Phenology and Fruit Development of Rambutan (*Nephelium lappaceum* L.) grown in Hawai‘i

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ABSTRACT
Flowering, flushing, and fruit development of 8 rambutan (*Nephelium lappaceum* L.) cultivars grown along the eastern coast of Hawai‘i Island were studied over 4 consecutive years (2002 Jan. to 2005 Dec.) at 2 orchards near Hilo, HI. Phenology data were collected at monthly intervals on 5 trees of each cultivar by estimating the percentage of the total canopy that was flowering, flushing, or had developing fruits. Development of individual 'Binjai' fruits was also monitored from anthesis until maturity at 2 locations. The data showed that cultivars generally flowered 2 to 3 times a year, and an individual tree could flower up to 3 times over a twelve month period. Major flowering periods occurred from July to August and additional flowering peaks occurred in April and October. Trees could exhibit vegetative flushing up to 3 times a year. Developing fruits exhibited a simple sigmoid growth pattern and matured approximately 18 to 20 weeks after anthesis. Weather in East Hawai‘i was very different from weather patterns found in the native growing region of Southeast Asia where monsoon seasons create distinct wet and dry seasons and individual trees flower only once a year. Hilo’s climate was stable throughout the year with mean monthly temperatures of 23.8°C and rainfall varying between 10 and 50 cm/month. The multiple flowering peaks coincided with periodic drier weather encountered in winter and summer and were influenced by non-synchronous vegetative flushing within the canopy.
KEYWORDS: flowering; fruit development; phenology; rambutan.

INTRODUCTION
Rambutan fruits are native to the humid tropical regions of the Malaysian Peninsula in Southeast Asia, and commercial orchards can be found in Indonesia, Philippines, Borneo, Thailand, and Northern Australia (Tindall et al., 1994). Rambutan cultivation in Hawai‘i began in the 1980’s, with current production concentrated on Hawai‘i Island (National Agricultural Statistics Service, 2005; Zee, 1993).

Rambutan flower induction occurs in response to water stress, and flowering intensity is related to the duration of the water stress period (Nakasone and Paull, 1998; Salakpetch, 2005; Tindall et al., 1994). Mean temperatures greater than 22°C and 2 to 4 weeks of water stress are required for flower induction (Nakasone and Paull, 1998; Salakpetch, 2005; Whitehead, 1959). Terminal buds from the latest must also be mature and at rest for induction to occur (Salakpetch, 2005). When trees have been exposed to sufficient water stress, leaf margins on terminal leaves curl upward toward the midrib, and about 10mm of irrigation is then required to initiate flowering and stimulate flower bud growth (Salakpetch, 2005). Excessive rainfall during the expected flowering season is detrimental to flowering and encourages vegetative growth. The majority of the world's rambutan production occurs in Malaysia, Thailand, and Indonesia, where the climate is highly influenced by yearly monsoons. Malaysia experiences two monsoon seasons resulting in distinct wet and dry seasons (Malaysian Meteorological Service, 2005). The northeast monsoon occurs from November to March, bringing heavy...
rainfall. The southwest monsoon arrives from late May to September and signifies the onset of drier weather. Rainfall varies between 200 and 500 cm per year and diurnal temperatures fluctuate between 22° and 30°C (Yaacob and Subhadrabandhu, 1995).

In Southeast Asia, rambutan flowers appear shortly after the dry season. Individual trees flower and fruit once a year; however, flowering of early and late bearing cultivars can produce 2 flowering and fruiting seasons during the year (Tindall et al., 1994). Fruit development studies of 'Seechompoo' in Thailand showed that growth followed a simple sigmoid curve, and fruits reached full maturity by the 16th week after anthesis (Kosiyachinda and Salma, 1987; Kosiyachinda et al., 1987).

While information on rambutan phenology and fruit development is available for Southeast Asia, there is no information on phenology and fruit growth for rambutan cultivars cultivated under Hawai’i’s stable climatic conditions. This report describes the flowering and flushing patterns of 8 cultivars grown in Hawai’i and also describes the development of rambutan fruits from anthesis to maturity.

MATERIALS AND METHODS

Rambutan Phenology. From 2002 Jan to 2005 Dec, phenological events for 8 cultivars ('R156 Red', 'Jitlee', 'Silengkeng', 'Rongrien', 'R9', 'Binjai', 'R167' and 'R134') were recorded monthly at an orchard in Onomea (19°49’N and 155°05’W, elev. 115 m). The 'R9' cultivar was also monitored at an orchard in Kurtistown (19°35’N and 155°04’W, elev. 250 m) from 2002 Jan to 2005 Dec. The Onomea site consisted of a deep Hilo silty clay loam soil and is in an area where many newly established orchards are located. The Kurtistown site consisted of a stony Ola’a silty clay loam soil.

Phenological data were collected by dividing each of 5 replicate trees for each cultivar into 4 quadrants and visually estimating the percentage of the terminal shoots in each quadrant that possessed panicles with flowers at anthesis, vegetative flushes, or immature and mature fruit. An estimate for each entire tree was based on the mean of the 4 quadrants. The means of 5 trees for each cultivar was used to determine phenological patterns at each location.

Fruit Growth and Development. Fruit growth and development was monitored on 'Binjai' fruits at the Kurtistown orchard beginning in 27 Apr 2004 and at an orchard in Pauka’a (19°45’N and 155°05’W, elev. 110 m) beginning in 15 Sep 2004. Fruits from 5 trees (15 panicles per tree) were monitored at each location. Length and diameter of one fruit per panicle from 15 panicles on each tree were measured in-situ at 2 week intervals to obtain a nondestructive measurement of fruit size. Fruit diameter was determined at the widest point of the pericarp perpendicular to the pericarp suture that ran the length of the fruit, and fruit length was measured from the blossom to the stem end. To obtain weight measurements, 3 randomly selected fruits per tree were harvested and weighed at 2 week intervals. Total soluble solids (brix) of the aril from 15 fruits per location were also determined with a refractometer from the 14th week after anthesis until full maturity.

Climatic Data Hawai’i. Climatological data consisting of minimum and maximum daily temperatures and daily precipitation were obtained for 2002 to 2005 from the National Oceanic Atmospheric Administration (NOAA) National Weather Service located 11 m above sea level at 19°45’N and 155°04’W in Hilo, Hawai’i. The NOAA station was located approximately 23 km from the Onomea and Kurtistown sites. To determine temperature and precipitation differences between the Hilo NOAA station and the Onomea and Kurtistown sites, historical climate data consisting of average monthly minimum and maximum
temperatures and average monthly total precipitation from Pepe'ekeo (elev. 30 m) and Kea'au (elev. 76 m) were obtained from the Western Regional Climate Center (WRCC) in Reno, NV. Twenty-three years of data from Pepe'ekeo and 46 years of data from Kea'au were obtained from the WRCC (2006). These locations are situated within 8 km of the Onomea and Kurtistown sites, respectively.

RESULTS AND DISCUSSION

Mean monthly NOAA weather summaries for Hilo from 2002 to 2005 are presented in Figure 1, and showed that temperatures were 2 to 3°C cooler than temperatures recommended for rambutan cultivation (Yaacob and Subhadrabandhu, 1995). Minimum and maximum temperatures in Hilo were between 18.0 and 29.2°C, and mean monthly diurnal temperatures ranged from 19.7 to 27.8°C. Historical climate data from the WRCC (2006) for Pepe'ekeo and Kea'au indicate that these areas were an additional 1 to 2°C cooler than the Hilo vicinity. Weather data from Chanthaburi (12°36’N and 102°06’E, elev. 3 m), Thailand showed that the warm and cool seasons were opposite to that of Hawai'i (WorldClimate, 2005). In Hawai'i the warmest temperatures occurred from mid-June and extended through early November. Unlike in the Malaysian region where yearly monsoons create distinct wet and dry seasons, the wet and dry seasons in Hawai'i were not very distinct (Figure 1). Drier weather occurred in December to January and between May and August. Historical records showed that Hilo, Pepe'ekeo, and Kea'au had similar rainfall patterns, however historically Kea'au and Pepe'ekeo received 250 and 130mm more rainfall than Hilo, respectively.

Contrary to the native growing environment in Malaysia where individual trees flower only once a year (Tindall et al., 1994), individual rambutan trees in Hawai'i could experience multiple flowering periods within one year. Figure 2 summarizes the flowering at Onomea for 8 cultivars ('R156 Red', 'Jitlee', 'Rongrien', 'R9', 'Binjai', 'Silengkeng', 'R167', 'R134') over the 4-year period. The major flowering period occurred from July to August while smaller flowering peaks occurred in March to April and occasionally in October. Within all cultivars, flowering intensity and period varied between years with some years exhibiting more intense flowering with multiple peaks. The annual flowering pattern for 'Jitlee' and 'Silengkeng' illustrated how the flowering pattern varied between years (Figure 3). 'Silengkeng' tended to exhibit a more extended flowering pattern in some years and tended to produce more panicles compared to the other cultivars. Although 2 flowering and fruiting seasons can occur within a year in Southeast Asia, this is due to early-bearing cultivars flowering from February to March and late-bearing cultivars flowering in June to July (Tindall, 1994, Tindall et al., 1994).

Flowering at Onomea was most consistent during July and August (Figures 2 and 3) which coincided with the onset of drier weather conditions in May (Figure 1). Although drier weather also occurred in December and January, it appeared that length and intensity of the dry periods were not sufficient to induce consistent flowering in late spring (March-April).

'Jitlee', 'R156 Red', 'Silengkeng', and 'Rongrien' tended to flower more intensely than other cultivars at Onomea (per. observ.). During late summer in 2002 to 2005, 'Silengkeng' and 'Jitlee' had an average of 27.0% and 21.8% of the canopy in flower, respectively, compared to 'R9' where only about 13.6% of the canopy was in flower. 'Silengkeng' also tended to produce larger panicles and flowered more profusely and for a longer duration than the other cultivars. Within individual trees, 'Silengkeng' could bear flowers up to 10 months of the year, whereas other cultivars tended to flower during 6 to 7 months of the year.
A comparison of flowering of the 'R9' cultivar at Onomea and Kurtistown showed that the flowering intensity differed with planting location (Figure 4). Similar to Onomea, flowering on individual trees in Kurtistown could occur twice a year. The soil in Kurtistown was stonier than at Onomea, thus exposing trees to a higher level of water stress during drier periods. The flowering peak in the summer of 2002 at Kurtistown, was much lower than in the spring. Moderately dry weather earlier in the year may have promoted the heavy flowering during the spring, leaving a relatively small number of terminals available for flowering following the dry period during the summer.

Vegetative flushing occurred during nearly all months of the year (Figure 5). A large amount of vegetative flushing was evident from May to June following the fruit harvest in December and January and the heavy rains in March. Greater amount of flushing occurred during warmer months with less vegetative activity evident during the coolest periods of the year. Rainfall in East Hawaii throughout the year did not allow terminal buds to remain at rest for long periods and resulted in non-synchronous flushing within trees. In Malaysia, flushing occurs twice a year, following harvest and during the rainy season (Whitehead, 1959). The dry monsoon season synchronizes terminal maturity and allows terminals to enter a resting phase until moisture returns.

All shoots will not respond to conditions that promote flowering unless competency of the target meristematic cells receiving the inductive signals is achieved (Bernier, 1988 and Bernier et al., 1981). Rambutan terminal buds must be mature and at rest to be competent and respond to the inductive signal (water stress) for flower initiation. In the absence of synchronized growth and a consistent inductive signal, uniform competency within the rambutan canopy, orchard or cultivar cannot be achieved and will result in inconsistent and unpredictable flowering.

Growth of 'Binjai' fruits followed a simple sigmoid growth curve (Figure 6), and was similar to growth patterns observed with 'Seechompoo' fruits in Thailand (Kosiyachinda and Salma, 1987; Kosiyachinda et al., 1987). Fruit development and harvest in Hawai’i lagged by 2 to 4 weeks when compared to fruit grown in Thailand. Our observations showed that seed development began before the 6th week after anthesis, and seed filling and the hardening of the cotyledons began in the 8th to 10th week. Aril development began 10 to 12 weeks after anthesis and color break of the pericarp occurred in the 14th to 16th week. The fruits reached maturity 16 to 20 weeks after anthesis. At 18 weeks after anthesis, mature fruits grown in Pauka’a were 42.5 mm x 33.7 mm in size, weighed 31 g, and had brix readings of 19.1%.

The growth pattern for 'Binjai' fruits at Kurtistown was also similar to 'Seechompoo' fruit development in Thailand (per. observ.). Fruits grown in Kurtistown (elev. 250 m) required about 2 weeks longer to reach maturity compared to fruits from Pauka’a (elev. 110 m). Cooler temperatures may have contributed to a longer maturation period. At 20 weeks after anthesis, mature fruit from Kurtistown was 47.4 mm x 33.4 mm in size, weighed 35.0 g, had a brix reading of 18.4% and was comparable to 'Binjai' fruit quality reported from Australia. Mature 'Binjai' fruits grown in North Queensland, Australia were approximately 48 mm x 40 mm in size, weighed 32 to 41 g, and had a total soluble solids content of 18 to 21% (Watson et al., 1988).

Rambutan trees at Pauka’a were younger with a smaller canopy, supported a greater fruit load than the Kurtistown trees, and were not irrigated. Tree age, size, fruit load, and difference in cultural practices and growing location may have contributed to the difference in final fruit size and length of time to maturity. According to Lim and Diczbalis (1998), daily irrigation is
essential during fruit filling until maturity and is critical in areas with high soil porosity and high pan evaporation.

Results of this study showed that multiple flowering and flushing peaks can occur on rambutan trees cultivated in East Hawaiʻi. The tree is native to the Malay Peninsula where distinct wet/dry monsoon seasons produce consistent and intense flowering following the dry period and a single production season. Maturation of terminal shoots is non-synchronous in Hawaiʻi, and vegetative flushing can occur in response to a significant amount of rainfall, harvest, or pruning. Flushing typically occurs 3 to 4 times yearly with more pronounced flushing in May and smaller flushes in August and November. Yearly flowering in Hawaiʻi appears to coincide with two induction periods. Major flowering periods can occur during spring and summer, indicating that trees encounter inductive conditions between December to February and during May to July. Seed filling begins 8 to 10 weeks after anthesis and aril development occurs 10 to 12 weeks after anthesis. Harvesting occurs 16 to 20 weeks after anthesis when soluble solids are 18% or greater. Late-summer and winter harvests are typical.

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LITERATURE CITED
Figure 1. Mean monthly minimum and maximum temperature and rainfall from 2002 Jan to 2005 Dec in the Hilo, Hawai‘i. Error bars represent ± SE.

Figure 2. Flowering pattern of rambutan cultivars ('R156 Red', 'Jitlee', 'Silengkeng', 'Rongrien', 'R9', 'Binjai', 'R167' and 'R134') at Onomea (elev. 115 m). Error bars represent ± SE.
Figure 3. Annual flowering pattern for ‘Jitlee’ and ‘Silengkeng’ rambutan at Onomea (elev. 115 m) from 2002 Jan to 2005 Dec. Error bars represent ± SE.
Figure 4. Annual flowering pattern for ‘R9’ rambutan at Onomea (elev. 115 m) and Kurtistown (elev. 250 m) from 2002 Jan to 2005 Dec. Error bars represent ± SE.
Figure 5. Vegetative flushing pattern of rambutan cultivars ('R156 Red', 'Jitlee', 'Silengkeng', 'Rongrien', 'R9', 'Binjai', 'R167', and 'R134') at Onomea (elev. 115 m). Error bars represent ± SE.

Figure 6. Growth of ‘Binjai’ rambutan fruit at Pauka’a (elev. 110 m).