VEGETATIVE FLUSHING AND FLOWERING OF MACADAMIA INTEGRIFOLIA IN HAWAII


Department of Horticulture, Beaumont Research Center,
University of Hawaii at Manoa, 461 W. Lanikaula St., Hilo, HI 96720, USA


ABSTRACT
A study of the flowering pattern of 3 macadamia cultivars, 'Kau' (HAES 344), 'Keaau' (660), and 'Kakea' (508) was conducted at an orchard near Hilo, HI (elev. 27 m). A phenological study was also conducted to examine the flushing behavior of 9 years-old macadamia trees and the relationship between the age of vegetative flushes and flower production on the 3 cultivars. Vegetative flushes that emerged throughout 1988 on the 'Kau', 'Keaau', and 'Kakea' cultivars were tagged to determine the frequency of flushing. During the next 3 flowering seasons (1988-89, 1989-90, 1990-91), raceme production by the flushes were observed. Studies of the flowering pattern showed that all cultivars had broad flowering peaks with flowering being most abundant between January and April. Vegetative flushing occurred year-round for all cultivars but was more prominent during fall (October, November, December) which coincided with the period of nut maturation. 'Keaau' also displayed a period of active vegetative flushing during spring (April & May) near the end of the flowering season. Vegetative flushes emerged from both axillary and terminal buds. A small amount of flowering occurred during the 1988-89 flowering season in 'Keaau' and 'Kau' within 1 year after vegetative flush emergence, however, for all cultivars, flowering on the 1988 flushes increased through 1990-91. Flowering that occurred in 1989-90 and 1990-91 was not restricted to flushes that emerged during a single period in 1988. Most of the racemes developed on flushes that were produced in the spring and fall of 1988.

Macadamia integrifolia trees in Hawaii lack synchrony in the development of vegetative and reproductive buds, and as a result trees can possess young vegetative flushes at nearly all periods of the year. The flushes emerge from buds at branch apices and from vegetative buds in leaf axils. Up to 3 buds are found in each leaf axil (Storey et al., 1953), however, during normal flushing only a single shoot will develop within each leaf axil.

Another characteristic of macadamia in Hawaii is a protracted flowering season that extends over several months. Up to 300 flowers are borne on each raceme with most of the flowers on an individual raceme opening within a single day (Urata, 1954). In some instances, up to 5 days are required before anthesis is complete on the entire raceme. In Hawaii racemes at anthesis are observed between November to May with several peaks occurring during the flowering season (Nagao and Sakai, 1988, 1990). Following pollination, fruits develop and mature at about 28 to 30 weeks after anthesis (Jones, 1939; Jones and Shaw, 1943; Sakai and Nagao, 1985). Due to the extended flowering season, some fruits are nearly mature as the flowering season approaches completion. Therefore, during some periods of the crop cycle, fruits, flowers, actively growing and dormant vegetative buds will be found on an individual tree.

As fruits mature and begin abscising, multiple harvests are required to gather the entire season's crop which leads to increased production costs. Production strategies that lead to more synchronous flowering and fruit development will benefit the industry. Although observations indicate that a lengthy period exists between shoot development and raceme production on that shoot, a systematic study of vegetative flushing and flowering has not been conducted. An initial step in the development of strategies to obtain more synchronous development within macadamia trees, is to obtain baseline data on the flowering and vegetative flushing pattern of various cultivars and determine the relationship between flowering and the vegetative growth pattern.

MATERIALS AND METHODS
Flowering pattern of macadamia trees in Hawaii
This study was conducted on grafted macadamia trees growing in an orchard near Hilo, Hawaii (elev. 27m). Three branches 20-37 mm in diameter were selected on 20 'Kau' (HAES 344), 12 'Keaau' (660), and 12 'Kakea' (508) trees. Branches that were selected were situated around the outside canopy of the trees and had flowered in the previous season. The 'Kau' trees were planted in 1980, the 'Keaau' and 'Kakea' in 1973. Trees were monitored by recording the number of racemes at anthesis on each branch at 2 week intervals during the 1988-89,1989-90 and 1990-91 flowering seasons.
Relationship between flowering and vegetative growth of macadamia

Two branches (21-29 mm diameter) were selected on each of 5 trees of 'Keaau', 'Kau', and 'Kakea' to examine the relationship between the age of vegetative flushes, season of flushing and flower production. Vegetative shoots (flushes) produced on these branches during a single year (1988) were tagged to indicate all growth (length) that occurred during the year. This was done to determine the seasonal frequency of vegetative flushing during the year and to monitor the subsequent flowering activity of these flushes in later years. The flush length monitored for flowering was therefore constant, any subsequent growth of these shoots (terminal or axillary) was not monitored for flowering. These flushes were monitored during subsequent flowering seasons (data from the 1988-89, 1989-90, 1990-91 seasons are reported here). On each selected branch, the number of tagged flushes ('shoots') produced during a given period in 1988 that flowered and the number of racemes production by those 'shoots' were recorded. The study was initiated on 9 years-old trees in an orchard near Hilo, Hawaii (elev. 27 m).

Flowering pattern of macadamia trees in Hawaii

Extended flowering patterns were associated with each cultivar studied (Fig. 1). Within a given year, two or three periods of peak flowering could be observed. Flowering usually began in December and could extend up to 30 weeks. Generally flowering was most abundant during an 8-10 week period between late-January and early-April, however, flowering peaks could be observed as late as in May. Anthesis tended to occur earlier in the season in 'Keaau' compared to 'Kau' and 'Kakea'. In all 3 cultivars, both the 1989-90 and 1990-91 flowering seasons were characterized as having late flowering peaks during May.

Figure 1, Flowering pattern for M. integrifolia cvs. Keaau (660), Kakea (508) and Kau (344) trees in Hilo, HI, elevation 27m.

Relationship between flowering and vegetative growth of macadamia

A small amount of flowering occurred during the 1988-89 flowering season in 'Keaau' and 'Kau' within a year after vegetative flush emergence, however, in all cultivars, flowering on the 1988 flushes increased through 1990-91 (Fig. 2). Flowering was not restricted to flushes that emerged during a particular period in 1988. Maximum flowering of the 1988 flushes occurred in the 1991 flowering season on the flushes during their third year of development. Data on subsequent years is being collected. Most of the racemes developed on flushes that were produced in the spring and fall. Flowering on a single flush could also occur during 2 consecutive flowering seasons, and racemes emerged from both from apical and axillary buds on those flushes.
Vegetative flushing occurred year-round in all cultivars but was more prominent during the fall (October, November, December) and coincided with the period of nut maturation (Fig. 3). 'Keaau' also displayed a period of active vegetative flushing during the spring (April & May) near the end of the flowering season. Vegetative flushes emerged from both axillary and terminal buds.
Studies of vegetative flushing patterns in Australia showed that major flushes occurred in late summer and in early Spring with smaller flushes occurring during other periods (Stephenson et al., 1986). Maximum flushing coincided with periods when temperatures were between minimum and maximum threshold temperatures of 10 and 30°C. Optimum temperatures for shoot development were about 25°C. Weather data from a floral phenology modeling study of the 'Ikaika' (333) cultivar near Hilo (Hwang, 1991; Hwang et al., 1992) showed that maximum and minimum temperatures in the area of our study were between the thresholds described by Stephenson et al. (1986). Thus, the mild temperatures near Hilo were conducive to vegetative growth and encouraged continuous flushing in the 3 cultivars.

Our results showed that macadamia flushes flower within 1, 2 or 3 years after development and perhaps beyond. It did not appear that the extended flowering in a given season was related to the period of development of the vegetative flushes. Racemes that developed early or late in the flowering season were not associated with a specific set of flushes. Unlike mango or litchi where inflorescences are produced from terminal buds, macadamia racemes developed from both terminal and axillary buds.

Data from a phenological study of the 'Ikaika' cultivar growing at Keaau (elev. 27 m) and Honomalino (elev. 695 m) on the island of Hawaii showed that the extended flowering pattern occurred at both locations (Hwang, 1991; Hwang et al., 1992). Trees at the Honomalino site tended to have a broader flowering pattern, but began flowering earlier than trees at the Keaau site. Our results along with Hwang's (1991, 1992) data show that non-synchronous flowering is a characteristic of all major cultivars in Hawaii and that growing site, influences the time for the onset of flowering. However, the extended flowering patterns for macadamia in Hawaii occur at both low and high elevations.

A strategy to inhibit late season flowering in May is important to the macadamia industry since these peaks produce an off-season crop that often does not warrant harvesting because of the associated low yields. However, if the crop is not harvested, presence of these nuts on the orchard floor reduces the quality of the early harvests in the subsequent season as these nuts are harvested with the next season's crop. Gibberellic acid has been shown to inhibit flowering of macadamia when applied prior to anthesis (Nagao and Sakai, 1990), and it may be possible to develop a strategy to concentrate flowering by timing GA application to suppress late season flowering.

The timing and intensity of flowering of macadamia in Australia was related to the amount of carbohydrates stored in wood tissues in the summer prior to the flowering season (Stephenson et al., 1989). Stored carbohydrates tended to be greater in trees in which there was an absence of a crop and a restriction of vegetative growth in the previous season. These trees also exhibited more intense and advanced flowering. Increased flowering was also reported in Hawaii when trees were girdled prior to the onset of the flowering season (Nagao and Sakai, 1990).

Information on environmental factors involved in macadamia flower induction and development has been obtained through a number of controlled environment (Nakata, 1976; Sakai et al., 1982; Stephenson and Gallagher, 1986), and field experiments (Moncur et al., 1985) in Hawaii and Australia. These growth chamber, glasshouse and field studies indicate that flower induction and development occurred best at night temperatures between of 15 and 18°C. Recommended planting sites for macadamia orchards in Hawaii are between 90 to 610 m (Nagao and Hirae, 1992). In these locations optimum temperatures for floral induction and development are present during several months of the year and likely contributes to the protracted flowering pattern for this crop under Hawaii conditions.

In conclusion, vegetative flushing occurred year-round on the 'Keaau', 'Kau' and 'Kakea' cultivars and was most prominent in the spring and fall. Vegetative flushes on the 3 cultivars can flower within one year after emergence. However, flowering increases as the flushes age being most abundant during the third year after shoot development. The pattern after the third year is being determined.

ACKNOWLEDGMENT

We gratefully acknowledge the Mauna Loa Macadamia Nut Corporation for use of their field facilities for this research. This research was supported in part by the U.S. Department of Agriculture under CSRS Special Grant No. 87-CSRS 2-3090 and 88-34135-3604, managed by the Pacific Basin Administrative Group (PBAG).

Literature Cited


