

Flowering and fructification phenology in *Macadamia integrifolia*

Fenología de floración y fructificación en *Macadamia integrifolia*

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Abstract

In the rural area of Timbío, located in the Cauca region of Colombia, an area of 287 ha is planted with different varieties of macadamia (*Macadamia integrifolia*), which still have not realized their full potential. In this research, the phenology of the flowering and fructification of five macadamia varieties: HAES 294, HAES 344, HAES 741, HAES 788, HAES 800 was evaluated. Forty inflorescences per variety were selected in order to determine: inflorescence period, number of flowers/inflorescence, number of fruits/bunch and fruit diameter. Additionally, the most important phenological stages of the two processes were defined. Flower growth lasted between 57 and 62 days, and the inflorescence had five stages: flower buttons, differentiation of flower units, end of growth, flower opening and pollination. Differences in the inflorescence period were statistically significant and ranged from 10.7 to 15.7 cm, with the HAES 788 variety having the longest inflorescences and the HAES 800 variety the shortest. The number of flowers/inflorescence ranged from 89 to 135: HAES 800 had the fewest and HAES 294 the most. The biggest fruits were obtained from HAES 788, HAES 800 and HAES 294 with an average diameter of 3.1 cm, and the smaller fruits, with a 2.8 cm average diameter were obtained from HAES 344 and HAES 741. Three stages were identified: fruit tie-up, morphologic development and physiological maturity; the duration of which ranged from 210 to 234 days. The average number of fruits/bunch for HAES 344, HAES 294, HAES 788 and HAES 741 ranged from 3.2 to 3.9, and for HAES 800 was 1.2 fruits/bunch.

Key words: *Macadamia integrifolia*, *Macadamia ternifolia*, phenology, nuts, fructification, crop physiology, flowering

Resumen

En Timbío, departamento del Cauca (Colombia) existen aproximadamente 287 ha cultivadas con diferentes variedades de macadamia (*Macadamia integrifolia*) que aún no expresan su mejor potencial. Durante un año a partir de 2005 se evaluó el comportamiento fenológico de floración y fructificación en las variedades: HAES 294, 344, 741, 788 y 800. Se seleccionaron 40 inflorescencias por variedad para medir: longitud de inflorescencia, número de flores/inflorescencia, número de frutos/racimo y diámetro de frutos y, definir las principales etapas fenológicas. El crecimiento de la flor se extendió entre 57 y 62 días y la inflorescencia presentó cinco fases: aparición del botón floral, diferenciación de unidades florales, finalización del crecimiento, apertura floral y polinización. La longitud de inflorescencia fue estadísticamente significativa y varió entre 10.7 y 15.7 cm, la variedad HAES 788 presentó las inflorescencias más largas y HAES 800 las más cortas. El número de flores/inflorescencia varió entre 89 y 135, la variedad HAES 800 mostró el menor número y la HAES 294, el mayor. Los frutos más grandes fueron producidos por HAES 788, 800 y 294 con diámetro promedio de 3.1 cm y los más pequeños, de 2.8 cm, por HAES 344 y 741. Se identificaron tres etapas: amarre de frutos, desarrollo morfológico y madurez fisiológica cuya duración varió entre 210 y 234 días. El número de frutos/racimo varió, en promedio, entre 3.2 y 3.9 para HAES 344, 294, 788 y 741, y fue de 1.2 frutos/ racimo para HAES 800.

Palabras clave: *Macadamia integrifolia*, *Macadamia ternifolia*, Proteaceae, nuez de macadamia, fenología, fisiología vegetal, floración, fruto seco.

Introduction

The macadamia (*Macadamia integrifolia*) originates from southeast Queensland and northeast New South Wales, Australia, although its development as a commercial improved crop has occurred principally in Hawaii. Plantations also exist in South Africa (24 y 30° S), Florida (25° N), California (33° N) and Costa Rica (8° y 11° N) (Rincón, 2000).

The adequate range of temperatures for the production of macadamia is found between 18 °C and 26 °C, with the optimum between 20 °C and 23 °C. For an optimum flowering, night temperature must not exceed 20 °C nor fall below 18 °C, outside of this range raceme formation is inhibited. For adequate plant growth, the temperature must be between 18 °C and 29 °C; average temperatures less than 17 °C retard growth, with a delay in the initiation of production, the maturation of pollen. Additionally, pollination is irregular, the thickness of the cortex greater, and the nut loses organoleptic quality, and oil levels (Armadans, 1998). The greatest photosynthesis rate is obtained at 29 °, and this decreases as the temperature

increases. The greatest photosynthesis activity occurs between 17 °C and 25 °C. The percentage of high quality nuts increases under conditions in which the temperature increases over the development period of the fruits (Rincón, 2000).

This species adapts well to sites located between 1000 and 1500 m.a.s.l. Outside of this range, problems are seen with flowering, lower production levels, and lower quality nuts. The tree is highly sensitive to drought, making the distribution of precipitation through time more important than the actual level of precipitation the appropriate range of annual precipitation is between 1500 and 3000 mm. Relative humidity required for this crop is between 70 and 80%, when it is lower, problems with drought stress arise, and when it is higher, phytosanitary problems occur (Rincón, 2000).

In the farms Santa Clara and Gibraltar, located in the municipality of Timbío, Cauca Department (Colombia) there are 287 ha planted with macadamia that produce, on average, 4.9 kg/tree per year of nut in the shell. However, trees producing 20 kg annually are known (Barona et al., 1999). The present study had the objective to study the stages of development, in order to know the flowering and fruiting phenology of the *Macadamia integrifolia* crop in the municipality of Timbío, and to determine the effects of climatic factors on the different stages.

Materials and methods

The farm, Santa Clara is located at 2° 25' N and 76° 41' O, at 1700 m.a.s.l., with a relative humidity of 81%, average temperature of 18.2 °C –a maximum of 23.3 °C a minimum of 14.5 °C– and mean annual precipitation of 2151 mm distributed over 258 days (Box 1) (Fedecafé, 1999). The *Macadamia integrifolia* was planted in 1992.

Cuadro 1. Registros de clima en la zona durante el periodo de evaluación. Timbío, Cauca, Colombia.

Fecha	Temperatura (°C)					Humedad relativa (%)				Prec. (mm)
	Mínima	Máxima	Media	Máx. absoluta	Mín. absoluta	1	2	3	Promedio	
Abr-05	15.6	24.6	20.1	27.4	13.6	96.6	62.13	83.43	80.72	100
May-05	15.24	24.7	20.5	27.2	13	96.8	59.8	86.38	80.93	98
Jun-05	14.23	24.8	19.52	27.6	10.2	97.5	56.7	77.1	77.1	43
Jul-05	13.1	25.8	19.48	28.2	9.2	95.3	45.7	60.09	67.03	32
Ago-05	12.87	26.49	19.6	28.4	8.8	95.16	43.8	61.83	66.93	32
Sep-05	12.96	25.47	19.22	30	10.4	92.5	41.3	59.8	64.533	127
Oct-05	14.79	23.9	19.35	26.8	13.6	96.64	59.29	89.51	81.813	269
Nov-05	15.2	22.9	19.05	25.6	11.6	96	64.5	92.96	84.487	519
Dic-05	14.8	22.38	18.6	26.6	12	93.9	68	92.8	84.9	277
Ene-06	14.8	22.38	18.8	25.2	13.6	96.4	65	88.8	83.4	259
Feb-06	15.6	23.8	18.44	25.8	12.4	97.32	61.28	86.1	81.567	124
Mar-06	15.38	23.41	19.4	26.8	13.8	96.83	64.54	88.77	83.38	209
Abr-06	14.99	23.32	19.16	25.2	12.6	96.9	63.7	90.2	83.6	214

Fuente: Federación Nacional de Cafeteros de Colombia (Fedecafé, 2006).

Box 1. Climate data for the zone during the evaluation period. Timbío, Cauca, Colombia.

The farm has the varieties HAES 294, 344, 741, 788 y 800, planted in intercalated rows. For the study four trees per variety were chosen randomly. In the varieties HAES 294, 741, 788 and 800, 40 inflorescences were marked in the initial state, while for the variety HAES 344 10 flower buds were taken from one tree. In order to identify the flower buds, daily visits were made, and then two visits were made each week to evaluate the variables: inflorescence length (cm/week) and number of flowers/inflorescence. In fruits the following variables were registered: diameter from day 42 until physiological maturity, and number of fruits / raceme. Observations were made from April 2005 to April 2006. The results were analyzed using descriptive statistics, and mean comparisons with the Duncan test.

Results and discussion

Flowering Phenology

A progressive development in the length of the inflorescences of the varieties was observed until day 48, with fruit formation beginning on day 56 (Box 2). Inflorescence length is presented from higher to lower for the five varieties as: HAES 788, 741, 294, 344 and 800 (Box 3); with the last being statistically different in comparison with the other four varieties. Rincón (2000) confirms that the macadamia inflorescences may present a variable length between 10 and 25 cm, coinciding with the results obtained in this study. Gil (1996) found that the length of the inflorescence determines the number of flowers.

Cuadro 2. Longitud de inflorescencia por variedad de *Macadamia integrifolia* a través del tiempo de observación. Timbio, Cauca, Colombia.

Día	Variedad HAES (no.)	Longitud (cm)	C. V (%)	Día	Variedad HAES (no.)	Longitud (cm)	C.V. (%)
1	788	0.60 a*	42.77	35	788	13.53 a	29.69
	294	0.54ab	54.72		741	12.43 a	25.61
	741	0.50 ab	54.92		294	11.99 ab	26.135
	800	0.44 b	48.04		344	10.03 bc	26.12
	344	0.41b	46.02		800	8.93 c	31.47
7	788	1.86 a	39.62	42	788	14.92 a	20.49
	741	1.66 ab	46.81		741	13.42 a	20.18
	294	1.59 abc	47.49		294	12.5 ab	23.61
	344	1.27 bc	59.91		344	11.4 bc	24.56
	800	1.20 c	41.91		800	10.14 c	23.74
13	788	4.13 a	38.60	48	788	15.52 a	24.73
	741	3.82 a	45.21		741	13.95 ab	18.23
	294	3.61 ab	46.76		294	12.6 bc	23.23
	344	2.76 bc	43.22		344	12.0 bc	11.54
	800	2.55 c	45.73		800	10.72 c	21.95
20	788	7.53 a	31.36	56	788	15.76 a	23.54
	741	7.47 a	39.59		741	14.12 ab	18.45
	294	6.87 ab	39.88		294	12.6 bc	23.23
	344	5.22 bc	30.65		344	12.1 bc	11.54
	800	4.53 c	45.35		800	10.76 c	21.66
28	788	11.05 a	35.53				
	741	10.65 a	33.55				
	294	10.19 ab	31.13				
	344	9.31 bc	20.54				
	800	7.07 c	37.96				

* Valores en una misma variedad seguidos de letra iguales no difieren en forma significativa ($P < 0.05$), según la prueba de Duncan.

Box 2. Inflorescence length for varieties of *Macadamia integrifolia* over observation time. Timbio, Cauca, Colombia.

The high coefficient of variation of the measures was possibly due to the genetic varieties, the attack by cutting insects, pathogens, and brusque changes in climate that could have altered the precision of the results.

Observations. As a result of the field observations on phenology in the macadamia, in Timbío, Cauca, it is possible to make the following observations:

- The floral units of the raceme dispersed forming between four and six rings along the rachis. The total number of flowers was constant, while the space between the rings was variable.
- The variety HAES 788 revealed the greatest raceme length from the initiation of flowering, and the variety HAES 344 the least, with 0.19 cm difference. The varieties HAES 788, 741, 294 and 344 presented raceme lengths between 10 and 11 cm, while HAES 800 showed a shorter length (8.9 cm).
- At the end of inflorescence growth, enlarged flowers were observed, of a pale green color, indicating the closeness to opening. The changes in length were not significant; between days 41 to 43, the variety HAES 788 presented the longest inflorescences (15.5 cm) followed by HAES 741 (13.4 cm), HAES 294 (12.5 cm), HAES 344 (11.4 cm) and HAES 800 with the shortest inflorescences (10.7 cm), this length has a direct incidence in the number of fruits per inflorescence, and so in production (Gil, 1996).
- The variety HAES 294 was the most precocious in achieving the maximum inflorescence length at day 40, while the varieties HAES 741, 344 and 788 reached their maximum size between the days 41 and 43; the variety HAES 800 on day 46, being significantly different to the growth that occurred in the variety HAES 294. (Box 2)
- Flower opening started indistinctly from the base to the apex or from the middle upwards. For Armadams (1998) this process started at the base, which does not coincide with the observations of this study.
- The color of the inflorescence changes to white-cream. It was observed that the caliz has a tubular form. The four stamens are fixed to four sepals with curved apices, the pistil is placed on a disc and ends in a long style (Rincón, 2000). Pollination was seen to be entomophilic, by insects in the orders Hymenoptera, Diptera, Coleoptera and Lepidoptera.
- The inflorescences of the varieties HAES 294, 741 and 344 opened between the days 51 and 55, while those of HAES 788 opened on day 57 and were different to HAES 294 and 800 (day 61). It is necessary to indicate that the most important stage in flowering is the flower opening period, as this determines the pollination and fruit formation. The inflorescences were open for few days, with the variety HAES 294 being the one with the longest

period of open flowers (6 days), followed by HAES 741 and 788 with 5 days, and HAES 800 and 344 with four days.

- The period between the bud and anthesis (open flower) varied between 51 and 61 days depending on the variety.
- During the pollination period, the inflorescence turns a brown color, the petaloid sepals disappear and the stigma becomes visible. Once fertilization has occurred, the stigma begins to widen to form the fruit.
- During the last phase of floral phenology, pollination occurs between the days 57 and 61 for the varieties HAES 294, 741 and 344 ($P < 0.05$), and between 62 and 66 days for the varieties HAES 788 294 and 800 with significant differences ($P < 0.05$).

The inflorescence of *M. integrifolia* from its appearance as a bud maintains a constant number of flowers and only varies in external factors such as climate and incidence of pests and disease, which may cause loss of production. In the box 4 it can be seen that the greatest number of flowers was obtained in the variety HAES 294 possibly due to the reduced space between the floral rings. The opposite was seen in the varieties HAES 788 and 741, although in both cases no significant differences were seen. The second group was formed by the varieties HAES 741, 344 and 800 with the last two being those that presented the shortest inflorescences, and the smallest number of flowers.

Cuadro 4. Numero de flores por inflorescencia en variedades de *Macadamia integrifolia*, Timbio, Cauca, Colombia.

Variedad HAES (no.)	Muestras (no.)	Flores (no.)	C.V.
294	135.17	135.17 a [*]	30.29
788	128.07	128.07 a	28.82
741	116.95	116.95 ab	35.76
344	109.05	109.05 b	16.05
800	89.65	89.65 b	44.75

* Valores en una misma variedad seguidos de letra iguales no difieren en forma significativa ($P < 0.05$), según la prueba de Duncan.

Box 4. Number of flowers per inflorescence in varieties of *M. integrifolia*, Timbio, Cauca, Colombia.

According to Rincón (2000) and Nagao (1992) the racemes of *M. integrifolia* possess between 100 and 300 flower units, a range that contrasts with that presented by the varieties HAES 294, 788, 741 and 344 that varies between 135 and 109, in contrast, the variety HAES 800 presented 89 floral unit, a greatly reduced number.

Fruiting phenology

The final development of the fruit is a function of the number of cells produced during the division period, and the volume reached by the cells during enlargement and maturation of the fruit, a property of each variety (Velarde, 1996). All the varieties showed exponential growth until day 112, the moment at which they showed the start of the process of physiological maturity. The varieties 788, 294 and 800 presented the greatest fruit diameter (3.1 cm) and the varieties HAES 741 and 344 a diameter of 2.8 cm with significant differences ($P < 0.05$) (Box 5.) Rincón (2000) considers that an adequate fruit diameter in the shell is 2.9 cm, coinciding with those observed in this study. On the other hand, Armadams (1998) found that the variety HAES 344 presented the greatest fruit size in the shell, a finding which does not agree with the results of this study.

Cuadro 5. Días a madurez fisiológica y diámetro de fruto en variedades de *Macadamia integrifolia*, Timbio, Cauca, Colombia.

Variedad	Muestras (no.)	Prom. (días)	Diámetro (cm)
294	25	210.56 a*	3.10
741	27	211.56 b	2.81
800	22	212.86 a	3.14
788	24	214.08 a	3.14
344	8	234.50 b	2.80

* Valores en una misma variedad seguidos de letra iguales no difieren en forma significativa ($P < 0.05$), según la prueba de Duncan

Box 5. Days to physiological maturity, and fruit diameter in varieties of *M. integrifolia*.

The coefficient of variation for fruit diameter was low (5.1% a 11%), possibly due to the fact that the size of this depends more on nutritional factors, which, in this case, were adequate for the crop (Box 6), and genetic characteristics, than on the insect and disease attacks.

Fruit phenology can be divided into the stages of fruit set, growth and physiological maturity of the fruit. Taking into account the duration of each of these, the results were analyzed by descriptive statistics, and the Duncan test.

Cuadro 6. Análisis foliar de *Macadamia integrifolia* cultivada en Timbío, Cauca, Colombia.

Procedencia	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	(%)				(ppm)					
Finca Santa Clara ^a	2.44	0.185	0.88	0.4	0.11	141	223.25	20.5	11.25	12.5
Rangos óptimos ^b	1.3	0.08-	0.65-	0.65-	0.09-0.11	20-200	100-1000	15-50	5-10	40-80
	1.5	0.9	0.80	0.75						

* Fuente: Análisis Foliar Macadamia. Timbío, Cauca. Laboratorio Disciplina de Suelos. Cenicafé.

** Fuente: Rangos óptimos de nutrimentos en hojas de macadamia. (Rincón, 2000)

Box 6. Foliar analysis of *M. integrifolia* cultivated in Timbio, Cauca, Colombia.

The fruit set consists of the period between pollination of the inflorescence until the moment when the fruits reach a diameter between 0.7 and 0.9 cm. At the start of this period, fruit set is abundant, but many of the young fruits fall to the ground (Rincón 2000). This stage was registered at 42 days after fertilization, when the fruits presented an adequate size for measurement.

The growth period is that between the moment when the fruit reaches an approximate diameter of 0.9 cm until the start of physiological maturity. Velarde (1996) considers that during this period high cellular division activity occurs, increasing the volume and weight until reaching a normal size, depending on the characteristics of the variety. In this case, the varieties HAES 788, 294 and 800 presented the greatest fruit size with 3.1, 3 and 2.9 cm diameter, respectively, and the varieties HAES 344 and 741 the smallest fruit size, with 2.7 cm. The varieties reached their greatest size between 116 and 120 days.

Physiological maturity starts when fruit growth finishes, and continues until the fruit falls from the tree. In this stage, a series of biochemical changes occur, leading to the accumulation of oil and special tastes in the fruit. Once finished, the cracking of the shell is seen, followed by fruit fall. The variety HAES 294 is the exception, as it presents with the pericarp open, and retains the fruits on the tree. In the present study, physiological maturity varied between 210 and 234 days post flowering. The varieties HAES 294, 741, 800 and 788 reached maturity between 210 and 214 days after the end of flowering, forming a group that present significant differences ($P < 0.05$) to the variety HAES 344 that reached maturity at 234 days, which is in agreement with the results of Rincón (2000) for this variety. The average fruits/raceme (in brackets) was similar in the varieties HAES 344 (3.9), 294 (3.3), 788 (3.2) and 741 (3.1), being greater ($P < 0.05$) than for the variety HAES 800 (1.3).

At the start of fruiting a massive fall of floral residues is seen, affecting between 70% and 95% of the total number of flowers, without affecting the harvest. Although in the *Macadamia* sp. crop racemes with approximately 30 fruits are seen in the fruit set stage, only between 1% and 3% of the flowers per inflorescence

reach maturity, a results which contrasts with that seen by Rincón (2000) and Boyton et al. (2002) who stated that the total proportion of flowers to reach maturity was 5%.

The significant reduction in yield for *M. integrifolia* in Timbío (Cauca), could be due to nutrient deficiencies in the soil, particularly calcium and borate, as shown in the results in Box 5. Other factors, such as insect attacks, and adverse environmental conditions in the zone could also limit fruit set, and reduce the number of fruits per raceme in the plantation. According to Velarde (1996) rain is a factor with a great influence on the pollination and fertilization process, and may limit the activity of pollination insects and sweep the pollen grains to the ground.

The coefficient of variation for the number of fruits / raceme varied between 108% and 165%, considered as high, although no parameters exist for comparison in *Macadamia integrifolia*. This range reflects a high variability, as within the same variety it was possible to find racemes with 15 fruits, while others only had one or no fruits. Determining that this variable is possibly conditioned by factors such as nutrient deficiencies, insect attack, and environmental conditions in the zone where the crop is located, that are impossible to control.

Conclusions

- Five flowering phenology phases were identified: bud, differentiation of flower units, end of bud growth phase, opening of flowers, and pollination. The period between bud and pollination lasted between 57 and 66 days.
- During the fruiting period of 210 to 234 days, the stages of fruit set, growth and physiological maturity of the fruit were identified.
- The length of the inflorescence ranged between 10.76 and 15.76 cm, the number of fruits per inflorescence was between 89 and 135, the diameter of the fruits between 2.8 and 3.14 cm, the number of fruits / raceme between 1.2 and 3.9 with a fruit set of between 1.4% and 3%, with the variety HAES 800 showing the best behavior.
- From the results of this study, se it may be considered that the varieties HAES 788 and 294 are the most promising for commercial crops in the zone of Timbío, Cauca.

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