Temperatures during the growing season significantly influence fruit growth and development from 120-150 days in Hawaii. Fruit set as the plants head into winter months can take 90 days longer to reach maturity in some cooler growing areas of the world. Under these cool conditions, planting field increments at regular intervals will not produce a consistent supply of fruit, especially during winter months due to the 'winter' delayed fruit development effect.

Final fruit size is determined in the first 4-6 weeks of fruit development and temperatures play a dominant role in fruit size, especially in the cooler areas of Hawaii. Fruits that develop in the cooler season often have lower total soluble solids (sweetness) and smaller final fruit size. Fruits produced in less than ideal conditions can have a milky aftertaste, especially those harvesting in the cooler months of the year.

Day length is not believed to affect tree growth, fruit production or sex expression. Tree size and trunk diameter affect the storage of carbohydrates, and subsequently the allocation of sugars to produce high quality fruits.

Wind Damage

The Hoolehua area is consistently windy, and wind speeds of 40 mph over extended periods of time are not uncommon, so windbreaks are a must. Windbreak species can include Ironwood *Casuarina equisetifolia*, Panax *Polyscias guilfoylei,* and Dwarf Brazilian banana *Musa acuminata X balbisiana.* Papaya trees are delicate and require protection from strong wings. Some papaya cultivars can reach heights of 22-29 feet, though trees become more uneconomic to harvest above 12 feet due to increased time required to harvest each fruit.

Wind damage is insidious and can affect above and below ground parts. Flowers are susceptible to damage causing flower drop, incomplete pollination and ultimately fruit shape. Fruits are scratched by broken branches, affecting grade-out.

A young toppled papaya tree exposes its shallow root system. Papaya fields require wind protection, especially on Molokai.

Well-developed root systems, though shallow, can be uprooted by wind speeds of 40 mph especially if soil is softened by rain. Resulting loss in leaf surface can lead to flower and young fruit drop, and also low total soluble solids in the more mature fruit on the column. Full recovery of leaves from wind damage might take from 1 to 2 months if roots are not irreparably damaged.

The most essential requirement for optimal papaya production is well drained soil. Poor drainage, including flooding, will adversely affect root development and induce root rots such as ***Phythophthora*** and ***Pythium*** that are difficult to recover from due to slowed root growth of fruiting trees.

It's believed that roots reach its maximum growth before fruiting so it's important to encourage and nurture active root growth early in the life of the plant, from seedling to early fruiting. Any stunting from insufficient water or nutrients will adversely affect the total productivity of the tree and also fruit quality.

After transplanting, shoot growth is initially slow, though considerable root growth is taking place, extending out well beyond the canopy drip line. Stem growth is then rapid up to flowering. Root growth peaks at flowering then declines as the tree starts bearing. The rate of growth is strongly influenced by nitrogen and phosphorus supply, irrigation and temperature.

Red Flesh Breeds True

Red-fleshed varieties such as Sunrise will breed true for flesh color, although there can be some variation in the intensity of color, so selecting for intense reddish color should be a seed selection priority.

Flesh color can be a distinguishing characteristic in product identification and marketing, and an important selling point targeting the health-conscious consumer. Due to its reddish flesh color Sunrise contains slightly higher amounts of two important anti-oxidants, lycopene and beta-carotene, than yellow-fleshed varieties.

Red-fleshed cultivars are adapted to a wider range of climatic conditions compared to yellow-fleshed cultivars in Hawaii since yellow fleshed cultivars are more exacting in their requirements. Again, constant crop improvement through focused seed selection can create a superior variety adapted to your specific farm location.

It All Starts With Seed

Papaya seed can be harvested when the fruits reach beyond the 'color break' stage. Growers select seeds from trees with desirable characteristics, especially those with uniform fruit shape and minimal skips on the fruit column.

Selecting trees with a high percentage of marketable fruits is important. In Hoolehua's arid summer conditions, some trees will stretch and get too tall in a short time. Identifying compact plants allows for a longer harvest period. Individuals with a strong multiple fruiting habit appear to stretch less compared to those with single fruit, but this could also be the result of nutrient, heat or water stress or all of these.

A physiological disorder believed to be calcium deficiency can be aggravated by high nitrogen, low calcium, insufficient water, and root damage or all of the above.

Some research has shown that seeds harvested fresh from fruit have very low and variable germination. However, reports from Molokai papaya growers indicate they've had good success when planting fresh seed, just washed thoroughly and sown either in trays or directly in the ground. Also selecting fruits from over-mature fruits can

increase viability since most seed will be mature.

Seeds are can be dried to moisture levels of 9-12% for long term storage. Removal of the sarcotesta or the clear sac around individual seed, seed drying, and cool-temperature storage at 60^{o} F for 30-50 days will enhance uniformity of germination. Seeds processed by the removal of the sarcotesta, well dried and stored at 41^{o} F retain germination for 5 years.

Removing moisture from seeds through proper drying immediately after removal from the fruits and proper washing is critical to enhancing storage life, followed by storage at proper temperatures. Storing seeds at room temperature in Hawaii with high humidity can result in fungal growth and poor seed viability.

There are numerous methods to germinate seeds, in flats, cells, peat pots, poly pots, and directly in the ground. Although cost is a major consideration, growing vigorous seedlings is a critical step in the production process that cannot be overlooked. Stunting of seedlings in the early stages of development can affect tree productivity and fruit quality over the long term.

Hoolehua Hawaiian Homes farmer John Freeman cultivating his organic Sunrise papaya field.

Papaya seeds will usually germinate in two weeks in poly bags and are transplanted at the 8-12-leaf stage, after about 12 weeks. Sometimes grown in 1-2 inch cells, this method will stunt the early growth of plants if not transplanted before roots crowd the cell.

Seeds may be sown in trays in suitable medium such as peat-based mixes, and transplanted at the two-leaf stage into small poly pots or peat pots. Recently transplanted seedlings should be hardened gradually in sunlight and field-transplanted around 1 ½ to 2 months after germination, at about 8 inches high.

In the early seedling stages, papaya is susceptible to salt stress, so caution should be exercised when using salt-based fertilizers, both conventional and organic, in the transplant and early growth stages.

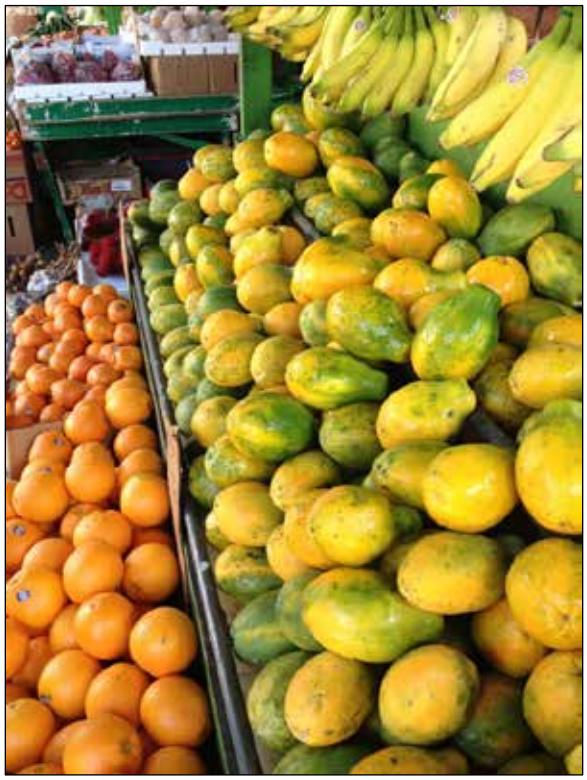
Sunrise papaya has a hermaphrodite-to-female ratio of 2:1; 2/3's of seeds in a fruit will produce hermaphrodite trees and 1/3 will produce female trees. To assure at least 2 seedlings are hermaphroditic, a minimum of 4 seedlings are sown per hole, but sowing 2-3 times more seeds may be more desirable to select superior seedlings since seeds are cheap and plentiful.

In-row spacing can range from 5 to 7 feet between planting holes, while between-row spacing can range from 10-12 feet to facilitate equipment access to cultivate for weed control, spray, and also harvest.

In Molokai's central plains of Hoolehua where most of the papaya production occurs, annual rainfall ranges from 20-60 inches and fields require weekly irrigation. Water requirements as high as 2 inches is required under arid summer conditions due

to strong prevailing trade winds that rapidly dry soil surfaces.

There are many options to establish seedlings. They can be direct seeded or transplanted. Drip irrigation, poly pipe with emitters, and micro-sprinklers are some of the irrigation methods utilized by farmers. After establishment, most farmers will convert to micro-sprinklers to evenly distribute water over the entire root system.



Papaya for sale in an open-air display in Chinatown Honolulu. This variety is most likely one of Hawaii's genetically-modified cultivars.

Drip irrigation, including double-line drip has not been as effective in optimizing growth as irrigating the total root area with micro-sprinklers. Irrigation amounts should be closely monitored by determining evapotranspiration rates since root development is critical for optimal growth. Over-watering can create ideal conditions for the spread Pythium root rot, a major disease of papaya in Molokai conditions.

There are many options for field preparation, especially in rough terrain. Ideally, ripping down to 20 inches is desirable on heavy or compacted soils so roots can penetrate deeply. Although some recommendations include creating planting holes of 12–18 in with a soil auger attached to tractors, the red soils of Ho'olehua are amenable to direct seeding or transplanting after cultivation without drilling holes.

Weed control is important in early stages of establishment since weeds can overrun seedlings. Regularly or weekly scheduled hand weeding is practiced in rows. The use of plastic mulch has been employed in seedling rows to minimize weeds.

When disks are used between rows to control weeds, caution must be exercised in preventing damage to roots. Any disking after trees are fruiting can create irreparable damage to roots since they won't regenerate at that stage of crop development.

Seedlings are monitored for the first signs of sex differentiation. Usually, the most robust trees are females and are culled. There has been on-going research to look at methods of propagating only hermaphrodites to cut down on the time it takes to manage seedlings you're not going to grow to maturity. Methods include rooted cuttings and micro-propagation, and this will probably be what the future will look like for papaya production.

Customizing soil health programs starts by building organic matter including cover and green manure crops. A soil sample can identify basic nutrient needs starting with pH adjustment and including phosphorus,

potassium, magnesium, and calcium. Nitrogen is always assumed to be in short supply.

Crop nutrition programs in commercial organic systems are a challenge since it's difficult to supply the needs of the crop over the entire crop period in such a heavy fruit producer like papaya. Yields of 80,000 pounds per acre per year are not unheard of.

Adjusting the pH between 5.5 and 6.5, preferably above 6, and supplying adequate calcium is important, and may include one or more calcium sources to meet optimal levels for both pH and Calcium.

Based on the experiences of Kauai papaya growers in conventional farming systems, Sunrise papaya is a heavy feeder of phosphorus, especially when roots are rapidly developing. Some Kauai farmers were applying ½ -1 pound of treble superphosphate 0-46-0 per hole before transplanting. They also believe that potassium is important to enhance fruit sweetness and optimal levels should be maintained especially prior to harvesting.

The use of organic fertilizers such as Honolulu-manufactured tankage, including bone and blood meal, will help to extend the availability of nitrogen and phosphorus over the majority of the crop production season at rates above 2000-3000 pounds per acre due to its slow release characteristics. In most of the Oxisols of Hoolehua, native potassium is adequate and in some cases, abundant.

Biochar is being tested and seem to have benefits other than calcium and potassium supply, including improved aeration and possibly enhanced nutrient exchange. Farmers have been spraying and injecting manure teas, and could utilize tankage with worm castings that appear to improve breakdown of nutrients. Fertigating with additional filtration prevents clogging of filters and irrigation lines, and prematurely wearing out the fertilizer injector.

Black Spot, Cercospora papaya is a fungus that favors wet conditions and is uncommon on Molokai due to prevailing dry and windy conditions.

The key in pulling all pieces of your farm puzzle together is matching all components to your farming system and finding a middle road between an extensive and sustainable system versus an intensive high-return and high-input production strategy. As we move more toward a sustainable system, fine-tuning this system is the key in preventing the depletion of key soil nutrients in one season, and papaya will need to be one piece of a larger crop rotation system on the farm.

Major pests include mites, both spider and broad mites, and control measures have included regular Sulfur sprays, and more recently utilizing Jadam natural farming methods of creating liquid Sulfur. This liquid seems to coat the entire plant and doesn't leave a Sulfur powder residue on fruits.

The main disease on Molokai is Powdery Mildew, which is also controlled with Sulfur. Humid areas with warm days and cool nights are ideal for the spread of this fungus. Cultural control methods to slow the spread of this disease include adequate spacing to encourage air circulation, and more importantly growing healthy, stress-free plants.

Anthracnose Oidium caracae can be a serious post-harvest fungus in which infection starts in the field. Moist field conditions and poor plant health can aggravate this problem

Anthracnose fungus *Oidium caracae* can become a problem during moist periods of the year or when plants are weak and susceptible to this disease. Sulfur can also help to mitigate this problem, but good soil health and a balance of nutrients can prevent this disease from taking hold.

Disease control starts by growing a healthy plant, but more importantly in knowing how to grow healthy papaya. However, when conditions are ideal for these diseases, it can be a perfect storm!

Nutritionally speaking, papaya is higher in key nutrients than apple and orange, including Potassium, Vitamin C, Vitamin A, and Beta-carotene!

There's much more to know about growing papaya than a short newsletter can convey. Observation has always been a farmer's most important tool to refine and improve his production system, and experience an important teacher that can be priceless. In farming, you control the things you have control over and for the rest, you hope for the best.

For more information on papaya production in Hawaii, check out the CTAHR Publications website at: http://www.ctahr.hawaii.edu/Site/Info.aspx

REFERENCES: *Information contained in this newsletter was gleaned from many sources, including Tropical Fruits, Volume 1, 2nd Edition by Robert E. Paull and Odilo Duarte, CTAHR publications on papaya, and also from personal experience growing papaya on Molokai. Special thanks to Dr. Robert Paull for reviewing and giving valuable input into this newsletter. Thanks also go to fellow Molokai Extension Agent Alton Arakaki, and Kauai papaya grower Sherwood Conant for sharing their knowledge on things papaya.*

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Well, that's it for this quarter! There's a lot to reflect on as we head into a New Year. It's about fine-tuning and readjusting your farming system to make it work better for you. It's about teaming up with others who have similar values. We need to work smarter and not harder so our backs can hopefully last as long as our brains. Happy Holidays to you and yours, and have a productive and prosperous New Year!

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