# Hawaii Agriculture Research Center

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# Jatropha Research at Kunia for 2009 and 2010

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## Introduction and Background

Biofuels agricultural research is of particular importance to Hawaiian Electric Company, Inc. (HECO) for many reasons:

- Hawaii has had a renewable portfolio standard (RPS) law since 2001. This RPS law was recently updated and now suggests 40% of Hawaiian electricity must be generated from renewable sources by 2030.
- Hawaiian Electric Company, Inc. signed the Hawaii Clean Energy Initiative (HCEI) in October 2008 with State of Hawaii to commit to a renewable future.
- Biofuel electrical generation can be a major contributor in the renewable energy portfolio. It is the key to securing firm dispatchable renewable power as opposed to "as available" renewable energy generation such as wind resources. It also is a key to the transportation sector's mandate for renewable fuel.
- Supply and demand for biofuels are currently at an imbalance. The company greatly wants to stimulate a sustainable local agricultural biofuel industry. In order to attract such an industry it is imperative for the company to obtain knowledge of the best local yield species of crops in order to standardize fuel specifications and limit variability in supply as well as assure acceptable constituents in the end product - all of which centers around various issues with adaptability, food crop displacement and land use, infrastructure changes and investments, supply politics and ultimately the cost benefits/detriments to the rate payers.
- Future planning based on agricultural research requires immediate research due to the time required for species lifecycles and fruition periods. The company wishes to make educated decisions and planning in the use of biofuels for the future benefit of all stakeholders and thus greatly values the present and future findings and direction for biofuels crop research as to shape such decisions.

HECO and EPRI have provided initial funding to initiate research to drive biofuels for power and transportation closer to commercial reality. This work will provide interested parties, including land owners, farmers, energy developers, and researchers, the tools to properly select crops that are most likely to suit the technical and economic needs of a biofuels industry. The project, begun in 2007, is executed by using the talents of Hawaii Agriculture Research Center (HARC) and its subcontractors (University of Hawaii-Manoa (UHM) and University of Hawaii-Hilo (UHH) researchers) for biofuel crop research as described in the paragraphs above.

HARC has concentrated on jatropha crop plantings and research, UHM on jatropha plantings and tissue culture research and UHH on oil palm plantings and research. The remainder of this report contains results and current findings originating from the local Oahu agricultural studies (HARC's field plots located at Kunia in central Oahu) planted in 2007 with continuing research through at least 2011. The report contains the findings up to February 2010.

This report is a work in progress and will have research results added when available as part of the continued funding for local agricultural research. This report is exclusive to the HARC research on biofuels which has focused on jatropha as the most promising crop on Oahu—UH Hilo and Manoa's contributions will be reported elsewhere. The current and future findings of this study will play an important role in the implementation of agricultural lands on Oahu (as well as other islands) for jatropha cultivation and ultimately a firm power renewable fuel.

## Isolation Plots

The objective of this work is to determine if seeds could be produced in partial isolation that will result in uniform trees. Past plantings with seeds from India, Madagascar and Honduras at Kunia have resulted in highly variable trees in size, form and fruiting. We know that clonal material will produce uniform trees, but it is costly to plant large acreages; planting seeds is the most cost-effective method.

The isolation plots planting materials were selected from superior trees from trial F2 (planted on September 2007) with seed origins from India and Madagascar. These selections were made by Mike Poteet, former lead scientist at HARC, based on height, branching, flowering and fruiting. Ten cuttings were planted in plots isolated by at least 300 ft from other jatropha plants. The plant spacing was 4 ft and an area of 48 $ft^2$ per tree was used to calculate yield per acre. A total of 14 selections were planted in 10-tree plots in August 2008. The actual number of surviving trees in each plot is recorded in Table 1 at the end of this report. The isolation plots have the code "iso" in the ID.

All seeds from the isolation plots were harvested from time of planting to January 2010. A future growout trial was initiated near the end of February 2010 at Kunia. Fruits were produced as early as 8 months after planting. The four best yielding selections, based on the fruit and seed weights, will be planted in this replicated trial described below under the heading "Plans for 2010." This trial should provide information on whether a farm can be planted from seeds instead of clonal materials. These four isolation selections will also be included in a replicated yield trial at Kunia along with 10 other new selections from Trial F3.

The yield results for the isolation plots are included in Table 1. Some of the seed yields were estimated from a subsample to determine seed weight from the fruit weight. The yield from the planting date is expressed in pounds per acre of seed, annualized weight and oil (assuming 30 and 45 percent oil content of dry fruits and seeds, respectively, and oil density of 7.68 pounds per gallon).

The best four isolation plots will be sampled on a monthly basis to develop a yield by time relationship which will be valuable to plan harvesting frequency.

## Trial F3 (Field NB1)

This trial consisted of seeds planted from five origins (Honduras, Pearl City but labeled as Kunia, India, Madagascar and Pahala, Hawaii) and two rows of each origin were irrigated with normal amounts based on USDA Class A, pan evaporation and two rows with 62 percent of the normal amount. This trial was planted with seeds on July 31, 2008. A complete weather station (pan evaporation, temperature, solar radiation, rainfall, relative humidity and wind speed) is maintained at Kunia about 500 yards from this trial.

Trees were first selected visually based on fruits on the tree and ground, form, height and vigor from each origin and irrigation treatment. The fruits were collected from each of these 28 selected trees to determine the 10 most promising trees for inclusion in the yield trial along with the four isolation selections. The yields of each tree are presented in Table 2. The ID provides the row (buffer to row 20) and the tree position in a give row.

## Findings

Initial Selection of Promising Trees

Early selection of trees with high yield potential can reduce the time to commercialization. Height, branching, flowering, cluster and fruit measurements were taken after 8 months of planting at Kunia and used as initial selection criteria. We found the number of fruits at about 10 months to have the strongest correlation to seed yield at 15 months. Plant height shows moderate correlation to later yield which can be measured very early in the crop. Branching, flowering and fruit clusters had mixed results. More observations and measurements are needed to obtain more accurate and significant regression relationships of these early measurements to future seed yield. Other criteria such as the ability to tolerate pruning and shaping are needed to select trees for mechanical harvesting.

Isolation Selections

From the trees in the isolation plots, seed yield was the final selection criteria. Fourteen trees of all selections including F3 were ranked in order of highest seed yield (see Tables 1 and 2). Four of the isolation plots had high yields with two having the first (iso 3, India origin) and second (iso 8, Madagascar origin) highest yields. The isolation plots received normal irrigation. Iso 3 and iso 8 trees were tall at 9.2 and 7.9 ft, respectively at 14 months after planting.

**The best two selections based on yield after 445 days at Kunia. Top photo is iso 3 from India with the highest yield of all selections including F3, and the bottom photo is iso 8 from Madagascar (second best yield). Photos taken on November 11, 2009.**

F3 Selections

Of the trees selected in F3, the Pahala trees with normal irrigation had the best yield and third best overall to iso 3 and 8. The Pahala trees were uniform in height and shape within each irrigation regime. With normal irrigation, the trees were about 8.5 ft tall and with low irrigation the height was 7.2 ft tall at 14 months. The trees of the other origins were highly variable compared to the Pahala trees. It is believed that the Pahala seeds were obtained from a few or a single tree that was planted in the 1920s. It seems that this tree has also adapted to the high rainfall conditions at Pahala and perform better with adequate irrigation.

**Pahala trees with normal irrigation in rows 17 and 18 (left) and low irrigation in row 19 (right). These plantings had uniform trees. The normal irrigated trees were the tallest in F3.**

The Madagascar origin was the most drought-tolerant with little or no average height difference between the normal and low irrigation regime. The Madagascar trees were the shortest at 6.2 ft at 14 months in F3, but the yields with low irrigation were the most promising of all origins. Three trees had high yields with low irrigation and ranked 7, 12 and 13 of all selections including the isolation plots. The Madagascar seeds were said to have been developed under very low rainfall conditions and may have achieved better water use efficiency to give adequate yields with less water. These selections may have great importance for water-short areas in Hawaii.

**Madagascar trees with normal irrigation in rows 10 and 11 (left) and low irrigation in rows 12 and 13 (right). Both treatments had similar tree heights suggesting better adaptation to less water than the other origins.**

The Honduras origins were not outstanding in yield, but the high variability within the five rows makes it ideal for future selection of other traits. Some trees had very large leaves that were twice the size of the typical leaves found in the other origins. A few trees may have only male flowers. More observations will be continued of the Honduras trees.

**Honduras tree with large leaves (left) and smaller, normal leaves (right).**

The Pearl City (Kunia) and India origins had only one promising tree each, though the single India tree had the third best yield of F3 and ranked 6th overall.

Fruit and Seed Subsamplings

Forty-four subsamples of 16 to 38 fruits were collected to measure the fruit and seed weights and calculate the total seed weight per tree without husking each fruit. The average dry fruit weight was 3.01 g (min. of 2.21 g and max. of 3.69 g) with a standard deviation of 0.276 g. The average seed weight was 0.73 g (min. of 0.64 g and max. of 0.84 g) with a standard deviation of 0.049 g. The ratio of seed to fruit weights was an average of 0.69 with a standard deviation of 0.053. The single fruit and seed weights and their ratio appeared to be similar among origins.

Pruning Treatment in F3

Flowering was delayed about 6 months with two pruning events conducted within the first year of the crop. Yield measurements to compare the pruned and unpruned plots will be difficult because of the significant variation among the trees within each plot of Honduras, Kunia, India and Madagascar. We will use the more uniform Pahala trees to measure the effect of pruning on yield. This task will commence in late February 2010.

Nontoxic Mexican Cultivar

Seeds were planted from Mexican origin, which are thought to be nontoxic, unlike all other species of jatropha, which are toxic. The seeds collected to date will be analyzed for the toxin usually found in jatropha. The trees in these plantings were severely infested with the spiraling whiteflies that defoliated the trees. The whiteflies were not found on other plantings of jatropha at Kunia which are believed to contain the toxin. This infestation may be a biological indication that the toxin is not present in the Mexican seedlings. One tree only in F3 was observed to have the whiteflies and will be checked for the toxin as well.

**Before and after whitefly damage of the Mexican origin seedlings.**

Chinese Origin with High Oil Content

Seedlings were planted of a cultivar said to have high oil content. To estimate oil yield, oil content of 45 percent was used in the attached tables. This variety from China is said to have oil content greater than 50 percent. Seeds will be collected to analyze for oil content. If true, this variety will be used to make hybrids with other selections.

## Plans for 2010

Harvesting

The selected trees in F3 and the four isolation plots will continue to be harvested on a monthly basis to determine the relationship between climatic factors, flowering and yield. This information will be important to determine the harvest frequency and identify trees that have seasonal flowering. Harvest cost will be an important factor affecting the economics of jatropha production.

HARC will be cooperating with University of California at Davis in testing mechanical harvesters at Kunia. Equipment from UC Davis will be shipped soon to Kunia for harvest trials in May.

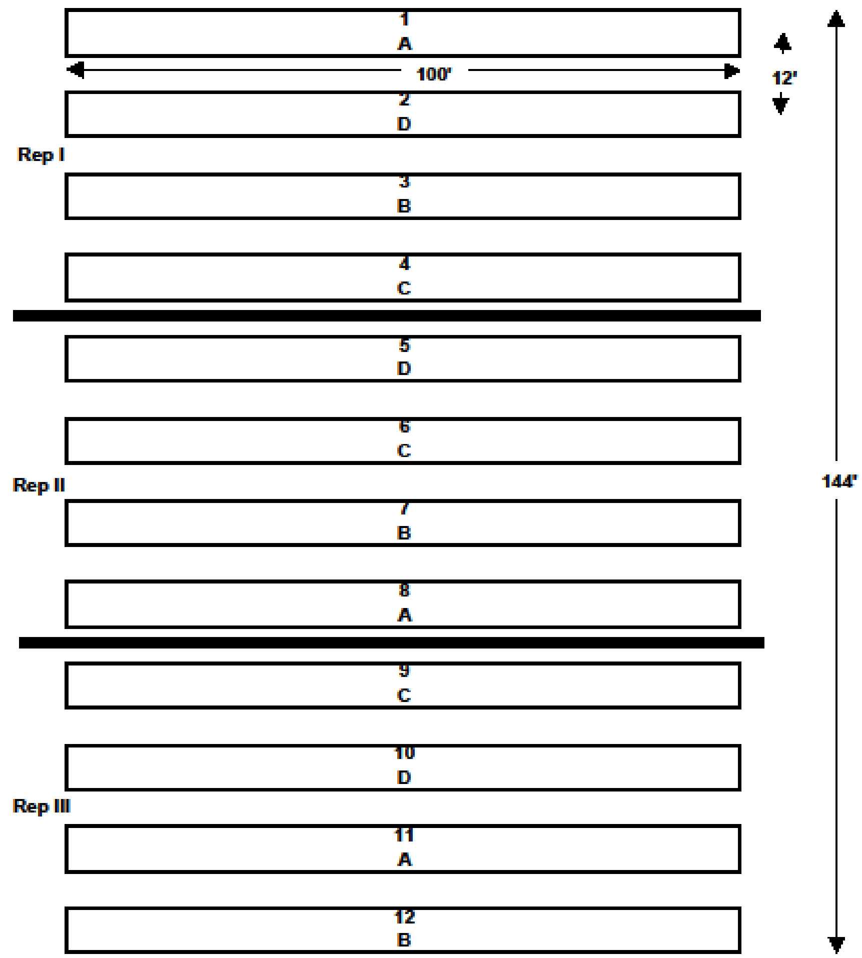
Continue Observations and Measurements in F3

We will continue to make closer observations of trees in F3 and select additional trees that may have useful characteristics and properties that could be used for developing new varieties. The effect of pruning will be measured, and promising pruned trees will be selected. Uniform trees will be fertilized and some left unfertilized to measure its response on growth and yield. Our observations from some isolation plots linked with coffee fields and fertilized monthly show little or no leaf drop during winter. The unfertilized trees often lose 30 to 60 percent of their leaves.

Isolation Growout

The seeds collected from four isolation plots will be planted in the layout shown below. This trial was initiated below F3 near the end of February 2010.

## Growout of Selected Isolation Plots Compared to Pahala Seeds




| Treatment | Selection | Origin |
|---|---|---|
| A | iso2 | India |
| B | iso3 | India |
| C | iso8 | Madagascar |
| D | P17-5 | Pahala |

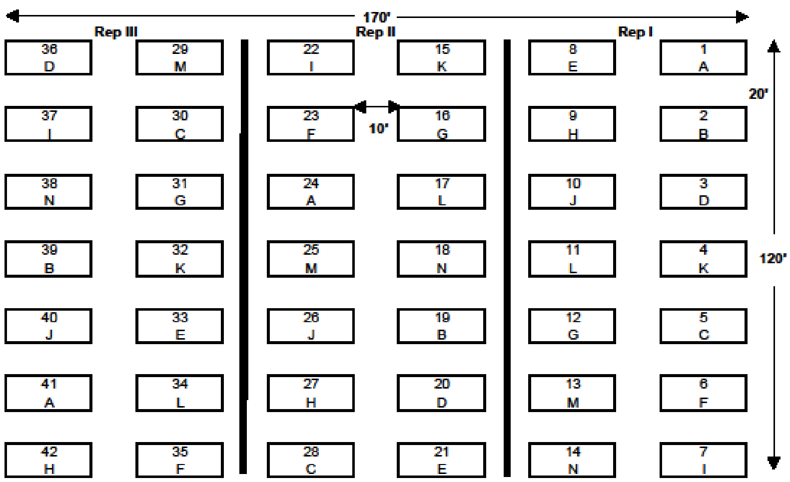
Seeds for treatments A, B, and C were collected from plots started from cuttings and planted in isolation from other jatropha plants at Kunia. The Pahala seeds were obtained from F3 without isolation. The Pahala trees were planted from seeds in F3 and were found to be more uniform than trees from other origins.

Each plot will be a single 12-ft row of 25 trees spaced 4 ft apart. At least 3 seeds will be planted per hole and thinned to a single plant per hole. Each treatment will be replicated 3 times for a total of 75 trees per treatment. This trial will be planted downslope of the selection yield trial with a separate submain. This trial will be completed before the yield trial.

## Yield Trial with 14 Selections

The 14 selections with the highest seed yields will be planted from cuttings in the layout shown below.

**Jatropha Yield Trial of 14 Selected Trees in Field NA2 at Kunia**




| Code | Selection | Code | Selection |
|---|---|---|---|
| A | liso3 | H | Hb-2 |
| B | Miso8 | I | M9-72 |
| C | P17-2 | J | K6-74 |
| D | liso2 | K | M11-81 |
| E | M10-40 | L | H2-7 |
| F | I13-34 | M | liso1 |
| G | M11-65 | N | M12-81 |

The trees will be planted 4 ft apart, and 7 rows spaced 20 ft so the distance between trees are far enough to separate the yield from adjacent plots. Calculate the yield on the per tree basis and estimate yield for a field with 12-ft row spacing. Each plot consists of one row with 5 trees planted from cuttings from the same selected tree for all three replicates. A total of 15 cuttings will be required for each selection. Start additional 5 cuttings in the greenhouse of each selection on the same day as the field planting. Irrigate the field prior to planting. Irrigate all with 508-12-340 T-Tape (need 1200 ft). After shoots emerge, fertilize with 16-16-16 at a rate of about 250 lb/acre.

## DNA Analysis of Jatropha Trees at Kunia

UC Davis will conduct DNA analysis to determine genetic differences among these selections. The Pahala and Madagascar analyses are of primary interest. About 30 seeds of each of the 14 promising selections to be planted in the yield trial were shipped on February 5, 2010 to UC Davis. We would like to also conduct analysis on the Honduras trees with large and normal leaves and investigate other anomalies.

Table 1. Harvest results for isolation and Mexican plots.

| | | | | | | | | | Subsample (Calc. Seed wt. From fruit wt.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Plant | Origin* | Date | Age (d) | Age (yr) | Intv* (d) | no. trees | Total fruit wt (g) | #fruit | fruit wt (g) | wt per fruit | #seed | Seed wt (g) | g/seed | Seed wt to fruit wt | Total seed wt (g) | Yield lb/A | Annual yield lb/A | Oil yd/yr gal/A | Rank |
| Iso 1 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 2531.9 | 562.8 | 570.7 | 33.5 | |
| Iso 1 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | 80 | 9 | 2745.1 | 19 | 55.1 | 2.90 | 54 | 35.7 | 0.66 | 0.65 | 1778.6 | 395.4 | 1803.9 | 105.7 | |
| | | | | | | | | | | | | | | | | 4310.5 | 958.2 | 784.9 | 48.8 | 10 |
| Iso 2 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 2797.8 | 622.0 | 630.6 | 37.0 | |
| Iso 2 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | 80 | 9 | 2109.5 | 18 | 54.2 | 3.01 | 53 | 33.9 | 0.64 | 0.63 | 1319.4 | 1130.6 | 5194.3 | 304.5 | |
| Iso 2 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | | 9 | 2684.1 | 18 | 54.6 | 3.03 | 52 | 36.1 | 0.69 | 0.66 | 1774.7 | | | | |
| Iso 2 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | | 9 | 3066.0 | 19 | 54.9 | 2.89 | 54 | 36.3 | 0.67 | 0.66 | 2027.2 | | | | |
| Iso 2 | 8/15/08 | India | 1/15/10 | 518 | 1.42 | 78 | 9 | 313.5 | 17 | 53.7 | 3.16 | 42 | 27.5 | 0.65 | 0.51 | 160.5 | 35.7 | 167.0 | 9.8 | |
| | | | | | | | | | | | | | | | | 8079.7 | 1788.1 | 1286.8 | 74.2 | 4 |
| Iso 3 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 8 | | | | | | | | | 3775.3 | 944.2 | 957.3 | 56.1 | |
| Iso 3 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | 80 | 8 | 5330.7 | 28 | 103.2 | 3.69 | 79 | 58.9 | 0.75 | 0.57 | 3042.4 | 2764.6 | 12613.2 | 739.4 | |
| Iso 3 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | | 8 | 2999.1 | 18 | 56.8 | 3.16 | 52 | 39.9 | 0.77 | 0.70 | 2106.8 | | | | |
| Iso 3 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | | 8 | 3796.2 | 16 | 48.3 | 3.02 | 45 | na | na | 0.70 | 2657.3 | | | | |
| Iso 3 | 8/15/08 | India | 10/29/09 | 440 | 1.21 | | 8 | 4917.4 | 16 | 48.3 | 3.02 | 41 | 31.9 | 0.78 | 0.66 | 3247.7 | | | | |
| Iso 3 | 8/15/08 | India | 1/15/10 | 518 | 1.42 | 78 | 8 | 1044.3 | 18 | 51.2 | 2.84 | 49 | 36.1 | 0.74 | 0.71 | 736.3 | 184.1 | 861.7 | 50.5 | |
| | | | | | | | | | | | | | | | | 15565.8 | 3892.8 | 2743.0 | 160.8 | 1 |
| Iso 4 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 688.3 | 153.2 | 155.4 | 9.1 | |
| Iso 5 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 10 | | | | | | | | | 239.2 | 47.9 | 48.5 | 2.8 | |
| Iso 5 | 8/15/08 | India | 11/9/09 | 451 | 1.24 | 91 | 10 | 2574.9 | 18 | 56.8 | 3.16 | 52 | 36.5 | 0.70 | 0.64 | 1654.6 | 331.0 | 1327.8 | 77.8 | |
| | | | | | | | | | | | | | | | | 1893.8 | 378.9 | 308.7 | 18.0 | |
| Iso 6 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 10 | | | | | | | | | 203.5 | 40.7 | 41.3 | 2.4 | |
| Iso 6 | 8/15/08 | India | 11/9/09 | 451 | 1.24 | 91 | 10 | 676.2 | 16 | 56.4 | 3.53 | 43 | 35.9 | 0.83 | 0.64 | 430.4 | 86.1 | 345.4 | 20.2 | |
| | | | | | | | | | | | | | | | | 633.9 | 126.8 | 102.6 | 6.0 | |
| Iso 7 | 8/15/08 | India | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 643.7 | 143.1 | 145.1 | 8.5 | |
| Iso 7 | 8/15/08 | India | 11/9/09 | 451 | 1.24 | 91 | 9 | 817.5 | 16 | 56.7 | 3.54 | 46 | 36.4 | 0.79 | 0.64 | 524.8 | 116.7 | 467.9 | 27.4 | |
| | | | | | | | | | | | | | | | | 1168.5 | 259.8 | 210.2 | 12.3 | |
| Iso 8 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 10 | | | | | | | | | 1138.2 | 227.7 | 230.9 | 13.5 | |
| Iso 8 | 8/15/08 | MD | 10/29/09 | 440 | 1.21 | 80 | 10 | 5255.5 | 38 | 125.1 | 3.29 | 105 | 85.7 | 0.82 | 0.69 | 3600.3 | 1303.7 | 5948.2 | 348.7 | |
| Iso 8 | 8/15/08 | MD | 10/29/09 | 440 | 1.21 | | 10 | 4392.6 | 17 | 59.2 | 3.48 | 50 | 39.3 | 0.79 | 0.66 | 2916.0 | | | | |
| Iso 8 | 8/15/08 | MD | 1/15/10 | 518 | 1.42 | 78 | 10 | 1232.1 | 28 | 94.8 | 3.39 | 80 | 64.5 | 0.81 | 0.68 | 838.3 | 167.7 | 784.8 | 46.0 | |
| | | | | | | | | | | | | | | | | 8492.8 | 1699.2 | 1197.3 | 70.2 | 2 |
| Iso 9 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 10 | | | | | | | | | 757.9 | 151.6 | 153.7 | 9.0 | |
| Iso 9 | 8/15/08 | MD | 11/9/09 | 451 | 1.24 | 91 | 10 | 4119.3 | 18 | 56.9 | 3.16 | 51 | 38.6 | 0.76 | 0.68 | 2794.5 | 559.1 | 2242.5 | 131.5 | |
| | | | | | | | | | | | | | | | | 3552.4 | 710.7 | 676.2 | 39.7 | |
| Iso 10 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 559.5 | 124.4 | 126.1 | 7.4 | |
| Iso 10 | 8/15/08 | MD | 11/12/09 | 454 | 1.24 | 94 | 9 | 3630.3 | 17 | 49.7 | 2.92 | 46 | 32.5 | 0.71 | 0.65 | 2373.9 | 527.7 | 2049.2 | 120.1 | |
| | | | | | | | | | | | | | | | | 2933.4 | 652.1 | 624.3 | 36.7 | |
| Iso 11 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 9 | | | | | | | | | 876.3 | 194.8 | 197.5 | 11.6 | |
| Iso 11 | 8/15/08 | MD | 11/13/09 | 455 | 1.25 | 95 | 9 | 1602.6 | 17 | 59.5 | 3.50 | 50 | 40.0 | 0.80 | 0.67 | 1077.4 | 239.5 | 920.2 | 53.9 | |
| | | | | | | | | | | | | | | | | 1953.7 | 434.3 | 348.4 | 20.4 | |
| Iso 14 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 10 | | | | | | | | | 295.7 | 59.2 | 60.0 | 3.5 | |
| Iso 14 | 8/15/08 | MD | 11/16/09 | 458 | 1.25 | 98 | 10 | 1791.2 | 19 | 56.8 | 2.99 | 49 | 39.5 | 0.81 | 0.70 | 1245.6 | 249.2 | 928.2 | 54.4 | |
| | | | | | | | | | | | | | | | | 1541.3 | 308.4 | 246.8 | 14.4 | |
| Iso 15 | 8/15/08 | MD | 11/17/09 | 459 | 1.26 | 459 | 10 | 489.9 | 17 | 37.5 | 2.21 | 48 | 31.6 | 0.66 | 0.84 | 412.8 | 82.6 | 65.7 | 3.8 | |
| Iso 16 | 8/15/08 | MD | 8/10/09 | 360 | 0.99 | 360 | 8 | | | | | | | | | 60.4 | 12.6 | 12.8 | 0.7 | |
| Mex 17 | 6/24/09 | Mexico | 1/15/10 | 205 | 0.56 | 205 | 12 | | | | | | | | | 118.1 | 18.4 | 34.6 | 2.0 | |

Table 2. Harvest results from selected trees in F3.

| ID | Plant | Origin* | Date | Age (d) | Age (yr) | Intv* (d) | no. trees | Total fruit wt (g) | Subsample (Calc. Seed wt. From fruit wt.) #fruit | fruit wt (g) | wt per fruit | #seed | Seed wt (g) | g/seed | Seed wt to fruit wt | Total seed wt (g) | Yield lb/A | Annual yield lb/A | Oil yd/yr gal/A | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B,2 | 7/31/08 | Hd-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 972.7 | 22 | 69.5 | 3.16 | 63 | 47.4 | 0.75 | 0.68 | 663.4 | 1327.3 | 922.8 | 54.1 | 8 |
| B,14 | 7/31/08 | Hd-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 509.8 | 18 | 57.2 | 3.18 | 63 | 47.4 | 0.75 | 0.83 | 422.5 | 845.2 | 587.6 | 34.4 | |
| 1,30 | 7/31/08 | Hd-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 284.5 | 16 | 42.7 | 2.67 | 36 | 27.5 | 0.76 | 0.64 | 183.2 | 366.6 | 254.9 | 14.9 | |
| 2,7 | 7/31/08 | Hd-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 609.8 | 18 | 48.3 | 2.68 | 51 | 38.3 | 0.75 | 0.79 | 483.5 | 967.4 | 672.6 | 39.4 | 14 |
| 3,4 | 7/31/08 | Hd-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 391.6 | 22 | 62.8 | 2.85 | 65 | 43.3 | 0.67 | 0.69 | 270.0 | 540.2 | 375.6 | 22.0 | |
| 4,60 | 7/31/08 | Hd-L | 1/7/10 | 525 | 1.44 | 525 | 1 | 58.8 | 12 | 35.7 | 2.98 | 34 | 23.3 | 0.69 | 0.65 | 38.4 | 76.8 | 53.4 | 3.1 | |
| 6,13 | 7/31/08 | Kunia-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 274.8 | 15 | 48.1 | 3.21 | 41 | 33.0 | 0.80 | 0.69 | 188.5 | 377.2 | 262.2 | 15.4 | |
| 6,74 | 7/31/08 | Kunia-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 770.4 | 18 | 52.8 | 2.93 | 53 | 37.7 | 0.71 | 0.71 | 550.1 | 1100.5 | 765.1 | 44.9 | 11 |
| 7,86 | 7/31/08 | Kunia-L | 1/7/10 | 525 | 1.44 | 525 | 1 | 319.1 | 16 | 44.8 | 2.80 | 46 | 32.3 | 0.70 | 0.72 | 230.1 | 460.3 | 320.0 | 18.8 | |
| 8,7 | 7/31/08 | Kunia-L | 1/7/10 | 525 | 1.44 | 525 | 1 | 396.5 | 17 | 48.5 | 2.85 | 48 | 33.7 | 0.70 | 0.69 | 275.5 | 551.2 | 383.2 | 22.5 | |
| 8,72 | 7/31/08 | MD-h | 1/7/10 | 525 | 1.44 | 525 | 1 | 860.8 | 16 | 43.9 | 2.74 | 46 | 32.8 | 0.71 | 0.75 | 643.1 | 1286.8 | 894.6 | 52.4 | 9 |
| 10,40 | 7/31/08 | MD-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 1061.2 | 16 | 48.9 | 3.06 | 44 | 34.2 | 0.78 | 0.70 | 742.2 | 1484.9 | 1016.9 | 59.6 | 5 |
| 11,22 | 7/31/08 | MD-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 419.9 | 20 | 55.4 | 2.77 | 52 | 39.4 | 0.76 | 0.71 | 298.6 | 597.5 | 409.1 | 24.0 | |
| 11,28 | 7/31/08 | MD-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 466.4 | 17 | 47.9 | 2.82 | 46 | 31.5 | 0.68 | 0.66 | 306.7 | 613.6 | 420.2 | 24.6 | |
| 11,66 | 7/31/08 | MD-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 911.5 | 16 | 41.5 | 2.59 | 43 | 30.8 | 0.72 | 0.74 | 676.5 | 1353.5 | 926.8 | 54.3 | 7 |
| 11,81 | 7/31/08 | MD-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 783.5 | 17 | 45.3 | 2.66 | 46 | 31.5 | 0.68 | 0.70 | 544.8 | 1090.0 | 746.4 | 43.8 | 12 |
| 12,81 | 7/31/08 | MD-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 690.8 | 19 | 52.8 | 2.78 | 51 | 37.7 | 0.74 | 0.71 | 493.2 | 986.8 | 675.8 | 39.6 | 13 |
| 13,34 | 7/31/08 | India-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 987.4 | 16 | 50.8 | 3.18 | 46 | 35.4 | 0.77 | 0.70 | 688.1 | 1376.6 | 942.7 | 55.3 | 6 |
| 14,22 | 7/31/08 | India-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 397.8 | 18 | 55.4 | 3.08 | 52 | 39.4 | 0.76 | 0.71 | 282.9 | 566.0 | 387.6 | 22.7 | |
| 14,74 | 7/31/08 | India-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 517.5 | 16 | 45.1 | 2.82 | 42 | 29.9 | 0.71 | 0.66 | 343.1 | 686.4 | 470.1 | 27.6 | |
| 16, | 7/31/08 | India-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 397.6 | 19 | 54.5 | 2.87 | 55 | 37.7 | 0.69 | 0.69 | 275.0 | 550.3 | 376.8 | 22.1 | |
| 16,8 | 7/31/08 | India-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 272.1 | 19 | 56.2 | 2.96 | 51 | 38.4 | 0.75 | 0.68 | 185.9 | 372.0 | 254.7 | 14.9 | |
| 17,2 | 7/31/08 | Pahala-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 1209.2 | 16 | 51.8 | 3.24 | 44 | 35.7 | 0.81 | 0.69 | 833.4 | 1667.3 | 1141.8 | 66.9 | 3 |
| 17,82 | 7/31/08 | Pahala-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 453.7 | 28 | 75.4 | 2.69 | 72 | 52.3 | 0.73 | 0.69 | 314.7 | 629.6 | 431.2 | 25.3 | |
| 17,74 | 7/31/08 | Pahala-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 603.0 | 17 | 51.8 | 3.05 | 50 | 35.7 | 0.71 | 0.69 | 415.6 | 831.5 | 569.4 | 33.4 | |
| 18, | 7/31/08 | Pahala-h | 1/15/10 | 533 | 1.46 | 533 | 1 | 394.5 | 16 | 46.8 | 2.93 | 45 | 32.9 | 0.73 | 0.70 | 277.3 | 554.9 | 380.0 | 22.3 | |
| 19,8 | 7/31/08 | Pahala-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 636.6 | 18 | 53.8 | 2.99 | 54 | 37.8 | 0.70 | 0.70 | 447.3 | 894.9 | 612.8 | 35.9 | |
| 20,11 | 7/31/08 | Pahala-L | 1/15/10 | 533 | 1.46 | 533 | 1 | 416.6 | 17 | 51.2 | 3.01 | 48 | 34.7 | 0.72 | 0.68 | 282.3 | 564.9 | 386.8 | 22.7 | |

*MD = Madagascar
-h =2X amount of irrigation of -L
Intv = Interval between sampling (days)

**Assumptions:**
Oil density 7.6768 lb/gal
Seed oil content 45%