GROWING CHINESE WATER CHESTNUTS IN HAWAII

Steve Hopkins
Rain Garden Ornamentals
49-041 Kamehameha Highway
Kaneohe, Hawaii 96744

stevehopkins@hawaii.rr.com
www.raingarden.us

BACKGROUND AND INTRODUCTION

The Chinese water chestnut, *Eleocharis dulcis* ((Burm. f.) Henschel), is a member of the sedge family (Cyperaceae). It is a true aquatic that can only grow in water. The plant has a rush-like appearance with 4-6 tubular stems that are upright and about 3 to 4 feet tall. The plant produces 1 to 2-inch brown corms on rhizomes at its base under the soil. The corms have white flesh which has a crisp texture and sweet nutty taste. Water chestnuts are fairly high in sugars (2-3%), and also contain about 18% starch, 4-5% protein, but less than 1% fiber (Burt 1999). Water chestnuts are an important ingredient in Asian cuisine and culture. It is used in cooking, drinks, and also for medicinal purposes. The crisp texture is retained after processing or cooking due to the presence of hemicellulos containing ferulic acid in the cell walls[1]. In cooking, water chestnuts are often included in stir-fry mixes. It also forms the basis for sweet drinks and can be made into syrup used in deserts.

Water chestnuts are grown throughout much of Asia. Japan and Taiwan each produce about 1,100 tons annually and Australia produces 16-22 tons[1]. Most of the production is from China and Thailand. Much of the production is canned although the canned product is considered inferior to fresh product for most uses. The U.S. annually imports about $40 million of canned or other semi-preserved water chestnut product from Asia. The U.S. also imports more than 550 tons of fresh product. Water chestnuts were introduced into the U.S. in the 1930's and there have been attempts at commercial production in Florida, Georgia and California[2], plus limited attempts in Hawaii[3].

It may be important to note that there is another plant called water chestnut, *Trapa bicornis*. That plant is not related to *Eleocharis dulcis*, has dense floating leaves and produces a horn-shaped nut. This "other" water chestnut is very invasive in natural

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[1] Midmore, D.J. 1998. Chinese waterchestnut. *In*: K. Hyde (Ed.): The New Rural Industries, RIRDC, Barton, 181-187.
[2] Diver, S. 2000. Chinese water chestnut. Current Focus report. Appropriate Technology for Rural Areas. University of Arkansas, Fayetteville, AR.
[3] Stephens, J.M. 1994. Waterchestnut *Eleocharis dulcis* (Burm. f.) Trin. ex Henschel. Fact Sheet HS-683, Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

habitats and has a reputation of being difficult to control.

TRADITIONAL CULTURAL PRACTICES

It is possible to grow water chestnuts anywhere that there are at least 220 continuous frost-free days per year. In China, it is grown at latitudes of 21^{o}N to 34^{o}N[4]. However, areas with cool climate do not produce the large corms which bring the highest prices in the market. Therefore, tropical and subtropical regions (including Hawaii) have an advantage over areas such as the mainland U.S.

The corms typically form three to eight inches under the soil surface. The effect of a hard pan or impermeable barrier which is less than 8 inches below the soil is unknown. In order to maintain water levels and conserve nutrients, there must be little percolation of water through the soil. This is usually associated with a large percentage of clay. But in heavy clay soils, the corms are difficult to harvest and the amount of hand labor is large. There are likely to be accumulations of silt and organic matter, but the substrate must be consolidated enough to support foot traffic for planting and harvesting. The ideal soil from a management is sand and organic matter as it supports the weight of workers when saturated or submerged. The combination of a plastic pond liner to prevent percolation and a substrate of sand to facilitate planting and harvesting, would demand higher capital costs, but lower operating labor costs.

Mature corms which have been properly stored are used to plant the crop. Corms are planted 4 inches deep at densities of 0.2 to 0.5 corms per square foot. Corms will sprout at a soil temperature above 55^{o}F[5]. Each planted corm can multiply and can produce up to 0.4 pounds per square foot of corms at harvest. Intensively managed crops may yield 0.8 lbs/sq.ft/year[2].

While water chestnuts are grown under water, water level management and manipulation is required to produce a crop. Planting is facilitated by having the soil submerged only several inches. Thus, it is important that the planting bed be flat or terraced so uniform water levels can be maintained across the pond. When the plants reach about 8 inches tall, the pond is fully flooded and remains flooded at least until the end of the growing season[1]. These water level manipulations mandate that the production pond be constructed or modified for water chestnuts. Natural ponds, ditches or other water bodies are unlikely to be suitable[3]. The water level manipulations also require dependable supplies of water. Taro lo'i have characteristics suitable for water chestnut production.

All of the water chestnut's growth goes into stem formation through the spring and summer. When the photoperiod falls below 12 to 12.5 hours of light per day, corm formation begins. As the corm matures the stems turn brown and die off[4]. The sugar

[4] Li, M., V. Kleinhenz, T. Lyall, and D.J. Midmore, 2000. Response of Chinese Water Chestnut (*Eleocharis dulcis* (Burm. f.) Hensch) to Photoperiod. Journal of Horticultural Science and Biotechnology 75(1): 72-78.
[5] Burt, J. 1999. Chinese water chestnuts for the fresh market. Farm Note 128/99 (Perth, AU).

content (a quality characteristic) continues to increase, but if harvest is postponed too long, corms may begin to sprout and loose their marketability.

It has been reported that a water chestnut crop removes 0.08 ounces per square yard of nitrogen, 0.01 oz./sq.yd. of phosphate, 0.15 oz./sq.yd. of potassium, 0.003 oz./sq.yd. of calcium and 0.015 oz./sq.yd. of magnesium[1]. Recommended fertilization rates are 0.07-0.10 oz./sq.yd. each of nitrogen, phosphate and potassium[6]. All agree that nitrogen fertilizer is best applied in the ammonium (NH^{4+}) form, for this is the favored form for uptake by water chestnuts, and is less easily leached than nitrate (NO^{3-}). It has been suggested that half of the nitrogen should be applied before planting (basal application) and the other half applied three months later as a side dressing. If there is a greater percentage of nitrogen in the basal application, the result is greater stem biomass at the expense of corms. However, if a greater percentage of nitrogen is applied as a side dressing, the result is a great number of corms of non-marketable size. A slow-release nitrogen fertilizer would make the dual application unnecessary.

Insect pests of water chestnut are known, but are not devastating. Green and long-horned grasshopper, snout moth, rice water weevil and mole crickets have been reported as pests in other parts of the world. A rust (*Uromyces* sp.), stem blight (in very acidic soils), and a wilt caused by a strain of *Fusarium oxysporum* (in China only) have also been reported.

Historically, and to date throughout most of the traditional production regions in Asia, water chestnuts are harvested by hand. Individual corms must be dug from the substrate by hand, taking care not to damage the brown corm covering. Damaged corms are susceptible to bacterial rot and have a short storage life. Obviously, carefully hand digging each corm from a clay substrate is very labor-intensive. In Australia, mechanical harvesters resembling gladiolus corm harvesters have been developed[1]. The mechanical harvesters are expensive, cost-prohibitive for an individual grower and only feasible for very large producers or cooperatives.

Hawaii has several significant inherent advantages which make water chestnut production a promising aquaculture crop. The climate is sub-tropical so the growing season is long and there is no danger of corms being damaged by cold temperatures. A large segment of the population is of Asian ancestry and there is a strong local demand for traditional ingredients used in Asian cooking. However, Hawaii has high labor costs so a cost-effective harvesting procedure is needed.

DEVELOPING A PRODUCTION AND HARVESTING SYSTEM FOR HAWAII

To overcome the labor constraint to digging water chestnuts by hand at harvest, a mechanization process was envisioned. This is similar to a system used to farm clams

[6] Kleinhenz, V, Midmore, DJ, 1998: Mineral nutrition of Chinese water chestnut [*Eleocharis dulcis* (Burm. F.) Hensch]. *In*: Book of Abstracts. 4th Australian Horticulture Conference. 'Managing our future' for Innovation, Sustainability, Continuity, 14-17 October, 1998. Australian Society of Horticultural Science. Melbourne. 61.

in shallow water. While water chestnuts and clams seem to have little in common, they actually present the identical problem with respect to harvest. Both are orbs buried in the substrate. A solution is to bury netting under the substrate before the crop is planted. At harvest time, the net is pulled up with the aid of a moderate-pressure water hose. As the netting is pulled up, the hose is used to wash the substrate material through the netting and the crop (be it clams or water chestnuts) is retained on top of the netting where they can be handled *en masse*.

To test this concept, three small prototype water chestnut ponds were constructed. The ponds measured about 6 feet x 20 feet. The site is fairly low-lying, but the percolation rate often makes it impossible to keep water impounded and to control water levels during the summer. Therefore, the test ponds were lined with a cross-laminated high density polyethylene pond liner material (Permalon X-210™) with a backing of 30# roofing felt. About eight inches of soil were excavated and the excavated material was used to build twenty-four inch high berms around the perimeter of the ponds. This resulted in a final depth of about thirty-two inches.

A plastic netting material was laid in the bottom of the pond, on top of the liner, before substrate was added. A different type of plastic netting was used for each pond. Each type of netting had a mesh opening of one-half inch. The first netting type is a heavy extruded polyethylene material. There is no doubt that this material is strong enough and reusable. The second material is a woven polypropylene material with a hexagonal mesh which is probably strong enough and may, or may not, be reusable. The mesh strands have a tensile strength of sixty pounds. The third material is an lighter expanded polyethylene material often used as a bird/predator barrier. This material is relatively light weight, may be strong enough and may, or may not, be reusable. The relative costs of these materials are summarized in Table 1.

Table1. Cost comparison of plastic mesh material.

MATERIAL DESCRIPTION	ROLL SIZE ft^2	MATERIAL COST ($\$/ft^2$)	SHIPPING COST ($\$/ft^2$)	TOTAL COST ($\$/ft^2$)
Square extruded polyethylene	200	$0.42	$0.25	$0.67
hexagonal woven polypropylene	1400	$0.18	$0.07	$0.25
expanded polyethylene	1400	$0.08	$0.04	$0.12

After laying down the netting, eight inches of substrate was added. This harvesting procedure demands that the soil remain friable. If the soil firmly consolidates, it can not be washed through the netting at harvest. Clay soil will break into large clods which require a lot of water and water pressure to break them up and wash them through the netting. Sand remains friable even after being compacted and submerged. In Hawai'i, two types of sand are readily available; coral sand and basalt sand. Both have a high initial pH (about 7.5) but basalt has somewhat less buffering capacity. Since the pond is lined, water retention and downward leaching of nutrients is not an issue. For the soil-less mix used in the prototype ponds, an inexpensive grade of sand, locally called "stone wall" was used. This material is screened to remove large pieces of aggregate, but has a wide range of particle sizes; from quarry dust to about one-quarter inch in diameter.

There are many well-chronicled advantages to incorporation of organic matter into soil, especially if the mineral soil is sand[7]. To some extent, organic matter would provide a cation exchange complex with which to bind nutrients. However, any organic matter added to the sand must also be able to pass through the harvest netting. Composted green waste is readily available at a reasonable cost from several recycling centers in Hawaii. This material is screened at the composting site to remove large particles which would be retained on the harvest netting. There have been several evaluations of this material as a substitute for peat in soil-less potting mixes[8,9].

Because water retention and downward nutrient leaching are not of concern in the lined pond, it was unclear whether the incorporation of organic matter would have a significant impact in this application. Therefore, an eight-inch partition was placed in the center of each pond. On one side of the partition, the soil-less mix was one-third sand and two-thirds compost. On the other side of the partition, the mix was two-thirds sand and one-third compost.

In the spring, water chestnut seed corms were first planted in shallow nursery tanks with a gravel substrate. After the corms sprouted and were six to

[7] Albre, W.A. 1938. Loss of soil organic matter and its restoration. Soils and Men, Yearbook of Agriculture 1938. pp. 347-360. USDA.

[8] Rauch, F.D., H.M. Gitlin, R. Watanabe and R. W. Stanley. 1997. Plant growth in potting media using compost. CTAHR Horticulture Research Note HRN-010.

[9] Yogi, J., D. Hensley and J. Hollyer. 1997. Substituting Hawaii compost for peat in growing media for hibiscus. CTAHR Horticulture Research Note HRN-012.

twelve inches high, they were transplanted to the three prototype ponds. The water depth over the substrate was raised from two inches to eighteen inches after several weeks.

Several weeks after putting water in the ponds, a large number of mosquito larvae were noted. To control the mosquitos, several dozen small ornamental fish (*Xiphophorus variatus*) were stocked into each pond. Since these fish readily reproduce, their numbers increased many fold over the course of the season. Prior to harvesting the water chestnuts, the fish were removed from the ponds with traps and were sold to a ornamental fish wholesaler. Fish sales were not considered in the artesian economic analysis.

When the crop was harvested in late winter, the number and total weight of corms in each of the two soil-less mixes, in each pond, were compared. The results (Table 2) indicate that the soil-less mix made up of two-thirds sand and one-third compost produced more corms and larger corms. Statistical analysis indicates that the differences are significant (p>0.1). These results were a little surprising. The sandy substrate was easier to work with, both at planting and at harvest. However, we expected to see the higher percentage of compost have a beneficial effect on production.

Table 2. Harvest data from the ponds comparing two soil-less mixes.

TREATMENT	POND	TOTAL NO.	TOTAL POUNDS	NO./POUND	NO/SQ.FT.
mostly sand	1A	857	34.3	25.0	7.1
	2A	1290	43.0	30.0	10.8
	3A	1243	53.5	23.2	10.4
	mean	1130.0	43.6	26.1	9.4
mostly compost	1B	777	28.3	27.5	6.5
	2B	934	36.0	25.9	7.8
	3B	846	40.1	21.1	7.1
	mean	852.3	34.8	24.8	7.1

The depth of the substrate in the ponds was based on information in the literature which indicated that corms could develop to a depth of eight inches. However, this depth of substrate made lifting the net at harvest more difficult than it needed to be. The light and inexpensive expanded polyethylene netting tore several times during the harvesting process. The medium weight, woven polypropylene netting did not tear and would be reusable. The heavy extruded polyethylene netting proved to be too stiff and was more difficult to work with than the less expensive woven material.

While the pond trials were underway, some smaller trials were being conducted in two-foot diameter plastic tanks. Eight inches of sand/compost mix (50:50) was placed in eight separate tanks (control) and only four inches of the same soil-less mix was placed in eight other tanks (soil depth treatment). The fertilization rate was proportional to the substrate depth so the tanks with half as much substrate had half as much fertilizer. The tanks were planted with sprouted corms from the nursery in the spring. When harvested in the fall, the average number of corms in the tanks with the shallow soil depth was slightly higher (Table 3), but the differences were not significant ($p<0.05$). So, reducing the soil depth to only four inches does not adversely affect production and will make the harvesting process much easier as only half as much material will have to be washed through the netting.

We did not find any information in the literature about the effect of various planting densities on corm production. The obvious speculation is that higher planting densities produce more corms, but the corms may be smaller and nutrient requirements higher. In the prototype ponds and in other tank trials, the planting density was 0.3 corms per square foot. To gain some insight into the effect of higher planting densities, we compared the results to a planting density of 0.6 corms per square foot. This trial was also done in the two-foot diameter plastic tanks. Eight tanks planted with 0.3 corms per square foot were compared to eight tanks planted with 0.6 corms per square foot. As seen in Table 3, the total number of corms produced was nearly twice as high at the higher planting density and these differences were statistically significant ($p>0.05$). However, the corm size was smaller at the higher planting density, but the difference was not statistically significant ($p<0.05$). The fertilization rate was the same in both treatments. Further trials comparing higher planting densities and using higher fertilization rates are needed.

In the prototype ponds, an inexpensive 16-6-8 fertilizer was incorporated into the soil-less mix at a rate of 0.4 ounces per square yard (1,100 pounds per acre). An additional side dressing of 0.4 ounces per square yard was applied in September. The nitrogen was in the form of ammonium sulfate. In the plastic tanks, used for the substrate depth trial, the planting density trial, and the control tanks, a slow release 18-6-12 fertilizer (Apex Blue™) was incorporated into the soil-less mix at the rate of 0.8 ounces per square yard. In an additional eight tanks, the Apex Blue slow release fertilizer was replaced with Agritab™ fertilizer tablets. One tablet was placed in each tank and each tablet weighed 0.75 ounce with a 20-10-5 formulation plus minors. The tablets were inserted into the substrate when planting seed corms. This fertilization regime delivered over 2.1 ounces per square yard of a formulation with higher nitrogen content.

As can be seen in Table 3, corm production in the tanks fertilized with 0.8 oz./sq.yd of slow-release Apex Blue™ was much higher than in tanks fertilized with 2.1 oz./sq.yd. of Agritab™ and the differences were statistically significant (p.0.05) for both corm number and corm size. The foliage in the tanks fertilized with Agritabs™ was dense, had good color and did not appear to have been "burned" by over-fertilization. We suspect the nitrogen was depleted through vegetative uptake and volatilization early in the season and was no longer available late in the season when corms were being formed.

Table 3. Harvest date for the tanks comparing soil depth, planting density and fertilization regime.

TREATMENT	REPLICATE	TOTAL NO.	TOTAL POUNDS	NO./POUND	NO./SQ.FT.
control	1	42	1.4	30.1	13.4
control	2	122	4.5	27.3	38.9
control	3	43	1.5	29.3	13.7
control	4	52	1.9	27.3	16.6
control	5	66	2.5	26.2	21.0
control	6	50	1.9	26.1	15.9
control	7	42	1.3	32.5	13.4
control	8	52	1.7	31.5	16.6
	mean	**58.6**	**2.1**	**28.8**	**18.7**
depth	1	77	2.8	27.2	24.5
depth	2	106	4.0	26.5	33.8
depth	3	34	1.3	25.5	10.8
depth	4	86	2.4	35.4	27.4
depth	5	86	3.3	26.5	27.4
depth	6	44	1.5	28.5	14.0
depth	7	44	1.6	27.4	14.0
depth	8	46	1.6	29.6	14.6
	mean	**65.4**	**2.3**	**28.3**	**20.8**
density	1	122	4.4	27.6	38.9
density	2	142	5.1	27.7	45.2
density	3	142	4.7	30.5	45.2
density	4	93	2.2	42.9	29.6
density	5	94	3.0	31.6	29.9
density	6	56	1.9	29.8	17.8
density	7	86	3.0	28.9	27.4
density	8	45	1.4	32.4	14.3
	mean	**97.5**	**3.2**	**31.4**	**31.1**
fertilizer	1	29	0.9	32.6	9.2
fertilizer	2	13	0.4	30.8	4.1
fertilizer	3	26	0.7	36.6	8.3
fertilizer	4	27	0.9	29.8	8.6
fertilizer	5	15	0.5	33.2	4.8
fertilizer	6	3	0.1	33.7	1.0
fertilizer	7	12	0.4	31.4	3.8
fertilizer	8	5	0.1	59.0	1.6
	mean	**16.3**	**0.5**	**35.9**	**5.2**

Based on this information, future trials will use only four inches of a sandy substrate with at least one ounce per square foot of a slow-release fertilizer.

MARKETING

The water chestnut corms produced in these trials were test marketed in several outlets. Much of the product was sold directly to retail establishments in the Chinatown section of Honolulu (primarily Wing Cheong and Wah Wah Seafood). The price received was $0.75 per pound for ungraded corms. With some grading, the price is about $1.00 per pound and the culled corms can be used for planting the subsequent crop. The retailers were pleased with the taste and freshness of the local product.

We retailed some of the corms ourselves at our rustic roadside flower stand. We had half-pound packages of corms for $1.00 per package and one-pound packages for $1.50. More half-pound packages were sold, presumably because a household does not need many corms to make a dish. We have reasonably brisk roadside sales of flowers, but few water chestnuts were sold.

There is also a market for water chestnut corms in the water garden trade as it makes an attractive an unusual water garden plant. A local aquarium fish broker has sent test samples to mainland wholesalers. They would be sold by the piece, but at a price equivalent to about $2.00 per pound.

ARTESIAN ECONOMICS

A thorough economic analysis of waterchestnut production in Hawaii is not yet possible. However, based on the preliminary information above, the following production assumptions, costs and returns may be realistic:

Production	**500.0**	**lbs/1000 sq.ft**
Revenue *	**500.0**	**$/1000 sq.ft**
Labor Demands **	**24.3**	**hr/1000 sq.ft**
Direct Costs ***	**73.7**	**$/1000 sq.ft**
Labor Rate	**17.58**	**$/hr**

* revenue at $1.00/lb.
** fertilization, planting and harvesting only
*** fertilizer and water only

The production assumption of 0.5 pounds per square foot is slightly greater than that of the prototype ponds, but below that of several treatments in the experimental tanks. The revenue is based on a farm gate price of $1.00 per pound. The labor demands include time for fertilizing, planting and harvesting only and do not include facility construction, marketing or other indirect costs. Direct costs include fertilizer (1 oz/sq.ft of a slow-release fertilizer costing $1.00/lb) and water ($1.00/1000 gallons). The $18/hr labor rate is a calculated return for the time spent fertilizing, planting and harvesting.

CONCLUSIONS

In conclusion, water chestnuts can be successfully grown in Hawaii. The largest production cost is harvesting labor but this cost can be reduced by using a layer of plastic mesh buried under four inches of a sandy soil. Fertilization requirements are relatively high and a good quality slow-release fertilizer is important. There is a ready market for the product, but the farm gate price will depend on the marketing strategy. The return on direct labor costs may be acceptable for small integrated farms.