

Specialty Crops for Pacific Island Agroforestry (<http://agroforestry.net/scps>)

**Farm and Forestry  
Production and Marketing Profile for**

# **Macadamia Nut**

*(Macadamia integrifolia and M. tetraphylla)*

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## USES

Dried kernels are roasted and manufactured by processors and industrial users into a wide number of products featuring whole or half kernels that are unsalted, dusted with finely ground confectionery salt, or flavored. Chocolate-coated kernels have become a major product. Second grade and broken kernels (pieces) are used in confectionery products such as brittles and candies or diced for use as garnishes, ice cream, sherbets, cakes, and pastries. Kernels are also milled into a premium nut butter and the oil is extracted for use in food and cosmetics.

## BOTANY

### Taxonomy

#### *Preferred scientific names*

*Macadamia integrifolia* Maiden & Betche

*Macadamia tetraphylla* L.

#### *Family*

Proteaceae

Although other macadamia species are found in the Proteaceae family, only *M. integrifolia* also called “smooth shell macadamia” and *M. tetraphylla* L. known as “rough shell macadamia” along with interspecific hybrids of these species are economically important members of the family because of their edible kernels. “Smooth shell” and “rough shell” are terms derived from the smooth characteristic or pebbled appearance of the outer surface of the shell that encases the edible kernel. In Australia macadamia is also occasionally referred to as Queensland nut or bauple nut.

### Description

Trees are evergreen and can attain heights of 19 m with canopy widths of 13 m. The bearing life of a tree is not known, but the productive life of orchard trees can be 40 to 60 years or longer with proper soil management and suitable climates. *M. integrifolia* is the principal species under cultivation because of its higher quality kernels. Kernels from *M. integrifolia* contain 75–79% oil and 4.57% total sugar, whereas, *M. tetraphylla* kernels contain about 5% less oil and a higher sugar content. Due to their lower oil and higher sugar content, *M. tetraphylla* kernels are more variable in color, texture, and flavor when roasted and considered inferior to *M. integrifolia* for processing. Additional characteristics of *M. integrifolia* include presence of three leaves at each node, light green or bronze colored young leaves, and mature leaves that are 10–15 cm in length with about a 1.3 cm long petiole. Flowers are white or creamy white. *M. tetraphylla* leaves are longer, lack or have very short petioles, occur in whorls of four, and are more spiny and serrated



Top: Mature *M. integrifolia* (smooth shell macadamia) nuts: in-husk, in-shell, and kernels. Middle: Flowering of *M. integrifolia*. Honey bees are very important pollinators of macadamia nut. Bottom: Flowering of *M. tetraphylla* (rough shell macadamia) in New South Wales, Australia. Note the reddish coloration of the blossoms and the arrangement of four leaves at each stem node.

along the margin. Young leaves and flowers are purple or reddish in color.

The mature fruit is a dehiscent follicle that splits along a single suture in the “husk” (pericarp), which remains green at maturity. The “shell” develops from the seed coat and is composed of thick-walled cells that enclose the “kernel” (embryo and cotyledons). During selection of new cultivars, an open micropyle (opening in the shell) at maturity is considered a problem, because it serves as an entryway for insects, molds, and moisture, which can reduce kernel quality.

Smooth shell macadamia flowers are borne on pendulant racemes possessing 100–300 perfect white or cream-colored flowers on the rachis, which can be 20 cm in length. Individual flowers are about 12 mm in length. The pistil of each flower contains two ovules and a 10 mm style capped with a small stigmatic surface. Surrounding the pistil are four stamens. It is estimated that 10,000 racemes are produced on a 15-year-old tree during the flowering season.

### Native area

Macadamia is native to Australian subtropical rainforests. Native habitats for *M. integrifolia* are along eastern Queensland within latitude 25.5–28.3°S, while *M. tetraphylla* is found naturally further south from southern Queensland into the northeast coastal area of New South Wales, extending over a 120 km range between 27.6 and 29°S latitude. Both species overlap in southern Queensland where interspecific hybrids grow naturally. Today *M. integrifolia* is found in the wild in southeast Queensland and the Australian Environment Protection and Biodiversity Conservation Act has classified the species as “vulnerable.” Although not critically endangered, it could face a risk of extinction in the wild in the medium-term future.

*Macadamia* species have been found in New Caledonia and the Celebes in Indonesia. Six species have been identified from New Caledonia. A New Caledonian species, *M. leptophylla* (Guillaumin) Viro, locally known as “white beech,” is considered a good timber tree and reportedly has edible seeds used for food by the indigenous people.

## PRODUCTION

### World distribution and production

Major production areas occur in Australia, Hawai‘i, South Africa, Kenya, Malawi, Guatemala, Brazil, Costa Rica, and Zimbabwe. High market value of kernels and a need to diversify agriculture have led to increased production in some underdeveloped countries. Hawai‘i Island was once the largest producer and marketer, but production has remained



In its native habitat macadamia can be found growing as an inconspicuous understory tree in the subtropical rainforests of eastern Queensland and New South Wales, Australia.

constant over the past 10 years due to absence of new plantings.

Macadamia’s association with Hawai‘i comes from a long history of production in the islands with its introduction into the islands in the 1880s. The foresight of Hawai‘i’s entrepreneurs in collaboration with the University of Hawai‘i transformed this inconspicuous forest tree into a thriving commercial industry in Hawai‘i, Australia, Africa and South and Central America. The first commercial orchard was planted from seeds on Round Top above Honolulu in 1925 followed by construction of a processing factory near Kaka‘ako in 1931. Scientists working with the Hawai‘i Agricultural Experiment Station (HAES) developed a grafting technique to clonally propagate high yielding cultivars; it remains the current technique used in all nursery operations.

Selection of new varieties by HAES scientists began in 1936 and continues today. Development of macadamia into an important industry was fostered by identification of new cultivars that can produce yields 3 to 5 times greater than seedling trees of comparable age and size. Cultivars from Hawai‘i make up the majority of the trees in orchards throughout the world and were developed from plants that were initially introduced into Hawai‘i between 1881 and 1892. Hawai‘i’s varieties were developed under mild growing conditions found in Kona, Ka‘ū, Hilo, and Hāmākua, and yields per tree in Hawai‘i have traditionally been higher than in other areas. Marketing strategies will need to continue promoting the Hawaiian grown concept to create a gourmet market for the Hawai‘i’s nuts. It will be difficult to compete with low cost producers in the industrial market where inexpensive foreign imported nuts are sold in bulk as an ingredient for manufacture into products such as cookies, candies, and ice cream.

Australia with 40% of the world's production is currently the largest producer and exporter. Australia's main production area consists of a 520 km strip along the eastern coast from Nambucca in northeast New South Wales to Bundaberg in southeast Queensland with isolated production on the Atherton Tablelands and in Western Australia. South Africa is becoming a more important producer since the country has 1.4 million juvenile trees not yet in production and another 934,000 trees coming into bearing. About 61% of the young trees have been planted in Mpumalanga province. Commercial production of *M. integrifolia* and *M. tetraphylla* in Pacific islands other than Hawai'i is nearly non-existent due to absence of processing infrastructure and the lack of field trials to evaluate production in suitable growing environments. In the 1960s macadamia was planted in Fiji, but due to regular cyclonic activity orchards perished and only isolated clumps of trees survive.

USDA Foreign Agricultural Service statistics show that world production is approximately 93,000 MT wet-in-shell nuts with the majority of production coming from areas in Australia, Hawai'i, South Africa, Kenya, Malawi, Guatemala and Brazil (USDA FAS 2004). Between 1996 and 2004, world production rose by 42% due to major increases from Australia, Guatemala, and South Africa. Data from the Southern African Macadamia Growers' Association show

that a total of 26,123 MT of kernels was produced in 2008 by Australia, South Africa, Hawai'i, Kenya, Malawi, Guatemala, Brazil, Costa Rica, and Zimbabwe (SAMAC 2009). Comparing production figures between producing areas is difficult, because uniform methods for computing production based on a standard in-shell moisture level or sound kernel recovery are not used. In 2008, 28 MT of kernels were imported to Hawai'i compared to the estimated 5,000 MT of kernels produced in Hawai'i. Imports figures do not include kernels that were trans-shipped into the islands from mainland U.S. ports receiving foreign kernels. Data on imports into various Pacific islands are not available (USDA NASS 2009).

### Environmental requirements

World production is generally found between 0 and 32° latitude and optimum production occurs where temperatures do not exceed 30°C or fall below 13°C. Maximum and minimum temperature ranges are related to optimum photosynthesis, vegetative growth, and floral development. Temperature is a dominant factor influencing vegetative growth with major flushes occurring at 20–30°C. Vegetative growth and dry matter production are optimal between 20 and 25°C, and below 10°C and above 35°C growth ceases. Where temperatures are consistently high, leaf growth becomes chlorotic and distorted. Trees are frost sensitive. Maximum net photosynthesis occurs at 14–25°C, decreases sharply at 26°C, and ceases above 38°C. Uniformly distributed rainfall of 1,200–2,300 mm/year is adequate with drier periods during flowering being less conducive to development of blossom diseases. Some of the best yields occur in the Kona district of Hawai'i where rainfall is 1,500 mm/year with a drier season from December to early summer when flowering and early nut development occur; mean annual temperature is 20.5°C, and average maximum and minimum temperatures are 25.5°C and 15.5°C respectively. Trees survive in areas with rainfall of 510 mm/year or less as in parts of South Kona in Hawai'i, but tree growth is slow and production is low during excessively dry years. Most orchards in Hawai'i are found at elevations of 60–610 m above sea level.

### Soil requirements

Growing sites differ widely with regard to soil composition and chemistry, but trees will perform best in well drained soils that have high organic matter content. Orchards on rocky lava soils in Hawai'i can be productive, but trees are susceptible to drought stress and require heavy fertilizer inputs in high rainfall areas. Deeper clay soils with a depth of at least 1 m are best, but soils that become waterlogged during prolonged wet weather should be avoided. Soil pH of 5.0–6.5 is optimal. Macadamia is moderately sensitive to salinity compared to other crops. Seedlings grown in silica sand exhibit no adverse effects when salinity in irrigation water is below 3.0 dS/m, but growth ceases above 7.0 dS/m. Seedlings grown in an Oxisol, containing 42% clay, 32% silt,



A promotional display at Honolulu International Airport reinforces the Hawai'i-grown macadamia nut identity by exposing visitors to various macadamia products (whole kernels, nut butter, candies, etc.) as well as recipes.

**Table 1. Elevation, rainfall, and temperature for Hawai'i**

|                               |  |
|-------------------------------|--|
| Elevation range               | <b>lower:</b> 60 m<br><b>upper:</b> 610 m      |
| Mean annual rainfall          | <b>lower:</b> 510 mm<br><b>upper:</b> 2,300 mm |
| Rainfall pattern              | It prefers uniformly distributed rainfall      |
| Dry season duration           | 2–3 months                                     |
| Mean annual temperature       | <b>lower:</b> 15.5°C<br><b>upper:</b> 25.5°C   |
| Minimum temperature tolerated | 0°C (does not tolerate frost)                  |

and 20% sand show a 50% reduction in growth at EC = 5.0 dS/m in the soil paste extract and at 6.6 dS/m in the soil solution. When EC in the soil paste is below 3.5 dS/m and below 5.0 dS/m in the soil solution, growth is not affected.

### Tree growth and nut development

Trees in Hawai'i come into bearing at about 3–4 years after transplanting into the orchard, but economic yields are not realized until 6–7 years. Under good growing conditions, trees are considered mature between the 10th and 16th year after planting. Branches cycle between an active growth phase and a resting phase, but the entire tree is not in synchrony with regard to vegetative flushing. A characteristic of macadamia trees is the presence of vegetative flushes on a tree throughout the year, however, major flushing peaks are present during the early spring (March in Hawai'i and August–September in Australia) and late summer (September–October in Hawai'i and mid January–March in Australia).

In Hawai'i, flowering occurs from late November to May with up to three discernible flowering peaks observed within a cultivar during the flowering season. Flowering in Australia is more concentrated than in Hawai'i, and maximum flowering occurs from August to September. Induction of flowering occurs when warm night temperatures are followed by cooler night temperatures below 20°C. For cultivars developed in Hawai'i, the night temperature range for optimum flower induction lies between 15 and 18°C. The period between exposure to cool temperatures and differentiation of floral buds can vary between 4 to 8 weeks.

Nuts mature about 30 weeks after flowering when kernels have an oil content of 75–79%, which contributes greatly to kernel quality. During the first 13 weeks after flowering little change in the oil content of the kernel occurs. During kernel growth, oil content increases to half of its final concentration by 19 weeks and reaches 67% at 30 days before maturity. Of the approximately 300 flowers borne on each raceme, between 6 to 35% of the flowers set initially, however, only about 0.3% of the flowers develop into mature fruit. A large drop of immature nuts occurs between 3 and 8 weeks after flowering followed by a gradual rate of drop of

larger immature nuts from 8–10 weeks after flowering until nut maturation.

### PROPAGATION

Propagation is by grafting onto *M. integrifolia* seedling rootstocks. For rootstocks, plant fresh in-shell nuts that sink in tap water, have kernels that do not rattle in the shell and shells that are not dark colored, bleached, or cracked. Seeds are germinated in beds or placed on benches under intermittent mist until shells begin to crack. Germination is best in nuts stored for less than 3 months at ambient temperatures and humidity; viability is lost after 12 months. Seeds are considered recalcitrant. Seedlings are planted into deep nursery pots after germination and kept in the nursery for 10–12 months before grafting. For successful grafting, branches (approximately 30 mm in diameter) for scion are girdled 6–8 weeks prior to grafting to stimulate carbohydrate accumu-



**Top:** Smooth shell macadamia branches in Hawai'i with flowering racemes, and racemes with nut set. **Bottom:** Nuts mature at about 30 weeks after flowering, and husks remain green.



Left: The side wedge is one grafting method to propagate macadamia trees. Right: Grafted macadamia trees in a nursery in Australia will be ready for planting out into the orchard at 10–12 months after grafting.

lation and the flowers and nuts removed. Grafting is more successful with scion from branches that are several years old. From the larger girdled branches, smaller diameter side or terminal branches that are 9–12 mm in diameter are cut into scion pieces 10–12.5 cm long with at least two nodes. A modified side wedge or a splice graft is used. In the modified side wedge method, the rootstock is topped at about 0.3–0.5 m above the soil surface where the rootstock and scion are similar in diameter. A diagonal cut is made into the rootstock beginning at one edge of the topped surface, and the base of the scion is cut into a wedge that is inserted into the diagonal cut on the rootstock. The graft union is secured with a rubber strip or plastic tape, and the scion and graft union wrapped with a flexible film such as Parafilm. A rapid splice graft technique utilizing a wood plane can be employed. A slanting cut of similar length, width, and angle is made with the wood plane on both the rootstock and scion, which are then placed together and secured with plastic nursery tape, then sealed with Parafilm. Trees are ready for planting into the orchard at 10–12 months after grafting. Bark and cleft grafts are used when topworking older trees, and inarching is occasionally done to invigorate trees by replacing a weak rootstock.

### Orchard establishment and management

Orchards are planted in blocks consisting of a mixture of two or more cultivars to optimize nut set and production. Some younger orchards in Hawai'i and Guatemala have been interplanted with coffee, but as trees become older, extreme shading will restrict production of the understory crop.

Although in its native growing in Australia, macadamia trees grow in the understory of subtropical rainforests, for maximum production cultivated trees perform best in open sunlight. Replenishing organic matter periodically under the trees is a good practice to sustain tree health. When the orchard is young, grass strips are maintained between the rows for erosion control, however as the orchard matures and tree canopies close-in, it becomes difficult to maintain these strips under the heavy shade. Mature nuts drop to the orchard floor where they are harvested mechanically or by hand, therefore a weed free or closely mowed orchard surface is best during harvesting. Trees are very susceptible to windthrow, and windbreaks of columnar araucaria (*Araucaria columnaris*, aka “Norfolk Island pine”), ironwood (*Casuarina* spp.), eucalyptus, or similar trees are recommended because of their upright growth habit and rapid establishment.

Planting grafted trees with healthy and well developed root systems will help insure long term health of the orchard is sustained. Poor transplanting practices cause tree losses due to transplant shock as trees age. Poorly developed root systems often lead to wind thrown trees or weak and unhealthy trees. When establishing a new orchard, use soil analysis to determine the lime and phosphate requirements since these nutrients should be applied prior to planting and incorporated into the soil when possible. Soils that are loose, moist, and easily penetrated by roots are ideal. Planting holes should be at least twice the size of the root ball and back filled with soil that has been amended as prescribed by soil analysis. Growers often use soil mixed with composted macadamia husks to back-fill planting holes as composted husks



Top left: A young, high-density orchard with grafted trees planted at close spacing at Bundaberg in Queensland, Australia to increase yields/ha during the early years of growth. Top right: Mature macadamia orchards in New South Wales and Queensland, Australia are hedged pruned and mechanically harvested. Middle left: Lower branches are pruned in Hawai'i to facilitate movement of equipment and to accommodate mechanical or hand harvesting. Middle right: Hedge pruning of orchards in Australia with large pruning equipment is done to manage canopy size for pest control and to encourage ground cover growth. Bottom left: Windbreaks of columnar araucaria trees protecting an orchard in Kea'au, Hawai'i from high winds. Bottom right: Macadamia trees are prone to wind damage and can be blown over by storm winds.

are a good source of nutrients, can retain moisture, and help with aeration. Since trees are kept in containers for 2 years, they should be inspected for kinked or circling roots that should be pruned off prior to planting since they constrict growth of lateral roots and weaken mature trees.

Pruning and training during the first 3 years after planting is needed to produce trees with strong branching systems that are less susceptible to breakage from high yields and strong winds. The goal is to develop a strong vertical central leader on a conical-shaped tree with scaffold branches occurring in whorls spaced about 0.5 m apart. At each whorl, there are two or three scaffold branches with wide crotch angles, of smaller girth than the leader, and spaced around the leader in a manner that growth of a branch does not interfere with another. In Hawai'i, periodic pruning of mature orchards is only done to remove lower branches that interfere with machinery movement in the orchard. In other producing countries, regular canopy pruning of mature orchards is practiced to maintain tree size and facilitate pesticide application into the canopy.

Macadamia trees require regular fertilization to sustain yields, and when neglected will exhibit chlorosis, defoliation, and dieback of terminal branches. Leaf tissue analysis is used to assess the nutritional status of trees by using recommended leaf nutrient element concentrations for bearing macadamia trees (Table 2). Leaf analyses help sustain good yields, avoid deficiencies or excessive fertilizer applications, confirm visual deficiency symptoms, and maintain proper tree nutrition through application of fertilizers with appropriate analyses. Soil analysis should be done to determine soil pH and salinity and confirm leaf analysis results. Foliar analysis is done in spring to coincide with the onset of a major vegetative flush. Leaves for analysis are taken from branches on which the terminal bud is at rest or just beginning its growth. Fully mature leaves are sampled from

**Table 2. Suggested leaf element concentrations for bearing macadamia trees. (Concentrations are based on leaf dry weight.)**

| Element        | Concentration |
|----------------|---------------|
| Nitrogen (N)   | 1.45–1.60 %   |
| Phosphorus (P) | 0.08–0.11 %   |
| Potassium (K)  | 0.60–0.70 %   |
| Calcium (Ca)   | 0.70–1.00 %   |
| Magnesium (Mg) | 0.08–0.10 %   |
| Sulfur (S)     | 0.18–0.24 %   |
| Manganese (Mn) | 50–1500 ppm   |
| Iron (Fe)      | 50 ppm        |
| Copper (Cu)    | 4–5 ppm       |
| Zinc (Zn)      | 15–20 ppm     |
| Boron (B)      | 40–75 ppm     |



Top: Mature nuts are green in husk and fall to the orchard floor where they are harvested mechanically or by hand at regular intervals to maintain kernel quality. Middle: Pinwheel harvesters can be used in smaller orchards where the topography and soil surface are suitable. Bottom: Large pinwheel harvesters can be seen operating in Australian orchards that have been established on flat terrain with a smooth soil surface.



### Establishment tips

Consider the following important points when establishing an orchard.

1. Orchards in warmer climates have experienced poor yields since high temperatures (above 30°C) are not conducive to regular flowering. Selection of appropriate growing environments is critical for consistent flowering.
2. Access to clonal germplasm for grafting is necessary for optimum production. Cultivar yields are 3–5 times greater than seedling trees of comparable age and size. In addition to poor yields, seedling trees are more variable and often have a longer juvenile period compared with grafted trees. Cultivar performance depends upon their adaptability to specific locations, and no single cultivar performs equally in all locations nor will it be superior in all characteristics.
3. Since economic yields are not obtained until 7 years after planting, establishment costs for macadamia orchards are high.

the second whorl below the terminal bud and come from branches on the outer edge of the tree canopy where they are exposed to full sunlight. Macadamia nut trees are not considered invasive, and require regular agronomic inputs (fertilizer, irrigation, weed control) for sustained production. Polyculture with macadamia is not common, because mature orchards tend to be extensive and tree canopies close in, which creates heavy shading of the understory.

## AGROFORESTRY

Intercropping with short-term crops can generate income for the first 7–10 years, before economic harvests of the nut occur. Macadamia can be cultivated in a permanent polyculture to diversify a farm's crop portfolio, similar to how some farms cultivate coffee trees together with macadamia in the Kona, Hawai'i. There is potential for cultivating with shade-tolerant specialty crops such as vanilla, black pepper, or cacao with proper pruning for light management. However, if pruning of macadamia is necessary to increase light penetration to the understory crop, trials have shown that regular pruning of the macadamia tree canopy will cause a reduction in nut yield. Macadamia can also be part of a diverse home garden or orchard for subsistence farming if obtaining maximum nut yield is not the primary goal.

### Cultivars

*M. integrifolia* cultivars developed in Hawai'i make up much of the grafted plantings for bearing orchards in the world and were developed from open pollinated seeds. Commercial cultivars have also been developed in Australia and South Africa. Cultivars are selected for their yield, kernel recovery and quality, precocity, tree growth habit, and absence of the "stick tight" condition, which prevents nuts from dropping after they mature. Hawai'i cultivars are known by their selection number rather than their cultivar name. Table 3 lists cultivars and selections most commonly planted throughout the world. Hawai'i's orchards are planted exclusively with *M. integrifolia* cultivars. *M. tetraphylla* selections and *M. integrifolia* × *tetraphylla* hybrids are usually grown in cooler semi-temperate environments as in parts of South Africa.



Left: Many farmers in Kona, Hawai'i have developed polycultures of macadamia nut and coffee. On this farm, coconuts have also been planted. Right: Due to macadamia's naturally dense canopy, intercrops such as coffee require heavy pruning of the macadamia canopy (see e.g., Elevation et al. 2009).

Cultivars are partially self-incompatible, and nut set on self-pollinated racemes is low. Therefore, planting a mixture of cultivars is necessary, because cross-pollination between cultivars increases nut set. Commercial orchards generally consist of block plantings with multiple cultivars since yield can increase 31–190% over block plantings of a single cultivar.

Identification and evaluation of new macadamia selections are ongoing in the University of Hawai‘i, Australia, South Africa, and Brazil. Criteria to initially select trees include an upright growth habit, darker green foliage, and freedom from an excessive number of stick tight nuts. Trees should also bear nuts averaging 132–154 nuts/kg, have 38–48% kernel recovery and 95% floaters, and possess kernel weights between 2.5 and 3.2 grams. The percent floaters (No. 1 grade kernels) refers to kernels that float in tap water, which means they have a specific gravity less than 1.0 and have 72% or more oil content. A lower number of floaters is due to reduced oil content in the kernels. Selection of macadamia cultivars requires long term commitment, because evaluation of new trees can take up to 10 years or more before promising selections can be propagated and evaluated in replicated field plots.

Macadamia germplasm can be obtained from nurseries in Australia and Hawai‘i and through the USDA Tropical Plant Genetic Resources and Disease Research unit (TPGR) at the Pacific Basin Agricultural Research Center in Hilo, Hawai‘i. The TPGR distributes small quantities of germplasm to researchers and the plant industry and may provide to private individuals when the material is not commercially available.

### Pest and disease management

Major insect pests and diseases in Hawai‘i and Australia are listed in Tables 4 and 5. Southern green stinkbug, fruitspotting bug, and banana-spotting bug damage nuts through the piercing-sucking action of mouth parts. Damage occurs at any stage of nut development, and feeding activity can cause premature nut drop, deform kernels or leave kernels with brownish pits. Microbial growth may be present on damaged kernels. Lepidoptera is another insect pest group found throughout macadamia growing areas. The caterpillar

**Table 3. Commonly planted macadamia cultivars and their species composition.**

| Cultivar   | Species Composition                            |
|--|--|
| Daddow, Kakea (HAES 508), Kau (HAES 344), Keauhou (HEAS 246), Makai (HAES 800), Mauka (HAES 741), Pahala (HAES 788), Purvis (HAES 294), HAES 842, HAES 849 | <i>M. integrifolia</i>                         |
| Hidden Valley A4, Hidden Valley A16, Beaumont, Nelmak 2  | <i>M. integrifolia</i> × <i>M. tetraphylla</i> |



Top: Mature orchard with closed-in trees of cultivars 344 and 788 in the Kona district of Hawai‘i. Bottom: An open micropyle (center nuts) is an undesirable characteristic, because it serves as an opening for the entry of insects and microorganisms into the kernel.

of *Cryptophlebia* species bores into husks and causes similar damage in Hawai‘i, Australia and South Africa. Larvae feed under the husk surface and bore through the shell and into the kernel if the shell has not hardened. Damage to young nuts can cause premature nut drop. The macadamia flower caterpillar attacks flower buds in Australia and can greatly reduce nut set. Tropical nut borer beetles cause serious damage in Hawai‘i by feeding on mature recently fallen nuts. Adult females bore through the husk or directly through the shell leaving a tiny circular entrance hole and lay eggs in the husk or kernel. Larvae hatch and eat through the kernel causing extensive damage.

Blossom diseases can cause significant losses, with raceme blight due to *Botrytis cinerea* fungus being most common. The disease develops on older floral tissues and is associated with high moisture, temperatures of 18–22°C, and relative humidity of 95–100%. *Phytophthora capsici* fungus blight infects racemes and young nuts and can develop to epidemic levels after a prolonged period of heavy rain and temperatures of 16.6–22.2°C. *Pseudocercospora macadamiae* sp. nov.

causes husk spot fungus disease of bearing trees in Australia and can cause heavy premature drop of nuts, particularly in older, less ventilated orchards.

Several fungi infect roots and trunks causing tree decline. *Phytophthora cinnamomi* causes trunk cankers in mature trees near or 1–2 m above the soil line. Infected trees are small in stature, chlorotic, with suckers occasionally sprouting from the rootstock, and with severe infections, tree death occurs. *Kretzschmaria clavus* causes root decay, eventually invades the trunk and at advanced stages, diseased trees appear weak and exhibit gradual defoliation before dying.

Integrated pest management (IPM) is employed to reduce pesticide use. Scouting and monitoring, use of resistant cultivars, application of insecticides with minimal impact on beneficials, insect mating disruption tactics, and a trend toward the use of natural enemies (bio-control) are part of IPM programs to suppress pest population and reduce damage. Success with IPM strategies is encouraging, as production costs are reduced, and good yields and quality nuts are obtained with minimal adverse affect on the environment.

Because *Botrytis* and *Phytophthora* blights and other fungal diseases are more common in cool, wet weather conditions, orchards established in relatively dry areas are less prone to these diseases. Dense and closed-in canopies of mature orchards favor disease development. To minimize disease oc-

currence, increase air movement through the orchard and reduce moisture accumulation within the canopy by pruning lower branches, controlling weeds and thinning out overgrown windbreaks. Pruning lower branches should be a regular orchard operation to facilitate harvesting, increase light penetration for growth of ground covers and increase air circulation.

Rats and wild pigs can also do substantial damage, particularly in orchards adjacent to forested areas. Rats will damage nuts on the tree or on the ground by chewing a 5–10 mm diameter hole through the shell and consuming the kernel. Wild pigs crush the shells in their teeth and consume the entire kernel. In Hawai'i losses due to immature nuts, mold, insect damage, and germination make up about 15% of the harvested crop. Restricting harvest intervals to less than 4 weeks will reduce damage from tropical nut borer, mold, and germination.

## POSTHARVEST CONSIDERATIONS

### Harvesting and postharvest handling

Nuts mature about 30 weeks after flowering, and drop to the orchard floor where they are harvested mechanically or by hand. Once-over harvest operations are not feasible due to the protracted flowering season and the extended

**Table 4. Major insect pests of macadamia in Hawai'i (H) and Australia (A).**

| Insect  | Organism responsible                  | Injury  |
|---|---------------------------------------|---|
| Southern green stinkbug (H)                   | <i>Nezara viridula</i>                | Piercing sucking insect causes pitting of kernel surface from feeding activity on in-husk nuts; mold and fungi introduced into kernels.                                   |
| Tropical nut borer (H)                        | <i>Hypothenemus obscurus</i>          | Beetle larvae feeding cause small pin holes through shell and kernels of mature nuts. Damage occurs after nut drop.   |
| Koa seedworm (H)                              | <i>Cryptophlebia illepipa</i>         | Moth larvae bore holes into husks and occasionally through shells. Feeding can cause premature nut drop, introduction of molds into kernels.                              |
| Litchi fruit moth, macadamia nut borer (A, H) | <i>Cryptophlebia ombrodelta</i>       |   |
| Flower caterpillar (A)                        | <i>Cryptoblabes hemigyrsa</i>         | Moth larvae feed on flower buds and reduce nut set.   |
| Fruitspotting bug                             | <i>Amblypelta nitida</i>              | Piercing sucking insect causes causes brown lesions on inside of husks of young nuts; pin point sunken marks on hardening shell, pitting of kernels occurs on older nuts. |
| Bananaspotting bug (A)                        | <i>Amblypelta lutescens lutescens</i> |   |

**Table 5. Major macadamia diseases in Hawai'i (H) and Australia (A).**

| Disease                 | Organism responsible                        | Symptoms  |
|-------------------------|---|---|
| Blossom blight (A, H)   | <i>Botrytis cinerea</i>                     | Fungus attacks flowers at anthesis or post anthesis; infected flowers covered with gray mycelium.                     |
| Phytophthora blight (H) | <i>Phytophthora capsici</i>                 | Fungus infects flowers at all stages and young nuts. Infected racemes turn brown and may remain on branch for months. |
| Husk spot (A)           | <i>Pseudocercospora macadamiae</i> sp. nov. | Fungus causes brown spotting on husk and premature nut drop.  |
| Trunk canker (A)        | <i>Phytophthora cinnamomi</i>               | Fungus causes cankers on trunk near or at soil line. Trees lack vigor, leaves pale green, and are stunted.            |
| Root rot (H)            | <i>Kretzschmaria clavus</i>                 | Fungus attacks roots and invades main trunk. Trees appear unthrifty, decline slowly, and die.                         |



Left: *Phytophthora* blight of racemes can be a problem during wet weather and destroys racemes at all stages during floral development and during the growth of the young nuts. Top right: Pitting of kernels is characteristic of damage caused by the southern green stinkbug, fruitspotting bug, and bananaspotting bug. The insect's mouth parts pierce through the hard shell and cause damage by feeding on the kernel and introducing fungi and bacteria. Bottom right: When nuts are not harvested and stay on the ground for extended periods, kernels become discolored (top row) and unusable.

maturation period, so harvesting occurs at about monthly intervals to maintain nut quality. Hand harvesting occurs in rocky and uneven terrain, but for the majority of orchards, harvesting is mechanized. Blowers separate leaves from the nuts, which are harvested with sweepers or pinwheel harvesters. Shakers that grip tree trunks and use a vibrating action to dislodge nuts into collection frames are used in some orchards, but predicting the optimum harvest date is difficult with this system, because flowering occurs over several months and nuts mature and drop to the orchard floor over an extended period. In Hawai'i, harvest occurs between August and February and from March to August in Australia and South Africa. In South Africa, growers often harvest from the tree early in order to minimize stinkbug damage.

The hard shells of macadamia nuts will not protect kernels from damage if nuts are not handled correctly after harvest. The length of time nuts can remain on the ground before harvesting depends upon weather, cultivar, and incidence

of tropical nut borers (TNB). Reduction in quality due to mold growth, and seed germination will occur more rapidly during wet weather, thus it is recommended that nuts be harvested at about 4-week intervals to insure quality. Some cultivars have thinner shells, which makes them more susceptible to germination and damage when harvest intervals extend beyond 4 weeks. Most varieties in Hawai'i can be harvested off the ground at up to 8-week intervals without drastically reducing kernel quality if conditions are dry and TNB populations are low. When nuts are kept in the field for more than 8 weeks kernels can become discolored and unusable.

Under favorable conditions, 10 year-old trees can produce up to 68 kg in-shell nuts/tree and have a recovery rate of 38% kernel from in-shell nuts. Husks can be composted and used as mulch or incorporated in planting media. Shells are used as mulch, burned as fuel to operate processing facilities, and can be processed into high grade charcoal.

Freshly harvested nuts should not be stored in bags. Rather, they should be de-husked within 24 hours and the drying process begun. Storage in bins causes mold growth on husks and imparts a foul odor to kernels. If nuts cannot be husked immediately, it is better to delay harvesting and have nuts remain on the ground in open air. Mechanical huskers have different designs but generally work by rubbing in-husk nuts against a metal or hard rubber surface. In-field huskers incorporated onto pinwheel harvesters can husk nuts as they are harvested and immediately recycle husk material back into the orchard.

In-shell nuts must be dried before further processing or bulk storage. The drying process is critical since it facilitates cracking and when done correctly, it improves kernel flavor and texture after roasting and stabilizes the chemical components to maintain quality and shelf life. Freshly harvested nuts vary in moisture content depending on location and harvest intervals. In wet areas moisture content is about 25%, while from dry areas it may be 10–15%. Large farms have silos fitted with fans to force ambient air through

the nuts and reduce moisture to about 10% before delivery to processors. Smaller growers often deliver in-husk nuts to processors where nuts are husked and dried for further processing. After drying with ambient air, nuts are dried at 38°C for 2–3 days, followed by 52°C for 4–5 days and 58–60°C for 1–2 days with forced-air driers to bring kernel moisture content down to 1.5%. If high temperature is applied to macadamia nuts with high moisture content, kernels develop brown centers when roasted due to accumulation of reducing sugars in the center of kernels. Under suitable conditions (storage under flowing dry compressed air or dry nitrogen at ambient temperatures), in-shell nuts can be stored for 12 months at 1.2% kernel moisture and will maintain their roasting quality and shelf life.

After drying to about 1.5% moisture, nuts are sorted into various sizes and cracked. Reduced moisture content causes the kernel to shrink and detach from the inner surface of the shell. Kernels attached to the shell are damaged during cracking and recovery of whole kernels is reduced. Dried



Top left: A simple vice-type hand cracker can be used to shell a few kilograms of nuts per hour. Bottom left: A small commercial drying oven can be used to complete the drying process at exact temperatures. Right: Even a small hand-cranked or motor-driven cracker can produce commercial quantities by hand or with a motor drive.

raw kernels are vacuum-packed into bulk foil pouches for storage or sale to processors and industrial users.

There is no single international standard for Style Specifications for raw macadamia kernels. Style Specifications (Style 1, Style 2, Style 3, etc.), based on size of the kernels, percentages of wholes, halves and pieces, are used when kernels are sold in international and domestic markets. Hawai'i grading standards for raw shelled nuts (Hawai'i Department of Agriculture 1986) and roasted kernels (Hawai'i Department of Agriculture, no date) are available.

## PROCESSING AND MARKETING

Kernels that are dried but not roasted possess good flavor, but unroasted kernels may encounter sanitation issues associated with harvesting practices since nuts are harvested from the ground and could come in contact with animal waste products and other contaminants. Manufactured products featuring unsalted, salted, flavored, or chocolate

coated whole or half kernels and other confectionery and bakery products with macadamia as an ingredient are well received by visitors in Hawai'i. Processors have also incorporated agritourism activities within their operations as a means to educate buyers and promote sales. Certified organic farms that produce macadamia exist. In order to label the nuts as organically grown, they must be processed in a certified organic facility. A limited demand for in-shell nuts exists among bird fanciers who feed in-shell nuts to hyacinth macaws because of the high fat content of kernels.

Country of origin labeling (COOL), administered by the USDA Agricultural Marketing Service, exists for macadamia nuts, but only applies to raw macadamia nuts sold at retail. Excluded from COOL labeling are macadamia nuts that have undergone a physical or chemical change such as cooking or roasting or kernels that have been combined with other food components such as chocolate. Labeling requirements for prepared foods are regulated by the U.S. Food and Drug Administration who should be consulted for



Top left: A common sight recently in Kona, Hawai'i, farmers are poisoning or cutting down their macadamia nut trees due to a weak market for nuts in-husk. Instead of selling the nuts to a processor, on-farm value-added processing and marketing products at retail can help restore profitability. Top right: After careful processing and sorting, a uniform and high-quality product can be displayed in clear packaging. Bottom left: Product diversification can allow farmers to reach new markets. Here, a Kaua'i farmer sells certified organic macadamia nut kernels and butter. Bottom right: A transparent, high-value oil can be separated from macadamia nut butter with a relatively inexpensive hydraulic press.

**Table 6. Nutritional composition in 100 g of dry roasted macadamia kernels from the USDA National Nutrient Database for Standard Reference (2008)**

| Component           | Content | Vitamins        | Content  |
|---------------------|---------|-----------------|----------|
| Water               | 1.61 g  | Ascorbic acid   | 0.700 mg |
| Protein             | 7.79 g  | Thiamin         | 0.710 mg |
| Total lipid         | 76.08 g | Riboflavin      | 0.087 mg |
| Carbohydrate        | 13.38 g | Niacin          | 2.274 mg |
| Total dietary fiber | 8.00 g  | <b>Minerals</b> |          |
| Total sugars        | 4.14 g  | Potassium       | 363 mg   |
|                     |         | Phosphorus      | 198 mg   |
|                     |         | Magnesium       | 118 mg   |
|                     |         | Calcium         | 70 mg    |

guidelines regarding labeling and packaging. Dry roasted kernels have a high percentage of monounsaturated fatty acids (59%), low levels of polyunsaturated fatty acids (1.5%), medium levels of saturated fatty acids (12%), 7.8% protein, and 8.0% dietary fiber. The nutritional composition of dry roasted kernels is shown in Table 6.

Home processing of macadamia can be accomplished to produce an acceptable product.

1. Remove the outer husk of freshly fallen nuts soon after harvesting.
2. Air-dry in-shell nuts for 2–3 weeks on screens by spreading them in layers not more than two nuts thick, in the

shade where there is good air circulation. Nuts are sufficiently dried when they rattle and kernels are loosened from the shell.

3. Crack nuts with a vise or cracker specially designed for cracking macadamia. Separate shells from the kernels, remove discolored and pest-damaged kernels, and begin drying.

4. Use a home food dehydrator in which the drying temperature can be well controlled. Dry kernels slowly at 38°C, for about 2 days, increase temperature to 52°C for 2–3 days and to 60°C for 2 days. It's difficult to predict length of the drying process. Check the texture of kernels periodically during the final drying by biting into a kernel. Completely dry kernels are very crisp. The drying process should be slow; if the temperature is too high, kernels can dry unevenly, change color, or have brown centers when roasted. After drying, kernels are ready for roasting. They can be stored in tightly sealed jars for a short while, but for longer storage, they should be frozen and thawed in a sealed jar.

5. To roast macadamia nuts, place dried kernels in an oven at 135°C for 20–30 minutes. Wire-screen trays are best for the roasting process. Check the color as roasting progresses, and roast to the desired golden color.

6. For salted macadamia nuts, coat roasted kernels lightly with a small quantity of salad oil. Apply the desired amount of powdered salt and shake to distribute the salt evenly.



Unique, eye-catching products can be minimally or highly processed. Left: Dry, unprocessed nuts-in-shell. Middle: Macadamia nut and chocolate spread. Right: Flavored kernels.

Place nuts in a jar to protect them from picking up moisture. If they are not to be consumed soon, they may be kept frozen for up to a year.

## VALUE-ADDED PROCESSING

As lower priced imported macadamia nuts become increasingly available, small farmers may be able to maintain profitability by adding value to their crop through processing and marketing their nuts, developing products to fill unique market niches (locally grown, baked goods, sauces, candies, oil, etc.). Value-added markets such as certified organic, 100% Hawaiian grown, minimally processed (raw, low temperature process), etc., are all product lines that can be explored.

## EXAMPLE SUCCESSES

### Monika's Mac Nuts

Monika Nauen bought an existing 6 ha macadamia nut farm near Pāhoa, Hawai'i in 1997 when the trees were 12 years old. With no background in farming but much enthusiasm, she learned by talking with other farmers about picking and processing, and by trial and error. Initially, Monika sold her husked nuts to large processors nearby.

Through the years, Monika has sold her products at retail as whole dehydrated kernels and as nuts in-shell. Because of the work involved in processing shelled nuts, she currently sells only partially dried nuts in-shell at retail and wholesale. Her processing includes husking, sorting, and air-drying in large open bins. Her primary retail market is bird breeders, and people who prefer vegan or raw food diets. These customers are willing to pay a premium to purchase fresh nuts in-shell, and do not mind cracking the nuts themselves. Customers find Monika by word-of-mouth and through her e-commerce Internet site.

Monika says that it is very difficult to be profitable on a small scale due to all the hard work with tree maintenance, prun-



Orchard at Monika's Mac Nuts.

ing, blowing the leaves, mowing grass, and moving bags into the husking station. Also, finding pickers is challenging, as young people today are not used to the hard work.

For now, Monika is content to keep her business small, focusing on a high-quality product that involves a level of production and marketing activity that is comfortable for her.

### Just MacNuts Butta'

This four-person team, Colleen, Joe, Kathie, and David of North Kohala, Hawai'i formed their business in 2008 when they realized that there was an unused supply of macadamia nuts on small farms in their community. Having abundant experience in business and marketing, they set their minds to making use of their local macadamia nut resources. Initially, they experimented with pressing macadamia oil, but soon realized that the labor and capital costs were prohibitive. They began experimenting with macadamia nut butter and gave samples to friends and neighbors to taste, and received very positive feedback.



Just MacNuts Butta' being sold at a farmers' market in Waimea, Hawai'i.



Knowing that in order to make money they would have to be conscientious about expenses, they have been able to start their business with a \$12,000 cash investment by purchasing used equipment and limiting other expenditures. A business plan guides their production and marketing. Working with the Hawai'i Department of Health (DOH), they were able to ensure that their on-farm husking and cracking operation was approved. Milling for nut butter is done in a certified kitchen. They sent product samples to DOH for testing and received a high food quality evaluation. Based in their previous marketing experience, they developed an attractive label.

Initially they found their nut suppliers by putting a notice up on local bulletin boards. Small growers with just a few to a few dozen trees from the neighborhood offered to bring in nuts. In the beginning there were some quality problems with some deliveries, and they have become very selective about which nuts they will accept.

With sales starting in June 2008, by the end of December 2008 their products were in grocery and health food stores throughout Hawai'i Island. Their products are now sold through gift basket companies, in liquor stores, tourist visitor centers, local cafes, and farmer's markets. Currently, they also have products in six stores on the island of O'ahu. Since the inception of Just MacNuts, the company has enjoyed continued growth while staying ahead of demand.

### **Ailani Orchards**

Elizabeth Jenkins and Barney Frazier purchased their farm near Na'alehu, Ka'u, Hawai'i in 2001. The farm had been abandoned, with most of the trees covered with vines. Early on they enlisted the help of twelve Barbados Blackbelly and St. Croix hair sheep, which have multiplied to a herd of 100 today. They now consider the sheep to be part of their staff, whose job it is to mow weeds.

Heavily focused on adding value for retail sales, Elizabeth and Barney do all of their processing themselves. They pick, husk, crack, sort, wash, and dehydrate their nuts, in addition to processing into specialty products. They use a special low-temperature (<math>40.5^{\circ}\text{C}</math>) dehydration process to dry their nuts, which they say preserves the Omega-3, -6, and -9 fats, enzymes, and delicate flavors compared with roasted nuts. The dehydration process allows them to market their products to health food enthusiasts who prefer "raw" food.

Elizabeth and Barney produce a range of macadamia nut products including nuts in-shell, whole kernel, butter, and butter mixed with white or dark chocolate. They also make a butter blended with honey they produce. They sell their whole nuts and macadamia nut butters at their roadside stand and refer return customers to their e-commerce web site for these and their other products. They maintain a client list primarily from visitors to their roadside stand, and send out periodic email offers, including notification of web



Roadside stand at Ailani Orchards, where many value-added macadamia nut products are sold.

specials. They do not have any other advertising. In addition to retail sales, they offer bulk pricing for large orders. However, they sell all their products directly to customers, rather than through distributors or retail outlets.

### **ECONOMIC CONSIDERATIONS**

Current costs of production for macadamia are not available and difficult to determine, because production can occur on small family farms or corporate farms cultivating a thousand or more hectares. Major expenses incurred by farmers include costs for fertilizer and herbicide and labor for harvesting and hauling the crop from the field. Hand harvesting is usually employed on smaller farms and in orchards with poor terrain and can account for 26% of the total expenses. Other expenses include labor for pruning, fertilizer, and herbicide application and leaf removal. Smaller farms do not have husking equipment and rely upon processors who may charge a husking fee upon delivery. Most small growers are multiple-income farm families, and macadamia nuts supply only a portion of their income.

Production figures compiled by the USDA National Agricultural Statistics Service and the Hawai'i Department of Agriculture show that from 2004 to 2009, total wet-in-shell (WIS) production in Hawai'i averaged 23,540 MT with an average yield of 3,610 kg/ha. Highly productive orchards found in good growing locations in Hawai'i have been known to produce up to 6,720 kg/ha. Due to fluctuating farm gate prices during 2004–2009, farmers received US\$1.13–1.55/kg for wet-in-shell nuts. Hawai'i has a well developed market for macadamia nuts representing a value at the manufacturing and retail sales level estimated in excess of US\$150 million annually. Visitors to Hawai'i purchase a large quantity of macadamia products (roasted kernels, chocolate covered kernels, and cookies) to take home.

The average U.S. import price of macadamia kernels was US\$6.79/kg in 2008. Major ports of entry were Houston (17.5%), Los Angeles (25.8%), and New York City (19.1%). Imports of macadamia kernels from foreign sources into the U.S. amounted to 6,789 MT in 2008 with the majority coming from Australia and South Africa. Principal markets for Hawai'i's production are the U.S. mainland and Hawai'i.

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### Recommended Web sites

- Australian Macadamia Society: <http://macadamias.org/>
- Hawai'i Macadamia Nut Association: <http://hawaiiamacnut.org/Content/default.asp>
- Southern African Macadamia Grower's Association: <http://www.samac.org.za/index.html>
- University of Hawai'i College of Tropical Agriculture & Human Resources: <http://www.ctahr.hawaii.edu/ctahr2001/>

Specialty Crops for Pacific Island Agroforestry (<http://agroforestry.net/scps>)

## Farm and Forestry Production and Marketing Profile for Macadamia Nut (*Macadamia integrifolia*)

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