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USE OF GIBBERELLIC ACID TO MANIPULATE FLOWERING IN THE 'HASS' AVOCADO: A PRELIMINARY REPORT

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Abstract

Inflorescence development of the 'Hass' avocado *(Persea americana* Mill.) was investigated at the macro and microscopic level. Near the end of shoot extension, two secondary axis meristems were present in the axils of inflorescence bracts. The primary axis meristem changed shape from conical to flattened to conical followed by the initiation of additional bracts and associated secondary axis inflorescence meristems rather than additional leaf primordia. No anatomical changes were associated with commitment to flowering. The transition phase from the vegetative to reproductive condition occurred in less than one month from the end of July through August for summer flush shoots. A period of dormancy was not prerequisite for the shift to inflorescence development. Commitment to flowering resulted in formation of additional bracts with secondary axis inflorescence meristems from August to October, anthesis was seven months later. Eleven stages of external bud and subsequent inflorescence development were correlated with organogenesis for use in predicting specific stages of inflorescence development in the field. Yield had little effect on the rate of inflorescence development, which correlated with the cumulative number of nights with temperatures < 15 °C, but the "on" crop reduced inflorescence number with a concomitant increase in the number of vegetative shoots. Gibberellic acid (GA_3) sprays at 25 mg-liter^{-1} in September reduced flowering intensity in "on" and "off" crop years. November sprays reduced inflorescence number in the "off" year with a concomitant increase in vegetative shoots; whereas the 2-fold increase in inflorescences in the "on" year was not significant. GA_3 caused precocious development of the vegetative shoot apex of indeterminate inflorescences. Control trees yielded 18 kg-tree^{-1} (an "off" crop year) whereas GA_3 applied in November, January, or March increased yield to 34.8, 27.3, and 33.9 kg-tree^{-1}, with more green late-harvested fruit (May). Kg-tree^{-1} of individual fruit weighing 135-177 g and 213-269 g increased 3-fold or 2-fold with GA_3 applied in November or March, respectively. GA_3 should prove useful in evening out alternate bearing in avocado.

Introduction

Exogenous gibberellins have been shown to alter floral development in temperate fruit trees, such as peach, apricot, almond, cherry, plum and apple (Bradley and Crane, 1960; Griggs and Iwakiri 1961; Guttridge, 1962; Hull and Lewis, 1959), as well as in tropical fruit trees, like mango (Kachru *et al,* 1972; Nunez-Elisea and Davenport, 1991) and citrus (Guardiola *et al,* 1977; Iwahori and Oohata, 1981; Nir *et al,* 1972). The results of these studies and others have created a consensus in the literature that the effect of exogenous gibberellins on flowering is highly influenced by concentration and time of application in relation to the stage of floral bud development. Guardiola *et al.* (1982) found that the application of GA_3 any time from early November until bud break resulted in a significant inhibition of flowering in several *Citrus* species. They concluded that flower meristems could be reverted to vegetative apices even after petal formation. In contrast, Lord and Eckard (1987) found that irreversible commitment to flowering of the 'Washington' navel orange probably occurred once sepals were initiated. GA_3 application (100 mg-liter^{-1}) prevented flowering in 90% of potentially flowering shoots only when applied to resting buds well in advance of sepal formation.

Application of GA_3, in lanolin paste, to apical buds of mango cv. Dashedari before floral initiation stimulated vegetative growth in 75% of shoots. However, once flower meristems were present, GA_3 did not inhibit flowering (Kachru *et al.,* 1972). In another study, Nunez-Elisea and Davenport (1991) sprayed GA_3 to deblossomed branches of 'Keitt' mango. A single application of either 10 or 50 mg GA_3·liter^{-1} delayed further flowering by more than four weeks. The greatest effect was observed with 250 mg-liter^{-1}. These authors proposed that the delay in flowering was due to repression in floral bud initiation. A promotive and/or inhibitory response to GA_3 application has also been reported for treatments made after floral initiation. Porlingis and Boynton (1961) found a dual effect of GA_3 on strawberry flowering. GA_3 accelerated the appearance of flowers that had differentiated at the time of application but inhibited the initiation of new flowers under inductive conditions. With coffee *(Coffea arabica* L.), application of GA_3 (100 mg-liter^{-1}) stimulated early anthesis of floral buds that were 4 mm long at the time of treatment (Schuch *et al,* 1990). No differences were apparent in the time of flowering for buds that were treated either earlier (< 4 mm long) or later at the candle stage (> 10 mm), which is just prior to anthesis. Thus, the effect of GA_3 was dependent on the stage of inflorescence bud development.

In the case of avocado, there is no published information on the effect of exogenous GA_3 on flowering. Considering the several physiological similarities reported for avocado, mango, and citrus (Bower *et al,* 1990; Nevin and Lovatt, 1989; Scholefield *et al,* 1985), it would be beneficial to conduct research to determine the role of GA_3 in avocado flowering. The results may provide information useful to commercial production of the avocado. Lord and Eckard (1985) proposed that careful documentation of the time and pattern of floral organogenesis is a necessary prerequisite to any attempts to manipulate flowering in woody perennials. Given that the response of various plant species to GA_3 was dependent on the stage of inflorescence and flower organogenesis a series of studies under controlled environment conditions and in commercial orchards was undertaken to determine when vegetative buds of the 'Hass' avocado change to inflorescence buds and to determine the time and pattern of subsequent organogenesis. This research was in

order to develop strategies using foliar applied GA_3 to regulate inflorescence phenology and intensity of flowering in order to increase yield and even out alternate bearing of the 'Hass' avocado.

Materials and methods

Inflorescence development

In a commercial 'Hass' avocado orchard, two apical buds (or expanding inflorescences) from 20 tree-replicates borne on summer shoots were collected weekly from July to August during an "on" and "off" crop year. Buds from each sample collected were sorted by shape and degree of expansion, fixed, sectioned and analyzed microscopically to determine anatomical development. Another study was undertaken to determine the stage of development during which commitment of the shoot primary axis meristem to flowering occurs in avocado. Three-year-old 'Hass' avocado trees on Duke 7 rootstock were induced to flower with low temperature treatments of 10-h days at 10 °C and 14-h nights at 7 °C for one, two, three, or four weeks in a growth chamber. At the end of the induction treatment, the temperature was increased to 25/20 °C (day/night) through the end of the study. To further test commitment to flowering, GA_3 (100 mg-liter^{-1}) was applied to apical and axillary buds at the end of 2, 4, and 6 weeks after exposure to low-temperature floral-induction treatments.

Effect of GA_3 on espression of flowering and yield

To quantify the effects of GA_3 on the 'Hass' avocado under field conditions, branches of 10-year-old 'Hass' avocado trees were sprayed with 0, 50, 100 or 1000 mg GA_3-liter^{-1} in November, December or January. All treatments were made after commitment to flowering and inflorescence initiation but prior to bud break. Another study was conducted to quantify the effect on yield of GA_3 canopy sprays during "on' and "off crop years of the 'Hass' avocado. GA_3 (25 or 100 mg-liter^{-1} plus Triton X-100 at 1 ml-liter^{-1}) was applied to separate sets of trees in September (during inflorescence initiation), November (end of inflorescence initiation), January (initial development of the perianth of terminal flowers), March (cauliflower stage), or monthly sprays from September through January. Control trees did not receive any treatment.

Results and discussion

A conical-shaped primary axis meristem was related to formation of leaf primordia or inflorescence bracts. Near the end of summer shoot extension, two secondary axis meristems were formed in the axils of inflorescence bracts. The primary axis meristem changed shape from conical to flattened to conical followed by the initiation of additional bracts and associated secondary axis inflorescence meristems rather than additional leaf primordia. The transition phase from the vegetative to reproductive condition occurred in less than one month from the end of July through August for summer flush shoots. A period of dormancy was not prerequisite for the shift to inflorescence development. Formation of microspores and ovule integuments occurred at the cauliflower stage

(elongation of secondary axes of the inflorescence); a stage that has been found to be responsive to treatments designed to improve pollen vigor, ovule viability, and yield. This shows how knowledge of developmental events related to flowering can be used to guide production strategies.

Commitment to flowering was determined by using temperature and GA_3. Anatomical sections of apical buds at the beginning of the low-temperature floral-induction treatments and after one, two, three, or four weeks of low temperature (83% of the buds were committed to flower by the end of week 4) were indistinguishable, having a conical primary axis meristem with two inflorescence bracts bearing secondary axis meristems without apical bracts. Commitment to flowering resulted in formation of additional bracts with secondary axis inflorescence meristems. In the field, secondary axis inflorescence meristems were produced from August to October, anthesis was seven months later. GA_3 application to apical and axillary buds when at least one pair of secondary axis meristems were present and thereafter had no effect on flowering. While there was no anatomical feature to mark commitment to flowering, the results defined a system in which regulation of flowering can be critically studied in the future.

Macroscopic grading was very reliable for predicting the microscopic stage of inflorescence development. Eleven stages of external bud and subsequent inflorescence development were correlated with organogenesis for use in predicting specific stages of inflorescence development in the field. Yield had little effect on the rate of inflorescence development, which was correlated with the cumulative number of nights with temperatures < 15 °C. The high yield during the "on" crop year (average of 66.1 kg-tree^{-1}) reduced inflorescence number with a concomitant increase in the number of vegetative shoots.

Application of GA_3 on branches stimulated apical growth of all shoots. Thus, if a inflorescence bud was already differentiated, the inflorescence developed in advance of inflorescences on branches not treated with GA_3. Early GA_3 treatment (Nov.) reduced flowering intensity by stimulating the expansion of inflorescences that were only partially formed, i.e. having fewer secondary axes. In addition, GA_3 caused precocious development of the vegetative shoot of indeterminate inflorescences relative to the flowers in the same inflorescence and relative to the vegetative shoot of indeterminate inflorescences from untreated branches. GA_3 treated branches reached the cauliflower stage of inflorescence development earlier than untreated controls, but the time of anthesis was not significantly affected by GA_3. Growth of axillary buds was inhibited with increased GA_3 concentrations.

GA_3 sprays to whole 'Hass' avocado trees in September reduced flowering intensity the two years of the study. November sprays reduced the number of inflorescences produced in the spring when the tree was bearing an "off' crop year with a concomitant increase in production of vegetative shoots; there was no effect in the "on" crop year. January and March applications had no effect on flowering or shoot production either year. GA_3 treatment did not affect flower parts. GA_3 had no. effect on time of flowering (days to presence of 50 inflorescences at anthesis per tree). Application of GA_3 (25 mg-liter^{-1}) in November or January stimulated the precocious development of the vegetative shoot of indeterminate inflorescences. The only effect on fruit set was that the November application of GA_3 (25 mg-liter^{-1}) increased fruit set in the "on" year and decreased it in the

"off' year. GA_3 was applied during the "on" crop year; thus, the yield data for the first year are for an "off crop: 18 kg-control tree^{-1}. GA_3 (25 mg-liter^{-1}) applied in November, January, or March increased yield to 35, 27, and 34 kg-tree^{-1}, respectively, but no treatment was significantly better than the control. The November GA_3 application resulted in approximately a 3-fold increase in fruit weighing 135-177 g compared to the control. The March application resulted in a 2-fold increase in fruit weighing 213-269 g. GA_3 (25 mg-liter^{-1}) applications in November, January and March increased the number of late-harvested fruit (May) with green skin, i.e. reduced the number with black skin, with no negative effects on internal fruit quality or maturity.

This study provides a visual index of the external characters of the inflorescence bud and subsequent inflorescence that researchers and growers can use in the field to predict specific stages of inflorescence development at the microscopic level within the bud or after bud break. Results of foliar GA_3 applications to avocado have not been previously reported. This study defined the effect of GA_3 dose and timing on vegetative shoot and inflorescence development, fruit set and fruit maturation. Our results establish that GA_3 causes precocious development of both the vegetative shoot apex of indeterminate inflorescences and the secondary axes of indeterminate inflorescences, but not of flowers. Depending on the time of application, GA_3 showed the potential to reduce flowering intensity, make leaves in indeterminate inflorescences sources rather than sinks during fruit set, and increased yield and fruit size. The larger leaves of G AS-treated trees protected fruit from sunburn earlier in their development and GA_3 kept the peel of late-harvested fruit green. The results of this research provide evidence that strategies using foliar-applied GA_3 to manipulate flowering can be developed at the commercial level to increase yield and fruit size and/or even out alternate bearing for the benefit of the avocado industry.

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