Effects of Gibberellic Acid on Flowering Reduction, Fruit Quality and Yield of 'd'Agen' Plum (*Prunus domestica* L.) in Mendoza, Argentina

Efecto del ácido giberélico sobre la reducción de la floración, calidad de fruta y rendimiento del ciruelo 'd'Agen' (*Prunus domestica* L.) en Mendoza, Argentina

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Originales: *Recepción:* 08/05/2025- *Aceptación:* 23/08/2025

Abstract

In Mendoza, the primary industrial plum-producing region in Argentina, the 'd'Agen' cultivar represents approximately 90% of the cultivated area. The limited implementation of fruit thinning has a detrimental effect on final fruit size. The objective of this study was to determine the timing of flower induction in 'd'Agen' plum and to evaluate the response to gibberellic acid (GA) application to reduce flower density and improve fruit size. Over three growing seasons in San Rafael (Mendoza), experiments were conducted on plants grafted onto 'Marianna 2624', spaced at 5x3 m and drip irrigated. GA (100 ppm) was applied at four distinct phenological stages: fruit set, young fruit, fruit near final size, postharvest, and a control with no GA application. In the first two seasons, the H phenological stage (fruit set, Baggiolini scale) was identified as the optimum time for reducing flowering via GA application. In the third season, increasing GA concentrations (0, 25, 50, 75 and 100 ppm) were evaluated. All concentrations reduced floral density compared to the control. However, fruit set was negatively affected by the 75 and 100 ppm treatments. The decline in flowering (between 60% and 90%) was incompatible with commercial yields. It was concluded that the optimal time for GA application to reduce floral density in 'd'Agen' plum was during phenological stage H. Further research is required to determine the most effective dose below 25 ppm.

Keywords
chemical thinning • flower induction • fruit load • fruit size • *Prunus domestica*

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Resumen

En Mendoza, la principal provincia argentina productora de ciruelas para industria, el cv. ‘d’Agen’ representa aproximadamente el 90% de la superficie cultivada. La limitada aplicación de prácticas de aclareo impacta negativamente en el tamaño de frutos. El objetivo de este trabajo fue determinar el momento de inducción floral y evaluar la aplicación de ácido giberélico (GA) para reducir la densidad floral y mejorar el tamaño de los frutos. Durante tres temporadas, en San Rafael (Mendoza), se realizaron ensayos con plantas injertadas sobre ‘Marianna 2624’, con espaciamiento de 5x3 m y riego por goteo. GA (100 ppm) se aplicó en cuatro estadios fenológicos: cuajado de frutos; frutos jóvenes; frutos próximos al tamaño final; postcosecha; y un control, sin tratamiento de GA. En las dos primeras temporadas, el estado fenológico H (cuajado de frutos, Baggiolini) resultó ser el momento óptimo para reducir la floración mediante aplicaciones de GA. En la siguiente temporada, se evaluaron diferentes concentraciones de GA (0, 25, 50, 75 y 100 ppm) aplicadas en dicha etapa. Todas las dosis redujeron la floración en comparación con el control. No obstante, las dosis de 75 y 100 ppm afectaron negativamente el cuajado de frutos. La reducción de la floración (entre 60 y 90%) resultó incompatible con rendimientos comerciales. La etapa fenológica H resultó el momento óptimo de aplicación de GA con el fin de reducir la densidad floral del ciruelo ‘d’Agen’. Se requieren investigaciones para evaluar la dosis más efectiva por debajo de 25 ppm.

Palabras clave

carga frutal • inducción floral • raleo químico • tamaño de fruto • *Prunus domestica*

Introduction

World production of dried plums is estimated at 270,000 metric tons, with the United States, Chile, France and Argentina as the primary producers and exporters (9). However, the United States and Chile together account for over 70% of global production. The predominant cultivar used for dehydration is ’d’Agen’, which accounts for over 98% of worldwide production (16). The increasing global demand for dried plums can be attributed to the well-documented health benefits of this fruit (13).

In Argentina, annual dried plum consumption is estimated at 3,500 metric tons (7). The province of Mendoza is the main contributor to the industry’s plum production, with 10,000 hectares cultivated and 51,317 metric tons of fresh fruit harvested during the 2020/21 season (9). The cultivated area underwent expansion between 1992 and 2010 (7), with the ‘d’Agen’ group occupying over 90% of the area (9). In the southern region of the province (departments of San Rafael and General Alvear), approximately 70% of “d’Agen” plums are cultivated and dehydrated (9), with 95% destined for export. However, the ‘Oasis Sur’ region is subject to high climatic risk, characterized by hailstorms and late frosts, resulting in substantial fluctuations in its annual production (8).

Under typical conditions, fruit trees often set more fruit than they can support to reach satisfactory commercial quality (12). In order to mitigate these effects, fruit thinning is implemented and is considered one of the most critical cultural practices in fruit tree management (12, 14, 15).

Floral induction marks the onset of the reproductive phase and, consequently, the initiation of competition among developing floral organs. Gibberellins have been identified as inhibitors of floral induction in several fruit tree species (1). A high fruit load, particularly in plants bearing fruits with numerous seeds capable of synthesising gibberellin, has been shown to induce alternate bearing patterns (10).

Aiming at efficacious agronomic intervention and regulation of floral density, knowing the precise temporal dynamics of floral induction across different crop and cultivar types turns imperative. The application of gibberellins during floral induction has been used to modulate flowering density in various crops, including citrus (1), apple (14) and stone fruit (2, 5, 6, 15). The reduction in floral bud number resulting from the application of GA decreases the time required for manual fruit thinning in peach trees (6). This finding was corroborated in other stone fruit species (5, 10). In the 'Opal' plum cultivar, gibberellin application during stage I of fruit development effectively reduced floral induction and the next year's crop load (11).

In European plum (*Prunus domestica* L.), fruit load can be managed through manual, mechanical or chemical thinning techniques. These practices are used to achieve marketable fruit size and to mitigate alternate bearing (11). However, manual thinning is applied in only approximately 10% of plum orchards in Mendoza, as it is not considered cost-effective (9). The price received by farmers is strongly dependent on fruit size, with annual decrease in the international prices of smaller fruits (49-62 fresh units per kg) (7).

Particularly considering 'd'Agen' plums, there is scarce experimental data on the use of chemical thinning to reduce crop load and improve fruit quality and profitability (11). Moreover, knowledge is limited regarding the timing of floral induction and the effect of GA on flowering reduction and fruit size improvement in this cultivar. The use of gibberellins has been identified as a potentially cost-effective strategy for crop load regulation and supporting agronomic decision-making under the environmental and production conditions of the Oasis Sur region in Mendoza.

The objective of this study was to determine the timing of floral induction and to evaluate the optimal concentration of gibberellic acid for reducing flower density and crop load, thereby improving the commercial fruit size in 'd'Agen' plums.

Materials and methods

The trial was conducted in a commercial plum orchard in the San Rafael department, Mendoza province (34°06'S, 68°33'W, 750 m above sea level). It spanned three consecutive growing seasons, from November 2018 to February 2021. On 5 October 2020, the occurrence of frost led to partial damage as the crop was at the flowering to fruit set phenological stages. These stages are particularly susceptible to frost injury in temperate fruit orchards (4).

European plum trees (*Prunus domestica* L.) of the 'd'Agen' cultivar, 12 years old, grafted onto 'Mariana 2624' (*Prunus cerasifera* x *Prunus munsoniana*) were used. The trees were cultivated in loamy soil, with drip irrigation and protected from hail damage by nets. They were selected based on their uniformity in canopy size and trunk diameter, and were trained in a narrow vase system, with a spacing of 5x3 m. Trunk cross-sectional area (TCSA) was measured at the beginning of each growing season.

Determination of Floral Induction Timing (2018/2019 season)

Gibberellic acid (GA) treatments (Gibberellin KA; S. Ando y Cía. S.A.) were applied at a concentration of 100 mg l^{-1} (ppm), with the solution pH adjusted to 5.5 using 1 M acetic acid. Manual spraying was performed until runoff, with an average application volume of 2.3 liters per plant. Applications were conducted in mid-morning at four phenological stages according to the Baggiolini scale (8), resulting in five treatment groups: T1, H stage (fruit set, 02/11/2018); T2, I stage (young fruits, 20/11/18); T3, J stage (fruit near final size, 02/01/19); T4, postharvest (one week after harvest, 15/02/19). A control group (T0) received no GA treatment.

Determination of the Gibberellin doses (2019/2020 season)

In this study, GA applications were performed on 1 November 2019 at stage H (fruit set). Five treatments were established based on GA concentration: Control (C, 0 ppm); T1 (25 ppm); T2 (50 ppm); T3 (75 ppm); T4 (100 ppm). Manual fruit thinning was not applied in any of the treatments.

To monitor the evolution of plant parameters in both trials, four branches of similar size were selected per tree during the winter period. These were distributed in the four quadrants of the canopy at a uniform height of approximately 1.5 m above ground level. The diameter of each branch at the point of insertion and its total length were measured. Reproductive structures (flowers and fruits) on the selected branches were counted weekly throughout the spring. Data were expressed as the number of flowers and fruits per unit of branch cross-sectional area (cm^2). The relative fruit drop rate (RFDR) was calculated for each interval between observation dates (13).

Harvesting began once the fruits reached a minimum soluble solids content of 22°Brix, as measured using an Arcano DBR0045nD digital refractometer, and a pulp firmness of 3-4 lb in^{-2}, as determined using a Turoni FT327 penetrometer equipped with an 8 mm diameter tip. The total weight and number of fruits per plant were recorded for subsequent analysis. Results were also expressed as the number of fruits per unit of trunk cross-sectional area (TCSA). A sub-sample of 50 fruits per plant was used to measure individual fruit diameter using a SCHWYZ digital caliper. Commercial fruit size was determined by randomly selecting three 1 kg samples per tree and counting the number of fruits in each. Fruit size classification followed the fresh weight standard of the Plum Exporters Committee of Mendoza (CECIM, unpublished data), which defined three categories: large fruits (< 34 fruits kg^{-1}), medium fruits (35-48 fruits kg^{-1}), and small fruits (49-62 fruits kg^{-1}).

In both experiments, a completely randomized block experimental design was used, with five replications per treatment, totaling 25 plants per trial. Irrigation (tree row) was used as a blocking factor. The experimental unit was the individual tree, while the observation unit comprised the selected branches. Data were then analyzed using analysis of variance (ANOVA) and means were compared using the DGC test at a 5% significance level. Statistical analyses were performed using the INFOSTAT software (3). A general linear and mixed model was used to analyze variables such as flowering density, fruit set, and fruit yield. Conversely, variables related to the dynamics of flower and fruit abscission, including the relative fruit abscission rate, were treated as repeated measures over time and analyzed with a general mixed model. Additionally, regression analysis was conducted to evaluate the relationships between crop load and individual fruit weight, as well as between floral density, fruit set, and fruit yield.

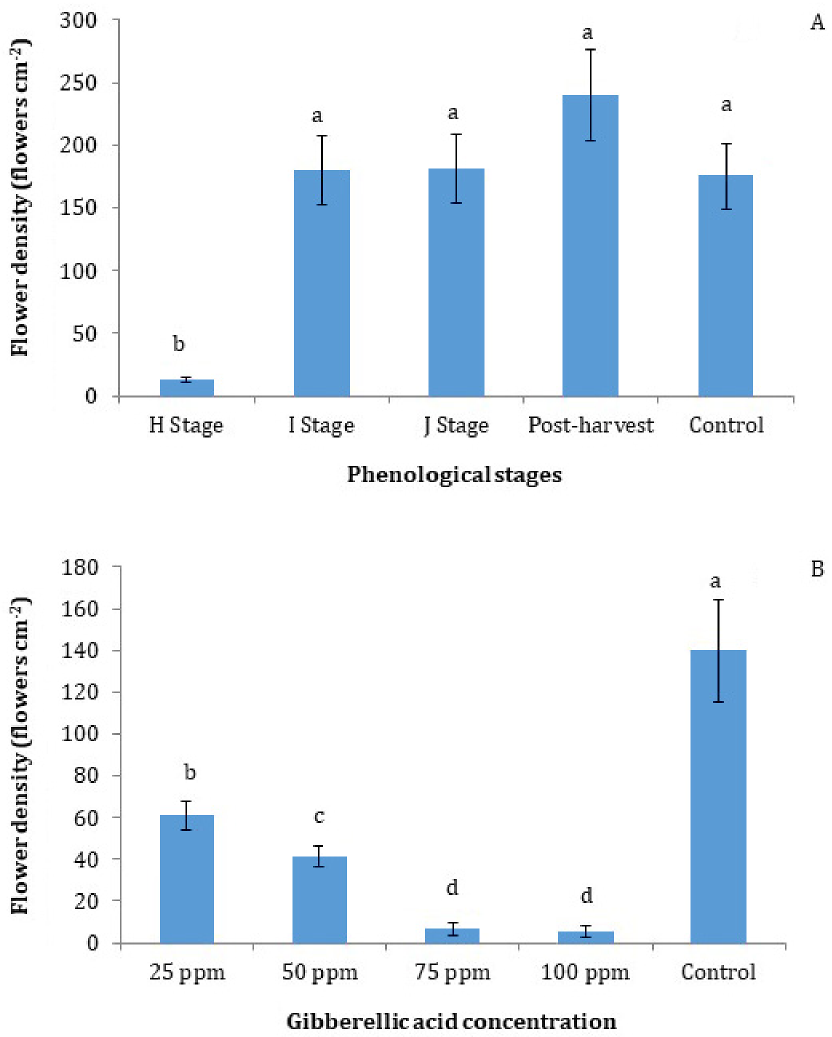
Results and discussion

Determination of Floral Induction Timing

In the control treatment, flowering density of ‘d’Agen’ plum reached approximately 180 flowers per cm^2 of branch cross-section area. The application of GA at 100 ppm during the phenological stage H, which corresponds with the fruit-setting period, five weeks after full bloom, resulted in a 90% reduction in the flowering density. In contrast, no effect on flower density was observed when GA was applied in the phenological stages I, J, and post-harvest (figure 1A, page 5).

The results indicate that the phenological stage H corresponds to the period of floral induction for the ‘d’Agen’ plums. This finding is consistent with previous observations in the European plum, cv. ‘Opal’, where the application of GA five weeks after full bloom was identified as the most efficacious timing for the reduction of flowering (11). Later applications of GA were ineffective, suggesting that floral induction had already occurred and that the buds were at a more advanced stage of floral differentiation. This finding is consistent with the established understanding that gibberellins are only effective when applied before or during the floral induction period (6).

In the second-year trial, ‘d’Agen’ plum exhibited high sensitivity to all GA concentrations applied at phenological stage H. Even the lowest dose (25 ppm GA) resulted in a significant reduction in flowering density, with a decrease of approximately 60% (figure 1B, page 5). Floral density declined exponentially with increasing GA doses, from 140 flowers cm^{-2} of branch cross-sectional area in the control to less than 10 flowers cm^{-2} in the 75 and 100 ppm GA treatments. Significant differences in flowering density were observed among the different GA concentrations, except between the 75 and 100 ppm treatments (figure 1B, page 5). The flowering response to the 100 ppm GA application at stage H was comparable in both years of the study (figure 1A, page 5).



Different letters on bars indicate significant differences, DGC test ($P < 0.05$). Vertical bars indicate standard error. Data correspond to the first year of the trial. H Stage: fruit set; I Stage: young fruits; J Stage: fruit near final size; Postharvest: one week after harvest; Control: without treatment.

Letras diferentes sobre las barras indican diferencias significativas, test DGC ($P < 0,05$). Barras verticales indican el error estándar. Los datos corresponden al primer año del experimento. Estado H: cuajado de frutos; Estado I: frutos jóvenes; Estado J: frutos próximos al tamaño final; Poscosecha: una semana posterior a la cosecha; Control: sin tratamiento.

Figure 1. Floral density per unit of branch cross-sectional area (flowers cm^{-2}) of 'd'Agen' plums in response to: (A) application of gibberellic acid (GA; 100 ppm) at different phenological stages of the previous growing season, and (B) different GA concentrations applied during stage H of the previous growing season.

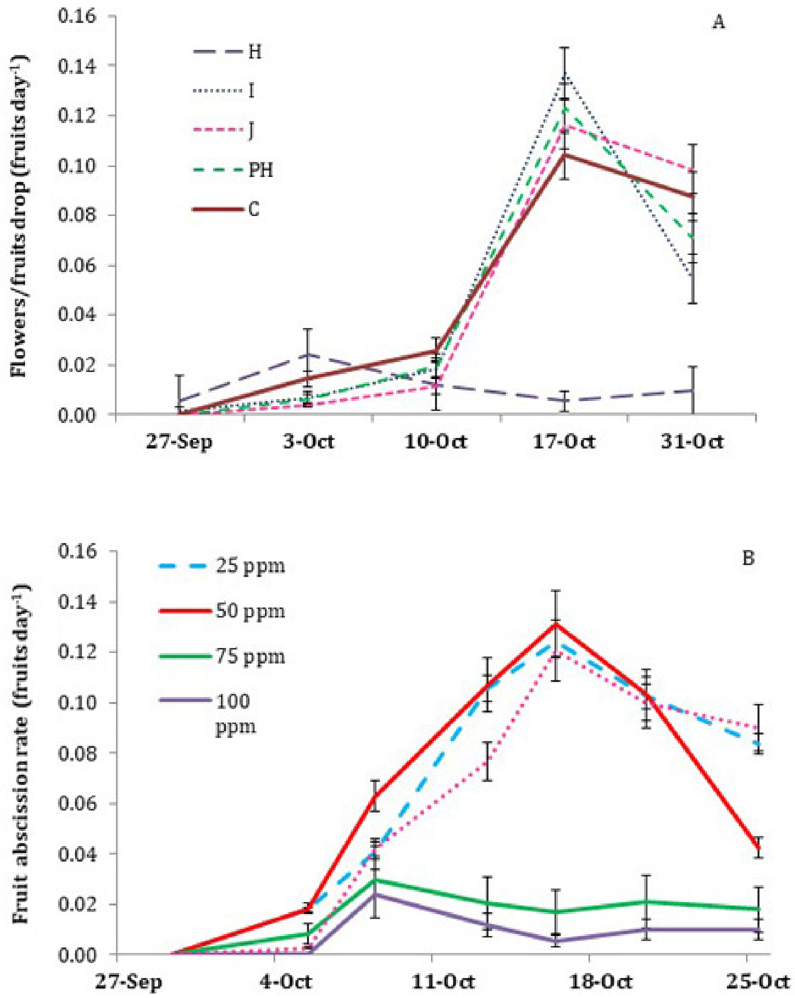
Figura 1. Densidad floral por unidad de área de sección transversal de rama (flores cm^{-2}) del ciruelo 'd'Agen' en respuesta a: (A) aplicación de ácido giberélico (AG; 100 ppm) en diferentes estados fenológicos de la estación de crecimiento previa, y (B) diferentes concentraciones de AG aplicado en el estado H de la estación de crecimiento previa.

The response of 'd'Agen' plum to increasing GA concentration is consistent with findings reported in other fruit-tree crops. In Japanese plums, the application of 75 and 100 ppm GA, 106 days after full bloom, resulted in a 75-90% reduction in floral density (1). Similarly, GA application 60 days after full bloom in peach trees reduced flower number and minimized the time required for manual fruit thinning in peach trees (6). Furthermore, the time required for final thinning was inversely correlated with GA concentration. In nectarines, cultivars 'May Fire' and 'May Glo' exhibited a 25-40% reduction in flowering following the application of 118 ppm GA, while the cultivar 'Zincal' showed a reduction of up to 65% (2). Comparable results have been reported in apricot and cherry trees, where 100 ppm GA effectively reduced flower density in the following season (10).

Abscission of Reproductive Structures

In the control group, the rate of flower and fruit drop increased markedly after 10 October and remained high until the end of the month. A similar trend was observed in the GA treatments at stages I, J, and post-harvest. However, GA application at stage H showed a one-week advance in flower and fruit drop compared to the other treatments (figure 2A).

In the second year of the study, the effect of different GA concentrations at stage H was assessed (figure 2B). The persistence of reproductive structures and their abscission rate in the 25 and 50 ppm GA treatments exhibited a similar trend to that of the control, while the 75 ppm GA dose resembled that of the 100 ppm GA treatment. The highest abscission rate was observed on 17 October, while in the 75 and 100 ppm GA treatments, the highest abscission rate was recorded one week earlier (7 to 9 October) (figure 2B), as was previously described for the application of 100 ppm GA at stage H during the first year of the study (figure 2A).



Vertical bars correspond to standard error. Data correspond to the first year of the experiment. H stage: fruit set; I stage: young fruit; J stage: fruit near final size; PH: post-harvest, one week after harvest; C: control plants without gibberellic acid treatment.

Barras verticales indican error estándar. Los datos corresponden al primer año del experimento. Estado H: cuajado de frutos; Estado I: frutos jóvenes; Estado J: frutos próximos al tamaño final; poscosecha: una semana posterior a cosecha; Control: sin tratamiento.

Figure 2. Evolution of flower/fruit abscission rate (flower/fruits day^{-1}) of 'd'Agen' plum in response to: (A) 100 ppm gibberellic acid (GA) application at different phenological stages of the previous growing season, and (B) different concentrations of GA applied during the pit-hardening stage of the previous growing season.

Figura 2. Evolución de la tasa de abscisión de flores/frutos (flores/frutos día^{-1}) del ciruelo 'd'Agen' en respuesta a: (A) aplicación de ácido giberélico (AG) en diferentes estados fenológicos, de la estación de crecimiento previa; (B) diferentes concentraciones de AG aplicadas durante el endurecimiento del carozo del fruto, de la estación de crecimiento previa.

The observations made in mid-October correspond to the first phase of fruit development, known as stage I, characterized by cell division (2). Additionally, in the second year, the occurrence of high temperatures and "Zonda" winds during the flowering period, followed by a late frost, affected the persistence of flowers and fruits. Despite these differing environmental conditions, the period of maximum fruit drop for the 'd'Agen' cultivar occurred in mid-October in both years. Furthermore, the H phase is also characterized by the sprouting and vegetative growth of the plant. These results are of great agronomic importance, as they indicate that the H phase is a sensitive period for the 'd'Agen' plum plant due to the competition between flower induction and developing fruits, as well as the increases in vegetative growth (12).

Gibberellins affect flower differentiation and sexual determination, resulting in abnormalities and masculinizing effects (16). This could explain the increase in flower/fruit drop in treatments with higher GA concentrations (75 and 100 ppm). However, this effect was only observed in treatments applied at the time of maximum sensitivity to flowering inhibition (H stage).

Fruit Set

Application of GA at the phenological stage H not only reduced flower density but also led to a marked decrease in final relative fruit set, which was less than 1% of the initial number of flowers. GA applications at the later phenological stage (stage I) also reduced fruit set by about 30% compared to later treatments, which achieved a fruit set percentage of around 12% (figure 3A, page 8).

In the second year, at different doses of GA during the H stage, the 75-ppm GA treatment exhibited the same negative effect on fruit set as the 100-ppm treatment during the two-year observation period. Conversely, lower concentrations of GA (25 and 50 ppm) did not affect fruit set (figure 3B, page 8). This reduction in fruit set can be attributed to the masculinizing effects of gibberellins, as previously discussed (16). In 'Patterson' apricot (15), fruit set was not affected by GA applications; however, in 'Opal' plum, fruit set for the following year was significantly reduced for all GA treatments compared to the control (11).

Fruit Size and Yield

In the first year of the trial, the application of 100 ppm GA during fruit set (stage H) improved fruit size at harvest in the following growing season by approximately 3 mm compared to later applications, which did not differ from each other or from the control (figure 4A, page 9). Furthermore, according to the regulations of the Plum Exporters Committee of Mendoza (CECIM), the application of gibberellins at stage H resulted in an improved fruit size category from 'small' (39-62 fruits per kg) to 'medium' (35-48 fruits per kg).

In the second year, the range of fruit sizes in the treatments was similar to that observed in the first year (figure 4A and 4B, page 9), despite the large difference in crop load between the two growing seasons. Fruit size differed significantly among GA concentrations, except between the 50 and 75 ppm treatments (figure 4B, page 9). According to the Plum Exporters Committee of Mendoza (CECIM), GA concentrations of 50, 75, and 100 ppm resulted in 'medium-sized' plums, whereas the 0 and 25 ppm treatments produced 'small-sized' fruits.

Fruit size is influenced by multiple factors, but it is well established that there is an inverse relationship between the number of fruits per tree and their final size (5). Fruit thinning reduces carbohydrate competition among the remaining fruits, promotes cell division and elongation, and thus ensures a commercially appropriate fruit size (2). By reducing flower density through gibberellic acid applications, competition between reproductive structures is decreased from the outset. As a result, this technique has the potential to produce larger fruit compared to traditional fruit thinning methods.

Means with different letters within columns indicate significant differences according to the DGC test ($P < 0.05$). Vertical bars represent standard error. H stage: fruit set; I stage: young fruit; J stage: fruit near final size; PH: post-harvest, one week after harvest; C: control, plants not treated.

Medias con diferentes letras en las columnas indican diferencias significativas según test DGC ($P < 0,05$). Barras verticales corresponden al error estándar. Estado H: cuajado de frutos; Estado I: frutos jóvenes; Estado J: fruto alcanzando el tamaño final; Estado PH: poscosecha, una semana posterior a la cosecha; C: Control, plantas sin tratamiento con AG.

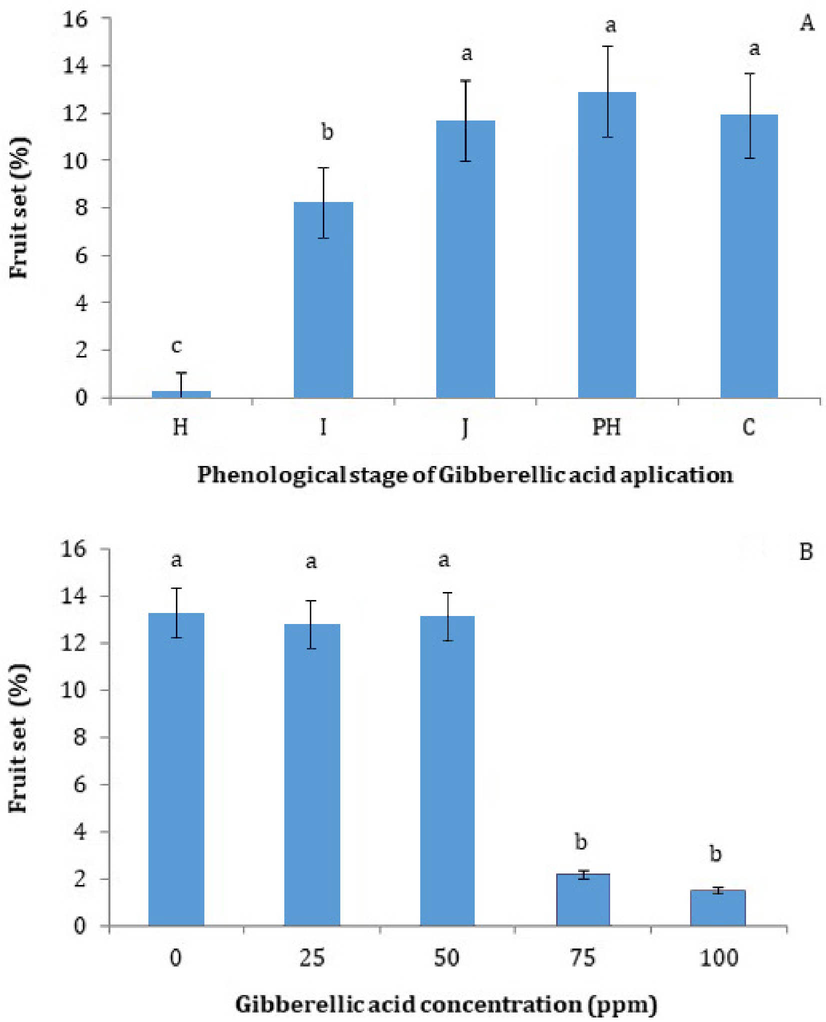
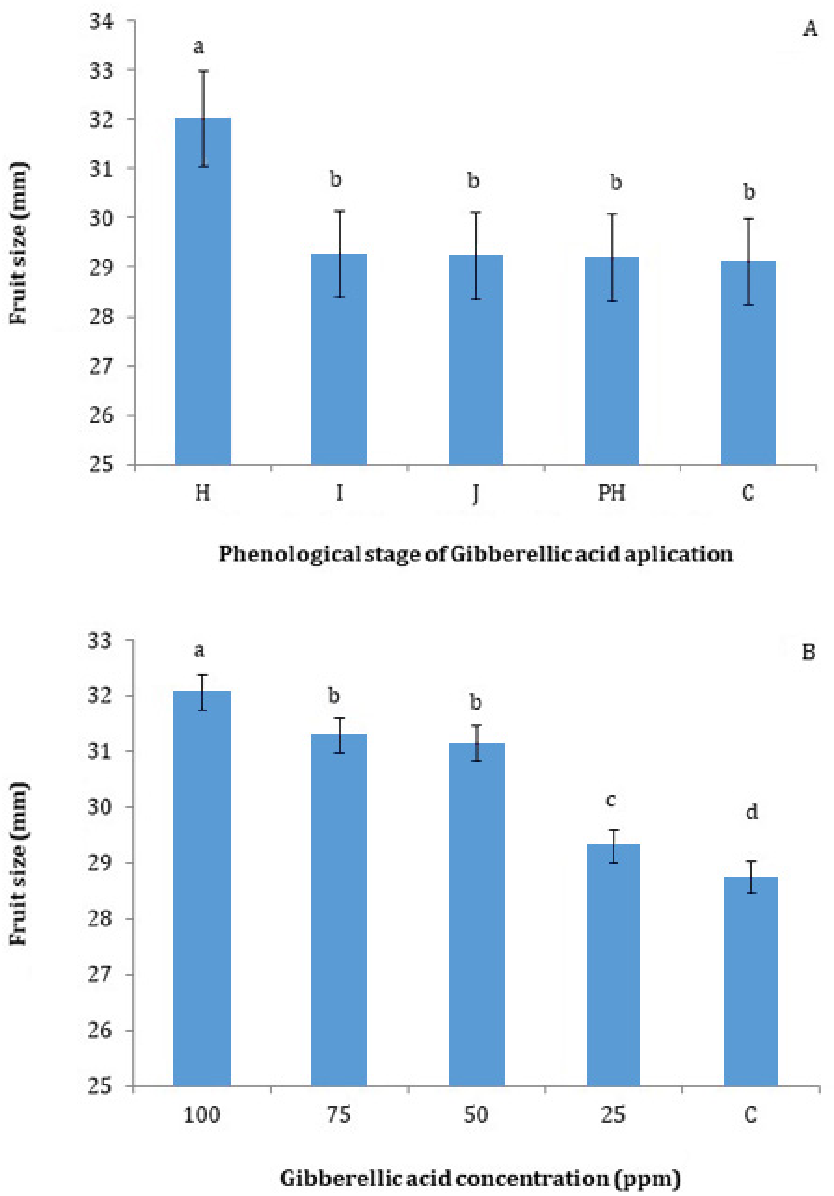


Figure 3. Fruit set (%) of ‘d’Agen’ plum plants: (A) treated with 100 ppm gibberellic acid (GA) at different phenological stages during the previous growing season, and (B) in response to different concentrations of gibberellic acid (GA) treatments applied at the phenological stage H of the previous season.

Figura 3. Cuajado de frutos (%) de plantas de ciruelo ‘d’Agen’: (A) tratadas con 100 ppm de ácido giberélico (AG) en diferentes estados fenológicos en la estación de crecimiento previa, y (B) en respuesta a tratamientos con diferentes concentraciones de AG aplicadas en el estado fenológico H (cuajado de frutos) durante la estación de crecimiento previa.

The reduction in flower density and fruit set percentage induced by 100 ppm GA applied at the phenological stage H in the previous growing season resulted in a decrease in the number of fruits per tree and total fruit yield, which decreased from over 30 kg per tree in the control to just over 8 kg per tree in the GA-treated trees (table 1, page 10). In contrast, the reduction in fruit set induced by GA at stage I had a significant effect on the number of fruits per plant and per unit of TCSA, but no effect on fruit weight or total fruit yield (table 1, page 10).

In the second year, significant differences were observed among GA treatments for all yield components. Treatments with higher GA concentrations resulted in greater reductions in crop load, both expressed as fruits per tree and per unit TCSA, as well as in total fruit yield (table 1, page 10). The 75 and 100 ppm GA treatments showed no significant differences in yield components, except for fruit weight. In contrast, the 25 and 50 ppm GA treatments and the control trees differed from each other and from the higher GA treatments in most of the parameters evaluated.



Columns with different letters indicate significant differences according to DGC test (*P* < 0.05). Vertical bars represent standard error. H stage: fruit set; I stage: young fruit; J stage: fruit near final size; Post-harvest: one week after harvest; Control: untreated plants.

Medias con diferentes letras en las columnas indican diferencias significativas según test DGC (*P* < 0,05). Barras verticales corresponden al error estándar. Estado H: cuajado de frutos; Estado I: frutos jóvenes; Estado J: fruto alcanzando el tamaño final; Estado PH: poscosecha, una semana posterior a la cosecha; C: Control, plantas sin tratamiento con AG.

Figure 4. Fruit size (mm) at harvest of ‘d’Agen’ plums, (A) treated with 100 ppm gibberellic acid (GA) at different phenological stages during the previous growing season, and (B) as a function of different GA concentrations (ppm) applied at the pit-hardening stage of the previous season.

Figura 4. Tamaño de frutos (mm) a cosecha del ciruelo ‘d’Agen’, (A) tratados con 100 ppm de ácido giberélico (AG) en diferentes estados fenológicos durante la estación de crecimiento previa, y (B) en función de diferentes concentraciones (ppm) de AG aplicadas en el estado de endurecimiento de carozo durante la estación de crecimiento previa.

Notably, crop load in the second year was about a quarter of that observed in the first year. This reduction was attributed to high temperatures and “Zonda” winds during full flowering, followed by spring frosts at the fruit set stage, which is the most sensitive period to frost (4). These events hindered the establishment of optimal gibberellin concentration for ‘d’Agen’ plums in our trials. In a year marked by extreme weather conditions, the reduction in flower density resulting from the application of GA at flower induction had a detrimental effect on the fruit yield per tree.

Table 1. Yield components of ‘d’Agen’ plums, (A) treated with 100 ppm gibberellic acid (GA) at different phenological stages during the previous growing season and (B) treated with different concentrations of GA in the previous growing season at fruit set (phenological stage H).

Tabla 1. Componentes del rendimiento del ciruelo ‘d’Agen’, (A) tratamientos con 100 ppm de ácido giberélico (AG) en diferentes estados fenológicos durante la estación de crecimiento previa, y (B) tratamientos con diferente concentración de AG en la estación de crecimiento previa en el estado fenológico de cuajado de frutos (estado H).

(A) Phenological stage	Crop load		Fruit weight (g fruit^{-1})	Fruit yield (Kg pl^{-1})	(B) GA (ppm)	Crop load		Fruit weight (g fruit^{-1})	Fruit yield (Kg pl^{-1})
	Fruits pl^{-1}	Fruits cm^{-2} TCSA				Fruits pl^{-1}	Fruits cm^{-2} TCSA		
Control	2178.7 a	38.7 a	15.7 b	34.6 a	0	542.4 a	10.1a	17.9 d	10.6 a
Stage H	377.8 c	6.8 c	21.5 a	8.1 b	25	393.7 b	7.5 b	18.5 c	7.1 b
Stage I	2111.4 b	38.4 b	15.6 b	30.9 a	50	281.1c	5.3 c	20.1 b	5.3 c
Stage J	2180.7 a	39.5 a	15.9 b	32.4 a	75	219.9 d	4.2 d	20.4 b	4.0 d
PH	2182.6 a	39.5 a	16.8 b	35.7 a	100	199.8 d	3.8 d	21.1 a	3.9 d

Different letters in the rows indicate significant differences between treatments according to DGC test ($P<0.05$).

References: H stage: fruit set; I stage: young fruit; J stage: fruit near final size; PH: post-harvest, one week after harvest; Control: plants not treated; GA: gibberellic acid.

Letras distintas en las celdas de cada columna indican diferencias significativas entre tratamientos según el test DGC ($P<0,05$).

Referencias: Estado H: cuajado de frutos; Estado I: frutos jóvenes; Estado J: fruto alcanzando el tamaño final; PH: poscosecha, una semana posterior a la cosecha; C: Control, sin tratamiento; GA: ácido giberélico.

When data on fruit number and size from both years are plotted on a single graph, it is observed that the initial phase of the experiment was characterized by a high crop load (2,178 fruits per tree in the control), with a negative linear correlation between fruit size and crop load (figure 5). This behavior has been observed in plums (5), and peaches (6, 12). Data from the second year showed a tendency on the left side of the graph, with fruit weight values slightly below the trend observed in the first year, but with increased variation in fruit size relative to crop load (figure 5). This response can be explained by the greater sensitivity of fruit size to change in the low crop load range of the response curve compared to the high crop load range, where fruit size tends to stabilize at lower values (11).

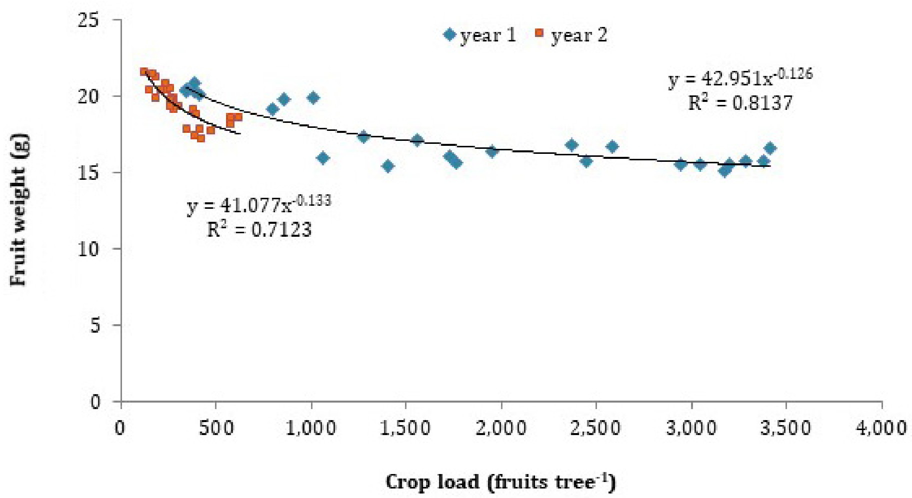


Figure 5. Relationship between crop load (fruits per plant) and fruit weight (g) over two growing seasons in ‘d’Agen’ plum. Data were collected during the 2019/2020 and 2020/2021.

Figura 5. Relación entre carga (frutos por planta) y peso de fruto (g) de dos estaciones de crecimiento de ciruelo ‘d’Agen’. Datos correspondientes a 2019/2020 y 2020/2021.

Fruit load in the second year was nearly one-quarter of that measured in the first year, while fruit size in the control treatment increased by only 2.2 g (14%) compared to the first year. In general, a reduction in flowering density in stone fruit trees allows for an increase in fruit size, although this typically results in a decrease in yield. This phenomenon has been observed in peach (6), nectarine, and cherry (2), as well as in European and Japanese plums (11).

Growth of individual plant organs can be constrained by assimilation capacity (source limitation) or the ability to utilize assimilates (sink limitation) (2). Fruit capacity to absorb assimilates is considered the primary factor influencing competition for these resources. This capacity is initially determined by flower quality, which is influenced by the nature of the inflorescence and the number of flowers produced per tree (5). Furthermore, the sink capacity may be affected by late frosts or other unfavorable environmental conditions that influence embryo growth. Such damage may result in premature fruit drop or become apparent during the ripening process. These factors can influence the shape, appearance, or size of the fruits (4). This may explain the limited response in fruit size during the second year of the study. Despite a reduction in crop loads compared to the previous year, no discernible difference in fruit size was observed between the two years. In situations where crop loads are low and the growing environment is conducive, source limitations are considered negligible, and sink strength becomes the main determinant of growth. This is representative of the second year of the study, during which each fruit tends to achieve its potential size or weight. Consequently, it is reasonable to hypothesize that the climatic adversities experienced during the second year affected sink strength and constrained fruit size, despite the low competition among developing fruits.

A positive correlation (r^2= 0.84) was observed between floral density and fruit set for the two growing seasons. However, when the 75 and 100 ppm gibberellin treatments, which directly affected fruit set, were excluded from the analysis, fruit set percentage was not influenced by floral density. This pattern was consistent across a wide range of flowering densities, from 40 to 250 flowers per square centimeter of branch. This finding is consistent with those reported for peach (15). Consequently, a positive linear relationship was evident between floral density and fruit yield in the ‘d’Agen’ plum trees ($y = 0.1496x + 1.65$; $r^2 = 0.86$).

To achieve a yield of between 20,000 and 25,000 kg ha^{-1} (30–35 kg per tree) for ‘d’Agen’ plums, it is necessary to have a crop load of between 2,000 and 2,500 fruits per plant. This corresponds to an average fruit size of approximately 29 mm or between 16.0 and 16.5 g per fruit, as evidenced by the data obtained in this experiment. These values align with the typical dimensions of a small plum, and achieving at least 20 grams per fruit is necessary to reach the medium size category.

To reach the target yield components mentioned above, a floral density of over 150 flowers per cm^2 of branch is required. The lowest gibberellin dose used in the present study (25 ppm) resulted in a reduction in floral density of approximately 60%, with values falling below 100 flowers per cm^2. This is insufficient to achieve the anticipated yield components. Therefore, reducing floral density to improve fruit size of ‘d’Agen’ plum without a significant reduction in yield would require the use of a gibberellin concentration lower than 25 ppm, not evaluated in this study.

On the other hand, the most consistent response in increased fruit size was observed with a crop load under 1,000 fruits per tree (figure 5, page 10), insufficient for an acceptable fruit yield. Therefore, the reduction in floral density should be less drastic than that achieved in this study. Moreover, agronomic management should be complemented with practices that promote the final fruit size. These included adjustments to pruning techniques, fertilization, irrigation during critical periods of the crop, and direct techniques aimed at improving fruit size (12).

Conclusions

The reduction of flowering density with gibberellic acid application during the previous growing season allowed the determination that the phenological stage of fruit set (stage H, occurring five weeks after full bloom) corresponds to the moment of floral induction for ‘d’Agen’ plums. Gibberellic acid application effectively reduced floral density and modified fruit size at harvest. However, all tested concentrations excessively reduce the floral density needed to achieve an acceptable fruit yield. Therefore, future research should focus on evaluating gibberellic acid concentrations below 25 ppm, and refining this technique in response to interannual variability.

References

1. Agustí, M.; Reig, C.; Martínez-Fuentes, A.; Mesejo, C. 2022. Advances in Citrus flowering: A review. Frontiers in plant science. 13:868831. DOI: 10.3389/fpls.2022.868831
2. Cerri, M.; Rosati, A.; Famiani, F.; Reale, L. 2019. Fruit size in different plum species (genus *Prunus* L.) is determined by postbloom developmental processes and not by ovary characteristics at anthesis. Scientia Horticulturae. 255: 1-7. DOI:10.1016/j.scienta.2019.04.064
3. Di Rienzo, J. A.; Casanoves, F.; Balzarini, M. G.; González, L.; Tablada, M.; Robledo, C. W. 2020. InfoStat 2020. Centro de Transferencia InfoStat. FCA. Universidad Nacional de Córdoba. Argentina. http://www.infostat.com.ar
4. Drepper, B.; Bamps, B.; Gobin, A.; Van Orshoven, J. 2021. Strategies for managing spring frost risks in orchards: effectiveness and conditionality-A systematic review protocol. Environmental Evidence. 10: 32. DOI:10.1186/s13750-021-00247-7
5. Erogul, D.; Sen, F. 2015. Effects of gibberellic acid treatments on fruit thinning and fruit quality in Japanese plum (*Prunus salicina* Lindl.). Scientia Horticulturae. 186: 137-142. DOI:10.1016/j.scienta.2015.02.019
6. Giovanaz, M. A.; Fachinello, J. C.; Spagnol, D.; Weber, D.; Carra, B. 2016. Gibberellic acid reduces flowering and time of manual thinning in "Maciel" peach trees. Revista Brasileira de Fruticultura. 38(2): e-692. DOI:10.1590/0100-29452016692
7. IDR (Instituto de Desarrollo Rural). 2015. Informe por producto: Panorama del Sector Ciruela Deshidratada de Mendoza. Argentina http://www.idr.org.ar/wp-content/uploads/2016/04/Panorama-Ciruela-deshidratada-2015-.pdf/ (Access: 29 April 2025).
8. IDR (Instituto de Desarrollo Rural). 2020. Informe anual: Fenología de frutales 2020. Mendoza. Argentina. https://www.idr.org.ar/fenologia-de-frutales/ (Access: 29 April 2025).
9. IDR (Instituto de Desarrollo Rural). 2021. Censo de ciruela para industria. Producción primaria. Recolección geoespacial de producción primaria e industrial. Mendoza. Argentina https://www.idr.org.ar/wp-content/uploads/2022/10/censo_produccion_ primaria.pdf (Access: 29 April 2025).
10. Kaur, A.; Maness, N.; Ferguson, L.; Deng, W.; Zhang, L. 2021. Role of plant hormones in flowering and exogenous hormone application in fruit/nut trees: a review of pecans. Fruit Research. 1: 15. DOI:10.48130/FruRes-2021-0015
11. Lammerich, S.; Kunz, A.; Damerow, L.; Blanke, M. 2020. Mechanical crop load management (CLM) improves fruit quality and reduces fruit drop and alternate bearing in European plum (*Prunus domestica* L.). Horticulturae. 6: 52. DOI:10.3390/horticulturae6030052
12. Reginato, G.; Sotomayor, J. P. 2020. Cómo cosechar para obtener fruta de calidad en ciruelo europeo. Extension UC Davis Chile. https://www.plataformaextension.cl/ciclos/ciruelo-europeo/ (Access: 29 April 2025).
13. Sidhu, R. S.; Bound, S. A.; Hunt, I. 2022. Crop load and thinning methods impact yield, nutrient content, fruit quality, and physiological disorders in 'Scilate' apples. Agronomy. 12: 1989. DOI:10.3390/agronomy12091989
14. Wang, S.; Wang, Q.; Jiang, W.; Wang, Y.; Yan, J.; Li, X.; Wang, J.; Guan, Q.; Ma, F.; Zhang, J.; Zheng, Q.; Zou, Y.; Xu, J. 2024. Evaluating the sustainable cultivation of 'Fuji' apples: suitable crop load and the impact of chemical thinning agents on fruit quality and transcription. Fruit Research. 4: e009. DOI: 10.48130/frures-0024-0002
15. Yañez Toro, R. M. 2019. Regulación de la carga frutal en duraznero y nectarino (*Prunus pérsica*) cvs. Elegant Lady y Ruby Diamond mediante el uso de giberelinas y su efecto sobre el retorno floral bajo las condiciones de Chile central. Master's thesis, Agronomy and Forest Engineering Course. Pontificia Católica de Chile University.
16. Zhebentyayeva, T.; Shankar, V.; Scorza, R.; Callahan, A.; Ravelonandro, M.; Castro, S.; DeJong, T.; Saski, C. A.; Dardick, C. 2019. Genetic characterization of worldwide *Prunus domestica* (plum) germplasm using sequence-based genotyping. Horticulture Research. 6: 12. DOI:10.1038/s41438-018-0090-6

Acknowledgements

This study was funded by INTA in collaboration with Universidad Nacional del Litoral (CAI+D 2024, 85420240100028LI; and PEICID-2023-045).