PROCEEDINGS

Fifteenth Annual International Tropical Fruit Conference

October 21-23, 2005

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Hawaii Tropical Fruit Growers

and

County of Hawaii
Department of Research
and
Development
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Hawaii Tropical Fruit Growers

Welcome to Hawaii Tropical Fruit Growers’ 15th Annual International Tropical Fruit Conference. The 2004 – 2005 tropical fruit season in Hawaii was a huge year for our sector of the Hawaii agriculture industry and HTFG takes great pleasure in supporting our members and our industry.

I will now call to order the annual Member’s Meeting of HTFG.

I’ll begin by providing an update of our achievements in each of HTFG’s Focus Areas:

Managing the Organization:
Throughout 2005 the HTFG Board met quarterly by teleconference. This allowed us to conduct business with the maximum efficiency and minimum expense. Kristin McGrath resigned as our Executive Director and we were successful in recruiting and hiring Lily Armstrong as our new Executive Director beginning in June. We appreciate all of the hard work and innovation that Kristin provided us and we welcome Lily to our organization. Also in 2005, the Cacao Chapter became active with Gini Choobua as Chapter President and Board Member.

Research:
The Research Committee updated our research priorities for 2005 which allowed us to present a grant request to the Hawaii Department of Agriculture, via the Farm Bureau who was administrating the grant process for HI DOA. We were successful in receiving a $72,000 grant to fund our top research priorities as well as some of our promotional priorities. The grant includes $30,000 for “Optimal Field Management Strategies for Several Commercial Tropical Fruits” and $30,000 for “Rambutan Shelf Life Improvement”. We will be investing the grant money in these research topics over the next couple of years and reporting the results back to our membership.

Information:
Our local Chapters have continued hosting informational meetings for their membership throughout the year. West Hawaii Chapter has been particularly active. We’ve participated in two trade shows, thanks to the assistance of a County of Hawaii grant, during which we provided fruit sampling and provided information about the fruit and our organization. We participated in the Ulupalakua Thing in Maui in April as well as the Hawaii Lodging, Hospitality and Food Services Expo in Honolulu in July. We will be participating in the Big Island Festival in November. We’ll provide the HTFG booth at the Festival and we’re sponsoring the Chef’s Tour to visit farms and sample fruit. In addition to providing grants to help us fund this conference and to participate in trade shows, County of Hawaii also provided grants to assist West Hawaii Chapter’s 12 Trees Project with signage and displays and also to print tropical fruit recipe cards. With Ken Love’s valuable skills, we were successful in designing and printing our HTFG 2006 Tropical Fruit Calendar. There’s a copy of the new calendar in each of the conference packets. Also thanks to Ken Love, we have been able to use a portion of his web site www.hawaiifruit.net
for our HTFG information. Thanks to Lily Armstrong, we’ve launched our own web site www.hawaiitropicalfruitgrowers.org and it will continue to be developed and improved over time.

**Representation:**
We continued to provide input and recommendations to the U.S. delegation to the CODEX International Standards for Rambutans. We were successful in tightening the standards to make them more competitive which we believe will benefit Hawaii fruit growers. We continued our participation in the Hawaii Farm Bureau Federation Commodity Advisory Group. Doug MacCluer is our representative to the CAG and participates with the CAG to provide guidance to the Farm Bureau, Department of Agriculture, and State Legislature on our behalf. Doug is also a member of the State Agriculture Committee.

**Community Service:**
At the Board Meeting today we selected a student in the West Hawaii Community College Culinary Program to receive our $500 HTFG Culinary Scholarship.

**Summary:**
Our organization continues to grow and prosper. At this time in 2004 we had 112 members. We now have 150 members including 26 commercial growers. Our treasury remains healthy with over $35,000 in the coffers. However, we need more participation in both the State and Chapter Boards of Directors. It’s an excellent opportunity to be of service to your agricultural community. Anyone interested in participating in any of the Boards, please talk to me or to any of the Chapter Presidents.

In accordance with the HTFG by-laws, it is my responsibility to nominate a slate the 2006 HTFG Board of Directors. I hereby nominate the following individuals to the Board:
- Bob Hamilton – 2005 Vice President
- Leslie Hill – 2005 Treasurer
- Doug MacCluer – 2005 CAG Representative
- Ken Love – 2005 West Hawaii Chapter President
- Don Baker – 2005 East Hawaii Chapter President
- Gini Choobua – 2005 Cacao Chapter President
- Jenny Johnson – 2005 Research Committee Chairperson
- Richard Johnson – 2005 President

The Board, after being elected by the membership will select the HTFG officers for 2006. Are there any nominations from the floor? (There were none).

(A motion to approve the slate as presented was moved and seconded and the motion was approved by a voice vote.)

The County of Hawaii has been most supportive of HTFG and I’d now like to introduce the Mayor of the County of Hawaii, Mayor Harry Kim, who will give the County’s welcoming address. Mayor Kim
Featured International Speaker

The featured international speaker at the 15\textsuperscript{th} Annual International Tropical Fruit Conference is Surmsuk Salakpetch, P.h.D. from the Chanthaburi Horticultural Research Center in Thailand. Dr. Salakpetch obtained her Bachelor of Science degree from Kasetsart University in Thailand, a Master of Science degree from the University of Western Australia and her Doctorate in Horticulture from the University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources. She is currently the Director of the Center and a horticulturist who has conducted extensive research on a variety of tropical fruit crops including rambutan, durian and mangosteen. Dr. Salakpetch was the invited speaker at the 10\textsuperscript{th} Annual International Tropical Fruit Conference in 2000 and was an audience favorite due to her extensive knowledge of tropical fruit production. Presentations by Dr. Salakpetch at this year’s conference will cover information on current and promising tropical fruit industries in Thailand, post harvest research on Sapindaceaeous crops and production technologies associated with tropical fruits including mangosteen and durian. Dr. Salakpetch has published extensively and among her accomplishments are discoveries on the involvement of water stress in flower induction of mangosteen and factors affecting the long juvenile period of this crop.

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THAILAND
An Overview of Tropical Fruit Production in Thailand

Surmsuk Salakpetch
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1. Introduction

Although rice and para-rubber are ranked high rank in agricultural export value, tropical fruit crops are also an important component of agricultural production in Thailand. Since 1996 exports of fresh fruit and its products from Thailand have displayed upward trends. The principal fruits that are exported are pineapple, longan, durian, lychee, mangosteen, mango, pummelo and rambutan, and together these fruits contributed to 63% of the total fruit and products export value of US $ 976.3 million in 2004. Fresh longan and durian contributed to 34 and 26% of the total fresh fruit export value (US $ 150.2 million) in 2004, respectively.

This paper describes the fruit industry in Thailand and gives information on three valuable crops (longan, lychee and rambutan) and two potential fruits in Hawaii (durian and mangosteen). Information on potential fruits for development in Thailand are also included.

2. Industry Status

An analysis of the fruit industry in Thailand using the SWOT (Strength, Weakness, Opportunity and Threat) technique showed that Thailand had developed packages of technology to improve the production of many fruit crops. Thai growers also have the competency to produce quality fruit due to the integration of their experience with technology. The lack of diversity of fruit products is an important issue for further development. Post harvest handling should be developed, and the fruits need to be treated properly to improve fruit quality if the export destinations are beyond markets found in Asia. Non-tariff barrier is a big issue for fruit trade in the world. The government’s fruit policies still focus on encouraging commercial production of fruit for export, local consumption and processing. The strong points and opportunities analyzed by the SWOT technique will be used as a driving force to fulfill the implementation of these policies. At the same time, the weakness and threats will be lessened or developed into strengths and opportunities.

Areas under fruit cultivation (durian, longan, rambutan, pineapple, mangosteen and banana) have been increasing gradually from 2000. In 2003, the total area cultivated with fruit trees was 503,482 hectares with a total production of 4,018,106 tons. Fruit crops for commercial production have been planted in the eastern, northern and southern parts of Thailand.

3. Fruit Research and Development Program

The research and development program for fruits in Thailand is focusing on developing an appropriate package of technologies for improving productivity and quality, and with benefits the fruit producers. Post harvest handling and management is also a challenging area. The Quality Assurance (QA) system will be improved and made equivalent to acceptable international systems. The Quality Management System of Thailand has been modified and is based upon Good Manufactured Practices (GMP), Good Agricultural Practices (GAP), and the
Hazard Analysis and Critical Control Point (HACCP), Quality Assurance (QA), Sanitary and Phytosanitary (SPS) and ISO methods. Although processed fruit has been industrialized and exported for decades, diversification of fruit processing is still a trend in research. Fruit species and other downstreaming activities, and zoning areas for fruit grown for factories and export are emphasized. Plant improvement is still of interest.

4. International Fruit Trade

In 2001, the total export of fresh fruits and products from Thailand was US $ 699.8 million while the total value of fruit imported was US $ 94.2 million. The value of imported temperate fresh fruit was US $ 62.3 million. Fresh apple and its juice dominated these imports and accounted for 51% of the total imported value. Others imports included preserved citrus (8.5%), table grape (7%) and other fruit juices and nuts.

The export of fresh fruit has exhibited an increasing trend between 2000 and 2004 (Table 1). The value dropped from US $ 148.1 million to US $ 103 million in 2003, because the Taiwanese government didn’t allow the import of fresh mangosteen and rambutan. It was claimed that those two crops were the host of Bactocera carambolae Drew & Handcock and B. papayae Drew & Handcock, respectively. Luckily, the export of longan, durian and mangosteen was expanded to China markets which enabled the export value of fresh fruit to increase to US $ 150.2 million in 2004. The breakdown on the fresh fruit exported is as follows: longan (35.1% of total exported value of fresh fruit), durian (29.9%), mangosteen (6.3%), lychee (4.6%), mango (3.3%) and rambutan (1.2%). Hong Kong, China, Taiwan, Singapore, Japan, the United Arab Emirates, the United States of America (U.S.A) the Netherlands, Denmark and the United Kingdom are major markets for these fruits from Thailand.

Table 1 Exported values of fresh and processed fruits, Thailand, 2000-2004.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fresh</th>
<th>Dried</th>
<th>Frozen</th>
<th>Canned</th>
<th>Preserved added sugar/salt</th>
<th>Preserved by sugar</th>
<th>Juice</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>123.3</td>
<td>68.6</td>
<td>29.5</td>
<td>231.9</td>
<td>71.0</td>
<td>32.1</td>
<td>104.2</td>
<td>660.6</td>
</tr>
<tr>
<td>2001</td>
<td>135.0</td>
<td>39.1</td>
<td>25.7</td>
<td>248.6</td>
<td>95.3</td>
<td>41.7</td>
<td>114.4</td>
<td>699.8</td>
</tr>
<tr>
<td>2002</td>
<td>148.1</td>
<td>41.6</td>
<td>24.5</td>
<td>273.6</td>
<td>127.9</td>
<td>44.4</td>
<td>140.7</td>
<td>800.8</td>
</tr>
<tr>
<td>2003</td>
<td>103.0</td>
<td>149.4</td>
<td>19.7</td>
<td>317.4</td>
<td>132.7</td>
<td>28.0</td>
<td>191.0</td>
<td>921.6</td>
</tr>
<tr>
<td>2004</td>
<td>150.2</td>
<td>105.8</td>
<td>17.8</td>
<td>330.7</td>
<td>170.5</td>
<td>31.8</td>
<td>169.4</td>
<td>976.3</td>
</tr>
</tbody>
</table>

Source: Department of Customs, Ministry of Finance and Office of Agricultural Economic, Ministry of Agriculture and Cooperatives, Thailand.

About 75% of the total value of dried fruit was dried longan, which was exported to China and Hong Kong. Dried banana and preserved banana with sugar were very popular in the U.S.A, China and Japan markets. Frozen durian, pineapple, longan and mangosteen were...
exported to Hong Kong, U.S.A, Australia, Japan, Korea, France and Denmark and accounted for 99% of the total value of exported frozen fruits.

About 75% of total value of dried fruit was dried longan which was exported to China and Hong Kong. Dried banana and preserved banana by sugar were very popular in U.S.A, China and Japan markets. Frozen durian, pineapple, longan and mangosteen were exported to Hong Kong, U.S.A, Australia, Japan, Korea, France and Denmark and accounted for 99% of total value of exported frozen fruits.

The total export value of processed fruit, dried and frozen fruit were excluded, contributed to 70% of total value of fruit export. Pineapple has been the major product among lychee, longan and rambutan. The U.S.A, European Union (EU) countries, Singapore, Malaysia, Korea and Australia are major market outlets for these products. Canned mango and papaya are also the interest of Australia, Japan, U.S.A, the EU countries and the United Kingdom.

Overall, the total value of exported fruit and its products has increased from US $ 660.6 million in 2000 to US $ 976.6 million in 2004. The United States of America, the EU, Canada, the United Kingdom and Australia are major markets for dried, frozen and other processed fruit while Asian markets (China, Hong Kong, Japan, Indonesia and Singapore) are big markets for fresh fruit. The export market for fresh fruit will be expanded to the EU and other countries in Europe, U.S.A and Canada.


These fruits are commonly found in Thailand and have potential for development into a larger amount in export volume, if agro-techniques and post harvest management can be developed. Those that have the highest potential are described below, namely longkong, Java apple, pummelo and dragon fruit.

5.1 Longkong (*Aglaia domestica* Correa cv. longkong)

Longkong is probably derived from a natural hybrid of langsat (*A. domestica* Griff.) and duku (*A. dookoo* Griff.). Longkong has been cultivated in the eastern and southern Thailand. The globular fruit develops on catkin inflorescences and are borne in clusters. The yellow rind peels easily and cleanly from the clear, white, translucent and juicy aril. Longkong has almost no seeds and is very sweet with a mild aroma and a perfect combination of a little sourness, which makes the fruit so delicious. The fruits are mostly consumed fresh locally and do not store long after harvest.

In 2004, Thailand exported only 60,570 tons to Hong Kong, U.S.A, Vietnam and Bangladesh by air. Although longkong seems to have a high potential for export, there are some problems that limit the export volume. Fruits brown rapidly at warm temperatures and low humidity. Fruits will detach easily from cluster about 3 to 4 days after harvest. Fruit could be stored for 14 to 16 days at 18°C but browning of the peel and detached fruits can occur. Packing plays an important role in keeping the fruit in good condition en route to the market. Optimum temperature and relative humidity are also important in storage condition of the fruit.
Chanthaburi Horticultural Research Center has recently begun studies to develop post harvest handling and management strategies for longkong. Refrigerated marine container 1x20 feet reefer with Advanced Fresh Air Management (AFAM+) at 16°C with 9%O₂, 12%CO₂ and 96% relative humidity was storage condition is being compared to 16°C 1x20 feet reefer with a normal refrigeration system.

5.2 Java apple (*Syzygium samarangense* (Blume))

Java apple, a pear-shaped, tender and juicy fruit with a sweet and pleasant aroma, is a common fruit throughout Southeast Asia. The fruit color varies from green and greenish red to dark red, depending on the variety. The fruit weighs from 70 to 200 g. Java apple is consumed fresh and is well known among the Thais. The variety with a dark red color, called Thap-Thim-Chan (ruby from Chanthaburi), is exported mostly to Hong Kong and China due to its flavor and attractive color. The Chinese use the fruit to pay respect to their gods in various Chinese festivals.

Fruits are always bagged during their growth and development to protect from the oriental fruit fly and to help color development. Pruning and flower thinning techniques are being investigated to improve yield and quality of fruits. Also, post harvest treatments should be properly administered to improve quality. The fruit is handpicked when the whole fruit appears red. The skin of the fruit is delicate so during transport, fruits must be handled with care to avoiding bruising. Fruits are always protected with foam nets or wrapped with soft paper when exported.

5.3 Pummelo (*Citrus grandis* (L.) Osbeck.)

Pummelo is quite a common fruit crop in Thailand. It has been designated as one of the major crops among longan, lychee, mandarin, mango and orange in Vietnam. It has a thick green rind, which is beneficial for export and long shelf life. Its shelf life may be as long as several months with acceptable quality. Pummelo has some similarity with grapefruit. It can be grown throughout Thailand, but the main growing area is in the country’s central plain. The color of the rind changes and the oil glands become more prominent and shiny at maturity. The flesh can be easily separated from the mesocarp and contains lots of juice. The flesh color is light yellow, light green or pinkish red depending on the variety. The taste will vary from sweet and slightly sour to sweet and scented which makes pummelo attractive to consumers. Pummelo is ideal for long transport due to the presence of its thick rind and excellent keeping quality. Thailand is now seeking long distance markets other than Hong Kong, China, Singapore and Canada, which are existing markets for pummelo.

5.4 Dragon fruit (*Hylocerus undatus* (Haw) Brit.&Rose)

The Thai call it ‘Kaeo Mangkon’ while in Vietnamese it is called ‘Thanh Long’ which means dragon’s eyes. A plant belongs to the cactus family and climbs on any type of support. Thai growers use cement poles as supports for dragon fruit plants. The fruits have very attractive colors ranging from brilliant reddish pink and bright yellow depending on varieties and have several greenish, soft flat scales protruding out towards the end of the fruit. The shape of the fruit is similar to the eyes of dragon, the imaginary Chinese animal. The fruit contains high levels of vitamin C, calcium, potassium and fiber. The flesh is pure white or yellow or dark red, soft and juicy with numerous edible small black seeds. Its taste is pleasant, mildly sweet and
sour, and it has a characteristic aroma. Consumers feel pleasant when eating it especially during hot weather. Fruits are claimed to help the digestive system, prevent cancer and also reduce cholesterol. The fruit is considered by some as a health food. Until recently, Vietnam was the leading producer of dragon fruits on a commercial scale. Dragon fruit was imported to Thailand and has been cultivated in the eastern region of the country for more than 5 years. Dragon fruit is exported mostly to Hong Kong, China, Singapore and Taiwan, the same markets as Vietnam.

Dragon fruit is considered to have great potential as an export commodity to countries like China because of its attractive color and shape supplemented with its high nutritional value, pleasant taste and aroma. The red-fleshed cultivars are sweeter, with more vitamin A. A variety with a self pollinating flower will be released in the near future (Chomchalaw, 2004).

6. Conclusion

Thailand has suitable climatic conditions for the growth of tropical fruits. Also, growers are capable of high quality production to meet requirement of markets. Major tropical fruits such as durian, mangosteen, longan, lychee and rambutan are favored by Asian people. Thailand has the advantage of exporting quality fruit to Asian markets, which do not produce these crops or cannot produce enough to meet their demands. Better orchard management by applying a package of technologies that improve efficiency in the production of quality produce, and the introduction of Quality Management System (QMS) to assure on farm quality are new trends in tropical fruit production in Thailand. Post harvest technology and management of these perishable fruits are also being improved to extend shelf life and to fully exploit long distance market outlets

References

Post Harvest Research and Treatments on Rambutan
(Nephelium lappaceum L.), Lychee (Litchi chinensis Sonn.) and Longan (Dimorcarpus longan Lour.) in Thailand

Surmsuk Salakpetch
Chanthaburi Horticultural Research Center, Chanthaburi, Thailand

1. Introduction

Rambutan, lychee and longan fruits are internationally valuable commodities, however they are very perishable. This limits marketing in many countries without high quality storage facilities. The fruits must be marketed and consumed quickly, otherwise the peel turns to a dull brown color (lychee) or black (rambutan) or rots (longan). Since rambutan, lychee and longan do not have a long shelf life, technology to prolong their shelf life has been the major area of post harvest research and development in Thailand and other countries, and has focused on these fruits due their high value. Hydro coolers or cool rooms together with various modified atmospheric packaging (MAP) or controlled atmospheric (CA) condition is frequently used to prolong shelf life. Although many post harvest studies have been published, implementation of these studies to commercial scale by researchers is also essential.

This paper reports on the post harvest knowledge, technology and management of those three fruits in Thailand.

2. Post harvest knowledge and management of rambutan in Thailand

Thailand now exports fresh rambutan to the Netherlands, Canada and Denmark by airfreight and to Malaysia by land. There is no sea transportation for rambutan from Thailand. It has been reported that 2% O₂ and 5 to 10% CO₂ are the safe levels for low O₂ and high CO₂ controlled atmospheric (CA) storage conditions for rambutan. If O₂ level is too low, rambutan may develop off-flavors while too high CO₂ levels will cause peel browning, off-flavor and watery flesh. This knowledge has not been implemented into a system on a commercial scale.

Fresh rambutan weighing about 500 and 1,000 g was kept for 23 days at 10 °C when they were packed in a linear low density polyethylene (L-LDPE) bag that was 70 µm thick and had O₂ transmission rate (OTR) and water vapor transmission rate that were 2,600 ml m⁻² day⁻¹ and 4.56 g m⁻² day⁻¹, respectively and flushed with mixed gases 5:5 O₂:CO₂. When a high density polyethylene (HDPE) bag in which O₂ transmission rate (OTR) and water vapor transmission rate were 5,688 ml m⁻² day⁻¹ and 6.70 g m⁻² day⁻¹ respectively, was used, rambutan could be kept for 26 days. This technology is now being modified and implemented on commercial scale. Modified atmospheric packaging (MAP) and a refrigerated marine container 1x20 foot reefer with AFAM+ (Advanced Fresh Air Management) at 13 to 14 °C will be used to implement this concept. The target group is high end destinations in Europe where minimal cut tropical fruits and vegetables from Thailand are favored.
It has been reported that more than 20% CO\textsubscript{2} level and/or less than 1% O\textsubscript{2} level can be harmful to rambutan kept at 12.2 °C for up to 14 days. Low relative humidity will cause water loss and browning. It has been also shown that elevated CO\textsubscript{2} retards color loss and low O\textsubscript{2} slow aging of fresh rambutan. Chanthaburi Horticultural Research Center (CHRC) together with Horticultural Research Institute conducted an experiment to investigate post harvest treatments for extending shelf life of rambutan under simulated conditions for export by sea using refrigerated marine containers. Fresh rambutan was carefully harvested and transported to CHRC where the investigation was conducted. The rambutan was packed in 3 different packaging systems and then put in 20-kilogram plastic fruit basket compared to packing in 20-kilogram plastic fruit basket with and without paper lining. The sensational newspaper, which had 1-inch diameter hole and each hole was 3 inches apart, was reused for lining. The rambutan was kept in a refrigerated marine container 1x20 foot reefer with AFAM+ at 12°C, 12% CO\textsubscript{2}, 9% O\textsubscript{2} and 96% relative humidity and was compared to 12°C, ventilation 15cbm/hr, 1x20 foot reefer with normal refrigerated system. It has been suggested that AFAM+ will minimize fresh air vent openings, which in turn limits water loss and permits the buildup of relative humidity and CO\textsubscript{2} to optimum level. The investigation showed that outer appearance and eating quality of rambutan at 15 to 18 days after keeping in AFAM+ reefer were commercially acceptable. The quality of the fruit in baskets which were lined with paper looked better than that in the baskets without paper lining. All fruits kept in a normal refrigerated system reefer were non-usable at 10 days after storage. The result will be adapted for trial shipments of fresh rambutan in the 2005/2006 production year to Hong Kong and China for which transit time is up to 4 and 15 days, respectively.

3. Post harvest knowledge and management of lychee in Thailand

Without specialized treatment, the lychee skin browns within a day, but the aril deteriorates more slowly. Lychee fruits are prone to water loss at warm temperatures and low relative humidity. The water loses from the peel causes the dull brown color of the peel. The aril is unaffected at this stage. Eventually, the aril loses water and the fruit becomes soft. A number of measures were developed to prolong shelf life of lychee. It has been said ‘with precaution against dehydration and rots, along with sensible orchard management and post harvest handling, lychee may keep for 2 to 3 weeks.’ One of the sensible orchard management strategies is picking the lychee at the right stage of development.

In practice, Thai growers harvest lychee on the basis of taste and fruit appearance. When the fruit is mature, fruit skin becomes flat. Fruits are harvested when 50% of the fruit surface turns to a pink or red color and the protuberances are wider or about 4 months after anthesis, depending on cultivars. Harvesting may be carried out by removing the whole fruit panicle using scissors, which is tied up to the end of the pole, or by cutting or twisting the stems of individual fruit and taking the fruit to the shade house in the orchard for sorting and grading. Harvesting must be done with care to avoid tearing or bruising the skin. Also, to avoid mechanical injury on the skin, careful handling of fruit in the orchard is needed.

Pest and/or mechanically damaged and inferior fruits are removed during sorting. Fruit are normally graded during or after sorting. Uniform sized and unblemished fruit are the market requirements. Lychee can be packed on panicles or as individual fruit, depending on the market
requirement. When fruits on the panicles are required, each panicle must contain not less than 3 fruits and panicle stalk must be about 15 cm long. Individual fruit must be de-stalked and left with at least a 2 mm long stem. Selection of packaging materials and methods depends on market preferences and availability. Fruit panicles or individual fruits are packed carefully in 10-kilogram rectangular plastic basket (35x50x16 cm; width x length x height) with all of its sides ventilated. The basket is lined with a piece of sponge at the bottom and on the top of the basket. Also, 10-kilogram cardboard boxes may be used. Lychee baskets will be dipped in iced clean water with a temperature that is about 5°C, for 2 to 3 minutes and loaded into a 2°C 1x40 feet normal refrigerated system reefer. Small pieces of ice, about 20 cm thick, will then be topped onto each stack of 10 fruit baskets. This practice may keep the fruit stay longer due to the cold from ice layers. On the other hand, it may promote fungal activity if temperature in the reefer fluctuates.

Fruits can remain fresh for 7 to 10 days when kept in sealed polyethylene bags and stored in a home refrigerator. The storage life of the fruit can be about 2 to 3 weeks when stored at 5°C. Sulfur dioxide is used to fumigate lychee fruit to reduce browning and to protect the fruit from rots. This treatment procedure is done for export fruits only. The treated lychee stays fresh with acceptable eating quality for about 4 to 6 weeks. Also, a combination of cold temperatures and fungicidal treatment can keep fruit fresh for 3 weeks at 12 °C and 4 weeks at 2 °C.

A reduction in concentration of ascorbic acid, phenols, sugar and organic acids after storage can cause fruit to have unacceptable quality to the consumer, however dipping fruits in ethephon can improve the quality of the harvested fruit. A dip in an ethephon solution at 2.5 g per 1 liter water for 5 minutes resulted in a 50% increase in total sugar, a 20% increase in ascorbic acid and an increase in the ratio of total soluble solids and titratable acidity from 20 to about 30 to 40 over 3 days. However, this practice is not commonly used in Thailand.

Carbon dioxide (CO₂) levels greater than 15% or oxygen (O₂) level less than 1% can cause off-flavor in lychee fruits. Elevated CO₂ can result in a graying of the aril. Skin browning may be suppressed for up to 5 weeks at 0°C with 5% O₂. It has been suggested that lychee can be shipped and kept in a properly sealed AFAM+ refrigerated container at about 2.2°C (36°F) with 5% CO₂ and 16% O₂ for up to 3 weeks.

The Horticultural Research Institute collaborated with Chiangmai Royal Agricultural Research Center and studied the incorporation of a hot water spray into the packing line of lychee to kill insects. The aim of the study was to modify the use of hot water treatment on a commercial scale. The study did not give satisfactory results because fruits were damaged during the process. Further investigation is required to develop an effective strategy on a commercial scale.

Recently, New Zealand has announced the conditions that will allow importation of lychee and longan fruits from Thailand. The agreement was in place on August 31, 2005 and will be reconsidered by Ministry of Agriculture and Forestry of New Zealand and Ministry of Agriculture and Cooperatives of Thailand in 2008. Lychee exported by airfreight must be treated by vapor heat at ≥ 47 °C for at least 20 minutes. Cold disinfection treatment at 0 °C for 10 days, or 0.56 °C for 11 days, or 1.11 °C for 12 days, or at 1.67 °C for 14 days is allowed for
the fruits exported by sea freight. These are the requirements proposed by the Import Health Standard of New Zealand.

Also, lychee and longan fruits exported to Australia must be treated at $\leq 1 \, ^\circ C$ for at least 15 days or at $\leq 1.39 \, ^\circ C$ for 18 days to ensure that the egg of the fruit fly is killed. Apart from cold treatment by the exporters, 600 fruits will be sampled by Australian quarantine officials to examine egg and damage from fruit fly.

4. Post harvest knowledge and management of longan in Thailand

Longan is normally grown in the northern parts of Thailand where most of the commercial production is harvested during June to August. Recently, the central and eastern parts of the country was not only successful in producing a good crop but also was able to produce off-season fruit, or produce at least a month or two prior to the main production in the north. The commercial cultivars grown in Thailand are Daw, Seechompoo, Haeo and Biew Khiew, and take about 5 to 5.5 months after anthesis to harvest. *Daw* fruits are compressed round and droop-sided. Fruit skin is thick, rather tough and opaque white. The fruits of *Seechompoo* are rather round with rather thick reddish brown skin. The aril is medium thick, a bit crispy and sweet with a mild aroma. Seeds are rather small. Since the peel contains a high concentration of phenols compared to other cultivars, this may lead to rapid browning of the peel after harvest. Based on some observations, cool temperatures and high relative humidity may slow down the activity of phenolic compound in the peel. *Haeo* is a late bearing cultivar. The fruits are large, round and droop-sided with a compressed base. When the thick brownish skin is peeled away, a thick, dry, crispy and opaque white sharply sweet aril is revealed. *Biew Khiew* fruits are rather large, compressed round and very droop-sided with a thick brownish green peel. The aril is thick, crispy, rather translucent and sharply sweet with 22 to 23 °Brix (sugar content) readings.

At the fully mature stage, the fruits normally enlarge maximally with a smooth outer skin and netted lines inside. A change in skin color is one of the maturity indices. A common practice is to taste the fruit to determine sweetness before harvesting. Fruits are harvested by cutting off the entire fruit panicles. The freshly harvested fruit are sorted to remove damaged and inferior fruits. The entire surface of each fruit and its panicle must be carefully examined to ensure that damaged fruits are not included.

Grading is the next step after sorting to separate fruits into different grades to suit the market requirements. Grading may be carried out during sorting in some areas. Grading system is normally based on fruit size, skin color and the amount of area with blemishes. Export markets usually require higher standards (uniform and unblemished fruits) compared to domestic markets. If the markets require bunched longan, the panicle stalks will be trimmed to 15 cm in length and fruits which have not attained the appropriate size within a particular panicle and don’t have a standardized appearance will be clipped off. The panicles will then be bundled together. If individual fruits are required, the fruit stalk must be left on the each fruit but cannot be less than 5 mm in length. The fruit bunches or individual fruits are then packed in a 10-kilogram rectangular plastic basket with a cover and lined with a piece of sponge at the bottom.
and the top of the basket. The baskets can be stored in cold room while waiting for sulfur dioxide fumigation.

Fruit for export markets will be fumigated with sulfur dioxide to inhibit fungal activity during transport. The longan baskets are placed in a room that is durable, strong and able to withstand sulfur dioxide corrosion. The room has a stainless steel door with a rubber seal to prevent sulfur dioxide leakage. Normally, the capacity of the room can vary and will hold about 200 to 1,000 of the 10-kilogram baskets. The baskets must be spaced away from the walls and spaced from each other to enable the sulfur dioxide to distribute evenly. Sulfur powder is then placed on the heat-proofed container and burned by a gas stove for about 50 to 90 minutes, depending on the size of the room. After fumigation, the baskets will be loaded into a 1x40 foot refrigerated marine container at 5°C with 90 to 95% relative humidity or at 10°C. The fruits can be kept for 40 to 45 days at 5°C and 20 days at 10°C. Sometimes, longan fruits are dipped in 2 to 5°C clean water for 10 to 15 minutes and allowed to dry before packing.

Sulfur dioxide fumigation of longan fruits has been used successfully in Thailand since the treatment was able to overcome many of post harvest problems. However, sulfur dioxide fumigation is facing increasing consumer and regulatory resistance to its use. Without the use of sulfur dioxide, major problems may be expected from the lack of control of storage quality and post harvest diseases by a large part of longan industry. Handling practices to improve the effectiveness of storage facilities especially in the absence of sulfur dioxide needs to be refined.

In some countries, the fruit of longan may be dipped in 5% hydrochloric acid for 20 minutes. With this treatment, the skin color could be slightly improved and did not change easily from dehydration or chilling damage which allowed fruit to be stored in low humidity and cool temperatures for over 40 to 60 days. Hydrochloric acid treatment is not a common practice in Thailand.

New Zealand requires that longan be treated by vapor heat at ≥ 47 °C for at least 20 minutes if it is transported by air. The fruit exported by ship must be subjected to cold disinfestation treatment at 0.99°C for 13 days or at 1.38 C for 18 days.

5. Conclusion

There are many scientific studies, particularly at the laboratory scale, on post harvest research aimed at prolonging shelf life of rambutan, lychee and longan in Thailand and other countries. Most of the results showed how combinations of low temperatures and high relative humidity could extend the shelf life. Controlled atmospheric (CA) continues to be an area of interest. Trial and error studies on the commercial scale are always made by traders who have little knowledge about post harvest technology but have a lot of experience in trade. Eventually, the proper commercial scale post harvest handling and management strategies may be developed. However, a large amount of money, time and fresh produce were invested in this effort.

Collaboration among researchers, exporters and sea freight owners to explore commercial scale of post harvest management and quarantine treatments of some tropical fruits is the new trend in the research and development program in Thailand. Modified atmospheric packaging
(MAP) is an area that needs further development. Successful post harvest handling and management treatments will overcome the bottlenecks associated with these three valuable crops.

Since the future of sulfur dioxide post harvest treatment is uncertain, an alternative to sulfur dioxide is required. Although Thailand exported a large volume of tropical fresh produce by sea, there still were gaps in knowledge to enable more efficient transport by sea. To provide better information to distribution cold chain and cold chain assurance will give benefit to extending shelf life of fresh produce and ensure that all quality produces will be delivery with acceptable quality to customers.

References:
Durian (*Durio zibethinus* L.) Flowering, Fruit Set and Pruning

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1. Introduction

The Chanthaburi Horticultural Research Center (CHRC) was assigned by the Department of Agriculture to be responsible for research on 3 main tropical fruit crops in the country (durian, mangosteen and rambutan) and other horticultural crops grown in the eastern region of Thailand. CHRC has developed a package of technology to induce early and improved production of durian and then transferred the technology to extension personnel and growers. It was emphasized to growers that a thorough understanding of the crop physiology of durian can help them manipulate the flowering and fruit setting processes, and also have an affect on fruit quality. Thus they can produce a high volume of durian with a quality that is acceptable to the market. The fruits can be harvested at the time that markets require the fruits, and it can then be sold at a desirable price.

The concept of flowering and fruiting and management to improve flowering, fruit set, fruit growth and fruit development are included in a package of technology to improve durian production and will be fully discussed in this paper. Pruning techniques are also included in this presentation.

2. Concept of flowering process in durian and management

2.1 Concept of flowering process in durian

Flower induction in durian requires both internal and external factors. The competence of durian trees is considered as an **internal factor**. When the term competence is discussed, the discussion focuses on assimilate supply and a critical balance of a group of plant hormones. The **external factor** is primarily a dry period which should occur continuously for 7-14 days. Both factors together will trigger the flowering process (Figure 1). Low temperatures, about 20-22°C, and relative humidity, 50-60 %, are factors required for flower development.

![Figure 1](image-url)

**Figure 1** Flowering process of durian
**Stage I**: This stage encompasses the vegetative growth period of durian. During this period, the tree are grown and manipulated to produce maximum amount of photosynthates and assimilates. Cultural techniques such as pruning, fertilization, irrigation, and crop protection at an appropriate time, will stimulate leaf flushing and help new leaves to grow in a healthy manner. Healthy leaves will photosynthesize efficiently, and once the maximum photosynthates are produced in healthy trees, adequate amounts of photoassimilates are then stored for the flowering process.

**Stage II**: When a continuous dry period occurs which is the appropriate environmental condition for flower induction, a balance and the appropriate level of a specific group of plant hormones will be attained to begin the flower induction process. The interaction of these factors and the internal assimilate reserves cause the tree to enter into the induction period.

**Stage III**: After the induction period, the tree will proceed to an evocation period. During this period, numerous physiological and biochemical events occur at the molecular to the morphological levels. Under favorably inductive conditions, a complete sequence of evocational events will be the result. This will cause the appropriate tissues to progress to a point where the flower bud is then initiated beneath the bark on durian branches.

**Stage IV**: During this period cell differentiation occurs. At the end of this period, the appearance of flower bud which resembles a very small, fresh and creamy white spot can be detected on the branches.

**Stage V**: Buds begin to swell during the first phase of this stage. After the bud swells, the durian flower buds will develop sequentially until bloom. Energy that was stored during the Stage I will be utilized continuously during the development of the flower buds.

Durian flowers are borne in clusters on main and lateral branches, but are not found on the trunk. Each inflorescence contains 8 to 20 or more, large pendulous flowers. It takes about 2 months for flowers to progress from emergence to full bloom. At flower opening, the green epicalyx splits to reveal 5 slightly golden united sepals and 5 yellowish white petals. A large receptive stigma, which is covered with stigmatic fluid, protrudes at about 1 p.m., about 2 hours before opening, and remains in that condition until the following morning, which is approximately 18 to 20 hours after being receptive. Durian flowers usually open in the late afternoon, but anther dehiscence does not occur until about 6 to 7 p.m. or later depending on the variety. By midnight, all flower parts including stamens, and except for the pistil, fall to ground. However, all flower parts may remain attached until the following morning if the recommended water management regimes described below are applied during the floral growth and development stage.

### 2.2 Management for flower induction and development

Before flowering, durian trees should be healthy with brightly colored and mature shiny leaves. Damage from pests on leaves should be less than 5% of the total leaf area of the whole tree. Mechanical and/or pest damages on branches should be on less than 5% of the total
branch number. The trees must be free from Phytophthora disease. A healthy tree exhibits a high degree of vigorous vegetative growth and is ready to flower when an appropriate inductive treatment is applied.

2.2.1 Water management to stimulate flowering process

A dry period for 7 to 14 consecutive days, which results in about –0.8 MPa leaf water potential, is needed to trigger the emergence of flower buds. After exposure to an optimum level of drought, the tree leaves show symptoms of water stress by being oriented in a downward direction. Under normal environmental conditions, when temperatures are about 18 to 35°C, irrigation of about 10 mm (1 mm = 1 liter water per 1 m² of area under canopy) is applied. The second irrigation regime will be required when tiny and creamy white spots of the flower buds emerge. The flower buds can be first observed on small branches. After the emergence of floral buds, irrigation of 60% of the daily pan evaporation is required for about a week to promote growth during this initial stage of floral development. To obtain normal flower growth at the later stages of flower development, irrigation of about 75 to 85% of the daily pan evaporation is suggested.

If the temperature is lower than 18°C, irrigation at about 20 to 25% of the daily pan evaporation is required every other day until the flower buds can be observed on small branches. Water is then applied to obtain normal growth of the flower buds. On the other hand, if the temperature is higher than 35°C, irrigation with 10 mm is applied as an initial application. Seven days after that first application of water, irrigation of about 40 to 50% of the daily pan evaporation is applied at 3-day-intervals until the flower buds can be observed. Water of 75 to 85% of the daily pan evaporation is then applied to promote normal growth and development of flower buds.

2.2.2 Fertilizer application to promote growth and development of flower buds

When the number of flowering branches are less than 60% of total number of branches that are able to flower and the density of flowers is less than 3 inflorescences per 1 meter of branch length, fertilizer management is required to increase the number of flowering branches and flower density. Potassium nitrate (13N-0-46K₂O) at 100 to 200 g and sea weed extract at 60 ml in 20 liter water are foliarly sprayed at an early stage of flower emergence when a very small and creamy white spot, is detected. The application is able to promote an increase in flower number.

2.2.3 Pests during flower growth and development

Chilli thrips (Scirtothrips dorsalis Hood), African red mites (Eutetranychus africanus Tucker) and flowering eating caterpillar (Pubjemama vesiclora Walk.) are known to damage the durian flowers. Phytophthora palmivora and anthracnose (Colletotrichum zibethinum Sacc.) can also damage the flowers if the microclimate is warm and humid.

2.2.4 Flower thinning

At about 5 weeks after flower emergence, if the density of flowers is more than 6 inflorescences per 1 meter of branch length or if various stages of flower development are observed on the same branch, flower thinning is required. The inflorescences on branches with a
diameter smaller than 2 cm or at the terminal end of any branch should be thinned out. Inflorescences on the same branch should be the same stage of development. An optimum density of flowers is 3 to 6 inflorescences per 1 meter of branch length and about 30 cm. apart.

2.3 Management to promote fruit set

Durian pollen is released mainly in clumps, indicating that it is not distributed by wind. Moths may be involved in pollen transfer. It was shown that if more pollen lands on the stigmatic surface, a higher amount of fruit set will be the result. This knowledge has led to hand-crossed pollination being a common practice to improve fruit set in durian.

The viability of durian pollen is variable among cultivars. Fresh pollen of Kradumthong, Monthong, Chanee, and Kanyao cultivar has 83, 90, 94, and 96% viability, respectively. The pollen will lose its viability when it is older. Drastic environmental conditions, e.g. rain, heavy dew and temperatures lower than 18°C, can damage and destroy the pollen. The germination ability of durian pollen will decrease dramatically one day after shedding.

Pollen grains of 4 main cultivars of durian, collected from semi-irrigated trees, require about 25% sucrose solution for germination while those collected from regular irrigated trees germinated well at 35% sucrose solution (Figure 2). The concentration of stigmatic exudate is about 20 to 25%. If rain or dew occurs at the time that stigma is receptive, the stigmatic exudate will be diluted and be in an unsuitable condition, for germination and consequently, the pollen cannot germinate or may die. The pollen can also be leached from the stigmatic surface by heavy rain and dew. This discovery explains why there is no fruit set when it rains or when relative humidity is high during full bloom. Also, it explains the need for proper water management before full bloom to improve the set of durian fruit.

![Germination & death of pollen, collected from regular and semi-irrigated Kradumthong durian at anthesis, in various concentrations of artificial media.](image)
2.3.1 Fertilizer application to promote fruit set
Calcium (Ca), boron (B), magnesium (Mg), and potassium (K) have been proposed as the main nutrients for pollen germination and pollen tube growth. It was demonstrated that durian pollen requires Ca at 50-90 ppm, B at 30-60 ppm, Mg at 15-30 ppm and 15-30 ppm K for germination. Lower and higher concentrations will cause poor germination and tube growth. It was found that durian leaves contain Ca, K, and Mg at higher levels than the optimum for germination, whereas B is at a lower level. This will lead to a unbalanced ratio between Ca and B, compared to a balanced ratio of 200:1 Ca:B. Therefore, durian growers spray calcium and boron when flowers have developed to the sixth week after emergence to promote germination of pollen.

2.3.2 Water management to promote fruit set
About a week before bloom or when flowers are at about the 7th week after emergence, irrigation is reduced from the normal rate to 20 to 25% of the daily pan evaporation until bloom. If temperature is greater than 36°C, daily irrigation at a recommended amount is needed. Full bloom occurring at 3 p.m. is an indication that water management has been applied properly.

The process of fruit set occurs over about 3 days after anthesis. After the fruit has been set, irrigation is gradually increased to about 60 to 70% of the daily pan evaporation within 3 weeks after anthesis to promote normal growth of the young fruit and to prevent young fruit drop.

2.3.3 Assisted pollination to increase number of fruit set
When about 25% of total flower number on the whole tree flowers is at bloom, hand-crossed pollination using pollen from different varieties or from the same variety but different trees is recommended. The optimum time should start pollination is from 6:30 to 9:30 p.m. or later, which is the effective pollination period for durian.

2.4 Management to promote fruit growth and development
The source-sink concept is the main principle behind improving production of durian fruits with acceptable quality. It was reported that developing durian fruits act as stronger sinks when compared to mangosteen and rambutan fruits. This is supported by the growth pattern of durian fruit which shows dramatic increases of up to 16 g/fruit/day, at 8-12 weeks after anthesis (Figure 4). Therefore, enormous amounts of assimilates will be required to support fruit growth.

To obtain better production of durian with marketable quality and with market acceptance, the source-sink concept and appropriate cultural techniques (irrigation, fertilization, and pest control) should be managed in the following manner during fruit growth.
2.4.1 Fruit thinning

In Thailand, fruit thinning is one of the important cultural techniques to promote growth and affect shape and quality of fruits. The first thinning should be done when the fruits are at 4 to 5 weeks after anthesis. Very small fruits, deformed fruits, fruits located at inappropriate positions on the branch or fruits from different flower flushes must be thinned out. The fruit number left on the tree after the first thinning should be 2 to 3 times higher than the expected number that the particular trees is able to retain. About 330 healthy mature leaves can produce sufficient assimilates for the growth of a single fruit until harvest.

A week later, the second thinning may be necessary if small fruits, slow growing fruits (spine color is brownish red instead of bright green color) or fruits damaged by pests are detected. After the sixth week of growth, fruit growth and development should be carefully examined every week until the tenth week after anthesis. If small misshapen fruits that are narrow at the end or at the top are found, thinning out of these fruits is required. Altogether, thinning should be carried out about 5 times.

2.4.2 Fertilization and irrigation

The recommended fertilizer to encourage fruit growth is 12N-12P₂O₅-17K₂O+2MgO or 8N-24P₂O₅-24K₂O or 13N-13P₂O₅-21K₂O. This should be applied when fruits are at 5 to 7 weeks after anthesis. Another fertilizer, 0-0-50K₂O, should be applied when fruits are at 9 to 10 weeks after anthesis to improve pulp quality.

Figure 4  Development of durian fruit, cv. Chanee.
Irrigation rates to promote normal growth and development of durian fruits are 70% of the daily pan evaporation at 3 to 4 weeks after anthesis, 75% at 5 to 7 weeks after anthesis, 85% at 8 to 10 weeks after anthesis, and reduced to 75% at 11 to 12 weeks and to 60% of the daily pan evaporation for fruits older than 12 weeks after anthesis.

2.4.3 Pests during fruit development
Durian seed borer (*Mudaria luteileprosa* Holloway), fruit boring caterpillar (*Conogethes punctiferalis* Guenee), mealy bugs (*Planococcus minor* Maskell and *P. lilaccinus* Cockerell) are major pests found during the development of durian fruit. Fruit rot caused by *Phytophthora palmivora* Butler, *Phomopsis* sp., *Colletotrichum* sp. and *Lasiodiplodia* sp. are also problems.

2.4.4 Control of young shoot development during fruit growth
New young vegetative shoots during fruit growth will compete with the developing fruit for assimilates. This is one of the major factors leading to immature fruit drop, misshapen fruits at 5 to 8 weeks after anthesis and hard or mummy fleshed fruits at 8 to 12 weeks after anthesis. The recommended irrigation regime from 3 to 4 weeks after anthesis can reduce new shoot development to a certain degree. Growers should carefully examine the trees and if vegetative shoots are found one or two sprays of potassium nitrate at 150 to 200 g per 20-liter water is recommended to inhibit growth of new shoots. If later stages of vegetative development are detected, growers spray a mixture of 30 ml instant carbohydrate solution, 30 ml humic acid and 60 g 15N-30P2O5-15K2O or 10N-20P2O5-30K2O foliar fertilizer together with 50 ml mepiquat chloride (25% active ingredient) in 20 liters of water. The mixture of fertilizer will serve as food for young shoot and mepiquat chloride, which is synthetic growth retardant, will retard growth of new shoot by reducing the level of endogenous gibberellins in the tree.

2.4 Harvesting index and harvesting techniques
Durian fruits (*Durio zibethinus* Murr.) normally drop when ripe. In Malaysia, Indonesia and the Philippines, fruits are allowed to fall on the ground and picked daily, but Thai growers detach the fruit at the stage when fruits are of physiologically mature. The fruit will ripen to excellent eating quality about 3 days after harvesting.

2.4.1 Harvesting index
Days from full bloom to harvest is one characteristic that determines the maturity of fruits. The fruit of the commercial varieties in Thailand take about 90 to 135 days from anthesis to physiological maturity, depending on varieties, position of fruit on a tree, cultural techniques and environmental conditions.

Indices of maturity can be observed by the change in rind color from waxy fresh green to slightly rusting, a dry look or freckles, and browning at the ridges of the fruits.

Tips of spines may turn to a brown color and become slightly dry. The spines also become more flexible and can be pushed inwards more easily than those of the immature fruits.
Changes also occur to the fruit peduncle: swelling of a portion of peduncle close to the abscission (break) point, roughening (sandy-feeling) on the peduncle surface, increase in stiffness of the peduncle-stem (determined by holding and swinging the fruit).

The aril will turn from off-white to pale yellow, creamy or yellow, depending on the variety. The color of the seed will turn to a reddish brown.

The acoustic method of tapping the fruit whereby the tapping sound changes from tight to loose can be used as one of harvesting indices. As the fruit matures the aril lifts away from the husk leaving an open space which accounts for the hollow sound.

The indices mentioned above are classified as subjective indices. Chanthaburi Horticultural Research Center, Kasetsart University and Chiangmai University developed an objective index using pulp dry weight e.g. pulp dry weight of mature Kradumthong fruit is $\geq27\%$, Chanee is $\geq30\%$ and Monthong is $\geq32\%$. This index was accepted by growers and traders and suitable for distant markets.

2.4.2 Harvesting techniques

Mature fruit can be harvested at any time of the day except when it rains, because the tree is very slippery and the harvesters cannot judge the fruit maturity correctly. When harvesting, the harvesters climb into the canopy and use a sharp knife to cut the fruit stalk above the abscission mark or the break point. The harvested fruit will then be dropped individually to a collector under the tree who uses a jute sack, which acts as a cushion, to collect the fruit.

3. Pruning to control canopy of durian

In Thailand, durian plants are normally propagated by grafting or inarching (approach grafting) and the position of the graft should be at about 30-35 cm. above ground level. This results in a reduction in the risk of phytophthora disease occurring in the scion. When cultivated under orchard conditions, durian trees are distinctly pyramidal in shape, while in trees grown under jungle conditions or under jungle-like conditions the lower branches are self-pruned and the bearing branches will be very high overhead in the canopy. Therefore, it is important to pay a great deal of attention to the training and pruning of durian trees when grown under orchard conditions.

3.1 Training and pruning juvenile trees

Pruning should be carried out regularly from the time of planting to build up a strong framework of branches. The following practices are employed:

- When durian plants are established after transplanting, the first objective is to ensure that 4 to 6 strong, lateral and wide-angled branches are selected as the main or primary limbs and the lowest branch should remain at least 60 cm above the ground level. These branches should be about 10 to 15 cm apart, increasing to 30 cm apart in the mature tree.
- Remove lower branches to allow only one main trunk to develop.
- Remove water sprouts, water shoots, narrow-angled and open-angled limbs and any unhealthy shoots.
A year later, another 6 strong, lateral and wide-angled branches are selected as the main or primary limbs. At this stage, about 10 to 12 primary limbs should be developed and the highest branch should be about 2 meters above ground level.

- When durian plants are 3 years old after transplanting, the lowest branch should be about 1 meter above ground level. In this case, 1 to 3 lower primary limbs can be cut.
- To encourage vigorous growth of the primary limbs, secondary and tertiary limbs should be removed. This results in production of long primary limbs. The length of primary limbs represents the canopy size.

3.2 Pruning mature trees

Since durian produce flowers and fruits on branches, strong healthy and productive branches should be left on the tree. Productive branches should have a diameter of about 4 to 10 cm and are in the position that they can receive a photosynthetic photon flux density (PPFD) more than 90 µmol m\(^{-2}\) s\(^{-1}\). Unproductive branches have diameters wider than 10 cm or less than 4 cm. The current practice to encourage production of the productive and strong healthy branches is as follows.

- Excessive small branches inside the canopy should be removed to increase ventilation and light penetration in the canopy. Branches that receive PPFD less than 90 µmol m\(^{-2}\) s\(^{-1}\) are unable to produce new vegetative shoots and can dry up and die.
- When the diameter of primary limbs close to 10 cm, the secondary branches should be encouraged to increase number of productive branches.
- Immediately after harvesting, complete fertilizer such as 16N-16P\(_2\)O\(_5\)-16K\(_2\)O and cow manure are applied to strengthen the tree. The damaged, diseased, dried and unused branches should be pruned off to promote the emergence of new shoots.
- The main trunk and the primary limbs can be topped and trimmed regularly to obtain a desirable shape of the canopy so that the cultural practices described above can be employed in an efficient manner.

4. Conclusion

The appropriate package of technology to improve durian productivity and quality has been developed over several years. It has been developed based upon an understanding of several factors and concepts: the crop (durian), necessary production materials, environmental physiology, source-sink relationships and the interaction between the crop, production materials, environmental physiology and source-sink relationships. When the production technology was transferred to growers, these concepts were also transferred. The growers then understood why and when the particular cultural techniques had to be carried out. If some cultural techniques in the technology package did not have promise or was not effective in some areas, growers provided feedback to CHRC. More research and observation trials were then conducted to keep the technology up to date and applicable under various environmental conditions. The technology that has been transferred to Thai growers is detailed in this paper.
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relationship affecting fruit development and fruit quality in durian, *Durio zibethinus* Murr.
Mangosteen (*Garcinia mangostana* L.) Juvenility and Pruning in Thailand

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1. Introduction

In most parts of Southeast Asia, mangosteen is often grown as a component of a mixed crop planting. Commercial orchards, which are more efficient in the utilization of resources, can be seen in Thailand. Mangosteen is a slow growing tree that can grow up to 10 to 25 meters high, but it has a long juvenile period. The trees begin to bear fruits 10 to 12 years after seeding. However, if the plant is well cared, fruiting can begin at 7 to 8 years after seeding. The technology to improve mangosteen production has been established and transferred to growers. Pruning techniques and how the young plants should be cared after transplanting are also included in the technology.

Descriptive information on pruning of mangosteen trees, and how juvenility research has been implemented are described in this paper.

2. Implementation of juvenility research

The only method to propagate mangosteen is by seed which produces a true-to-type seedling. The seedlings should be grown in a highly fertile potting mix and kept under 50% shade in the nursery. Since the seedlings grow very slowly, they take up to 2 years to be strong and large enough to transplant to the field. Grafting has also been attempted in Thailand, and in Australia and Malaysia, to reduce the juvenile period, but the technique has not been developed commercially. The observation in Thailand showed that if tertiary limbs are chosen as scions, the grafted plants tend to grow horizontally after planting out in the field. Grafted mangosteen plants were planted in the field at the Chanthaburi Horticultural research Center and compared to the seeding plants. They both produced first fruit at the same time, about 7 to 8 years after planting, under proper irrigation and fertilization.

As a general practice, a complete fertilizer of 16N-16P₂O₅-16K₂O and irrigation with an amount of water about 70% of daily pan evaporation is applied regularly to accelerate growth of mangosteen seedlings grown under the nursery conditions. Sprays of foliar fertilizer may be required. Under these conditions the plants will produce the secondary branches and increase in leaf number and area before transplanting.

Growing mangosteen together with durian, rambutan or longkong is a common practice in Thailand, because growers experienced that the young plants require nurse trees or artificial shade to encourage their growth. By intercropping the trees in this manner, growers will not lose income during the mangosteen’s juvenile period. They will make a decision at 6 to 7 years later as to whether mangosteen will be the main crop or be continued as part of a mixed planting. If mangosteen is grown alone in a newly planted orchard for large scale production, growers normally keep the plants under 50% shade conditions for about a year, and a row of banana may
be planted between each row of young mangosteen. After field transplanting, irrigation at an amount equivalent to 60% of daily pan evaporation is applied regularly. A complete fertilizer, 16N-16P₂O₅-16K₂O, and animal manure (chicken manure is preferred) are also recommended to promote the growth of the young mangosteen plants. The plants should be kept well protected from the major pests including: chilli thrips (*Scirtothrips dorsalis* Hood), and mangosteen thrips (*S. oligochaetus* Karny), leaf miners (*Phyllocnistis* sp. and *Acrocercops* sp.) and leaf eating caterpillars (*Stictoptera columba* (Walker), *S. cucullioides* (Guene), and *S. signifera* (Walker)). Protection from pests reduces any interference with vegetative growth. With good planting materials, and under proper cultural techniques, the mangosteen trees can produce its first fruit at 6 years after transplanting.

3. **Pruning to control growth of mangosteen trees**

Unlike durian, it is not necessary to prune mangosteen during its juvenile period. Since mangosteen trees produce flowers and fruits on the terminals of new growth on small twigs that develop from the main stem or large branches, a large number of strong healthy and productive branches and terminal shoots should be left on the tree. The current practice that is used to encourage production of those productive and strong healthy shoots is described below.

- Immediately after harvesting, a complete fertilizer consisting of 16N-16P₂O₅-16K₂O and cow manure are applied to strengthen the tree. The dead and mechanically damaged branches from any heavy fruit load and from harvesting should be pruned off. Pruning applied together with fertilization will enhance synchronous leaf flushing.
- The main trunk and the side-branches can be topped and trimmed regularly to obtain a desirable shape and canopy for efficient implementation of cultural practices. The overlapping side-branches may result in a reduction in fruit production.
- The branches at the upper part of the tree should be removed to improve the light penetration and interception within the canopy and to encourage development of lateral branches inside the canopy. These branches will be trained as productive branches and can produce fruit within a year of training. Water sprouts developing near the main stem are always removed.

4. **Status and constraints in exporting mangosteen from Thailand**

- Formerly, Thailand exported only frozen mangosteen to Japan. Since 2003, Thailand can export fresh mangosteen to Japan by airfreight. However, the fruit has to be treated with vapor heat until the temperature inside the fruit is 46°C for 53 minutes to destroy eggs of the oriental fruit fly (*Bactocera dorsalis* Hendel), because it is claimed that mangosteen is a host of this type of fruit fly.
- Thailand gained a small amount of fresh export to Japan but lost a large amount of mangosteen export to the Taiwan market. For decades, Taiwan was the major market of fresh mangosteen from Indonesia and Thailand. Since Japan claimed that oriental fruit fly was one of the quarantine pests, Taiwan does not allow the import of fresh mangosteen from any country. It has been reported that oviposition or infestation by *B. dorsalis* has been found only on ripe damaged fruits (cracked fruits, pitted fruits or fruits with insect bores). It has never been found during on any stage of development in undamaged fruits. Similarly, a laboratory study with forced infestation showed that the fruit fly would infest only ripe fruits that had a 0.4 and 0.5 mm deep needle pierce on the skin. That particular depth would almost reach the fruit aril. It is a common practice in Thailand that only the fruit that turns from green yellowish to green
yellowish with a pinkish blush are being picked at harvesting. During harvesting and post harvest handling, mature fruit drop, over ripe fruit and mechanically damaged fruit must be sorted out. Although Thailand has procedures to prevent and correct physical, chemical and biological hazards during the production cycle, only vapor-heat treated fruit will be allowed into Taiwan and Japan. The treatment is very costly. In 2004, more than 95% of total export volume (26,763.3 tons) was exported to China and Hong Kong, which does not require vapor heat treatment for mangosteen.

- Thailand is seeking high-end markets for fresh mangosteen produce and Scandinavian markets are of interests. Thailand now can export fresh cut mangosteen, mango, pummelo and papaya and others to EU market, but these fruits have to be harvested from the EUREPGAP certified farms.

- Since mangosteen contains a large amount of antioxidants (xanthones i.e. mangostin), value added and other products created from mangosteen are being developed in Thailand.

5. Conclusion

Mangosteen, one of the outstanding fruit of the Guttiferae family, is excellent as a fresh fruit. Apart from consuming it fresh, mangosteen can provide a large amount of additional return from its products due to its high content of antioxidants. Since it normally takes more than 8 years for trees to bear its first fruit, this is a major deterrent to large scale production in some countries. Growers in Thailand realize that there is a long juvenile phase of mangosteen, so they plant mangosteen as a mixed crop with other tropical fruits or plant it together with cash crops to get returns during the mangosteen juvenile period. Cultural techniques to accelerate growth of young mangosteen and to control its canopy (both juvenile and mature trees) are recommended.

References:
Introduction
Longan (Dimocarpus longan Lour.), lychee (Litchi chinensis Sonn.), and rambutan (Nephelium lappaceum L.) are subtropical and tropical fruit of the Sapindaceae family. In Hawaii, production of these specialty fruit has increased rapidly following the decline of the sugarcane plantations. Longan, lychee, and rambutans are grown for local consumption and for export markets. Export potential has improved with the development of quarantine treatments for these fruit. As production and markets expand, nutritional information is needed for consumers purchasing specialty fruit. Also, reliable fruit composition data is necessary to evaluate diets for nutritional adequacy. The 2005 Dietary Guidelines Advisory Committee recommends increasing the dietary intake of vitamins A, C and E, Ca, Mg, K and fiber, which can be met by increasing the consumption of fruits and vegetables to 5-13 servings per day (USDA/HHS, 2004).

Many tropical fruit appear to be good sources of ascorbic acid (vitamin C), provitamin A, Mg, and K. However, fruit nutritional analyses rarely consider the effects of cultivar or environment on vitamin and mineral content. For longans, lychees, and rambutans, nutritional information is limited and was obtained from a few composite samples (Leong and Shui, 2002; Vinci et al., 1995; Wenkam, 1990; Wills et al., 1986). In most cases, the identity of the cultivar and the location of production were unknown. The nutritional composition of a fruit type at harvest can vary widely depending on cultivar, climate, soil type and fertility (Lee and Kader, 2000; Mozafar, 1994; Shewfelt, 1990). The vitamin C content of different cultivars may vary by a factor of 2-3 or higher in many fruits (Mozafar, 1994). Even within a cultivar, there is large plant-to-plant variation and within-plant variation in nutrient composition for fruit harvested from the same field (Shewfelt, 1990). The composite samples reported in the literature mask this variability. A greater number of samples, from identified cultivars, need to be analyzed from different locations to compile more representative nutritional data.

In addition to supplying vitamins, fruit contribute significant amounts of minerals to the human diet. Minerals are required for normal cellular function, and are critical for enzyme activation, bone formation, hemoglobin composition, gene expression, and amino acid, lipid and carbohydrate metabolism (IOM, 2000a, 2001, 2004). However, the mineral values reported in food composition tables often are based on non-representative samples or old methodology. Data are limited for the mineral content of longans, lychees, and rambutans.

Objectives
1. Determine the variability in vitamin C and mineral content of longan, lychee, and rambutan cultivars grown in Hawaii.
2. Provide current nutritional information to tropical fruit growers, the Hawaii Department of Agriculture, and the USDA National Nutrient Database.
Materials and Methods

Longan, lychee, and rambutan fruit were harvested from commercial orchards in the Hawaiian islands in 2003-2004. Longans were obtained from orchards in Kurtistown and Puueo on the island of Hawaii, and Kilauea on the island of Kauai. Lychees were harvested from orchards in Hakalau, Kurtistown, Puueo, and Waiakea on Hawaii Island, and in Kilauea on Kauai. Rambutans were harvested from orchards in Keaau, Kurtistown, and Pepeekee on Hawaii island.

Fruit were harvested from orchards with soils representing three orders (Andisols, Histosols, and Oxisols) in the soil classification system that are common in the agricultural areas of the Hawaiian islands (Uehara and Ikawa, 2000). A composite soil sample was collected from each orchard at the time of fruit sampling. Orchard elevation was measured with an altimeter, and elevations ranged from 30 to 200 m.

About 1.5 kg fruit (per tree) were harvested from six randomly selected trees at each orchard. Harvest maturity was based on full-size and peel color. Longan cultivars included Biew Kiew and Sri Chompoo. Lychee cultivars were Bosworth-3, Groff, and Kaimana. Rambutan cultivars included Jitlee, R9, R134, R162, Rongrien, and Silengkeng. Eight fruit per tree were combined to create composite samples for ascorbic acid (vitamin C) extraction and analysis. Individual fruit were peeled and de-seeded, and the edible tissue (aril) was used for analysis. Total soluble solids was measured using a refractometer.

Ascorbic acid (vitamin C) was analyzed using high performance liquid chromatography (HPLC) equipped with a photo-diode array detector (Lloyd and Warner, 1988; Vanderslice and Higgs, 1990). Ascorbic acid was extracted under low light and cold temperatures to minimize oxidation to dehydroascorbic acid. Fruit tissue (40 g) was blended with cold metaphosphoric-acetic acid solution (100 mL). All samples were kept on ice. The slurry was centrifuged, and the supernatant was collected. Samples were passed through C-18 Sep-Paks preconditioned with acetonitrile, followed by distilled water. Duplicate samples were filtered through 0.22 µm membranes into amber HPLC vials. HPLC analysis was performed on the same day as extractions. Vitamin C values were expressed as mg/100 g edible fresh weight.

Fruit samples were dried in an oven at 50 °C and prepared for mineral analysis at the USDA-ARS laboratory. Dried fruit tissue samples and soil samples were sent to the Agricultural Diagnostic Service Center (ADSC) at the University of Hawaii for complete mineral and soil analyses. Fruit mineral analysis was performed using inductively coupled plasma-atomic emission spectrometry (ICP-AES).

Results and Discussion

Ascorbic acid (vitamin C)

Ascorbic acid concentrations were determined for longans, lychees, and rambutans harvested from 30, 36, and 42 trees, respectively, in Hawaii. Longan fruit had the highest vitamin C content (60.1 mg/100 g) among the three specialty fruit tested (Table 1). Longans compare favorably to fresh papayas (51.2 mg/100 g), oranges (53.2 mg/100 g), and strawberries (58.9 mg/100 g) for vitamin C content (USDA-ARS, 2004; Wall, 2005). Ascorbic acid content was 63.3 mg/100g and 55.3 mg/100 g for the longan cultivars, Biew Kiew and Sri Chompoo, respectively. Lychee fruit had a mean ascorbic acid content of 27.6 mg/100 g. The early maturing lychee variety, Kaimana, had an average ascorbic acid content of 33.2 mg/100 g, and the later maturing, Groff and Bosworth-3, cultivars had 21.2 and 22.5 mg/100 g, respectively.
For rambutans, the average vitamin C content was 36.41 mg/100 g and ranged from 22.0 mg/100 g for R9 to 47.8 mg/100 g for R162 (Table 1). The Dietary Reference Intake (DRI) values for vitamin C are 90 mg for adult males and 75 mg for adult females (IOM, 2000b). Therefore, consumption of about 12 to 14 longan fruit would meet the daily vitamin C requirements for the average adult. About 10 to 12 rambutan fruit would provide the DRI, as well. Rambutans have a lower concentration of ascorbic acid, but the edible portion weighs twice as much as the longan aril. Depending on cultivar, consumption of 14 to 17 lychee fruit would meet the average adult DRI for vitamin C.

Mean ascorbic acid content of Hawaii’s longan (60.1 mg/100 g) was less than that listed by Tongdee (1997) (69.2 mg/100 g). The USDA nutrient database (USDA-ARS, 2004) lists longan vitamin C content as 84.0 mg/100 g based on two samples. Rambutans are not listed in the USDA database (USDA-ARS, 2004), but Leong and Shui (2002) measured 50 mg/100 g for an unidentified cultivar using HPLC analysis. The ascorbic acid content of Hawaii-grown rambutans ranged from 22 to 48 mg/100 g (Table 1), and this agrees with a report by Watson (1984). Lychees ranged from 21 to 36 mg/100 g for vitamin C content (Table 1). Vinci et al. (1995) reported lychee vitamin C as 22 mg/100 g for an unidentified cultivar using HPLC.

No correlation was found between ascorbic acid and total soluble solids (TSS) content for longans, lychees, or rambutans. TSS content is an estimate of fruit sugar content and eating quality. All three species are nonclimacteric, and will not continue to ripen and accumulate sugars after harvest. TSS content increases and acidity decreases as fruit ripen on the tree (Kosiyachinda et al., 1987; O’Hare, 1995; Paull et al., 1984). Depending on cultivar, TSS content at maturity ranges from 16-25 °Brix for longans, 13-20 °Brix for lychees, and 17-21 °Brix for rambutans (Kosiyachinda et al., 1987; Paull et al., 1984; Tongdee, 1997; Underhill et al., 1997). Therefore, Hawaii-grown fruit were within the soluble solids range reported by others (Table 1).

**Mineral content**

Longans are a good source of potassium (K) and copper (Cu). New DRI values have been established for K, and the daily adequate intake for adults is 4700 mg (IOM, 2004). Fresh longans (100 g) can supply 7% of the DRI for K and 29% of the DRI for Cu (Table 2). The cultivar, Sri Chompoo, averaged 334.4 mg K/100 g and Biew Kiew fruit averaged 318.6 mg K/100 g (Table 2). Copper ranged from 0.23 to 0.30 mg/100 g in longan fruit. Longans also may provide 3-5% of the DRI for phosphorus (P), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn). This study is the most complete analysis of longan fruit mineral content, and the values are higher than that listed by USDA (USDA-ARS, 2004). The USDA database (USDA-ARS, 2004) lists 21 mg P, 266 mg K, 1 mg Ca, 10 mg Mg, 0.13 mg Fe, 0.05 mg Mn, 0.05 mg Zn, and 0.17 mg Cu (per 100 grams longan fruit), but the data is based on one composite sample.

Consumption of lychee fruit (100 g) would meet 2-4% of the DRI for six minerals (P, K, Mg, Fe, Zn, Mn), and provide 22% of the DRI for Cu (Table 3). The results generally agree with the USDA database (USDA-ARS, 2004), but are higher for Mg, Na, Fe, Zn and Cu (Table 3). The lychee mineral contents of Bosworth-3, Groff, and Kaimana also fall within the range reported by Wenkam (1990) for cultivars, Brewster and Kwai Mi, grown in Hawaii.

Rambutans (100 g) are a good source of Cu (20% of the DRI) and Mn (8-10% of the DRI). Copper content ranged from 0.16 to 0.20 mg/100 g, and Mn content ranged from 0.07 to 0.38 mg/100g (Table 4). Rambutan consumption also meets 2-6% of the DRI for five minerals (P, K,
Mg, Fe, Zn). This is the most complete report for rambutan fruit mineral composition. Rambutan nutrient content is not listed in the USDA database (USDA-ARS, 2004) or by Wenkam (1990).

**Soil analyses**

The soil analyses are included for informational purposes only (Table 5). No attempt was made to record fertilization practices of the growers, and variability in fruit tissue and soil mineral analyses may reflect differences in fertilization patterns rather than inherent soil differences. The results for some nutrients (P, Ca, K, Mg) would be influenced by fertilizer applications more so than others (Fe, Mn, Zn). However, older soils on Kauai (Kilauea) tended to have higher Mn levels than the younger soils on Hawaii island. Zn was highest in the Olaa silty clay loam at Kurtistown. Hakalau and Waiakea soils had the highest Fe contents. High rainfall areas (Hilo soil series on Hawaii island) can leach nutrients such as K, Ca, and Mg to low levels, and this is apparent in the soil data. Also, plant nutrient uptake can deplete soil minerals. In general, fruit mineral content was not associated with soil mineral content (Tables 2 to 5) for the three fruit types.

**Conclusions**

Longan, lychee, and rambutans were harvested from different locations in Hawaii and analyzed for vitamin C and mineral composition. Different cultivars of each fruit type were analyzed, and samples were collected from orchards with various soil types. The data presented are the most complete analyses of vitamin C and mineral contents for longans, lychees and rambutans.

The daily vitamin C requirement for the average adult (75 to 90 mg) can be met by consuming about 12 to 14 longans, 10 to 12 rambutans, or 14 to 17 lychees. Among the three Sapindaceae species, longan had the highest vitamin C content (60.1 mg/100g). Average ascorbic acid content was 27.6 mg/100 g for lychees and 36.4 mg/100 g for rambutans. No correlation was found between ascorbic acid and total soluble solids (TSS) content for longans, lychees, or rambutans.

Longans are a good source of K (324.9 mg/100 g) and Cu (0.26 mg/100 g), and also may provide 3-5% of the DRI for P, Mg, Fe, Mn, and Zn. Lychee fruit consumption would meet 2-4% of the DRI for six minerals (P, K, Mg, Fe, Zn, Mn), and provide 22% of the DRI for Cu. Rambutan fruit are a good source of Cu and Mn, and also can provide 2-6% of the DRI for five minerals (P, K, Mg, Fe, Zn). Fruit mineral compositions were not related to soil mineral analyses.

**Acknowledgements**

The author thanks the Hawaii Department of Agriculture for funding this research, and Hawaii’s tropical fruit growers for supplying fruit for this study. The excellent technical assistance of Suzanne Sanxter, Sandra Silva, Ryan Bosma, and Thomas Winslow is greatly appreciated.

**References**


Table 1. Ascorbic acid (vitamin C), soluble solids, and moisture content of longan, lychee, and rambutan fruit grown in Hawaii.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Cultivar</th>
<th>Locationa</th>
<th>Ascorbic acid (mg/100 g)</th>
<th>Soluble solids (EBrix)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longan</td>
<td>Biew Kiew</td>
<td>Kilauea</td>
<td>44.65 ± 1.80b</td>
<td>18.63 ± 0.39</td>
<td>81.02 ± 0.37</td>
</tr>
<tr>
<td></td>
<td>Biew Kiew</td>
<td>Kurtistown</td>
<td>79.23 ± 2.62</td>
<td>19.90 ± 0.43</td>
<td>78.98 ± 0.28</td>
</tr>
<tr>
<td></td>
<td>Biew Kiew</td>
<td>Puueo</td>
<td>66.14 ± 2.78</td>
<td>18.88 ± 0.31</td>
<td>80.75 ± 0.49</td>
</tr>
<tr>
<td></td>
<td>Sri Chompo</td>
<td>Kurtistown</td>
<td>58.98 ± 2.60</td>
<td>20.37 ± 0.82</td>
<td>78.87 ± 0.90</td>
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<td>Sri Chompo</td>
<td>Puueo</td>
<td>51.55 ± 1.00</td>
<td>21.02 ± 0.83</td>
<td>77.83 ± 0.32</td>
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<td>Lychee</td>
<td>Bosworth-3</td>
<td>Hakalau</td>
<td>21.00 ± 0.60</td>
<td>19.93 ± 0.34</td>
<td>79.63 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>Bosworth-3</td>
<td>Kurtistown</td>
<td>24.03 ± 0.34</td>
<td>19.37 ± 0.27</td>
<td>79.05 ± 0.25</td>
</tr>
<tr>
<td></td>
<td>Groff</td>
<td>Kilauea</td>
<td>21.18 ± 0.77</td>
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<td>81.71 ± 0.40</td>
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<td>Kaimana</td>
<td>Waiakea</td>
<td>30.66 ± 1.14</td>
<td>18.97 ± 0.21</td>
<td>79.44 ± 0.15</td>
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<td>Rambutan</td>
<td>R9</td>
<td>Kurtistown</td>
<td>22.02 ± 2.66</td>
<td>∞</td>
<td>80.25 ± 0.49</td>
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<tr>
<td></td>
<td>Jitlee</td>
<td>Keaau</td>
<td>38.12 ± 1.31</td>
<td>18.18 ± 0.61</td>
<td>81.01 ± 0.56</td>
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<td>R162</td>
<td>Keaau</td>
<td>47.83 ± 3.28</td>
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<td>Rongrien</td>
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<td>39.34 ± 2.14</td>
<td>16.73 ± 1.03</td>
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<td>Rongrien</td>
<td>Pepeekeo</td>
<td>37.63 ± 3.85</td>
<td>18.03 ± 0.37</td>
<td>79.73 ± 0.23</td>
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<td>R134</td>
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<td>30.80 ± 1.64</td>
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<td>Silengkeng</td>
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<td>39.10 ± 2.72</td>
<td>16.82 ± 1.08</td>
<td>80.70 ± 0.97</td>
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*Dietary Reference Intake (DRI) (mg/day): *75, 90

*aHakalau, Keaau, Kurtistown, Pepeekeo, Puueo, and Waiakea are on the island of Hawaii.
*Kilauea is on the island of Kauai.
*bValues are means (± SE) of six replications per cultivar at each location.
*cDietary Reference Intakes (DRI) established by the Food and Nutrition Board of the Institute of Medicine, National Academy of Sciences (2000b). Values given are for adult females and males, ages 19 to 50 years.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>DRI *  (mg/100 gfw)</th>
<th>Biew Kiew</th>
<th>Sri Chompoo</th>
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<tr>
<td></td>
<td>DRI (mg/day)</td>
<td>Kilaeua b</td>
<td>Kurtistown</td>
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<td>700</td>
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<td>Calcium</td>
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<tr>
<td>Magnesium</td>
<td>320, 420</td>
<td>10.4 ± 0.5</td>
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<td>Sodium</td>
<td>1500</td>
<td>8.5 ± 1.1</td>
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**Micro**

<table>
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<td>Boron</td>
<td>ND</td>
<td>0.18 ± 0.01</td>
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* Dietary Reference Intakes (DRI) are the most recent set of dietary recommendations established by the Food and Nutrition Board of the Institute of Medicine, 2000a, 2001, 2004. Values given are for adult females and males, ages 19 to 50 years. For boron, ND = not determinable.

* Kilaeua is on the island of Kauai. Kurtistown and Puueo are on the island of Hawaii.

* Values are means (± SE) of six replications per cultivar at each location.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>DRI (^a) (mg/100 gfw)</th>
<th>Bosworth 3</th>
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**Macro**

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<th>Mineral</th>
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<td>3.1 ± 0.4</td>
<td>7.9 ± 0.8</td>
</tr>
</tbody>
</table>

**Micro**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>DRI (^a) (mg/100 gfw)</th>
<th>Bosworth 3</th>
<th>Groff</th>
<th>Kaimana</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mg/day)</td>
<td>Hakalau</td>
<td>Kurtistown</td>
<td>Kilauea</td>
</tr>
<tr>
<td>Iron</td>
<td>18, 8</td>
<td>0.43 ± 0.05</td>
<td>0.36 ± 0.04</td>
<td>0.41 ± 0.02</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.8, 2.3</td>
<td>0.07 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>Zinc</td>
<td>8, 11</td>
<td>0.16 ± 0.01</td>
<td>0.26 ± 0.02</td>
<td>0.28 ± 0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>0.90</td>
<td>0.20 ± 0.01</td>
<td>0.17 ± 0.02</td>
<td>0.23 ± 0.01</td>
</tr>
<tr>
<td>Boron</td>
<td>ND</td>
<td>0.09 ± 0.01</td>
<td>0.11 ± 0.01</td>
<td>0.12 ± 0.01</td>
</tr>
</tbody>
</table>

\(^a\) Dietary Reference Intakes (DRI) are the most recent set of dietary recommendations established by the Food and Nutrition Board of the Institute of Medicine, 2000a, 2001, 2004. Values given are for adult females and males, ages 19 to 50 years. For boron, ND = not determinable.

\(^b\) Hakalau, Kurtistown, Puueo, and Waiakea are on the island of Hawaii. Kilauea is on the island of Kauai.

\(^c\) Values are means (± SE) of six replications per cultivar at each location.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>DRI a (mg/100 gfw)</th>
<th>( \text{R9} ) Kurtistown b</th>
<th>Jitlee Keau</th>
<th>R162 Keau</th>
<th>Rongrien Keau Pepeekeo</th>
<th>R134 Pepeekeo</th>
<th>Silengkeng Pepeekeo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus</td>
<td>700</td>
<td>18.8 ± 0.8</td>
<td>17.6 ± 0.7</td>
<td>16.9 ± 1.8</td>
<td>17.1 ± 1.6</td>
<td>18.4 ± 1.0</td>
<td>17.8 ± 1.5</td>
</tr>
<tr>
<td>Potassium</td>
<td>4700</td>
<td>174.8 ± 7.6</td>
<td>197.6 ± 15.7</td>
<td>249.4 ± 26.1</td>
<td>229.0 ± 25.4</td>
<td>134.5 ± 10.6</td>
<td>139.2 ± 14.5</td>
</tr>
<tr>
<td>Calcium</td>
<td>1000</td>
<td>7.6 ± 0.6</td>
<td>6.8 ± 0.9</td>
<td>8.4 ± 0.7</td>
<td>8.7 ± 0.7</td>
<td>7.6 ± 1.0</td>
<td>8.6 ± 1.1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>320, 420</td>
<td>15.4 ± 0.5</td>
<td>16.6 ± 0.4</td>
<td>17.2 ± 1.3</td>
<td>16.6 ± 1.9</td>
<td>13.3 ± 0.6</td>
<td>16.3 ± 1.1</td>
</tr>
<tr>
<td>Sodium</td>
<td>1500</td>
<td>6.3 ± 0.6</td>
<td>5.7 ± 0.8</td>
<td>8.2 ± 1.2</td>
<td>6.5 ± 0.8</td>
<td>5.7 ± 0.6</td>
<td>6.2 ± 0.8</td>
</tr>
</tbody>
</table>

**Macro**

**Micro**

<table>
<thead>
<tr>
<th>Element</th>
<th>DRI a (mg/day)</th>
<th>( \text{R9} ) Keau</th>
<th>Jitlee Keau</th>
<th>( \text{R162} ) Keau</th>
<th>( \text{Rongrien} ) Keau Pepeekeo</th>
<th>( \text{R134} ) Pepeekeo</th>
<th>Silengkeng Pepeekeo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>18, 8</td>
<td>0.50 ± 0.05</td>
<td>0.49 ± 0.10</td>
<td>0.44 ± 0.02</td>
<td>0.53 ± 0.04</td>
<td>0.41 ± 0.04</td>
<td>0.42 ± 0.04</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.8, 2.3</td>
<td>0.11 ± 0.01</td>
<td>0.38 ± 0.18</td>
<td>0.30 ± 0.07</td>
<td>0.19 ± 0.03</td>
<td>0.07 ± 0.01</td>
<td>0.16 ± 0.02</td>
</tr>
<tr>
<td>Zinc</td>
<td>8, 11</td>
<td>0.26 ± 0.01</td>
<td>0.20 ± 0.01</td>
<td>0.22 ± 0.02</td>
<td>0.21 ± 0.01</td>
<td>0.23 ± 0.01</td>
<td>0.16 ± 0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>0.90</td>
<td>0.18 ± 0.01</td>
<td>0.17 ± 0.01</td>
<td>0.17 ± 0.02</td>
<td>0.17 ± 0.02</td>
<td>0.20 ± 0.01</td>
<td>0.18 ± 0.02</td>
</tr>
<tr>
<td>Boron</td>
<td>ND</td>
<td>0.12 ± 0.01</td>
<td>0.11 ± 0.01</td>
<td>0.16 ± 0.01</td>
<td>0.14 ± 0.01</td>
<td>0.13 ± 0.01</td>
<td>0.13 ± 0.01</td>
</tr>
</tbody>
</table>

---

aDietary Reference Intakes (DRI) are the most recent set of dietary recommendations established by the Food and Nutrition Board of the Institute of Medicine, 2000a, 2001, 2004. Values given are for adult females and males, ages 19 to 50 years.

bKurtistown, Keau and Pepeekeo are on the island of Hawaii.

cValues are means (± SE) of six replications per cultivar at each location.
Table 5. Soil classification and analysis for tropical fruit orchards in Hawaii.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Cultivar</th>
<th>Location</th>
<th>Soil classification</th>
<th>pH</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longan</td>
<td>Biew Kiew</td>
<td>Kilauea</td>
<td>Lihue silty clay</td>
<td>6.1</td>
<td>80</td>
<td>524</td>
<td>1186</td>
<td>478</td>
<td>68</td>
<td>273</td>
<td>286</td>
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<td>3</td>
</tr>
<tr>
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<td>Biew Kiew</td>
<td>Kurtistown</td>
<td>Olaa silty clay loam</td>
<td>6.2</td>
<td>225</td>
<td>372</td>
<td>1502</td>
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<td>37</td>
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<td>63</td>
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<tr>
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<td>Sri Chompo</td>
<td>Kurtistown</td>
<td>Olaa silty clay loam</td>
<td>5.9</td>
<td>255</td>
<td>286</td>
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<td>680</td>
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<td>Biew Kiew</td>
<td>Puueo</td>
<td>Hilo silty clay loam</td>
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<td>446</td>
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<tr>
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<td>913</td>
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<td>Hakalau</td>
<td>Hilo silty clay loam</td>
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<td>25</td>
<td>116</td>
<td>146</td>
<td>68</td>
<td>32</td>
<td>14</td>
<td>1853</td>
<td>7</td>
<td>3</td>
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<td></td>
<td>Kaimana</td>
<td>Hakalau</td>
<td>Hilo silty clay loam</td>
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<td>Groff</td>
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<td>Papai stony muck</td>
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<td>2351</td>
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<td>Rambutan</td>
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<td>1058</td>
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<td>14</td>
</tr>
<tr>
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<tr>
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<td>R162</td>
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<td>46</td>
<td>148</td>
<td>94</td>
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<td>1006</td>
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<td></td>
<td>Silengkeng</td>
<td>Pepeekeo</td>
<td>Hilo silty clay loam</td>
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<td>26</td>
<td>60</td>
<td>150</td>
<td>88</td>
<td>26</td>
<td>41</td>
<td>853</td>
<td>11</td>
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<tr>
<td></td>
<td>Rongrien</td>
<td>Pepeekeo</td>
<td>Hilo silty clay loam</td>
<td>5.6</td>
<td>19</td>
<td>46</td>
<td>82</td>
<td>60</td>
<td>22</td>
<td>22</td>
<td>696</td>
<td>12</td>
<td>4</td>
</tr>
</tbody>
</table>

Hakalau, Keaau, Kurtistown, Pepeekeo, Puueo, and Waiakea are on the island of Hawaii. Kilauea is on the island of Kauai.
Overview of Rambutan Phenology, Flowering, and Fruit Set in Hawaii

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Darsen F. Aoki, Kendra Y. Hara, Laura K. Pena

University of Hawaii
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Beaumont Agricultural Research Center
875 Komohana Street
Hilo, Hawaii 96720-2757

Introduction
Rambutan (Nephelium lappaceum Lim.) is an evergreen fruit tree native to the Malay Peninsula, and is a member of the Sapindaceae family which includes lychee (Litchi chinensis Sonn.), longan (Dimocarpus longan Lour.), and pulasan (Nephelium mutabile Blume). Rambutan is typically grown in regions within 18° of the equator, below 1,625 feet elevation, and requires approximately 80-200 inches of annual rainfall (Tindall, 1994a) with diurnal temperatures that fluctuate between 72°F and 90°F (Lim and Diczbalis, 1998). Fruits are eaten fresh, canned, prepared in dishes, used as a garnish and made into a drink. According to the 2003 Hawai‘i Agricultural Statistics Service, rambutan comprised about 39% ($834,000) of the specialty tropical fruit market, and had the highest gross sales for exotic tropical fruit crops grown in Hawaii (HASS, 2004).

Approximately 30 important cultivars are grown in Malaysia (Tindall, 1994b), however in Hawaii, only about 10 cultivars have been established. High yield, large fruit size, satisfactory sweetness, appearance, and regular cropping are criteria for selecting a cultivar. Perhaps the most appealing attribute of an excellent cultivar is a fruit with an aril (flesh) that does not adhere to the testa (seed coat). Popular cultivars in Hawaii include ‘Jitlee’, ‘Binjai’, ‘R156 Red’, ‘R167’, ‘R134’, and ‘R9’. The ‘Silengkeng’ cultivar is favored for its large panicles and is a reliable pollinator.

In this report we present information on flowering and vegetative flushing patterns for rambutan trees in Hawaii. Information is also presented regarding factors affecting fruit set and development under Hawaii conditions.

Climate in Rambutan Growing Areas
Hawaii
Cultivation of rambutan in Hawaii differs from many south-east Asian countries and Australia, because Hawaii’s climate is stable with little variation throughout the year. Steady rainfall and warm temperatures allow Hawaii’s rambutan trees to grow and flush year-round. As a result, terminal maturation is non-synchronous within the tree and throughout an orchard. Synchrony of flowering, fruit set, and harvest throughout an orchard is extremely difficult to acquire. In Hawaii, rambutan production is concentrated on the eastern side of Hawaii Island. Weather data from the Hilo International Airport (38 feet elevation) and UH Waiakea Experiment Station in Panaewa (574 feet elevation) for 2002-2004 show that heavier rainfall typically occurs during the winter (November to December) and spring months (March to April) with lighter showers taking place during the summer (July to August). The hurricane season is from June to November which can bring heavy rains and high winds. Weather data indicate that East Hawaii...
orchards located at elevations below 845 ft, receive approximately 120 inches of precipitation annually. The average monthly rainfall near Hilo airport is approximately 8.4 inches (Fig. 1) while the Waiakea Station receives nearly 10.5 inches. Rainfall patterns may vary greatly from one year to the next. In January and March 2003, less than 1.5 inches of precipitation was recorded for the entire month, however the same months in 2002 and 2004 recorded some of the highest rainfall totals for those years. The timing for occurrence of dry weather is important since it influences flowering. Although monthly rainfall averages differ between sites, typically, higher elevations receive more rain than near sea level.

Figure 1. Rainfall patterns in Hilo, Chanthaburi and Cairns.

Hilo weather data show that average monthly maximum temperatures are highest during the months of August and September while monthly minimum temperatures are lowest between December and February (Fig. 2). At Hilo Airport minimum and maximum temperatures as low as 59°F and as high as 91°F were recorded. Average minimum and maximum monthly temperatures ranged from 62.9 to 86.3°F.

Figure 2. Average minimum and maximum temperatures in Hilo, Chanthaburi and Cairns.

Chanthaburi, Thailand
Chanthaburi is north of the Malay Peninsula and is the location of large rambutan orchards. The weather and climate in Thailand are fairly predictable. Monsoons are common in this area, and as a result wet and dry seasons prevail. According to 2001-2004 data, at 78.7 feet elevation,
Chanthaburi received 100-125 inches of rainfall annually (Fig. 1). The monsoon season starts in mid-May and extends to October, and is the period when Thailand receives most of its precipitation. Rainfall occurs only during a few days out of the month during the dry months of November to early May. In some years, no precipitation is recorded in December and/or January. Average temperatures in Chanthaburi are higher than in Hawaii. During 2001-2004, Chanthaburi’s highest temperature was 93.2°F during the dry season and the coolest recorded temperature recorded was 59.2°F. The average monthly minimum and maximum temperatures ranged from 69.4°F and 92.7°F, respectively (Fig. 2). The temperature data show that temperatures in the native growing areas for rambutan are much warmer than those found around Hilo. The average minimum temperature in Hilo is 62.9°F, and the average maximum is 86.3°F. Also the monsoon climate synchronizes growth and enables Thai growers to have consistent and synchronized flowering and vegetative flushing.

**Cairns, Australia**

Rambutan is also produced in northern Australia near Cairns. Since Cairns is located below the equator, the winter and summer months are opposite to that found in Hawaii and Chanthaburi. Cool, dry winter weather occurs during July-September, whereas warm, wet summer weather prevails during December -February. Rainfall data from Cairns Aero Station at 9.8 ft above sea level between 1941 and 2004 shows a pattern similar to Chanthaburi. Cairns has distinct wet and dry seasons, with the dry season extending from May to October when rainfall is usually less than 3.7 inches each month (Fig. 1). The rainy season is from November to April when up to 17.8 inches of precipitation can fall in a month. Cyclones occur during the rainy season. Average minimum and maximum monthly temperatures range from 62.2°F to 88.5°F (Fig. 2). The highest daily maximum temperature recorded was 104.9°F while the lowest daily minimum temperature was 43.2°F.

**Rambutan Phenology in Hawaii**

**Flowering.** Rambutan flowering is stimulated by water stress, and symptoms of water stress in trees can be observed when leaves curl inward along the margins (Fig. 3). Since soil type influences water holding capacity of soils, water stress will be more evident in rocky soils, compared to silty clay soils or soils with high organic matter content which require longer dry periods to induce flowering. Instead of a single prolonged dry season as in Chanthaburi and Cairns, Hawaii tends to have two short periods of drier weather during the winter and spring. As a result, two flowering periods can occur in Hawaii (Table 1). One period is usually heavier than the other, but in some years, the dry seasons are not intense enough to elicit flowering during the two periods. Three flowering cycles sometimes occur, however, the duration of water stress is usually too brief to induce heavy flowering and poor fruit set and development are often the result.
Flowering occurs 1-2 months following a dry period, but the amount and duration of flowering is dependant on the intensity of the drought stress, the maturity of the terminals, flushing activity and tree health. Flower induction does not occur on terminals that are flushing or immature. Not all terminal shoots will respond to conditions that promote flowering, because the capacity for flowering is only associated with mature terminal branches. Responsive terminals have dark green leaves, dark brown stems, and are exposed to sunlight. Heavy flowering usually follows a long drought period but is affected by tree health and vigor, maturity of the terminals, amount of flushing and fruit load. Flower initiation may be hindered by heavy fruit set even in the presence of dry weather. Timing and severity of pruning can also affect flowering intensity. Anthesis within an orchard usually occurs over a 2-3 month period, but can extend over 5 months during prolonged dry periods. Anthesis of a single panicle occurs over 3-7 weeks for many cultivars, however, panicles on the Silengkeng cultivar can take up to 23 weeks to complete anthesis. Silengkeng trees produce large panicles and can take up to 9 months to complete its flowering cycle.

Three types of flowers can be observed on rambutan trees during flowering. They include stamineate true male (TM) flowers, hermaphroditic functionally female (HF) flowers, and hermaphroditic functionally male (HM) flowers (Fig 4). Panicles on grafted rambutan cultivars possess HF flowers intermingled with a very small percentage (<1.0%) of HM flowers (Fig. 5). Most cultivars have been selected for their high percentage of HF flowers and low percentage of HM flowers. The HM male flowers usually amount to 0.05%-0.9% of the total number of

<table>
<thead>
<tr>
<th>Flowering Seasons</th>
<th>July to August; thru Nov.; March to May;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Flowering Seasons</td>
<td>2</td>
</tr>
<tr>
<td>Flushing Seasons</td>
<td>Aug. to Sept.; May to June (after harvest); Oct.</td>
</tr>
<tr>
<td>Number of Flushing Seasons</td>
<td>3 to 4</td>
</tr>
<tr>
<td>Number of Harvesting Seasons</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Rambutan phenology in Hawaii.

Figure 3. Rambutan leaves exhibiting water stress symptoms.

Flowering occurs 1-2 months following a dry period, but the amount and duration of flowering is dependant on the intensity of the drought stress, the maturity of the terminals, flushing activity and tree health. Flower induction does not occur on terminals that are flushing or immature. Not all terminal shoots will respond to conditions that promote flowering, because the capacity for flowering is only associated with mature terminal branches. Responsive terminals have dark green leaves, dark brown stems, and are exposed to sunlight. Heavy flowering usually follows a long drought period but is affected by tree health and vigor, maturity of the terminals, amount of flushing and fruit load. Flower initiation may be hindered by heavy fruit set even in the presence of dry weather. Timing and severity of pruning can also affect flowering intensity. Anthesis within an orchard usually occurs over a 2-3 month period, but can extend over 5 months during prolonged dry periods. Anthesis of a single panicle occurs over 3-7 weeks for many cultivars, however, panicles on the Silengkeng cultivar can take up to 23 weeks to complete anthesis. Silengkeng trees produce large panicles and can take up to 9 months to complete its flowering cycle.

Three types of flowers can be observed on rambutan trees during flowering. They include stamineate true male (TM) flowers, hermaphroditic functionally female (HF) flowers, and hermaphroditic functionally male (HM) flowers (Fig 4). Panicles on grafted rambutan cultivars possess HF flowers intermingled with a very small percentage (<1.0%) of HM flowers (Fig. 5). Most cultivars have been selected for their high percentage of HF flowers and low percentage of HM flowers. The HM male flowers usually amount to 0.05%-0.9% of the total number of
flowers (Nakasone and Paull, 1998). The HM flowers usually first to open on panicles that have a combination of HM and HF flowers. The HM flowers are found in highest frequency during the first 3 weeks during anthesis, but as anthesis progresses nearly all of the remaining flowers are HF flowers.

If seeds are planted, some of the seedlings (25-50%) will develop into male trees that never fruit and possess only staminate true male flowers (Fig 5). These TM flowers are produced only on male trees. Panicles on male trees take approximately 24 to 46 days to complete anthesis. These trees act only as pollinators and do not produce fruit. Anthers on the TM flowers release pollen, which are dispersed by wind and insects and pollinate trees bearing HF flowers. The HF flowers, which develop into fruits and number between 200 and 800 on each panicle, do not shed pollen, and cannot pollinate other flowers. The HF flowers have an ovary and stigma, but their anthers do not dehisce during anthesis. HM flowers are less common during cooler months and
resemble HF flowers, but HM anthers shed pollen at anthesis. The TM and HM flowers are the pollen sources during pollination and for fruit set. Deformed, undersized fruits that lack a fleshy aril are a common occurrence without pollination (Fig. 6). Without male trees, pollination is dependent upon pollen from the low number of HM flowers. In Hawaii the ‘Silengkeng’ variety naturally produces more HM flowers than other cultivars which makes it a good pollinator tree. Grafted or air layered male trees planted within or around the perimeter of an orchard will also increase availability of pollen during flowering. Since some rambutan trees only produce HF flowers, Silengkeng trees or male trees must be present to pollinate flowers on these trees.

![Figure 6. Under-sized deformed fruit resulting from a lack of pollination.](image)

The plant growth regulator, naphthalene acetic acid (NAA) or NAA in the potassium salt form (K+NAA) or sodium salt form can be used to stimulate production of HM flowers with viable pollen male when it is applied to hermaphroditic female panicles during early stages of flower opening (Fig. 7). Aqueous sprays of the potassium salt of NAA (K+NAA) at 90 ppm stimulate HM development within 5 to 12 days after treatment. Re-treatment of additional panicles will continue production of HM over the entire flowering season. Maximum numbers of male flowers are produced at 6 to 8 days after treatment and induction ceases after about 12 days.

‘Rongrien’ and ‘Jitlee’ are examples of very responsive varieties and consistently produce male flowers after NAA treatment. Although ‘Binjai’, ‘R162’, and ‘R156 Red’ are very responsive to K+NAA, low numbers of male flowers are produced if panicles are not treated during the peak flowering period. Climate influences the effectiveness of K+NAA.
treatments. Rambutan trees grown in higher elevations did not respond as well as those at lower elevations, probably due to cooler conditions. Panicles with a more robust appearance are more responsive to NAA. Individual flowers respond to K’NAA treatment when they are at a stage of development where the white tip of the pistil is barely visible at the end of the flower (Fig 7). Since maximum production of male flowers occurs about 7 days after treatment, multiple applications on different panicles within an orchard will be necessary to insure that male flowers are present throughout the flowering season.

**Flushing.** Vegetative flushing on rambutan trees is promoted by rainfall, heavy irrigation, pruning, and harvest. In the presence of heavy rainfall, flushing can be reduced by cool weather and heavy fruit set and flowering. Although precipitation is generally high during the winter months, minimal vegetative growth occurs due to cooler temperatures. In Hawaii, flushing is highly non-synchronous (Table 1). Since the temperatures in Hawaii are fairly stable, precipitation can cause vegetative growth to occur at any time during the year. Unlike Chanthaburi and Cairns, Hawaii does not have a consistent long dry period when the terminals are allowed to mature and enter into a resting phase for flower induction. Pruning can synchronize flushing; however, some branches mature faster than others and will respond to rainfall sooner than others. In Hawaii, new flushes take 3-4 months to mature. Generally there are 2 principal flushing seasons that occur from May to June and August to September. These flushing periods occur after fruit harvest when the branches are also pruned. If the flowering
season is extended, harvesting will be lengthened by several months. Branches that flower early in the season will be harvested first, allowing these branches to flush. However, developing fruit may still remain on branches that flower in the latter part of the season.

**Fruit Development.** Fruit development begins shortly after anthesis. Although 2 ovaries are present on a female flower, one ovary aborts leaving the other to develop into a normal fruit. Occasionally, both ovaries will develop and two fruits will mature on the same peduncle. Rambutan fruit are green when immature and eventually turn red or yellow which is cultivar dependent. Rambutan fruits exhibit a sigmoidal growth pattern (Fig 8). Early in development, the fruits increase slowly in size and weight, but growth begins increasing exponentially when seed filling and aril development take place. Seed filling occurs 8-10 weeks after anthesis, and aril development begins from the 10 to 12 weeks after anthesis. Dry weather during this period can result in under-sized fruits. At 14 to 16 weeks, fruit growth rate decreases, and during these last few weeks before harvest, fruit color intensifies and total dissolved solids (BRIX) concentrations increase. Refractometers are used to determine BRIX readings which provide approximate levels of sugar concentration in the aril of the fruit.

Fruit harvesting begins about 16 weeks after anthesis. Harvested fruit should have BRIX readings of 18% or greater. Rambutan are non-climacteric fruit and do not ripen after harvest. Therefore, harvesting must be done at the peak of ripeness for overall color, texture, and flavor appeal. The main harvest season crop is in December and January, and a minor crop matures in August and September. During the main season, fruits mature faster and are harvested 2-4 weeks sooner compared to the minor season crop. At higher elevations, temperatures are cooler, and the time for fruit maturation is lengthened with increasing elevation. Generally the harvest season extends over a 2-3 month period. Following an extended dry season, fruit harvest maybe extended by 3 to 6 months due to a longer flowering period.

![Graph](image)

**Figure 8.** Growth pattern for rambutan fruits developing from flowering in July to August.
Estimating fertilizer application rates for rambutan trees during fruit development is important for sustaining production and maintaining tree health. Areas where rambutan trees are grown can differ widely with respect to weather, soil type, tree age and planting density, therefore, fertilizer application recommendations can vary greatly. Several factors will influence the fertilizer requirements for an orchard. During fruit development nutrients are mobilized into developing fruits, thus adequate amounts of nutrients must be available to the tree during this period to support fruit production. Also important are the amounts required for maintaining tree growth, and the amount of nutrients lost through leaching. An initial step for determining fertilizer requirements is to determine the nutrient elements contained in the harvested fruits. This represents the quantity removed by the crop and will need replacement through application of fertilizers. Mineral nutrient content of 3 rambutan cultivars grown at two different locations were analyzed to determine the approximate amount of nutrients accumulating in mature fruits at harvest. Table 2 provides a summary of the weight in pounds of macro nutrients found in 100 pounds of fresh fruit. The mean values for the three cultivars are 0.220, 0.025, and 0.222 pounds of N, P, and K respectively which will need replacement when 100 pounds of mature rambutan fruits are harvested.

| Nutrients (pounds) Accumulating in 100 lbs. of Fresh Rambutan Fruits |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| N                           | P               | K               | Ca              | Mg              | S               |
| 0.220                       | 0.025           | 0.222           | 0.047           | 0.030           | 0.019           |

Table 2. Nutrient accumulation in fresh rambutan fruits.

Additional amounts of fertilizer must be provided to the orchard to compensate for leaching, binding of elements to the soil, runoff and weed competition losses. Fertilizer must also be supplied to maintain a healthy tree canopy and to replace nutrients lost during branch removal. Larger fruit loads will also require more nutrients for good fruit development.

Summary
Rambutan is native to the Malay Peninsula and grown in Chanthaburi, Thailand and surrounding regions that possess monsoon climates with distinct wet (May to Oct) and dry (Nov to Apr) seasons. Chanthaburi, with its distinct wet/dry seasons, has consistent and intense flowering once a year following the dry period and a single production season. Yearly flowering in Hawai‘i is split between the two induction periods. Flowering can occur during the spring and summer, thus trees encounter flower induction conditions during January to February and during June and July. Anthesis in an orchard occurs over 2 to 3 months. Seed filling begins 8-10 weeks after anthesis and aril (flesh) development occurs 10 to 12 weeks after anthesis. Harvesting occurs 16 to 20 weeks after anthesis when BRIX readings are 18% or greater. Late-summer and winter harvests are typical. Maturation of terminal shoots is non-synchronous in Hawai‘i. Vegetative flushing can occur in response to a significant amount of rainfall, harvest, or pruning. Flushing typically occurs 3-4 times yearly with pronounced flushing in May and smaller flushes in August and November.
Panicles on grafted rambutan cultivars possess hermaphroditic functionally female flowers intermingled with a very small percentage (<1.0%) of hermaphroditic functionally male flowers.
If seeds are planted, some seedlings develop into male trees that possess only true male flowers and never fruit. The true male and hermaphroditic functionally male flowers are the pollen sources during pollination and for fruit set. Deformed, undersized fruits that lack a fleshy aril will be a common occurrence without pollination. Without male trees, pollination is dependent upon pollen from the low number of hermaphroditic functionally male flowers. The ‘Silengkeng’ variety naturally produces a higher proportion of hermaphroditic functionally male flowers which makes it a good pollinator tree. Grafted or air layered male trees planted within or around the perimeter of an orchard will also increase availability of pollen. The plant growth regulator, naphthalene acetic acid (NAA), applied to the hermaphroditic female panicles during early stages of flower opening can induce the development of hermaphroditic functionally male flowers with viable pollen. Re-treatment of additional panicles with NAA will continue production of hermaphroditic functionally male flowers over the entire flowering season.

**Literature Cited**


Exploring the Mechanisms and Alternatives to Potassium Chlorate Induced Flowering in Longan

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Abstract
Potassium chlorate induced flowering has dramatically improved the production of longan fruits from cultivars that do not readily flower in Hawaii and the production of off-season fruit. The explosive nature of potassium chlorate often makes this chemical difficult to obtain, costly to transport and dangerous to store. Sodium hypochlorite, the active ingredient in common household bleach, has been previously reported to enhance the flowering of longan. Here we demonstrate that treatments with chlorate, chlorite and bleach solutions all induce flowering in longan. Chlorate is present in bleach prior to application to soil. Chemically, bleach breaks down to chlorate when exposed to heat. This resulting chlorate is likely the cause of bleach induced flowering in longan. In addition to being an excellent tool for longan production, potassium chlorate induced flowering can serve as a “model” to understand flowering of fruit trees in subtropical and tropical climates. The goal of this research is to discover how potassium chlorate induces flowering in longan and use this knowledge to manipulate flowering in other fruit crops.

Introduction
Floral initiation in longan is often erratic and highly dependent upon the climate and weather, with cool and dry conditions favorable to flowering (Zee et al., 1998, Sabhadrabandhu and Yapwattanaphun, 2001). Even under favorable conditions for flowering, alternate or biennial bearing is a serious problem in longan production (Yen, 2000, Sabhadrabandhu and Yapwattanaphun, 2001, Menzel et al., 2002). The discovery of potassium chlorate induced flowering by Dr. Chung-Ruey Yen of the National Pingtung University of Science and Technology in Taiwan has solved the problem of alternate bearing and enabled the grower to produce off-season longan.

Dr. Yen was able to associate the use of fireworks during religious ceremonies with off-season production of longan flowers on trees near the temples in Taiwan. By applying discarded soil from a fireworks factory to the soil of longan trees, 5% of the canopy flowered within 110 days suggesting that the gunpowder from fireworks may contain the active ingredient for flower induction. The chemicals of gunpowder were added as single ingredients or combinations of ingredients to two varieties of longan. Potassium chlorate alone or in combination with other chemicals was found to increase the percentage of flowers to the same extent of gunpowder suggesting that potassium chlorate is the chemical controlling longan flowering (Yen, 2000; Yen et al., 2001). Since this discovery, potassium chlorate is used to induce off-season flowers and fruits in longan trees worldwide and has been a key factor for consistent fruit production in Hawaii (Choo, 2000; Yen, 2000; Yen et al., 2001, Sabhadrabandhu and Yapwattanaphun, 2001, Nagao and Hoa, 2000; Manochai et al., 2005). However, the mechanism of potassium chlorate induced flowering on longan is unknown.
Chlorate effect on nitrate reductase activity in longan.

In agriculture, chlorate has been extensively used as an herbicide to control problematic weeds such as bindweed (Latshaw and Zahnley, 1927; Neller, 1930; Loomis, et al., 1933). Investigation of the mechanism of chlorate by Borje Åberg in 1947 suggested that the toxicity of chlorate is caused by reduction of chlorate to chlorite and hypochlorite and hypothesized this reduction is carried out by nitrate reductase (reviewed by LaBrie et al., 1991). As predicted by Åberg, the majority of plant nitrate reductase enzymes reduce chlorate to the toxic chlorite. Chlorate has been useful in the isolation of genes involved in nitrate uptake or impaired nitrate reductase activity (LaBrie et al., 1991; Crawford and Glass, 1998; Meyer and Stitt, 2001; Crawford and Forde, 2002).

Similar to reports of potassium chlorate reducing the activity of nitrate reductase in Arabidopsis (LaBrie et al., 1991) our results demonstrate that nitrate reductase activity is reduced in longan trees treated with potassium chlorate. Leaf samples of ‘E-wai’ longan trees were obtained from a commercial longan orchard that had been treated with 400 g/tree of potassium chlorate in a 6” diameter around the tree base. Nitrate reductase activity was assayed two weeks after application of potassium chlorate (Scheible et al., 1997) using fully expanded leaflets closest to the growing meristem. Three replicates were taken from the each tree and the averages and standard error are shown in Figure 1. Nitrate reductase activity was monitored over time to confirm the linearity of the values. Nitrate reductase activity was approximately 50% less in the potassium chlorate trees compared to the untreated tree. Trees treated with potassium chlorate flowered approximately 10 weeks after application while untreated trees did not produce flowers.

Longan trees treated with chlorite and hypochlorite also have reduced expression of nitrate reductase two weeks after treatment and produced off-season flowers. Two ‘Egami’ trees grown at the Waiakea Research Station were randomly treated with one of following treatments: no treatment control, 300 g/tree KClO₃, 300 g/tree sodium chlorite (NaClO₂) or 300g/tree potassium nitrate (KNO₃) applied as a granular broadcast under the tree canopy or 2 gallons bleach (5.25% sodium hypochlorite) applied as a soil drench under the tree canopy. Leaf samples were collected and assayed for nitrate reductase activity for two consecutive weeks after the treatment. Trees treated with chlorate, chlorite and hypochlorite (bleach) resulted in higher nitrate reductase activity than control on week 1 but were reduced in week 2 (Figure 2). This increase activity in nitrate reductase activity in week 1 may be similar to the increased level of nitrate reductase gene expression by chlorate in Arabidopsis plants grown in the absence of nitrate (LaBrie et al., 1991). Although the link between reduced nitrate reductase activity and longan is currently unclear, this area will be further investigated.

Trees were monitored for flower emergence which commenced on October 22 until December 10, 2004. All the trees with the exception of control and KNO₃ treated trees produced flowers. On December 10, 2004, 12 weeks after treatment, the flowering percentages were control and KNO₃ (0%), KClO₃ (97.8%), NaOCl (76%) and NaClO₂ (93.4%) suggesting chlorate, chlorite and hypochlorite can all effectively induce longan flowering (Table 1).

Sodium hypochlorite (bleach) as an alternative to potassium chlorate induced flowering in longan.

Potassium chlorate is a useful method to produce off season flower and fruits in longan however, the explosive nature of this chemical often makes it difficult to purchase, ship and store. The improper mixture of KClO₃ and sulfur was responsible for an explosion at a longan processing plant in Chiang Mai, Thailand, killing 35 workers and injuring over 100. Lack of
personal protection equipment from prolonged use of KClO₃ by longan workers in Thailand also resulted in increased levels of anemia, thrombocytopenia, high serum creatinine and methemoglobinemia which are hypothesized to be related to KClO₃ toxicity (Wiwatanadate, et al., 2001).

Sodium hypochlorite (NaOCl) break down occurs via two main pathways, one pathway leads to the production of oxygen while the other leads to chlorate formation (Adam and Gordon, 1999). Decomposition of bleach to chlorate is catalyzed by increased sodium chlorate concentrations and elevated temperatures (Figure 3 and 4, Gordon et al., 1995). Non-perishable products such as bleach may be exposed to elevated temperatures during transportation and storage which could account for the presence of chlorate in the bleach. To test this hypothesis, 3 random containers of bleach were sent to NovaChem Laboratories Inc., Oxford, Ohio for chlorate analysis. The samples contained 6.18 to 8.39 g/L of chlorate which would be equivalent to 46.8 g to 63.5 g of chlorate in 2 gallons of bleach applied to the trees (Table 2).

‘Biew Kiew’ trees in Onomea Hawaii, were used to determine if the amount of chlorate found in bleach could induce longan flowering. Three year-old ‘Biew Kiew’ trees were selected for uniformity in vegetative flushing, and each treatment was randomly assigned to 3 trees. On May 18, 2005 plants were treated as follows: no treatment control; 300 g KClO₃/tree or 45 g KClO₃/tree as granular broadcast under the canopy; 2 gal bleach (5.25% sodium hypochlorite) applied as a soil drench under the tree canopy. KClO₃ applications of were immediately followed with 2 gal water applied over the KClO₃ on the soil surface. The 45 g of KClO₃ was the estimated amount of chlorate present in 2 gallons of bleach.

Treated trees began flowering 8 weeks after treatment (August 8, 2005) and produced new panicles until 16 weeks after treatment. Untreated trees did not flower, and trees treated with 300 g KClO₃ produced panicles on 95.5% of the terminals which was significantly greater than the 45 g KClO₃ (67 % flowering) and 2 gallons bleach (54.2% flowering) treatments (Table 3). The 45 g KClO₃ and 2 gallons bleach treatments were not significantly different suggesting that the chlorate in the bleach may be responsible for flower induction in longan.

Previous reports have indicated that hypochlorite enhances the natural flowering season of longan (Sriontipp et al., 2005) or induces marginal off-season flowering of longan (Nagao et al., 2003). This may have been due to the amount of chlorate in bleach and soil type. Storage of bleach (NaOCl) under elevated temperatures will accumulate more chlorate (Gordon et al., 1995). Longan trees at Onomea Orchards in a clay rich soil flowered on 54.2% of the terminals, whereas trees grown at the Waiakea site in a more porous a’a lava soil flowered on 76% of the terminals.

In addition to hypochlorite and chlorate, large quantities of sodium were also added to the soil. Soil analyses from trees treated with bleach and control trees at Onomea showed that at 14 weeks after treatment, soil from bleach treated trees contained 151.3 ± 36.8 mg/L (6.6 meq/L) of Na⁺ while soil from untreated control trees contained 37.7 ± 2.9 mg/L (1.64 meq/L) of Na⁺. Soil pH and salinity were not significantly different in soil samples from bleach treated and untreated trees. Although longan trees are sensitive to saline soil and water (Crane et al., 2000), tolerance levels of longan to Na⁺ are unknown. Longan trees treated with 2 gallons of bleach did not show symptoms of Na⁺ toxicity. Since Na⁺ is accumulating in the soil, precautions should be taken to monitor Na⁺ levels if multiple applications of bleach or sodium hypochlorite are used in the field.

These results demonstrate that chlorate, chlorite and bleach induce flowering in longan. These results suggest bleach may be an effective alternative to potassium chlorate. However, chlorate in the bleach is the cause for floral induction. Chlorate in bleach results from the
breakdown of sodium hypochlorite and is promoted by increased sodium hypochlorite concentrations and elevated temperatures. Additional experiments are being conducted to determine the possible role of reduced nitrate reductase activity on longan flowering and to discover alternatives to chlorate.

**Literature Cited**


Gordon, G., L. Adam, and B. Bubnis. 1995. Minimizing Chlorate Ion Formation in Drinking Water when Hypochlorite Ion is the Chlorinating Agent. AWWA-AWWARF, Denver, CO.


Figure 1. Nitrate reductase activity is reduced in ‘E-Wai’ trees treated with 400 g of potassium chlorate (KClO₃) as a soil application compared to control. Leaf samples for the nitrate reductase assay were harvested two weeks after treatment.

Figure 2. Nitrate reductase activity of field grown ‘Egami’ longan plants is reduced in potassium chlorate (KClO₃), bleach (sodium hypochlorite) and sodium chlorite (NaClO₂) treated trees and increased in potassium nitrate treated trees (KNO₃) two weeks after treatment.
Table 1. Flowering of ‘Biew Kiew’ and ‘Egami’ longan trees 12 weeks after treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Flowering</th>
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<tbody>
<tr>
<td>Control</td>
<td>0%</td>
</tr>
<tr>
<td>300 g KClO₃</td>
<td>97.8%</td>
</tr>
<tr>
<td>300g NaClO₂</td>
<td>93.4%</td>
</tr>
<tr>
<td>bleach</td>
<td>76.0%</td>
</tr>
</tbody>
</table>

Figure 3. Estimated amount of chlorate in a 5% sodium hypochlorite solution at various temperatures. Information derived from sodium hypochlorite decomposition program (Powell Fabrication and Manufacturing Inc.).
http://www.powellfab.com/products/SodiumHypo/sodium_hypo_decomp_program.html
Figure 4. Estimated amount of chlorate in a 6% sodium hypochlorite solution at various temperatures. Information derived from sodium hypochlorite decomposition program (Powell Fabrication and Manufacturing Inc.). http://www.powellfab.com/products/SodiumHypo/sodium_hypo_decomp_program.html

Table 2. Quantities of chlorate and sodium chlorate in bleach samples as analyzed by ion chromatography.

<table>
<thead>
<tr>
<th>Bleach</th>
<th>ClO$_3^-$ (g/L)</th>
<th>NaClO$_3$ (g/L)</th>
<th>(g/L)</th>
<th>Chlorate (g) in 2 gal.</th>
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</thead>
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<tr>
<td>Sample 1</td>
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<td>3.47</td>
<td>6.18</td>
<td>46.8</td>
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<tr>
<td>Sample 2</td>
<td>2.91</td>
<td>3.73</td>
<td>6.64</td>
<td>50.3</td>
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<tr>
<td>Sample 3</td>
<td>3.68</td>
<td>4.71</td>
<td>8.39</td>
<td>63.5</td>
</tr>
</tbody>
</table>
Table 3. Flowering of ‘Biew Kiew’ longan trees 12 weeks after treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
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<tr>
<td>Control</td>
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</tr>
<tr>
<td>45 g KClO₃</td>
<td>67.0 %</td>
</tr>
<tr>
<td>bleach</td>
<td>54.2 %</td>
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</table>
Rambutan (*Nephelium lappaceum*), Longan (*Dimocarpus longan*), and Starfruit (*Averrhoa carambola*) are a few examples of tropical fruit grown in Hawaii for the exotic fruit market. They have the potential to be affected by many fruit rot diseases, both pre- and post-harvest. These fruit diseases can decrease the marketability of fresh fruit and fruit for processing. A survey was conducted to determine what types of diseases are currently affecting production. A range of symptoms were observed and included brown to black lesions, watersoaking, darkening of the pericarp, and leaf spots. A variety of fungi were isolated on artificial media from infected fruit and leaf tissues. Field symptoms were reproduced by artificial inoculation of detached fruit. The results of this survey will be presented. The methods used to identify the fungi and the importance of these fungi as tropical fruit pathogens will be discussed.

How is disease caused? To study plant disease, there are a couple of principles that a plant pathologist depends upon. A convenient way of thinking about plant disease is by using a concept called the "Disease Triangle".

Disease represents the interaction between three factors (the three corners of the triangle): a susceptible host, a pathogen (disease causing organism) and a favorable environment (proper temperature, moisture, wind, etc.). If all of these factors are present, disease results; if one or more of the factors are not present, and then disease does not occur. Methods of disease control can be thought of as modifying the disease triangle by reducing or eliminating one of the corners of the triangle. For example, if you use resistant varieties in your orchard, you are eliminating the "susceptible host" and can thus reduce or prevent disease. Similarly, for some diseases, by removing diseased plant material, you can reduce or eliminate disease because you are eliminating the pathogen. Finally, you can reduce or eliminate a "favorable environment" for disease by doing something as simple as controlling the amount of watering.
Koch’s Postulates – Demonstrating the Pathogenicity of a Microorganism. How do we determine if the isolated organism is the cause of the disease? There are 4 steps that must be followed. Step 1: Association - The pathogen must be found associated with the disease in all of the diseased plants examined (consistently associated with the symptoms). Step 2: Isolation - Next the organism must be isolated and grown in pure culture, free from all other organisms, and its characteristics are described. Step 3: Inoculation - In the third step, the pathogen from the pure culture must be inoculated on healthy plants of the same species or variety from which they were originally isolated and must reproduce the same disease as was originally observed. Step 4: Re-isolation - Finally, the pathogen must be reisolated into a pure culture again, and its characteristics must be exactly like those observed in step 2. If all of those steps have been followed and proved true, then the isolated pathogen is identified as the organism responsible for the disease.

Fungal Isolation Protocol - In order to properly identify the fungi causing the disease, we need to isolate the fungi in a pure culture. It is best to isolate from a sample of an area that contains healthy and diseased tissue, where the fungi is actively growing. The sample is surface disinfested in bleach (to make sure what we isolate is the causal agent and not something surviving on the surface or a secondary infection), and then is dried under aseptic conditions in a laminar flow hood. The tissue is then placed on water agar (fungi grows from the diseased tissue into the agar), and the mycelium that grows out is transferred to a plate containing media that supports the growth of the fungi. This should result in a pure culture of the fungi.

How do we ID fungi? - We use a variety of methods to identify the fungi and they are based on morphology and physiology (size, shape, color, reaction on different media). We use microscopy to look at the mycelium and spores (reproductive structures). We can also use more newly developed techniques to determine the species of the fungi. They are molecular techniques, which mean that a portion of the fungi’s DNA is analyzed.

Plant disease surveys were conducted and the following fungi were found causing disease on tropical fruits located at the Tropical Plant Genetic Resource Management Unit, PBARC, USDA-ARS, in Hilo and in areas of the Hamakua Coast. Pictures of the commonly observed symptoms are included with the fungi identified as the causal agent of disease.

Common rambutan diseases -

*Lasmenia* sp.
Phomopsis sp.

Corky bark – unidentified fungi

Common longan disease -

Phomopsis sp.

Common starfruit diseases -

Colletotrichum sp.
Conclusions - A variety of symptoms were observed in the field, and included brown to black necrotic lesions on the fruit and leaves. The pathogens isolated and identified were able to infect several hosts and under the right conditions have the ability to cause significant losses. Multiple factors contributed to the onset of disease. Management strategies which include proper pruning, fertilization, irrigation/drainage, use of fungicides, removal of pests, and optimum postharvest handling/storage can decrease losses caused by these fungi.
Update on Quarantine Treatments for Exporting Tropical Fruits

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The Postharvest Tropical Commodities Research Unit at USDA-ARS PBARC is responsible for coordinating research efforts to develop new or improved postharvest treatments to control quarantine pests that restrict the export of tropical fruits and vegetables from Hawaii; to increase product quality, marketability, and safety, while reducing treatment costs; and to develop holistic approaches to quarantine security that result in realistic pest-risk analyses and reduced treatment severity. In other words we develop heat, cold, modified atmosphere, and irradiation treatments or systems approaches to control quarantine pests.

Since the opening of Hawaii Pride x-ray irradiation facility in 2000, a major focus of my research program has been to develop and improve irradiation treatments for exporting tropical fruits from Hawaii to the U.S mainland and foreign markets. Irradiation is currently an approved quarantine treatment or 10 fruits and 5 vegetables for export to the U.S. mainland. Certain fruits such as avocado are not tolerant of irradiation and therefore require alternative treatments.

In this paper, I discuss recent regulatory actions by USDA APHIS that will affect Hawaii and HTFG, and discuss current research in our laboratory in support of the tropical fruit industry.

Regulatory actions

New exports. Progress is being made on new export protocols for Hawaii’s tropical fruits. Pest risk assessments (PRAs; the first step in developing an export protocol) are in final review at USDA APHIS for cherimoya, soursop, breadfruit, jackfruit, dragonfruit, mangosteen, and Korean melon. The new fruits are bundled together and will soon be headed for risk mitigation review and rule making. Shortly before the HTFG meeting, an APHIS official was quoted as saying, “All [PRAs] are prepared and undergoing final scientific and administrative review”. All these fruits are expected to be approved for export using irradiation to control quarantine pests as no alternative treatments are presently available or under development.

Future PRAs. PERAL – Pest Epidemiological Risk Analysis Laboratory – is the group within APHIS’ Center for Plant Health Science and Technology (Raleigh, NC) that prepares PRAs. In 2000, APHIS had only 4 analysts preparing PRAs but this number has been increased to 40 during the past two years in part due to the high volume of requests from foreign countries (and Hawaii) to trade in fruits and vegetables. There is currently a backlog of 400 PRAs, but only 30 have sufficient information to complete the process. About one year is required to complete 30 PRAs with current staff. Foreign countries are encouraged to prepare their own PRAs or to contract them out. Guidelines are published to aid in preparation. At a minimum, countries should help by sending a list of pests associated with the crop. Hawaii is treated like a foreign country. Two years ago, APHIS-PERAL hired Dr. Nic Liquido as a specialist to handle Hawaii’s unique phytosanitary issues. He is located in Honolulu. Nic prepared the new PRAs for
the fruits mentioned above. HTFG should begin preparing a list and prioritizing additional fruits with significant export potential.

Irradiation research

This past year we finished two important irradiation studies. First, we showed that 150 Gy is sufficient to control melon fly, oriental fruit fly and Mediterranean fruit fly. Approved doses for the three fruit flies were 210-250 Gy, so the research showed that these doses can be reduced which should save treatment costs. More importantly, this research demonstrated that our fruit flies are in line with other fruit flies that are controlled at 150 Gy, which opened the door for the proposal of a generic irradiation treatment for this group of insects (see below). Second, we convinced APHIS that 400 Gy was probably sufficient to control Hawaii’s sweetpotato pests, resulting in an export protocol for sweetpotatoes that gave Hawaii Pride a significant boost in revenue. This was a watershed event because it signaled that APHIS was open to the idea of approving a single irradiation treatment for all or most insects on all commodities. The 400 Gy dose is now being proposed as a generic treatment for all insects except Lepidoptera pupae and adults, and mites (see below). We have since demonstrated that the three sweetpotato pests can be controlled at 150 Gy. We have ongoing irradiation research with white peach scale, coconut scale, banana moth (Opogona sacchari), and ants (all of which are quarantine pests of tropical fruits) to identify effective doses below 400 Gy.

Generic irradiation treatments

A generic treatment is the “holy grail” for a quarantine entomologist. A generic treatment is a single treatment that controls a broad group of pests without affecting the quality of a wide range of commodities. Traditionally, entomologists have developed treatments one pest and one commodity at a time, so generic treatments for broad groups of pests and commodities could save years of research time and resources. Generic treatments have been discussed for many years but never applied due to the lack of a solid scientific footing. Irradiation is the ideal technology for developing generic treatments because radiation—from an isotope source (cobalt-60) or x-rays—penetrates fruit easily and is effective against insects at doses that generally do not injure the fruit. Heat and cold quarantine treatments require development of treatment one insect and one fruit at a time.

On June 10, 2005, USDA APHIS published a rule proposing a generic irradiation dose of 150 Gy for all tephritid fruit flies. We currently irradiate all our fruit at 250 Gy for fruit flies. Lowering the irradiation dose for fruit flies would reduce costs and increase capacity for treatment facilities by decreasing the required treatment time, and could accelerate the approval of irradiation quarantine treatments for specific crops, and thereby rapidly expand exports. Also, if another fruit fly species should invade Hawaii, exports would not be interrupted. The same Proposed Rule includes a generic irradiation treatment of 400 Gy for all insects except Lepidoptera (moths and butterflies) pupae and adults, and mites. These generic treatments apply to all commodities. Therefore, fruits with no Lepidoptera quarantine pests associated with the fruit in the pupal or adult stage have a ready-made treatment.
Banana export rule changing

Irradiation has been proposed for all cultivars of bananas for the first time. This rule is part of the same Proposed Rule recommending generic irradiation treatments discussed above. The 400 Gy irradiation treatment for bananas will be an alternative to the non-host status treatment that has been available for several years but not widely used.

Avocado no can irradiate

Avocado is one of only a few fruits that really does not tolerate irradiation. Even at doses as low as 50 Gy avocados show darkening or discoloration of the flesh. A cold treatment was developed many years ago to export avocados from Hawaii to the U.S. mainland but has not been used. High pressure processing (HPP) is a possible alternative quarantine treatment for avocado.

Many years ago, researchers explored the use of high pressure to control quarantine pests but abandoned the idea when it was demonstrated that high pressure treatment at about 25,000 psi (lbs. per square inch) did not destroy fruit fly eggs.

High pressure processing technology has made many advances in the past 10 years and modern equipment can produce much higher pressures. HPP at 85,000-90,000 psi is now used commercially to control food-borne pathogens and spoilage organisms in a wide variety of processed foods. We conducted preliminary tests using HPP equipment at Avure Technologies in Kent, WA to determine whether high pressure could be used to control quarantine insects.

In the first experiment, third and fourth instar codling moths were put into apples and treated 24 h later at a series of pressures between 14,000 and 26,000 psi. (Naturally we were not allowed to bring fruit flies or other Hawaii pests to Washington State for the experiment!) Survivorship was counted after three days. Similarly, codling moth eggs on the surface of apples were treated at the same pressures and egg hatch was counted after 10 days. In all treatments apples with codling moths were vacuum sealed in plastic bags before treatment and removed from the bags immediately after treatment.

Results showed that mortality of codling moth larvae increased with increasing pressure (Fig. 1). Treatment at a pressure of 22,000 psi killed 95% of the larvae. Egg mortality was unaffected by high pressure treatment between 14,000-26,000 psi compared to the control (0 psi) treatment (Fig. 2). In a second study, codling moth eggs were treated at pressures from 30,000 psi to 80,000 psi in 10,000 psi increments. No eggs hatched after high pressure treatment between 30,000-80,000 psi indicating these pressures were lethal.

Apples treated with even low levels of pressure turn into applesauce. Other fruits with airspaces are similarly crushed by HPP. Avocados however tolerate HPP very well. We treated Hass avocados halves at 87,000 psi and the texture and taste of the flesh was excellent. Other local fruits that appear to tolerate high pressure treatment well are longan and lychee. Avocado and mango halves from Mexico are presently being treated with HPP and sold commercially in the southwestern U.S. Treatment of papayas halves is a potential application for Hawaii (Fig. 3).

Avure Technologies has agreed to loan us a small research scale HPP unit to conduct tests on Hawaii’s fruit flies and other quarantine pests to determine if HPP may have a future for exporting select fruits or vegetables from Hawaii.
Selected References


Follett, P. A. 2006. Irradiation as a methyl bromide alternative for postharvest control of Omphisa anastomosalis (Lepidoptera: Pyralidae), Euscepes postfasciatus and Cylas formicarius elegantulus (Coleoptera: Curculionidae) in sweetpotatoes. J. Econ. Entomol.


Fig. 1: High pressure treatment of codling moth larvae in apples. Mortality increased with increasing pressure.

Fig. 2: High pressure treatment of codling moth eggs on apples. High pressure at these levels had no effect on mortality compared with untreated controls.
Fig. 3. HPP treated papaya halves and slices.