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Original article

Influences of the meteorological variations on the avocado cultivars flowering of the Antillean group

Influencia de las variaciones meteorológicas sobre la floración de cultivares de aguacatero del grupo antillano

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ABSTRACT: The flowering-inducing stimulus of avocado trees grown under a tropical climate is a short-term water deficit, capable of stopping vegetative growth. The objective of this work was to analyze the influence of meteorological conditions on the expression of flowering in three avocado cultivars of the Antillean group. During 2019-2023 in cv. ‘Julio’ (early), ‘Govín’ (middle) and ‘Catalina’ (late) grafted onto the cv. ‘Perrero’, 10 years old, planted at 6 m x 10 m on a Red Ferralitic soil, phenological observations were made using the BBCH scale on 10 randomly selected trees with a fortnightly periodicity. The percentage of the flowered tree was determined and climatic variations were evaluated through meteorological variables: maximum and minimum temperatures, temperature amplitude, precipitation and number of days with rain. The relationships between flowering intensity and meteorological variables were established for two months before the sampling date through Principal Component Analysis. The highest percentage of flowering occurred for ‘Julio’ in January, 76 %; ‘Govín’ and ‘Catalina’ in March, 72 and 80 %, respectively. Meteorological variations influenced from two months before flowering, explaining around the 70 % of the accumulated variance by first two components. The association between slightly cold temperatures and a water deficit during the dry period favored the induction of the avocado flowering.

Key Words: change climatic, *Persea americana* Mill., phenology.

RESUMEN: El estímulo inductor de la floración del aguacatero cultivado bajo clima tropical es un déficit hídrico de corta duración, capaz de detener el crecimiento vegetativo. El objetivo de este trabajo fue analizar la influencia de las condiciones meteorológicas sobre la expresión de la floración en tres cultivares de aguacatero del grupo antillano. Durante 2019 - 2023 en cultivares de estacionalidad de cosecha diferentes ‘Julio’ (temprano), ‘Govín’ (media) y ‘Catalina’ (tardía) injertados sobre cv. ‘Perrero’, de 10 años de edad, plantados a 6 m x 10 m sobre un suelo Ferralítico Rojo se realizaron observaciones fenológicas por la escala BBCH a 10 árboles seleccionados al azar con periodicidad quincenal. Se determinó el porcentaje del árbol florecido y las variaciones climáticas se evaluaron a través de variables meteorológicas: temperaturas máximas y mínimas, amplitud de temperaturas, acumulados y número de días con precipitaciones. Las relaciones entre la intensidad de floración y las variables meteorológicas se establecieron para dos meses antes de la fecha de muestreo a través del Análisis de Componentes Principales. El mayor porcentaje de floración ocurrió para ‘Julio’ en enero, 76 %; ‘Govín’ y ‘Catalina’ en marzo, 72 y 83 %, respectivamente. Las variaciones meteorológicas influyeron desde dos meses antes de la floración, explicándose alrededor del 70 % por la varianza acumulada de las dos primeras componentes. La asociación entre temperaturas ligeramente frías y un déficit hídrico durante el período poco lluvioso favorecieron la inducción de la floración del aguacatero.

Palabras clave: cambio climático, fenología, Persea *americana* Mill.

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INTRODUCTION

The origin of the avocado tree (*Persea americana* Mill.) is located in the tropical zone of Continental America, encompassing the highlands of Guatemala, Mexico, and the lowlands of Central America. Based on its climatic adaptation, alternation, harvest season, and morphological characteristics of the leaves and fruit, three ecological groups were formed: Mexican, Guatemalan, and West Indian, each showing different physiological and phenological traits (1). The West Indian race originates from the tropical regions of Mexico and Central America and is adapted to warm and humid climates. Its fruits contain lower oil content compared to the other two races (2).

Throughout their life cycle, avocado trees go through two phenological development phases: vegetative and reproductive. Cultivars belonging to the West Indian group are grown under tropical conditions and are characterized by profuse and vigorous vegetative sprouting, to the detriment of the reproductive phase. This condition is mainly due to the characteristics of tropical climates, with high temperatures almost year-round and a temperature range between day and night of around 10 °C (3).

Avocado has genetic plasticity that allows it to adapt to different climatic environments, growing zones, and soil types. Flowering in this fruit species is extremely sensitive to temperature and it is mainly regulated by nighttime values ranging between 12 and 18 °C, depending on the climate type. It has been demonstrated that temperature is the main factor responsible for the transition of dormant buds to the reproductive phase and is decisive in the onset, duration, and intensity of the flowering process in subtropical and temperate regions (4, 5). However, in cultivars of the West Indian group grown in tropical climates, it is not clear which meteorological variables determine the induction and differentiation of the floral bud.

Of the three ecological groups, the West Indian has predominated in Cuba due to its excellent climatic adaptation and the Cuban preference for the size of its fruits. Among the most propagated cultivars are ‘Julio’, ‘Govín’, and ‘Catalina’, among others, which are classified according to harvest season as early, mid-season, and late (6).

Based on knowledge of the climatic variations that occurred during the first decades of the 21st century in the country (3), it is evident that climatic scenarios for avocado cultivation should focus on establishing commercial plantations in less warm areas. However, poor *in situ* studies that explain phenological processes and their relationship with climatic variables, which would allow for the optimization and updating of crop management technologies, as well as reducing risks associated with adverse climatic conditions. Under Cuba’s edaphoclimatic conditions, research on avocado phenology has focused on the morphoagronomic and qualitative characterization of avocado germplasm (6) and the chronological description of the occurrence of phenological stages in the annual cycle (7). Therefore, to date, there are no results explaining the influence of climate on the phenological phases of the crop under our conditions, which is why the objective of this study was to analyze the influence of meteorological conditions on the expression of flowering in three cultivars of West Indian avocado.

MATERIALS AND METHODS

Three commercial avocado plantations of the cultivars ‘Julio’, ‘Govín’, and ‘Catalina’, grafted onto cv. ‘Perrero’ and the pollinator cv. ‘Choquette’, were selected. These trees were 10 years old and established at a spacing of 6 m × 10 m on Ferralitic Red soil at the “26 de Julio” farm, part of the UBPC “30 de Noviembre” of the Specialized Fruit Company “Cítricos Ceiba”, located in Caimito municipality, Artemisa province, centered approximately at 22º55´ N and 82º40´ W. The plantations were rainfed. Phytotechnical care included the application of COMPOST fertilizer at a rate of 8 t ha^{-1} in 2019 and 2021, along with manual weeding throughout the experimental period (2019-2023).

In each plantation, ten trees were randomly selected, and the canopy of each tree was subdivided into four quadrants, resulting in 40 replicates per cultivar. Visual phenological observations were conducted biweekly during the November-April period of each experimental year (2019-2023), totaling twelve samplings annually. The observation method consisted of identifying the reproductive flowering phenological stage, macrostage 600 of development as described by the BBCH scale for avocado (8). The highest flowering percentage per sampling was determined, and the monthly average was calculated by averaging the values of the two samplings conducted each month, with $n = 40$ replicates per month, year, and cultivar. Meteorological data-maximum and minimum temperatures (°C), temperature range (°C), precipitation (mm), and number of rainy days-were provided by the Bauta Meteorological Station in Artemisa, part of the Institute of Meteorology.

Statistical analysis

To determine the date of occurrence of the highest flowering percentage by year and month, a Student’s t-test was applied for each cultivar. Prior to analysis, percentage values were transformed using arcsine $\sqrt{x} + 1$ and conditions of normality and homoscedasticity were verified. A probability level of $p \leq 0.05$ was used. The dependency relationships between flowering percentage and meteorological variables were analyzed for the two months preceding each sampling date using Principal Component Analysis (PCA) with the STATISTICA software, Version 7.

RESULTS AND DISCUSSION

The highest flowering percentages for the trees of the three cultivars were observed during the years 2020, 2021, and 2022, with statistically significant differences compared to 2019 and 2023 (Table 1). The months of peak flowering differed for the cultivar ‘Julio’ compared to ‘Govín’ and ‘Catalina’. For the latter two, March coincided as the peak flowering month, with percentages exceeding 68 %, while for 'Julio', January showed more than 74 %. In February of the years 2019 and 2023, the trees of all three cultivars exhibited the lowest values of total canopy flowering, below 59 %. In these two years, peak flowering for all cultivars occurred in February; whereas in the remaining years, flowering in 'Julio' occurred earlier than in the other two cultivars (March). Consequently, flowering was delayed in 'Julio' and was advanced in 'Govín' and 'Catalina' relative to the years of maximum flowering (2020-2023).

The results revealed that flowering in the cultivars 'Julio' (early-season), 'Govín' (mid-season), and 'Catalina' (late-season) did not cover the entire canopy of the trees, particularly during the years 2019 and 2023. As is known, flowering is the first physiological process involved in yield formation; its intensity and magnitude depend on the climatic characteristics of the dry period. High temperatures associated with increased rainfall inhibit floral bud induction and consequently reduce the number of flowers and overall production.

Regarding the inductive stimulus for flowering, it has been reported that in tropical conditions such as those in Florida, United States of America, flowering cannot be promoted by water stress due to the absence of low temperatures. Instead, it is triggered by a reduction in photoperiod, a factor that promotes flowering in West Indian avocado cultivars or their hybrids with the Guatemalan group (9).

Avocado trees exhibit a characteristic phenological behavior in which vegetative and reproductive phases overlap, shorten, or extend depending on climatic conditions, phytotechnical management, and the high genetic variability among ecological groups and cultivars within the same group. Moreover, the time between flowering and harvest depends on temperature. In cold climates, this period ranges from 10 to 14 months, whereas in warm climates, it lasts between 5 and 8 months (10).

The differences observed may be attributed to the resting period between fruit harvest and the induction and differentiation of the floral bud-a physiological process highly sensitive to climatic variations, particularly minimum temperature and accumulated precipitation during the dry season (November-April). A similar pattern has been observed in other fruit species such as *Mangifera indica* Lin. and *Citrus paradisiac* Macf grown under Cuba's Modified Tropical Climate conditions (11, 12).

Overall, this study found that not all years (2019-2023) presented favorable climatic conditions for floral bud induction and differentiation. Additionally, the time between harvest and subsequent flowering varied: cv. 'Julio' required nine months, 'Govín' eight months, and 'Catalina' only six months. Therefore, the time intervals between fruit harvest and the moment when trees reached the highest percentage of canopy flowering were shortened in accordance with each cultivar's harvest seasonality.

The influence of the resting period required by the trees remains imprecise, as West Indian group cultivars lack detailed and specific studies on their physiological and phenological responses under different cultivation conditions. In contrast, cv. 'Hass', grown in various climatic environments such as the Tropical Climate of Colombia, has shown differences in its vegetative and reproductive phases, as well as in the biological temperature thresholds required for flowering, compared to the climatic zones of Mexico and California (13).

Cv. 'Julio' exhibited dependency relationships between increased flowering percentages and meteorological variables occurring two months prior. Lower minimum and maximum temperatures, reduced accumulated precipitation, and fewer rainy days characterized these climatic conditions. This relationship was explained by an accumulated variance of 66.6 % in the first two Principal Components (PC1 and PC2) (Table 2).

For the cultivars 'Govín' and 'Catalina', the response to meteorological variations differed from that of cv. 'Julio'. The relationship between flowering percentage and climatic conditions was stronger and negative when, two months prior, higher values of minimum and maximum temperatures, accumulated precipitation, and number of rainy days were recorded. This was explained by a cumulative variance of 71.652 and 74.2398 % for 'Govín' and 'Catalina', respectively (Table 2).

The response of the trees to climatic conditions during the two months preceding peak flowering was characterized by slightly cool minimum temperatures (16 - 20 °C) and reduced precipitation (Table 3), which favored the induction and differentiation of floral buds under Cuba's tropical conditions. These results are consistent with findings reported by several authors working under tropical climatic conditions in Venezuela, Colombia, and Peru, using cultivars belonging to the West Indian ecological group (14-16).

Table 1. Highest flowering percentages for three avocado cultivars during the period 2019-2023. n = 40 replicates per month and cultivar

Cultivars					
'Julio'		'Govín'		'Catalina'	
Months- years	**(%)**	**Months- years**	**(%)**	**Months- years**	**(%)**
February 2019	50 b	February 2019	50 b	February 2019	48 b
January 2020	74 a	March 2020	68 a	March 2020	76 a
January 2021	76 a	March 2021	78 a	March 2021	80 a
January 2022	75 a	March 2022	71 a	March 2022	83 a
February 2023	56 b	February 2023	45 b	February 2023	59 b
DS= 8.5		DS = 14.20		DS = 15.06	
P = 0.03*		P =0.01*		P = 0.13	

Table 2. Relationships between the highest flowering percentages of avocado tree canopies from three cultivars and meteorological variables two months prior to the sampling date

Evaluated Climatic Periods	Two Months Prior to Flowering					
Cultivars	**'Julio'**		**'Govín'**		**'Catalina'**	
Factors	**CP1**	**CP2**	**CP1**	**CP2**	**CP1**	**CP2**
Eigenvalue	2.71128	1.2826	2.31642	1.982	2.39817	2.0562
Total Explained Variance (%)	45.18810	21.3774	38.60706	33.045	39.96959	34.2702
Cumulative Variance (%)	45.18810	66.5656	38.60706	71.652	39.96959	74.2398
Flowering (%)	-0.28998	**0.6796**	- 0.78567	-0.127	- 0.79680	-0.3466
Minimum Temperature(°C)	- 0.95247	-0.2137	0.58464	**0.780**	**0.94256**	-0.2802
Maximum Temperature(°C)	- 0.78138	-0.4144	**0.82695**	0.268	**0.90543**	0.2112
Temperature Range(°C)	**0.83889**	-0.2025	0.24310	**0.825**	-0.23429	**0.8445**
Rainfalls (mm)	**-0.63314**	0.1732	**0.67284**	0.503	-0.00258	**0.8103**
Total Rainy Days	0.06948	**-0.7295**	0.40207	**0.592**	-0.01123	**0.6655**

n = 25 replicates per cultivar

It has also been observed that avocado trees reach higher flowering indices when preceded by negative water balances (soil moisture deficit), coinciding with low rainfall values, high evapotranspiration, elevated temperatures, and increased solar radiation (17, 18). Conversely, reduced flowering was observed when precipitation increased to constant levels, accompanied by high cloud cover (19-21).

Meeting the tree's high water demand driven by the formation of new structures and an expanded area susceptible to water loss is a determining factor for the onset of anthesis and flower set. During flowering, approximately 13 % of the canopy's total transpiration is attributed to floral organs; therefore, water demands are high (13). However, abundant rainfall combined with elevated cloudiness reduces flowering, particularly during anthesis and flower set. Additionally, these conditions promote fungal development and negatively affect pollination due to decreased bee activity (16-18).

Furthermore, for cv. 'Hass' grown under the edaphoclimatic conditions of California, USA, higher crop coefficient (Kc) values have been identified during floral bud development and the flowering and fruit set phases, compared to the fruit growth and development phase (22).

Currently, the climatic scenario in many avocado-producing countries is undergoing changes due to the impacts of climate change, which has led to increased frequency and intensity of extreme weather events, droughts, high temperatures, hailstorms, precipitation variability, strong winds, and torrential rains. As a result, crop growth, productivity, and fruit quality are under serious threat (23).

The values presented in Table 3 may serve as a theoretical-practical guide to anticipate how flowering will manifest in a given year. Moreover, they could support the adoption of phytotechnical actions using growth regulators or girdling techniques to mitigate the impact of climatic variations.

These findings represent the first of their kind under the country's edaphoclimatic conditions. The analysis of phenological and meteorological variables revealed a climatic risk and a marked vulnerability of the crop under these conditions. Therefore, it is necessary to redesign cultivation technologies and implement phytotechnical practices that reduce phenological disruptions and, consequently, improve yield and fruit quality.

Table 3. Average values of meteorological variables two months prior to peak flowering in three West Indian avocado cultivars during the period 2019-2023. n = 25

			cv. 'Julio'		
Months	**Average Minimum Temperature (°C)**	**Average Maximum Temperature (°C)**	**Average Temperature Range (°C)**	**Accumulated Rainfall (mm)**	**Total Rainy Days**
November	19.6	31.4	11.9	280.6	3
December	22.2	31.1	8.9	702.0	6
January	19.6	28.8	9.2	359.2	3
February	17.3	27.6	10.3	436.3	6
March	16.2	26.7	10.5	326.4	5
			cvs. 'Govín' and 'Catalina'		
December	22.2	31.1	8.9	702.0	6
January	19.6	29.2	10.1	274.0	4
February	17.3	27.6	10.3	546.0	6
March	16.4	26.8	10.5	259.8	5
April	17.8	28.8	11.0	181.5	7

CONCLUSIONS

- The association between slightly cool temperatures and a water deficit during the dry season enhanced the induction of avocado flowering.
- The occurrence of anomalous precipitation distribution and elevated minimum and maximum temperatures during the dry season represents a climatic risk for avocado cultivation under Cuba's soil and climate conditions.

RECOMMENDATIONS

- Apply the knowledge generated by this study to redesign avocado cultivation technologies.
- Validate the results in other regions of the country.

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