

Foliar-applied GA₃ Advances Fruit Maturity and Allows Off-season Harvest of ‘Hass’ Avocado

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Abstract. Michoacán and Nayarit are, respectively, the largest and second largest avocado-producing states in Mexico. The main harvest of the ‘Hass’ avocado in both states is concentrated during November to December, which saturates the market and reduces the price of fruit and grower income. The goal of this research was to manipulate vegetative and reproductive growth of the ‘Hass’ avocado with properly timed foliar-applied plant bioregulators (PBRs) to shift the date of flowering and harvest to the period before or after the main harvest. Effects of canopy sprays of gibberellic acid (GA₃) or prohexadione calcium (a gibberellic acid biosynthesis inhibitor) applied at different stages of tree phenology on inflorescence development, time of anthesis, date of legal maturity for harvest of ‘Hass’ avocado fruit, yield, and fruit size were quantified. No PBR treatment influenced the time of anthesis. A single or double foliar application of GA₃ (50 mg·L⁻¹) ≈4 months (July) before the expected date of main harvest (November) resulted in ‘Hass’ avocado fruit reaching legal maturity (mesocarp dry matter 21.5% or greater) 24.8 to 28.2 d earlier than those of untreated control trees with no negative effect on yield or fruit size.

The ‘Hass’ avocado is grown in the state of Michoacán at altitudes from 1200 to 2400 m above sea level (MASL) under various microclimates, resulting in avocados that can be harvested throughout the year (Aguilera-Montañez and Salazar-García, 1991; Salazar-García et al., 2005). Peak harvest occurs in November through February and is accompanied by a decline in fruit price that reduces grower income. In the case of the state of Nayarit, the ‘Hass’ avocado is produced over

a narrower range of altitudes, from 800 to 1400 MASL, and harvest is concentrated during November to December with only a small amount of fruit harvested before or after this period. Management strategies that either alter the time or rate of vegetative and reproductive shoot development to modify the date of flowering and harvest or increase the rate of fruit development to reach legal maturity earlier are needed to broaden the harvest period and prevent the drop in fruit price. Plant bioregulators (PBRs) are known to influence growth and development and might prove useful as tools to achieve these goals.

Gibberellic acid (GA₃) is the PBR that is most frequently reported to successfully alter the date and intensity of flowering in fruit trees. GA₃ application to mango (*Mangifera indica* L.) caused inhibition of flowering and delayed the date of anthesis by more than 4 weeks in some cultivars (Kachru et al., 1972; Nunez-Elisea and Davenport, 1991). In a branch study with ‘Hass’ avocado trees, application of GA₃ at 50, 100, or 1000 mg·L⁻¹ in November, December, or January resulted

in a faster rate of inflorescence development from budbreak through the cauliflower stage of inflorescence development compared with untreated branches (Salazar-García and Lovatt, 1998). Development from the cauliflower stage to anthesis was delayed; thus, the time of anthesis was the same as untreated branches. GA₃ sprays to the canopy of whole trees in November, January, or March (cauliflower stage of inflorescence development) in California caused precocious development of the vegetative bud of indeterminate floral shoots relative to the development of the flowers (Salazar-García and Lovatt, 2000).

The results of this prior research identified treatments that could be used to manipulate floral intensity to break the alternate bearing cycle and provided evidence that foliar-applied GA₃ could be used to extend the harvest season by delaying blackening of mature avocado fruit without affecting its ability to ripen. Injection of a high concentration of GA₃ (2.5 g/tree) into the trunks of mature ‘Hass’ avocado trees in January when apical buds were at stage 5 of inflorescence development (initial development of perianth of terminal flowers; Salazar-García et al., 1998) delayed both inflorescence and flower bud development and the start of anthesis by 23 d (Salazar-García and Lovatt, 1999). The result was a highly desirable, short synchronized period of anthesis that occurred at the same time as maximum anthesis of the untreated control trees. Thus, contrary to reports for other fruit trees, GA₃ application did not delay the time of flowering of the ‘Hass’ avocado.

Another potential effect of GA₃ treatments is on fruit size. An increase on size of ‘Hass’ avocado was obtained in Israel with a canopy spray of 200 mg·L⁻¹ GA₃ at the time of fruit set (May) (Zilkah et al., 1987). In California, a lower dosage of GA₃ (25 mg·L⁻¹) applied when inflorescences of the ‘Hass’ avocado were at the cauliflower stage (March) at the start of an “off” bloom year increased 2-fold the production of commercially valuable large size fruit (213–269 g/fruit) compared with the control (Salazar-García and Lovatt, 2000). A delay in color break and blackening of the avocado fruit was observed for late-harvested fruit of GA₃-treated trees. In another study in California (Lovatt, 2004), GA₃ (25 mg·L⁻¹) applied when ‘Hass’ avocado were at the cauliflower stage had no significant effect on the number of days for fruit to ripen after harvest. The GA₃ significantly increased shoot elongation 30 d after treatment but significantly reduced total yield per tree and the kilograms and number of fruit in all size categories except sizes 40 or greater (270–325 g/fruit) compared with the control.

To achieve effects potentially opposite to those elicited from GA₃, prohexadione calcium (ProCa), an inhibitor of GA biosynthesis (BASF, 1998) was of interest. Foliar application of ProCa (150 mg·L⁻¹) to apple (*Malus pumila* Mill.) caused inhibition of vegetative shoot growth and delayed flower development, resulting in later periods of

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flowering and harvest than those of untreated control trees (BASF, 1997). Three successive applications of 250 mg·L⁻¹ ProCa to 'Hass' avocado trees in California during the cauliflower stage of inflorescence development, anthesis, and early fruit drop resulted in the vegetative shoot of indeterminate floral shoots being significantly shorter when measured 30 d after each ProCa application than those of untreated control trees measured on the same date (Garner and Lovatt, 2002). In contrast, the three ProCa applications had little effect on the growth of vegetative shoots. The treatment significantly reduced leaf maturation resulting in a lower proportion of source leaves during early fruit set during 1 year of the 2-year study. An additional study with the 'Hass' avocado in California showed that ProCa (125 mg·L⁻¹) applied at the cauliflower stage and again at anthesis did not affect the number of days to fruit ripening. ProCa inhibited the growth of the vegetative shoot apex of indeterminate inflorescences but not the growth of vegetative shoots. ProCa had no significant effect on total yield or the packout of fruit of sizes 60 (178–212 g/fruit) + 48 (213–269 g/fruit) + 40 (270–325 g/fruit) but increased the kilograms and number of fruit of sizes greater than 40 (greater than 325 g/fruit) in 'Hass' avocado (Lovatt, 2004).

To ensure that harvested fruit ripen normally and attain a satisfactory taste for the consumer, avocado legal fruit maturity standards have been established. Determination of mesocarp (pulp) dry matter is a technique used in avocado because it is a simple, fast, and accurate way to assess fruit maturity. In California, the standard for the 'Hass' avocado is 21.6% dry matter of fruit mesocarp (Arpaia, 1990). In Mexico, the minimum of 21.5% dry matter was established for the same cultivar (Salazar-García et al., 2005).

For the 'Hass' avocado industry in Nayarit to be sustainable, field management strategies that advance the date of harvest without reducing fruit number or size must be developed. With this objective, research was conducted to evaluate the capacity of foliar GA₃ or ProCa applied at different stages in the phenology of 'Hass' avocado trees to influence inflorescence development, date of anthesis, fruit maturation, and time of harvest. In addition, the effect of each treatment on yield and fruit size was quantified.

Materials and Methods

Plant material. Research was conducted during 2000–2001 (year 1), 2004 (year 2), and 2005 (year 3) and used 16- to 18-year-old 'Hass' avocado trees on a local "criollo" (West Indian) type seedling rootstock in two commercial avocado orchards in Nayarit, Mexico. The 'Alberto' orchard was located in Venustiano Carranza (21°32'N, 104°59'W; 900 MASL; 1300 mm annual rain; 21 °C annual average temperature). The 'Bernabé' orchard was situated in Xalisco (21°26'N, 104°55'W; 1100 MASL; 1185 mm annual rain; 21.7 °C annual average temperature).

Trees were spaced at 8 × 8 m and cultivated under rainfed conditions.

Treatments. In year 1, a total of six treatments were applied once in each orchard to separate sets of five trees each. Time of application was based on tree phenology using the visual scale developed by Salazar-García et al. (1998) to determine the stage of development of the apical inflorescence bud. GA₃ treatments (50 mg·L⁻¹), prepared from Progibb (4% GA₃; Abbott Laboratories, North Chicago, Ill.), were applied when apical buds were at stage S-5 (3 Oct. 2000) and stage S-8 (4 Jan. 2001), respectively. These treatments were tested for their capacity to advance the date of anthesis and harvest. Another GA₃ treatment (50 mg·L⁻¹) was applied ≈4 months before harvest (28 July 2001) to accelerate fruit development and rate of maturation. Foliar ProCa treatments (250 mg·L⁻¹), prepared from Apogee (27.5% prohexadione calcium; BASF Corp., Research Triangle Park, N.C.) were applied once when apical buds were at S-5 (3 Oct. 2000) and S-8 (4 Jan. 2001), respectively. ProCa treatments were evaluated for their capacity to slow inflorescence development and delay the date of anthesis and harvest. An additional treatment consisted of 50 mg·L⁻¹ GA₃ applied on 28 July 2000 followed by 250 mg·L⁻¹ ProCa applied on 7 Sept. 2000. This treatment was designed to obtain early bloom and harvest by stimulating the growth of a summer vegetative flush with the GA₃ application and then applying the ProCa treatment at the time that night temperatures start to decrease to harden the new tender summer shoots and enhance the transition from vegetative to reproductive growth. The control consisted of five trees per orchard that received only the surfactant Silwet L-77 (Loveland Industries, Greeley, Colo.) on 28 July at a rate of 1 mg·L⁻¹.

For year 2 (2004), treatments were modified and applied only in the Alberto orchard to the canopy of separate sets of 10 trees each. Based on year 1 results, only GA₃ was evaluated for its efficacy in accelerating fruit development and rate of maturation. GA₃ at 50 mg·L⁻¹ was applied on 15 July when fruit average length was 7 cm. An additional treatment consisted of two applications of 50 mg·L⁻¹ GA₃ on 15 and 31 July (average fruit length was 7 cm and 7.6 cm, respectively). There were two sets of control trees that were sprayed with 1 mg·L⁻¹ Silwet L-77; one set received one application of surfactant on 15 July and the other one was sprayed two times (15 and 31 July).

Based on year 1 and 2 results, in year 3 (2005), the most promising GA₃ treatment was reevaluated on 10 trees in the Alberto orchard. GA₃ was tested for its efficacy in accelerating fruit development and rate of maturation. A single treatment of two applications of 50 mg·L⁻¹ GA₃ on 15 and 31 July (average fruit length was 7 cm and 7.6 cm, respectively) was evaluated. To elucidate the influence of surfactant on the avocado response to GA₃ treatment, control trees were left untreated.

In the three experiments, PBR treatment solutions, containing 1 mg·L⁻¹ Silwet L-77 surfactant in water (pH 5.5 to 6), were applied at the rate of 10 ± 1 L of solution per tree to provide full canopy coverage. Treatments were applied between 0800 and 1000 HR with a backpack motorized sprayer (Model Efcó IS-2026; Reggio Emilia, Italy).

Date of flowering. Inflorescence development was evaluated only in year 1 for all trees at biweekly intervals from November 2000 to March 2001 (full bloom). Date of flowering was recorded as the elapsed time from 28 July 2000 to the presence of anthesis (S-11; Salazar-García et al., 1998) in 100 inflorescences per tree.

Type of growth produced by apical buds. Before the application of treatments in year 1, four branches 1 m in length of similar diameter and with at least 15 shoots each were selected evenly around each of five trees per treatment. At the end of the winter flowering period (March 2001), the number of floral shoots, vegetative shoots, and inactive buds (those that did not show any type of growth) on each branch were recorded.

Fruit mesocarp dry matter. In the 3 years of the study, the elapsed time from July until the fruit reached legal maturity, mesocarp dry matter 21.5% or greater, was measured at biweekly or monthly intervals. For each treatment, two fruit per tree were picked from the southwest side of tree's canopy, the most exposed to the sun at this latitude. Mesocarp dry matter was determined for 10-g fresh weight mesocarp obtained from the middle part of the fruit by drying the sample to a constant weight in a forced air oven at 70 °C. When, for a sampling date, the mesocarp dry matter had passed 21.5%, stepwise regression analysis was used to determine the exact date on which legal maturity was reached.

Rate of fruit growth. In year 3, the length of five tagged fruit per each of 10 trees was measured at monthly intervals after first GA₃ application (15 July) until fruit were harvested.

Yield and fruit size. Total yield per tree and the proportion of fruit of various sizes were determined at harvest on November for years 1 and 2 of the study and all tree replications. The weight of 100 randomly selected individual fruit per tree was used to calculate packout per tree. The following fruit grades (g/fruit) were used: marble (less than 135 g), second (135–169 g), first (170–210 g), extra (211–265 g), and super extra (greater than 266 g).

Statistical analysis. In year 1, a completely randomized design with five single-tree replications per orchard was used. For years 2 and 3, the same experimental design was used but with 10 single-tree replications. Means comparison were performed using the least significant difference test at $P = 0.05$.

Results

Date of anthesis. None of the PBRs evaluated in year 1 significantly changed the date of anthesis (S-11) in the experimental

orchards. The elapsed time from 28 July 2000 to the presence of 100 inflorescences at anthesis per tree ranged from 185 to 215 d in the Alberto orchard and from 208 to 232 d in the Bernabé orchard (data not shown). No significant effect of orchard location was detected.

Type of growth produced by apical buds. Application of either GA₃ or ProCa in year 1 did not affect the type of growth produced by apical buds of shoots from the spring and summer flushes during the 2000–2001 winter flowering period. Most tagged shoots in both orchards produced a greater proportion of inflorescences (62% to 84% at Alberto and 44% to 68% at Bernabé) than vegetative shoots. For both untreated and treated trees, all inflorescences produced were indeterminate (i.e., the apical bud of the primary axis continued the vegetative growth of the floral shoot). Irrespective of PBR treatment, all indeterminate floral shoots showed precocious development of the vegetative shoot at the apex of the inflorescence compared with the development of the flowers on the same floral shoot. The proportion of shoots with apical buds that remained inactive varied from 0% to 1.45%.

Date of legal fruit maturity. Variation in the response to treatments in the two orchards was not different; thus, a two-orchard average was used. In year 1, application of PBRs significantly shortened the time it took for avocado fruit to reach legal maturity. Fruit from untreated control trees took 103.8 d (from 28 July) to reach legal maturity (mesocarp dry matter 21.5% or greater) (Table 1). The greatest shortening in the time to legal maturity was obtained with a single foliar spray of 50 mg·L⁻¹ GA₃ in July (≈4 months before normal harvest); this treatment advanced the date on which fruit were legally mature by 28.2 d. Other treatments with ProCa or GA₃ advanced fruit maturity by 9 to 15 d (Table 1).

Based on year 1 results, the number of tree replications was increased by twofold in year 2 and only the Alberto orchard was used. For year 2, the effect of GA₃ treatments was consistent with year 1 results in advancing fruit mesocarp maturity. Two applications of 50 mg·L⁻¹ GA₃ when fruit were 7 and 7.6 cm long (15 and 31 July 2004, respectively) shortened the time to fruit legal maturity by 25.5 d compared with its respective control (two surfactant applications). A single application of 50 mg·L⁻¹ GA₃ on 15 July, when fruit was 7 cm, long advanced fruit mesocarp maturity by 14.4 d (Table 2). No effect resulting from the number of surfactant applications was detected.

For year 3, the effect of GA₃ treatment in advancing fruit mesocarp maturity was reconfirmed. Similar to years 1 and 2, two applications of 50 mg·L⁻¹ GA₃ when fruit were almost 7 and 7.6 cm long (15 and 31 July 2005, respectively) advanced legal fruit mesocarp maturity by 24.8 d compared with control (no surfactant applications) (Table 3).

Rate of fruit growth and dry matter accumulation. At the time of the first GA₃

Table 1. Effect of canopy sprays of gibberellic acid (GA₃) or prohexadione calcium (ProCa) on the date 'Hass' avocado fruit reached legal maturity (mesocarp dry matter 21.5% or greater).^z

Treatments	Days to 21.5% mesocarp dry matter ^y	Date of legal fruit maturity (2001)
50 mg·L ⁻¹ GA ₃ at S-5 (3 Oct. 2000)	94.5 bc ^x	17 Oct.
50 mg·L ⁻¹ GA ₃ at S-8 (4 Jan. 2001)	90.4 bc	13 Oct.
250 mg·L ⁻¹ ProCa at S-5 (7 Sept. 2000)	91.3 bc	14 Oct.
250 mg·L ⁻¹ ProCa at S-8 (4 Jan. 2001)	88.8 bc	12 Oct.
50 mg·L ⁻¹ GA ₃ on 15 July 2000 + 250 mg·L ⁻¹ ProCa on 7 Sept. 2000	94.8 b	18 Oct.
50 mg·L ⁻¹ GA ₃ , ≈4 months before harvest (15 July 2001)	75.6 c	29 Sept.
Control (1 mg·L ⁻¹ Silwet L-77)	103.8 a	27 Oct.
Least significant difference	6.1125	

^zAverage of the Alberto and Bernabé orchards in year 1 experiment (2000–2001).

^yCounting started on 28 July 2000.

^xMeans separation in columns by least significant difference test, *P* = 0.05.

Table 2. Effect of foliar-applied gibberellic acid (GA₃) on the date 'Hass' avocado fruit reached legal maturity (mesocarp dry matter 21.5% or greater).^z

Treatments	Days to 21.5% mesocarp dry matter ^y	Date of legal fruit maturity (2004)
One application of 50 mg·L ⁻¹ GA ₃ when fruit averaged 7 cm in length (15 July 2004)	83.5 b ^x	6 Oct.
Two applications of 50 mg·L ⁻¹ GA ₃ when fruit averaged 7 and 7.6 cm long (15 and 31 July 2004)	74.9 b	28 Sept.
Control, one application of 1 mg·L ⁻¹ Silwet L-77 when fruit averaged 7 cm in length (15 July 2004)	97.9 a	21 Oct.
Control, two applications of 1 mg·L ⁻¹ Silwet L-77 when fruit averaged 7 and 7.6 cm in length (15 and 31 July 2004)	100.4 a	23 Oct.
Least significant difference	9.5245	

^zData from the Alberto orchard in year 2 experiment (2004).

^yCounting started on 15 July 2004.

^xMeans separation in columns by least significant difference test, *P* = 0.05.

Table 3. Effect of foliar-applied gibberellic acid (GA₃) on the date 'Hass' avocado fruit reached legal maturity (mesocarp dry matter 21.5% or greater).^z

Treatments	Days to 21.5% mesocarp dry matter ^y	Date of legal fruit maturity (2005)
Two applications of 50 mg·L ⁻¹ GA ₃ when fruit averaged 7 and 7.6 cm in length (15 and 31 July 2005)	80.2 b ^x	3 Oct.
Control, no application of surfactant	105.0 a	28 Oct.
Least significant difference	9.4497	

^zData from the Alberto orchard in year 3 experiment (2005).

^yCounting started on 15 July 2005.

^xMeans separation in columns by least significant difference test, *P* = 0.05.

application of year 3 (15 July 2005), fruit length was similar and ranged from 7 to 7.1 cm. Measurements performed on August, September, and October showed incremental increases in fruit length. However, no effect of GA₃ applications was detected. GA₃ applications had a significant effect on fruit length from 30 Oct. through normal harvest (30 Nov.), at which time the length of GA₃-treated fruit was 0.4 cm greater than untreated control fruit (Fig. 1).

The effect of GA₃ treatment on mesocarp dry matter accumulation was noticeable. At the time of first GA₃ application, mesocarp dry matter was 16%. GA₃-treated fruit showed a greater rate of mesocarp dry matter accumulation, so that by 30 Sept., GA₃-treated fruit had attained legal fruit maturity (21.5% or greater mesocarp dry matter) (Fig. 1). Control fruit reached similar dry matter content a month later (30 Oct.).

Yield and fruit size. PBR treatments had no effect on total yield per tree in each year this parameter was evaluated (Tables 4 and 5). However, a dramatic increase in fruit size in response to PBRs was observed for year 1. For this year, average total yield from the two experimental orchards ranged from 105 to 119 kg per tree. Production of small size fruit of packing carton sizes marble plus second (less than 135 to 169 g/fruit) was reduced by application of 68.75 mg·L⁻¹ ProCa at S-5 (7 Sept. 2000) compared with the control (surfactant only [Table 4]). In addition, a substantial increase in the yield of commercially valuable large size fruit (first + extra + super extra; 170 to greater than 266 g/fruit) over that of the control was obtained with foliar sprays of 68.75 mg·L⁻¹ ProCa at S-5 (7 Sept. 2000), 50 mg·L⁻¹ GA₃ on 28 July 2000 + 68.75 mg·L⁻¹ ProCa on 7 Sept. 2000, or 50 mg·L⁻¹ GA₃, ≈4 months before harvest

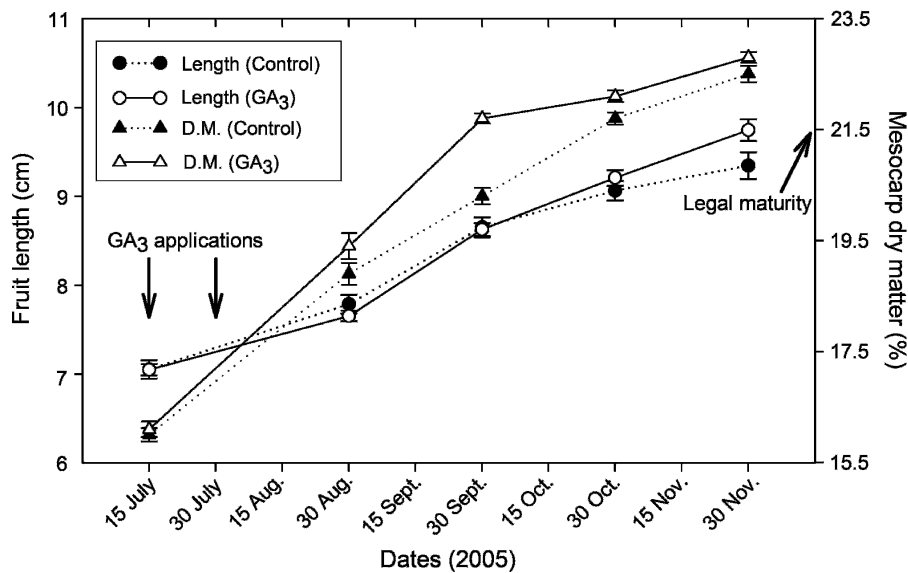


Fig. 1. Fruit growth (length) and mesocarp dry matter (DM) measured after applications of 50 mg·L⁻¹ gibberellic acid on 15 and 31 July 2005. Control was left untreated. Bars are standard errors.

Table 4. Effect of canopy sprays of gibberellic acid (GA₃) or prohexadione calcium (ProCa) on yield and fruit size of ‘Hass’ avocado trees.^z

Treatments	Total yield	Distribution of yield by size (g/fruit) ^y	
		M + S (<135–169 g)	F + E + SE (170– >266 g)
	<i>kg/tree</i>		
50 mg·L ⁻¹ GA ₃ at S-5 (3 Oct. 2000)	105 a ^x	65.5 ab	39.5 ab
50 mg·L ⁻¹ GA ₃ at S-8 (4 Jan. 2001)	107 a	64.9 ab	42.1 ab
68.75 mg·L ⁻¹ ProCa at S-5 (7 Sept. 2000)	110 a	57.5 b	52.5 a
68.75 mg·L ⁻¹ ProCa at S-8 (4 Jan. 2001)	111 a	65.9 ab	45.1 ab
50 mg·L ⁻¹ GA ₃ on 28 July 2000 + 68.75 mg·L ⁻¹ ProCa on 7 Sept. 2000	119 a	61.7 ab	57.3 a
50 mg·L ⁻¹ GA ₃ , ≈4 months before harvest, 7 cm long fruit (28 July 2001)	115 a	59.4 ab	55.6 a
Control (only surfactant)	105 a	81.9 a	23.1 b
Least significant difference	20.402	23.783	25.980

^zAverage of the Alberto and Bernabé orchards in year 1 experiment harvested on 13 Nov. 2001.

^yFruit size: M = marble; S = second; F = first; E = extra; SE = super extra.

^xMeans separation in columns by least significant difference test, *P* = 0.05.

Table 5. Effect of foliar-applied gibberellic acid (GA₃) on yield and fruit size of ‘Hass’ avocado trees.^z

Treatments	Total yield	Distribution of yield by size (g/fruit) ^y	
		M + S (<135–169 g)	F + E + SE (170– >266 g)
	<i>kg/tree</i>		
One application of 50 mg·L ⁻¹ GA ₃ when fruit averaged 7 cm in length (15 July 2004)	188 a ^x	85.7 a	102.3 a
Two applications of 50 mg·L ⁻¹ GA ₃ when fruit averaged 7 and 7.6 cm in length (15 and 31 July 2004)	178 a	87.2 a	90.8 a
Control, one surfactant application (15 July 2004)	172 a	81.5 a	90.5 a
Control, two surfactant applications (15 and 31 July 2004)	165 a	82.5 a	82.5 a
Least significant difference	34.285	24.004	26.509

^zData from the Alberto orchard in year 2 experiment harvested on 12 Nov. 2004.

^yFruit size: M = marble; S = second; F = first; E = extra; SE = super extra.

^xMeans separation in columns by least significant difference test, *P* = 0.05.

(28 July 2001) (Table 4). For year 2, there were no negative (or positive) effects of PBR treatments on yield. Total yield per tree in the Alberto orchard was greater than in year 1 and varied from 165 to 188 kg. Pro-

duction of small fruit sizes (marble plus second) ranged from 81 to 87 kg per tree and for larger fruit sizes (first + extra + super extra), it fluctuated from 82 to 102 kg per tree (Table 5).

A single or double foliar application of GA₃ (50 mg·L⁻¹) ≈4 months (July) before the expected date of the main harvest (November) shortened the time it took for ‘Hass’ avocado fruit to reach legal maturity (mesocarp dry matter 21.5% or greater) by 24.8 to 28.2 d. The fact that growers will be able to harvest their crop almost 4 weeks earlier will increase grower income by at least 50% as a result of the higher selling price of early-marketed fruit. This is the first time that a plant bioregulator has been used to successfully shorten the maturation time of ‘Hass’ avocado fruit. Furthermore, the research established that the application of GA₃ in July had no negative effects on yield or fruit size. These findings make important contributions to knowledge regarding both the horticulture and reproductive physiology of the avocado. The results demonstrate that stimulation of fruit development is a practical, alternate strategy to the widespread approach of advancing the time of flowering to achieve early fruit maturity and early harvest. No PBR effects were observed on the rate of inflorescence development or floral intensity in either orchard or year studied. A significant effect of July double GA₃ sprays on the rate of fruit growth was observed only after October.

Avocado fruit, although climacteric, are unique in that they do not undergo ripening while still attached to the tree. Thus, dry matter accumulation in avocado fruit occurs before and independently of the ripening process. Hence, legal maturity of avocado fruit is based on mesocarp dry matter content. GA₃ is well known for its ability to delay maturation, ripening, and senescence processes in many fruits. For example, GA₃ application delayed color break and blackening of the peel of late harvested avocado fruit (Salazar-García and Lovatt, 2000). The effect of GA₃ on developing avocado fruit appears to be like its effect on other developing tissues—stimulation of growth and addition of biomass. In avocado fruit, GA₃ apparently increased sink strength resulting in biomass accumulation and the observed increase in fruit growth rates of GA₃-treated fruit, particularly from 30 Oct. to harvest on 30 Nov. (Fig. 1).

Application rates of GA₃ and ProCa evaluated in the present study were based on rates previously tested in California (Garner and Lovatt, 2002; Salazar-García and Lovatt, 1999, 2000). In California, foliar applications of GA₃ at the same phenologic stages tested in the current research and at concentrations higher and lower than those used here significantly increased the rate of early inflorescence development, synchronized anthesis, altered floral intensity, and affected yield and fruit size (Lovatt, 2004; Salazar-García and Lovatt, 1999, 2000). Whereas an enhanced rate of inflorescence development was not observed in the current study, the greater synchrony in the date inflorescences reached anthesis was noted. It was important to demonstrate that the

applications of 50 mg·L⁻¹ GA₃ in July, that successfully shortens the avocado maturation period, does not cause the secondary effects of changing the date of anthesis or negatively affecting yield or fruit size. Further work needs to be conducted to determine whether the high concentrations or trunk injection of GA₃ tested in California (Salazar-García and Lovatt, 1999, 2000) will produce the same or different responses in the 'Hass' avocado under the growing conditions of Nayarit with regard to rate of inflorescence development, floral intensity, yield, and fruit size and provide a means for shifting anthesis, fruit maturity, and harvest date.

Under the climatic conditions of California, Salazar-García and Lovatt (1998) documented that 90% of the inflorescences produced by 'Hass' avocados were borne on indeterminate floral shoots. Similar results were found in the present investigation with the slight difference that no determinate inflorescences were observed in the orchards in the present study. In contrast to the results reported by Salazar-García and Lovatt (1998) for California, in Nayarit, it is typical for the vegetative shoot apex of indeterminate floral shoots to be more advanced developmentally than flowers borne on the same floral shoot. This condition is considered ideal. It favors high fruit set and yield by minimizing the competition between the setting fruit and growth of the vegetative shoot apex of the indeterminate floral shoot (Bower and Cutting, 1992; Cutting and Bower, 1990; Lovatt, 1990; Salazar-García and Lovatt, 1998; Whiley, 1990; Zilkah et al., 1987) and protects the young developing fruit from sunburn (Salazar-García and Lovatt, 2000).

In California, this ideal condition can be achieved with a single foliar application of GA₃ between November and March to stimulate the precocious development of the vegetative shoot apex of indeterminate floral shoots (Salazar-García and Lovatt, 2000).

Literature Cited

- Aguilera-Montañez, J.L. and S. Salazar-García. 1991. The avocado industry in Michoacán México. South African Avocado Growers' Assoc. 14:94-97.
- Arpaia, M.L. 1990. Estándares para paltas en California. 20 Oct. 2006. <http://avocadosource.com/journals/civdmchile_1990/civdmchile_1990_pg_15.pdf>.
- BASF. 1997. Technical data for BAS 125 W in apple trees. BASF Technical Information. Bull. 9618.
- BASF. 1998. Apogee™ plant growth regulator. Facts and research. BASF Corp., Research Triangle Park, N.C.
- Bower, J.P. and J.G.M. Cutting. 1992. The effect of selective pruning on yield and fruit quality in 'Hass' avocado. Acta Hort. 296:55-58.
- Cutting, J.G.M. and J.P. Bower. 1990. Relationship between auxin transport and calcium allocation in vegetative and reproductive flushes in avocado. Acta Hort. 275:469-475.
- Garner, L.C. and C.J. Lovatt. 2002. Prohexadione calcium and gibberellin₃ affect vegetative growth and development of the 'Hass' avocado. Proc. 29th Ann. Mtg. of the Plant Growth Reg. Soc. Amer. 1:99(abstr).
- Kachru, R.B., R.N. Singh, and E.K. Chacko. 1972. Inhibition of flowering in *Mangifera indica* L. by gibberellic acid. Acta Hort. 24:206-209.
- Lovatt, C.J. 1990. Factors affecting fruit set/early fruit drop in avocado. Calif. Avo. Soc. Yrbk. 74:193-199.
- Lovatt, C.J. 2004. Use of plant growth regulators to increase fruit set, fruit size and yield and to manipulate vegetative and floral shoot growth, p. 96-107. California Avocado Research Symposium, Riverside, Calif., 30 Oct. University of California, Riverside and California Avocado Commission.
- Nunez-Elisea, R. and T.L. Davenport. 1991. Flowering of 'Keitt' mango in response to deblossoming and gibberellic acid. Proc. Fla. State Hort. Soc. 104:41-43.
- Salazar-García, S., E.M. Lord, and C.J. Lovatt. 1998. Inflorescence and flower development of the 'Hass' avocado (*Persea americana* Mill.) during 'on' and 'off' crop years. J. Amer. Soc. Hort. Sci. 123:537-544.
- Salazar-García, S. and C.J. Lovatt. 1998. GA₃ application alters flowering phenology of the 'Hass' avocado. J. Amer. Soc. Hort. Sci. 123:791-797.
- Salazar-García, S. and C.J. Lovatt. 1999. Winter trunk injections of gibberellic acid altered the fate of 'Hass' avocado buds: Effects on inflorescence type, number and rate of development. J. Hort. Sci. Biotechnol. 74:69-73.
- Salazar-García, S. and C.J. Lovatt. 2000. Use of GA₃ to manipulate flowering and yield of 'Hass' avocado. J. Amer. Soc. Hort. Sci. 125:25-30.
- Salazar-García, S., L. Zamora-Cuevas, and R.J. Vega-López. 2005. Update on the avocado industry in Michoacán, México. Calif. Avocado Soc. Yrbk. 87:31-44.
- Whiley, A.W. 1990. CO₂ assimilation of developing fruiting shoots of cv. Hass avocado (*Persea americana* Mill.)—A preliminary report. S. Afr. Avo. Grow. Assoc. Yrbk. 13:28-30.
- Zilkah, S., I. Klein, S. Feigenbaum, and S.A. Weinbaum. 1987. Translocation of foliar-applied urea 15N to reproductive and vegetative sinks of avocado and its effects on initial fruit set. J. Amer. Soc. Hort. Sci. 112:1061-1065.