College of Tropical Agriculture and Human Resources
University of Hawai'i at Manoa

Garlic Production Guidelines for Hawai'i

At A Glance: Around 400 million pounds of garlic is produced annually nationwide. However, garlic production in Hawai'i is limited, with very few farmers who currently supply the local market. The aim of this guidance document is to increase the production and supply of Hawai'i-grown garlic.

Figure 1. Braided garlic grown at the Poamoho Research Station

Garlic (*Allium sativum L.*) is a member of the lily family that has been cultivated for thousands of years. It is native to Central Asia and northeastern Iran, distributed across the world by human migrations. This bulb is one of the most widely used crops, with large markets in the U.S. West Coast and Northeast. Approximately 2 pounds of garlic per capita are consumed each year, with around 400 million pounds produced annually nationwide. Garlic production in Hawai'i is limited, with very few farmers who currently supply the local market. The aim of this guidance document is to increase the production and supply of Hawai'i-grown garlic.

Garlic Types

There are two main subspecies of garlic: softneck and hardneck. Softnecks, which have a mild flavor and can have a long shelf life of 10 to 12 months, are most commonly found in grocery stores and markets. Hardnecks typically have a shorter shelf life (3 to 4 months) and produce subtle flavor differences. Hardneck garlic is easily identified by its long flower stalks, called *scapes*, which can be consumed at younger stages. Both hardneck and softneck garlic can be grown in Hawai'i.

Elephant garlic (*Allium ampeloprasum*) is commonly grown in Hawai'i. Although it possesses garlic-like characteristics, it is not true garlic, but rather, a type of leek.

Figure 2A. Cross section of hardneck (German White) bulb.

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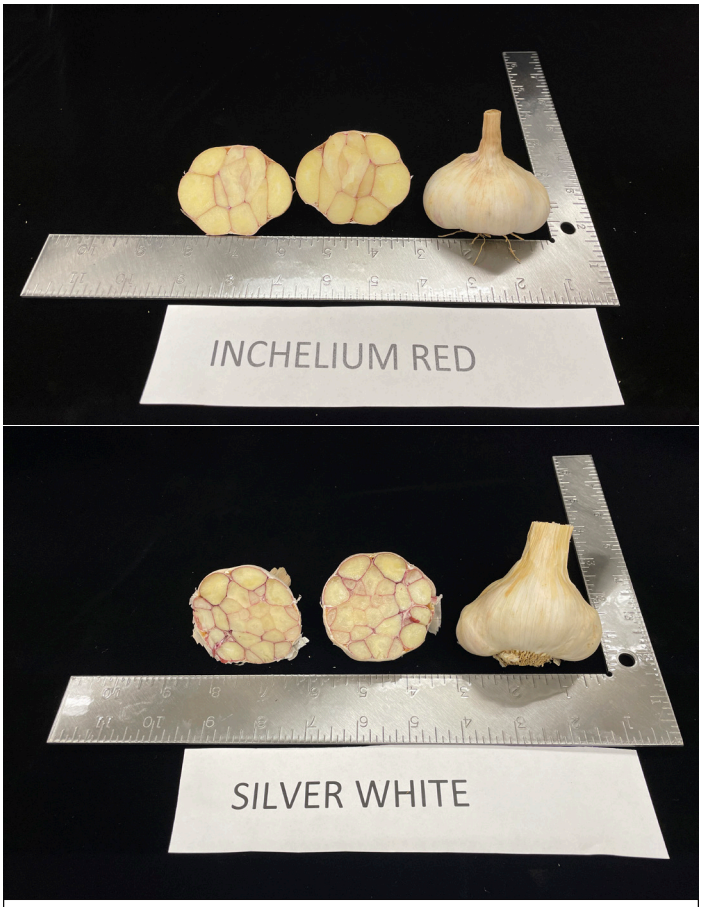

Figure 2B. Cross sections of softneck (Silver White and Inchelium Red) bulbs.

Elephant garlic cloves are very large with a mild flavor that can be slightly bitter, and often prepared and consumed like garlic. This bulbing leek also produces scapes that can be consumed similar to hardneck garlic types.

Site Selection

Garlic requires well-drained soil, free from pathogens such as *Fusarium* and other soil-borne bulb diseases that may affect plant health and marketable yields. Soils high in organic matter with a pH of 6.0-6.5 are preferred. Heavy clay soils and rocky soils are not as desirable, due to the potential for misshapen garlic bulbs. Lighter soils, with lower bulk density, are ideal for ease of harvesting. Incorporating the use of cover crops can help to increase organic matter and discourage the presence of pests, diseases, and weeds. Areas that experience heavy rainfall, especially during the maturation and harvest period, are not recommended for garlic production. Areas located at elevations above 500 feet, including Kula, Central O'ahu, and the Lālāmilo area of Waimea have demonstrated successful garlic production.

Garlic Propagule Vernalization

Garlic is propagated by planting individual cloves, commonly referred to as garlic seed. These seed cloves must undergo artificial vernalization for successful harvests in Hawai'i. Vernalization is the cooling of propagules to induce a plant's flowering process by natural exposure to prolonged cold winters or an artificial equivalent. During this process, the plants must be exposed to temperatures at or below 40° F (4° C) in order to produce large garlic bulbs successfully. If garlic is planted without artificial vernalization, growers will only experience vegetative growth and little-to-no bulb formation.

Refrigeration is needed to achieve proper vernalization for garlic production in Hawai'i. Field trials have shown that refrigeration at 40° F for 1 to 2 months, from October through December, is sufficient to mimic natural vernalization. In cases where garlic seed cloves are exposed to inadequate temperatures and grown under poor soil moisture and temperatures above 85° F (27° C), the garlic may revert to its previous state and result in poor bulb formation. Prolonging cold exposure may help prevent the devernalization of garlic grown under poor conditions.

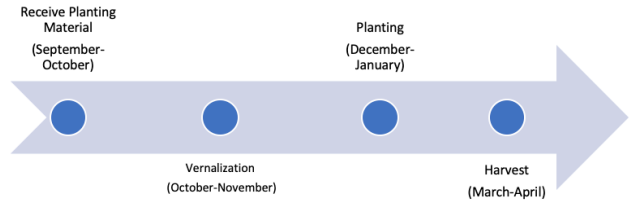

Figure 3. Generalized garlic production season

Planting

Garlic should be planted during the cool months of December to February in Hawai'i. When selecting planting dates, Hawai'i growers should consider rainfall in their areas. Wet weather can impact garlic plantings during maturation and bulb formation, ultimately affecting bulb size and quality. For this reason, it is recommended to time planting so that harvest occurs during a dry period, if possible.

Field preparation may include tilling and bed shaping for improved drainage. Individual seed cloves are planted at 4- to 6-inch spacing between plants within the rows, and rows can be spaced 6 to 12 inches on a bed. Beds can be of any width but typically range from 3 to 4 feet wide. Cloves should be planted at 1 to 1.5 inches deep and oriented root-side down in the soil.

Irrigation

Garlic requires a steady supply of soil moisture and can benefit from 1 inch (27,000 gal/acre) of water per week during the growing season. Water should be reduced or cut off during the bulb development and sizing period to increase bulb size and minimize bulb rot. Irrigation should be turned off approximately 90 days after planting to encourage bulb formation.

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Figure 4. Vernalized garlic cloves ready for planting at the Maui Agricultural Research Station on Maui

Fertilization

Soil sampling is recommended before planting to better understand the current nutrient status and specific fertilizer needs of the production field. In general, garlic requires heavy fertilization. On a per acre basis, the general nutrient requirements for garlic are 125 pounds of nitrogen, 150 pounds of potassium, and 150 pounds of phosphorus. Lime, if needed, and phosphorus and potassium fertilizers are applied pre-plant, based on soil test results. Nitrogen fertilization is usually split into 3 or 4 granular fertilizer applications or weekly injections of liquid fertilizer before bulbing, which is expected after six weeks. Nitrogen should not be applied after this stage to avoid excessive vegetative growth and encourage bulb formation. Fertilizers can be applied by banding granular fertilizers or by fertigation with liquid fertilizers.

Table 1. Example fertilizer schedule using liquid fertilizer urea (46-0-0)

Days after Transplant	Fertilizer
Pre-plant	Phosphorus and Potassium Based on Soil Test Results
7	54 lb. Urea/ac
14	54 lb. Urea/ac
21	54 lb. Urea/ac
28	54 lb. Urea/ac
35	54 lb. Urea/ac
42	54 lb. Urea/ac*

**Last nitrogen application prior to bulb formation*

Figure 5. Garlic plants with scapes, Scapes removed for garlic bulb production

Scape Removal

During bulb development, many varieties tend to initiate flowers, called scapes, from a single stem from the center of the leaf whorl with a flower head at the tip. If left to grow, the flower will develop bulbils, or tiny individual bulbs, that are genetically identical to the mother plant. While bulbils can be used as planting material after two years, scapes compete with bulb formation and will result in small bulbs if they remain on the plant. Removing scapes as soon as possible is essential to encourage marketable bulb development. Once removed, the edible young scapes can be bunched and sold as a secondary crop.

Weed Control

Garlic can easily be outcompeted by weeds, resulting in poor yields if weed pests are not properly managed. Therefore, it is best to use a combination of management strategies to minimize weed pressure, before and after planting. Management tactics *prior* to planting include:

- Crop rotations with cover crops
- Soil solarization
- Light exclusion over several weeks using weed mat
- Cultivation/tilling
- Sterile seedbed technique
- Applying pre-emergent herbicides

Mulches, such as clean straw or other materials, can also suppress weed pressure and help maintain soil moisture. After planting, growers can use a combination of hand removal, cultivation, and herbicide applications. There are a limited number of herbicides, including pre- and post-emergent herbicides, that are approved for use on garlic in Hawai'i. Please check with your local CTAHR Extension office for herbicides registered for use on garlic.

Insect Pests

Onion thrips (*Thrips tabaci*): If not managed properly, this pest can cause stippling, scarring, and a silvery appearance on foliage, which can significantly reduce yield. Rotating Allium crops (i.e., garlic, onion, green onion) with other types of crops may help break the breeding cycle

Figure 6. Leek moth larvae feeding damage on leaves and leek moth pupae

and minimize the presence of onion thrips. Insecticides are available and can be effective for the control of thrips. Please check with CTAHR Extension offices for insecticide recommendations.

Leek moths (*Acrolepia assectella*): Larvae cause 'window-pane' damage and tunnel through leaves. The damage from this pest can stunt plant growth and introduce rot, affecting the quality and marketability of garlic bulbs. Please check with CTAHR Extension offices for insecticide recommendations.

Diseases

Many diseases can affect garlic; however, few have been found on garlic grown in Hawai'i, where it has not yet been produced as a major crop. The garlic diseases presently found in Hawai'i are also major fungal diseases of bulb onion and green onion. Please check with CTAHR Extension offices for fungicide recommendations.

Fusarium basal rot: Garlic can become infected by the fungal pathogen *Fusarium oxysporum* at any stage of growth. Infection begins at the basal plate where all the leaves are attached. The symptoms include yellowing and dieback of leaves, beginning at the tips. The rotting continues upward from the basal plate to the neck of the bulb through the storage leaves.

White rot: Caused by *Sclerotium cepivorum*, this is one of the most widespread and destructive fungal diseases, causing major Allium crop losses worldwide. Symptoms may be visible at any stage of growth on the leaves, including a white, fluffy growth on the basal plate that can extend around the bulb causing leaf yellowing, wilting, dieback, and rotting of the roots. Once introduced, white rot can persist in soil for more than 20 years. Therefore, sanitation and avoidance of the pathogen is critical. Management of white rot starts with avoiding the pathogen by starting with clean seed material. This fungus can be introduced to garlic fields via infected seed cloves.

Downy mildew: This fungal disease, caused by *Peronospora destructor*, affects the leaves of garlic and other Allium crops. Downy mildew is most prevalent during cool, wet weather conditions that commonly occur at higher elevations in Hawai'i. The spores of this pathogen persist in soil and plant debris spread by air and wind. If spores land on garlic, they require the leaves to be wet in order for infection to occur. Early symptoms include elongated lesions on older leaves that are light-green to yellow. Lesions may also appear bluish-purple and have a grayish-white furry growth visible on the surface of the leaf during periods of high moisture. Affected leaves eventually fold over and collapse.

Purple blotch: This disease, caused by the fungal pathogen *Alternaria porri*, is most severe in areas with hot and humid weather. Symptoms first appear on leaves as tiny water-soaked flecks that eventually enlarge into reddish-purple ringed lesions surrounded by yellow discoloration. Heavily diseased plants may exhibit dieback. Necks and bulbs can also be affected.

Figure 7. Rust on garlic grown at the Lālāmilo Research Station

Garlic mosaic: The label "garlic mosaic" refers to a mosaic disease caused by a potyvirus. It usually occurs in combination with one or more other viruses. The primary potyviruses found in garlic are *Onion yellow dwarf virus* (OYDV) and *Leek yellow stripe virus* (LYSV). Symptoms include chlorotic mottling, a mild to strong mosaic, striping, and streaking of leaves, and will be more pronounced on younger leaves. Infected plants are stunted and bulb size is reduced. Because garlic is propagated vegetatively, one or more viruses are commonly present in all garlic. These potyviruses can also be transmitted by aphids.

Rust: This disease is primarily of garlic but also affects other Alliums. It is caused by the fungi *Puccinia allii*, which favors cool weather. Optimal conditions for infection occur during cool temperatures after wet periods. Symptoms of rust begin as small white flecks on leaves and stems. These develop into oblong, reddish-orange lesions that produce reddish airborne spores. Heavy infections cause wilting, yellowing, and drying of leaves.

Pink root: While a serious economic fungal disease of other Allium crops, Pink root, caused by *Phoma terrestris*, is a minor disease of garlic because it rarely causes economically significant damage. The most obvious symptom of this disease is pink-colored roots, which begin as light pink, then become red and purple before the roots eventually shrivel and die. Because this pathogen can persist in the soil indefinitely, a rotation with non-Allium, non-host crops is recommended for 3 to 6 years to reduce disease pressure in fields.

Harvest and Curing

The average yield of a garlic planting can range from 5,000 to 17,000 pounds per acre, depending on plant spacing and management practices. Bulb size is a function of vernalization, adequate initial vegetative growth, and remaining storage leaf growth under cold long days.

Maturity Indexes: Different varieties (types) are harvested at different stages of maturity, depending upon the market and variety. Temperature and moisture conditions during garlic growth can affect when garlic is mature. Delaying harvest can lead to the splitting of the bulb and loss of some of the scales. Harvesting too early may result in small bulbs with poor postharvest life. The most commonly used measure of maturity is the ratio of number of dried leaves to number of leaves still green. Frequently bulbs are harvested when the lower 40-60% of leaves are yellow.

Other growers, depending upon location and variety, will wait until all the leaves turn yellow and become dry. This harvest maturity index will impact how much cleaning will be necessary and how long bulbs can be stored after harvest. It is important to remember that the number of leaves equals the number of bulb wrapper layers (scales), so as the leaves turn brown and die, so do the bulb scales or wrappers that are protecting the cloves.

Figure 8. Harvested garlic with yellowed leaves

Figure 9. Garlic curing on wire racks at the Poamoho Research Station

Harvesting and Curing: To remove bulbs from the soil, a cutter bar or pitchfork can be used to loosen the bulbs from the soil. Once pulled, bulbs can be gathered in the field and left to field cure if there is no chance of rain. If rain is expected, plants should be collected and cured in a dark, dry, well-ventilated covered area. Plants can either be spread flat on benches, racks, slotted trays, or wire screens or by hanging bunches of 10 to 12 bulbs tied with string. Curing or drying of the bulbs for 10 to 14 days is necessary if harvested with some leaves still green. If harvesting takes place after the leaves (tops) have dried in the field, then minimal curing is necessary. When the tops (green leaves) have dried, the roots and the tops are cut off, leaving about one inch (25 mm) above the bulb.

Quality and Grading

Quality: Garlic bulbs are most appealing to consumers if they are white with a dried stem and outer scales (skin) and uniform in size. Dried stems and outer scales are signs that the bulb has been well cured. Some varieties may not be white but can range in color from deep-purple inner wrappers, purple-streaked, reddish-brown, or brown to pink.

The cloves should be firm when squeezed, uniform in size and color, and easy to peel. The number of cloves in each bulb can vary, depending upon variety and growing conditions and ranges from two to 16, with four to six being common. Some varieties may have two cloves in one wrapper scale.

The flavor of the cloves from different varieties is ranked from mild to strong in their hot and rich spicy flavor. Differences in flavors and clove sizes among varieties have led to preferences for specific culinary and processing uses.

Grading: The USDA recognizes one grade of garlic, U.S. No. 1, which requires a bulb diameter of at least 1 to 1½ inches (25.4 to 38.1 mm). In addition to the bulb size requirement, U.S. No. 1 garlic must consist of 1) bulbs of similar varietal characteristics that are mature, well cured, and compact; and 2) cloves that are well filled, fairly plump, free from mold, decay, shattered cloves, and damage caused by dirt or staining, sunburn, sunscald, cuts, sprouts, tops, roots, disease, insects, or mechanical or other means. Also, each bulb must be well enclosed in its outer sheath.

Postharvest Handling and Storage

Handling: As with all fruits and vegetables, the major causes of loss after harvest are due to poor handling and mechanical injury, poor storage conditions, and diseases. Careful handling is essential. Mechanical injury is a major problem for garlic, with the outer cloves showing discoloration and decay during storage. Types of mechanical injury include dropping the bulbs into deep bins and other types of impact, abrasion (rubbing against rough surfaces), and compression (held in bins that are too deep). Storage loss can be very high due to poor storage conditions that do not protect from sun exposure, lack of ventilation, and high relative humidity.

Cooling and Short-Term Storage: The dried bulbs, if well cured, are normally not cooled by refrigeration. The well cured bulbs are held in a cool, dry, and well-ventilated area in paper or mesh bags, and will normally remain in good condition for one to two months at 65-85° F (20-30° C). Garlic odor can be readily transferred to other fruit, vegetables, and other food products; hence, it needs to be stored separately.

The symptoms of the end of storage life include clove shriveling due to water loss, soft and spongy texture, and in some cases, a waxy appearance. A waxy appearance is common when the preharvest weather is hot during harvest, bulbs are exposed to the sun during curing in the field or after harvest, and there is poor ventilation during curing and storage. The waxy cloves are yellow amber and later become translucent, waxy, and sticky, with the scales showing no symptoms. If the storage area is not dry and has a high relative humidity, a number of diseases can occur including *Fusarium, Penicillium* (Blue mold), *Aspergillus* (Black mold), and *Botrytis* (Grey mold).

Long-Term Storage: Bulb postharvest life can be considerably extended up to 9 months by storage at about 32° F (0° C) and 60-70% relative humidity with good ventilation in vented bins or mesh bags. High relative humidity will favor mold growth as outlined above and if the bulbs are not well cured (dried). Another common problem with long-term storage is a loss of flavor and sprouting. There are approved chemicals that inhibit sprouting and are used by large growers worldwide.

Storage "Seed" for Next Planting: Bulbs to be used as seed for the next crop should be stored at 65-70% humidity and 50° F (10° C), with bulb dormancy declining with storage time. Lower temperatures (less than 40° F) often lead to side shoots and early crop maturation, while higher temperatures (greater than 65° F) lead to delayed sprouting and later maturity. Garlic cloves can also be stored for "seed" as for the whole bulb. The cloves should be of high quality with no mechanical injury or disease.

Value-Added Products

A common value-added product is peeled cloves. Peeling is done by hand or mechanically, and the cloves are sold in small bags. An acid treatment or edible coating is sometimes used. Stored peeled cloves held at 32° F (0° C) should maintain good visual quality and flavor for three weeks. Peeled garlic can be chopped, dried, and sold for stews and soups. Fresh chopped garlic can be sold in olive oil.

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