Post Petal Fall Applications of Gibberellins Improve Fruit Set on Pear

Jaume Lordan[1,]*, Pere Vilardell[2], Miquel Peris[1], Estanis Torres[1], Simó Alegre[1] , and Luis Asín[1]

[1]IRTA Fruitcentre, PCiTAL, Park of Gardeny, Fruitcentre Building, 25003 Lleida, Spain;

[2]IRTA Mas Badia Field Station, La Tallada de l'Empordà, Girona, 17134, Spain

*Corresponding author: E-mail address: Jaume.lordan@irta.cat

Post Petal Fall Applications of Gibberellins Improve Fruit Set on Pear

Abstract

Commercial pear production has become increasingly difficult over the last decade, with low fruit set being one of the main factors leading to poor yield of pear orchards. The use of gibberellins to increase fruit set has been widely reported, but in most of the cases these applications are made at full bloom or right after a spring frost has occurred. However, the increase in fruit set due to early applications of gibberellins such as at full bloom is often lost at June drop. Aim of this study was to assess dose and timing of different gibberellin applications made after petal fall to improve the final fruit set in pear orchards. Four experiments were conducted during four years (2010-2013) in mature pear orchards with 'Conference' as the scion cultivar. Fruit set and yield were increased when gibberellins were applied after petal fall, with a positive relationship with dose. Applications of GA_{4+7}+BA tended to promote higher fruit set and yield than GA_3, and in addition, they were less dependent to the moment of application. GA_{4+7}+BA showed an additive effect when performing multiple applications. Return bloom was slightly affected when gibberellins were applied after petal fall. The strategy that showed a better behavior to increase fruit set was GA_{4+7}+BA at 500 $mL \cdot ha^{-1}$ at H+14, which coincides with the weeks of the natural fruit drop.

Keywords: Abscission; fruit weight; GA_3, GA_{4+7}, *Pyrus communis;* return bloom; yield

Introduction

Pear (*Pyrus* spp.) is widely cultivated around the world, and can be consumed both fresh and dry (Ceylan et al., 2018; Çolak, 2018; Okatan et al., 2017). Commercial pear production has become increasingly difficult over the last decade, with low fruit set being one of the main factors leading to poor yield of pear orchards (Webster, 2002). Furthermore, even when fruit set seems to be good through self-pollination, most of the fruitlets can abscise shortly after setting (Warnier, 2000). In addition, fruitlet abscission on young trees is particularly severe (Webster, 2002). Italy and Spain are the most important pear (*Pyrus communis* L.) producing countries in Europe (Deckers and Schoofs, 2008). While 'Conference' is the second most important cultivar grown in Italy (Deckers and Schoofs, 2008); it is the most important cultivar grown in Spain (Iglesias and Casals, 2013), and in Northern Europe, with 80% of the acreage in the Netherlands (Heijerman et al., 2015), and 85% in Belgium (Vercammen, 2014). The achieved yield of pear orchards in Spain tends to be significantly lower than in other countries such as Belgium and the Netherlands, and it is assumed that this is caused by a poor fruit set.

Competition for resources between fruitlets and the actively growing shoots has been suggested to induce fruitlet abscission (Webster, 2002). In situations of poor setting, the first approach that is usually adopted is the use of plant growth regulators (PGRs). The options are diverse, and include gibberellins (GA_3, GA_{4+7} formulates), auxin-like substances (IAA, NAA and NAAm), cytokinins (zeatin-related and adenine-related molecules, kinetin and 6-BA), ethylene inhibitors (aminoethoxyvinilglycine), growth control regulators (prohexadione-Ca), and even the use of anti-gibberellin formulates (Carra et al., 2018; Costa, 2017; Pasa et al., 2017a; Vercammen et al., 2015; Webster, 2002).

The use of gibberellins to increase fruit set has been widely reported, but in most of the cases these applications are made at full bloom or right after a spring frost has occurred (Costa, 2017; Deckers and Daemen, 1996; Deckers and Schoofs, 2000; Lafer, 2008; Ozturk and Askin, 2015; Pasa et al., 2017b; Silva et al., 2010; Yarushnykov and Blanke, 2007). However, the increase in fruit set due to early applications of gibberellins such as at full bloom is often lost at June drop (Vercammen et al., 2015).

The goal of this study was to assess dose and timing of different gibberellin applications made after petal fall to improve the final fruit set in pear orchards.

Materials and methods

Experiments 1-3

Three field trials were conducted during three years (2010-2012) at the experimental station of IRTA (Institute of Research and Technology, Food and Agriculture) in Gimenells, Spain (41°39'22.25"N; 0°23'25.37"E), where we compared different timing and dose applications of gibberellic acid (Arabelex L®, GA_3 1.6%, Aifar Agrochimica S.R.L., Genova, Italia) and benzyladenine (BA) plus GA_{4+7} (Promalin®, a mixture of 1.9% BA and 1.9% GA_{4+7}, Valent BioSciences LLC., Libertyville, IL, USA) to improve fruit set on pear trees. The experiments were conducted in a mature pear orchard planted in 1994 with 'Conference' as the scion cultivar grafted on Quince BA-29 rootstock. Planting distance was 4 m × 1.5 m (1667 trees/ha). The experiments were organized in a randomized complete block design with four replications, with each experimental unit being a section of four trees. For each replication data was collected on those two central trees that were more homogeneous and representative of each experimental unit. In year 1 (Experiment 1), treatments included GA_3 at 1 g and 2 g of active ingredient per ha applied at petal fall (H) plus 7, 14, and 21 days (H+7, H+14, H+21, respectively) (Fleckinger, 1964) (Table 1). In year 2 (Experiment 2), treatments included GA_3 at 1 g and 2 g of active ingredient per ha and Promalin® at 500 $mL \cdot ha^{-1}$ applied at H+7, H+14, H+21, H+7 & H+14, H+14 & H+21 (Table 1). In year 3 (Experiment 3), treatments included GA_3 at 2 g of active ingredient per ha and Promalin® at 250 $mL \cdot ha^{-1}$ and 500 mL·ha^{-1} applied at H+7, H+14, and H+21 (Table 1). Control trees were not sprayed whatsoever.

Experiment 4

Four field trials were conducted in 2013 in four commercial orchards at Tornabous, Spain (41°41'59.41"N; 1°03'09.46"E), Puigverd d'Agramunt, Spain (41°46'37.05"N; 1°07'17.44"E), Bellpuig, Spain (41°37'31.56"N; 1°00'43.02"E), and Castellnou de Seana, Spain (41°38'52.74"N; 0°58'13.55"E), where we compared applications of benzyladenine (BA) plus GA_{4+7} (Promalin®, a mixture of 1.9% BA and 1.9% GA_{4+7}, Valent BioSciences LLC., Libertyville, IL, USA) at 500 mL·ha^{-1} applied at H+7, H+14, H+21, and H+7 & H+14 & H+21 (Table 1). The experiments were conducted in mature pear orchards with 'Conference' as the scion cultivar grafted on Quince BA-29 rootstock. Tornabous was planted in 1998 at 4 m × 1.2 m, Puigverd d'Agramunt was planted in 2006 at 4 m × 1.1 m, Bellpuig was planted in 1998 at 4 m × 1.5 m, and Castellnou de Seana was planted in 2001 at 3.8 m × 1.5 m. The experiments were organized in a randomized complete block design with four replications, with each experimental unit being a section of four trees. For each replication data was collected on those two central trees that were more homogeneous and representative of each experimental unit. Control trees were not sprayed whatsoever.

PGR application and Data Collection

All the chemical treatments were applied with a handgun sprayer until run-off. The spray volumes were 1000 L·ha^{-1}. Trees were drip-irrigated (climate is semi-arid Mediterranean, with a mean annual rainfall of 350 mm). Climatic variables such as maximum temperature (Tmax, ºC), minimum temperature (Tmin, ºC), and relative humidity (RH, %) were obtained from the closest automatic weather station in Gimenells, Spain (Table 2). Plots were managed within IPM management according to industry standards.

For each experiment, the following data was recorded for each single tree: (1) number of flower clusters, (2) fruit number, (3) yield, and (4) return bloom.

Fruit set was calculated from the final number of fruit per tree and the initial number of flower clusters per tree. All harvested fruit from each tree were graded for fruit weight and caliper distribution by a weight sizer machine (MAF RODA Iberica, Alzira, Spain). Return bloom was measured the following spring, by counting the total number of flower clusters per tree.

Data Analysis

Response variables were modeled using linear mixed effect models. A first analysis was carried out, then subsequent analyses were performed taking into account significance of interactions. Mixed models including treatment as fixed factor and block as random factor were built to separate treatment effects for flower number, fruit set, yield, fruit weight, percentage of yield >60 mm, percentage of yield >65 mm, and return bloom. For all the models, when the main effect (treatment) was significant, comparisons among treatments were made by Tukey’s HSD test at P values ≤ 0.05. Residual analysis (normal distribution of residuals) was performed to insure that model assumptions were met. Data were analyzed using the JMP statistical software package (Version 12; SAS Institute Inc., Cary, NC).

Results

Experiment 1

The initial number of flower clusters per tree was very similar for all the trees, with no significant differences among treatments (Table 3). Fruit set was increased when increasing the dose, and the highest values were when the application was made 14 days after petal fall, followed by 7 days after, and the lowest value for 21 days after. The highest fruit set was when GA_3 was applied at 2 g·ha^{-1} at 14 days and 7 days after petal fall (69 and 60, respectively), followed by 1 g·ha^{-1} at +14 days (58), and +7 days (44). The lowest values were for 21 days after petal fall at either 1 g·ha^{-1} or 2 g·ha^{-1} (42 or 40, respectively), and for untreated control trees (40).

Yield was similarly affected as fruit set, highest yields were for highest dose and when was applied at 14 or 7 days after petal fall. The highest yield was for GA_3 applied at 2 g·ha^{-1} at 14 days after petal fall (30 kg), followed by 2 g·ha^{-1} at H+7 (27 kg), and 1 g·ha^{-1} at H+14. Fruit weight was inversely affected than fruit set, the lowest dose had the largest fruit (145 g *vs* 138 g), and H+14 had smaller fruit (132 g) than when the GA_3 was applied at either H+7 (143 g) or H+21 (149 g). The largest fruit were for untreated control trees (158 g), for GA_3 at 1 g·ha^{-1} at H+7 (152 g), and for GA_3 at 2 g·ha^{-1} at H+21 (151 g). The smallest fruit were for GA_3 at 2 g·ha^{-1} at H+14 (129 g). GA_3 at 2 g·ha^{-1} at H+7 had 135 g fruit on average.

The percentage of fruit larger than 60 mm and 65 mm was similarly affected than fruit weight. The higher the dose the lower the value, whereas H+14 had lower values than H+21. The highest percentage of fruit higher than 60 mm was for untreated control trees (81%), followed by GA_3 at 1 g·ha^{-1} at H+7 (79%), with no significant differences with GA_3 at 2 g·ha^{-1} at H+7 (71%). GA_3 at either 1 g·ha^{-1} or 2 g·ha^{-1} at H+14 had the lowest values. None of the treatments statistically affected return bloom in the following year.

Experiment 2

The initial number of flower clusters per tree was very similar for all the trees, with no significant differences among treatments (Table 4). There were no significant differences for dose and time regarding fruit set, yield, fruit weight, and return bloom when GA_3 was applied.

Fruit set was increased when GA_{4+7} + BA was applied three times (350), and the lower values were when it was applied once at H+21 (230). The highest fruit set were when GA_{4+7} + BA was applied three times in the same season (350) and when applied at H+7 (258); however, this last treatment had no significant differences with control trees (171). No significant differences regarding yield were observed; however, there was a trend for higher yields when GA_{4+7} + BA was applied three times (43 kg) or only once at H+14 (42 kg) and H+21 (41 kg).

Fruit weight was significantly affected depending on the time that GA_{4+7} + BA was applied. The largest fruit were for H+14 (124 g), followed by H+21 (120 g), H+7 (109 g), and the smallest fruit when it was applied three times in one season (97 g). Control trees had the largest fruit (146 g), a second group with similar fruit weight comprised all the GA_3 treatments and GA_{4+7} + BA at H+14 and H+21. GA_{4+7} + BA at H+7 and when applied three times had the smallest fruit of all the treatments.

Control trees, GA_3 applied two times at 1 $g{\cdot}ha^{-1}$, GA_3 at 2 $g{\cdot}ha^{-1}$ H+21, and GA_{4+7} + BA at H+14 had the highest percentage of fruit larger than 60 mm or 65 mm, whereas the lowest values were when GA_{4+7} + BA was applied three times at H+7, H+14, and H+21. Return bloom was not affected for any of the treatments whatsoever.

Experiment 3

The initial number of flower clusters per tree, fruit set, and yield were very similar for all the trees, with no significant differences among treatments (Table 5). The largest fruit were observed when GA_3 was applied at H+14 (128 g), followed by H+7 (119 g), and the smallest fruit for H+21 (116 g).

GA_{4+7} + BA at H+7 had the highest percentage of fruit larger than 65 mm (32%), followed by H+21 (28%), and H+14 with the lowest values (22%). Control trees, GA_3 at 2 g·ha^{-1} H+14, and GA_{4+7} + BA at 250 mL·ha^{-1} at H+7 had the highest percentage of yield with fruits larger than 65 mm (35%), whereas lower values were associated when GA_{4+7} + BA was applied either at 250 or 500 mL·ha^{-1} at H+14 (21% or 23%, respectively). None of the treatments statistically affected return bloom in the following year.

Experiment 4

The initial number of flower clusters per tree was very similar for all the trees, with no significant differences among treatments (Table 6). For all the sites, fruit set was highest when applied three times in one season. In Bellpuig, control trees had the lowest fruit set, followed by H+21, and then higher values for H+7 an H+14, with no significant differences with H+7+14+21. A similar pattern was observed in Castellnou de Seana, with the lowest fruit set for control trees, H+7 and H+21. In Puigverd d'Agramunt differences among treatments were less apparent. Fruit set was highest when GA_{4+7} + BA was applied three times, with the lowest value for control trees. In Tornabous, there were no significant differences between control trees or when GA_{4+7} + BA was applied once at H+7, H+14, or H+21.

Control trees had significantly less yield than GA_{4+7} + BA applied three times in Bellpuig. In Castellnou de Seana, both GA_{4+7} + BA at H+14 and H+7+14+21 had higher yield than control trees (25 kg and 28 kg *vs* 21 kg, respectively). In Puigverd d'Agramunt, both GA_{4+7} + BA at H+7 and H+7+14+21 had higher yield than control trees (21 kg and 23 kg *vs* 14 kg, respectively). There were no significant differences among treatments in Tornabous.

Fruit weight was similarly affected in all four sites. Overall, the largest fruit were for control trees, then there was a group comprised for H+7, H+14, and H+21. The smallest fruit were observed when GA_{4+7} + BA was applied three times in one season. A similar pattern was observed for percentage of fruit larger than 60 mm or 65 mm. The highest percentage was for control trees, whereas three applications in one season had the lowest. Return bloom was affected by the treatments, but it varied depending on the site. In Bellpuig, the highest return bloom was for control trees, followed by one application of GA_{4+7} + BA, and then when three applications were made in one season had the lowest values. A similar pattern was observed in Castellnou de Seana, but with no significant differences among H+7 and H+14 *vs* H+7+14+21 in this case. In Puigverd d'Agramunt return bloom for control trees was not statistically different than when one single application of GA_{4+7} + BA was done. In Tornabous, the highest return bloom was for GA_{4+7} + BA at H+7 (204), followed by control trees (182), H+21 (170), H+14 (139), and H+7+14+21 with the lowest value (129).

Discussion

Fruit set and yield were increased when gibberellins were applied after petal fall, with a positive relationship with dose. The use of gibberellins to increase fruit set has been widely reported, but in most of the cases these applications are made at full bloom or right after a spring frost has occurred (Costa, 2017). Sprays of GA_3 and GA_{4+7}+BA up to 4 days after a frost damage have been reported to increase fruit set in 'Conference' (Deckers and Schoofs, 2000). In some cases, fruit set increase on 'Durondeau' and 'Conference' pears has been reported when applications were even made at green cluster after a frost event (Deckers and Daemen, 1996). Vercammen et al. (2015) suggested that the increase in fruit set due to early applications of gibberellins is often lost at June drop. To our knowledge, there are no studies that have reported use of gibberellins sprayed after petal fall to increase fruit set. Yarushnykov and Blanke (2007) reported increased fruit set when combined applications of GA_3 and GA_{4+7} were done at full bloom or before, but still 25%

of the fruitlets were lost during the June drop. On the other hand, Lafer (2008) did not report an increase in yield when 10 mg·L^{-1} of GA_3 were applied at full bloom on 'Williams', and Vercammen and Gomand (2008) did not see any significant increase when either GA_3 or GA_{4+7} were sprayed at full bloom on 'Conference' pears. Full bloom applications of GA_{4+7}+BA did not increase fruit set on 'Garber' pears either (Silva et al., 2010). Use of other hormones such as thidiazuron (TDZ) at full bloom has been reported to increase fruit set in 'Packham's Triumph' pears (Pasa et al., 2017b). Furthermore, application of growth regulators such as prohexadione-Ca at 2-3 weeks after full bloom have been reported to increase fruit set on 'Conference' pears (Vercammen and Gomand, 2008). It is thought that fruit abscission in pear is stimulated by ethylene, often produced in response to some type of stress (Webster, 2002). Therefore, biosynthesis ethylene inhibitors could play a role in fruit set. In this regard, applications of aminoethoxyvinilglycine (AVG) two weeks after full bloom were reported to increase fruit set in 'Packham's Triumph' pears (Dussi et al., 2000). Pasa et al. (2017a) reported that AVG sprays on 'Rocha' pears at both one and two weeks after full bloom increased fruit set, but late applications after petal fall have not been reported.

Gibberellin sprays after petal fall did increase fruit set in our study, and these applications were made in the weeks prior to the natural fruit drop or at the beginning, so that fruit loss was reduced. The best results were when applied at H+14. Applications at H+7 had similar results to those performed at H+14, but lower fruit set and yield was observed when sprays were made at H+21. Applications of GA_{4+7}+BA tended to have higher fruit set and yield than GA_3, and in addition, they were less dependent to the moment of application. GA_{4+7}+BA showed an additive effect when performing multiple applications. In this sense, three sprays (H+7, H+14, H+21) doubled the fruit set when comparing to control trees. The increase in fruit set with single sprays of GA_{4+7}+BA reached a maximum of 124% (Experiment 4 in Puigverd d'Agramunt), and in addition they also implied, in many cases, significant increase in yield. In the case of GA_{4+7}+BA, a maximum increase in yield of 36% was achieved (Experiment 4 in Puigverd d'Agramunt), although the average was significantly lower. The fact that there were higher differences in fruit set than in yield is due to the loss of fruit weight. This implies that in some situations, use of gibberellins to increase fruit set may be less valuable due to the reduction in fruit size. However, in most of the cases, the final economic value was higher when gibberellins after petal fall were applied. The final fruit size of pears at harvest is determined by both cell division and cell expansion within the fruits, and most cell division occurs in the first few weeks following flower fertilization, which is thought to be influenced by the relative sink strength of the fruit and the availability and efficiency of the supply of assimilates and nutrients to it (Webster, 2002). In a recent study with apple (*Malus* × *domestica* Borkh.), natural fruitlet abscission was highly correlated to the initial number of flower clusters per tree, indicating the greatest impact of flower density on carbohydrate balance (Lordan et al., 2019). All of the performed experiments in our study where within a radius <50 km, with no important differences in terms of climatic data (data not shown). In addition, when comparing within the same location, the maximum difference that we observed among years was ~2 units for either ºC or % RH (in April when the treatments were sprayed). Therefore, it is difficult for us to evaluate how these treatments would be affected by different climate regimes, since differences among years seemed more related to the initial number of flower clusters per tree than weather parameters, affecting the aforementioned carbohydrate balance.

Gibberellins have been reported to increase sink demand in Japanese pear (*Pyrus pyrifolia*, cultivar 'Kousui'), which induces changes in activities of sugar metabolizing enzymes, improving fruit size (Zhang et al., 2007). In another study, Zhang et al. (2005)

reported gibberellin applications during the rapid fruit growth period to increase carbon partitioning to the fruit. In our study, when gibberellins were applied more than once in one season, yield and fruit set were so high that fruit weight was significantly compromised. In addition, fruit weight tended to be larger for control trees than when gibberellins were applied. Therefore, in situations where fruit set and yield are increased by application of hormones, irrigation and nutrition should be also improved in order to not compromise fruit growth. Shackel et al. (1999) reported that water deficit by only 65% of evapotranspiration (ET) caused significant reductions in fruit growth. A slight increase in fruit weight by nitrogen fertilization was also reported by Toselli et al. (1998). Therefore, since cell expansion is mostly influenced by the availability of water to the tree (Webster, 2002), significant increases in fruit set must be foreseen in order to adjust the irrigation and fertilization program to maximize fruit weight.

In some studies, the use of gibberellins have been reported to affect fruit shape (Herrero, 1988; Vercammen et al., 2015); however, we did not see any difference when comparing with control trees (data not shown). Yarushnykov and Blanke (2007) did not see significant increase in abnormal fruit shape when spraying GA_3 and GA_{4+7} on ‘Alexander Lucas’ pears. Similarly, Deckers et al. (2000) reported good fruit shape when GA_3 and GA_4 were applied on ‘Conference’ pears.

Return bloom is another facet that needs to be taken into consideration. In our study, return bloom was slightly affected when gibberellins were applied after petal fall. However, return bloom was considerably reduced when doing three sprays in the same season. Conversely, with the exceptions of two locations in Experiment 4, we did not see significant differences with control trees in terms of return bloom when only one application per season was made. Actually, the number of fruit per tree the following year was similar for all the locations of Experiment 4 (data not shown). In previous studies, it has been concluded that losses in the return bloom of 20-30% do not affect the final production of trees (unpublished data). Deckers and Schoofs (2000) reported that GA_3 severely reduced return bloom when applied at full bloom, whereas GA_{4+7} had less negative effect. Yarushnykov and Blanke (2007) observed slightly less return bloom, but differences were not significant with control trees. In another study, return bloom was not affected by GA_3 when applied at full bloom on 'Williams' pears (Lafer, 2008).

This new approach to improve fruit set in pears is still compatible with the current management strategy that growers are using, so they can combine applications at bloom or before with applications of gibberellins after petal fall.

In conclusion, the strategy that showed a better behavior to increase fruit set was GA_{4+7}+BA at 500 $mL \cdot ha^{-1}$ at H+14, which coincides with the weeks prior the start of the natural fruit drop or just after its start. It is worth mention to discard repeated applications since they cause excessive fruit set, which can greatly reduce fruit weight. When expecting important increase of fruit set, orchard management must be optimized in order to reduce the loss of fruit size by increasing the number of fruit per tree. Special attention should be addressed to fertigation and hand thinning to eliminate any fruit that will not reach 55 mm.

Acknowledgements

The authors have declared that no competing interests exist. This study was partially financed by project *INIA RTA03-030-C2-2* and *PRODUPERA-Millora de la productivitat de pera Conference', operació 01.02.01 del PDR de Catalunya 2014-2020*. We thank Ignasi Bros, Josep M. Torres, Marc Franquesa, Josep Anton Teixidor and Jaume Badia for all the resources invested in this trial.

References

Carra, B., M.S. Pasa, C.P. da Silva, C.V. do Amarante, C.A. Steffens, V.A. Bartnicki, M.N. Ciotta, P.C. Mello-Farias, and T. Einhorn. 2018. Early spring inhibition of ethylene synthesis increases fruit set and yield of ‘Rocha’pear trees in Southern Brazil. Scientia Horticulturae 232, 92-96.

Ceylan, F., M.G. Akpınar, A.-M. Cherciov, B. Özkan, and M. Gül. 2018. Consumer preferences of organic products for Romania. International Journal of Agriculture, Forestry and Life Sciences 2(2), 47-55.

Çolak, A. 2018. Present condition of apple production in Usak province. International Journal of Agriculture, Forestry and Life Sciences 2(2), 189-193.

Costa, G. 2017. Bioregulators Application in Pear Production. Innovation in Fruit Growing Belgrade, Serbia.

Deckers, T. and E. Daemen. 1996. Effect of GA3, GA4/7 on fruit set and fruit quality of the pear cultivars Conference and Durondeau. Acta Horticulturae 423, 229-236.

Deckers, T., E. Daemen, and D. Vermeiren. 2000. Amelioration de la mise à fruits chez Conferénce sur des arbres jeune. Comparaison des resultats aux gibbérellins GA3 and GA4. Le Fruit Belge 483, 51-55.

Deckers, T. and H. Schoofs. 2000. Improvement of fruit set on young pear trees cultivar Conference with gibberellins. Acta Horticulturae 596, 735-743.

Deckers, T. and H. Schoofs. 2008. Status of the pear production in Europe. Acta Horticulturae 800, 95-106.

Dussi, M., D. Sosa, and G. Calvo. 2000. Effects of Retain™ on fruit maturity and fruit set of pear cultivars Williams and Packham’s Triumph. Acta Horticulturae 596, 767-771.

Fleckinger, J. 1964. Le bon jardinier. La maison rustique. Paris, 362-372.

Heijerman, G., P. Roelofs, and M.J. Groot. 2015. Profitability of the Dutch growing system of 'Conference'. Acta Horticulturae 1094, 233-238.

Herrero, M. 1988. Fruit shape as a response to time of GA3 treatment in 'Agua de Aranjuez' pear. Acta Horticulturae 256, 127-132.

Iglesias, I. and E. Casals. 2013. Evolución de la producción de pera en España y análisis del mercado. Vida rural 367, 36-43.

Lafer, G. 2008. Effects of different bioregulator applications on fruit set, yield and fruit quality of 'Williams' pears. Acta Horticulturae 800, 183-187.

Lordan, J., G. Reginato, A. Lakso, P. Francescatto, and T. Robinson. 2019. Natural fruitlet abscission as related to apple tree carbon balance estimated with the MaluSim model. Scientia Horticulturae 247, 296-309.

Okatan, V., M. Polat, S. Ercisli, and M.A. Askin. 2017. Some pomological and chemical properties of local pear varieties in Usak, Turkey. SCIENTIFIC PAPERS-SERIES B-HORTICULTURE 61, 11-13.

Ozturk, G. and M.A. Askin. 2015. Various gibberellin treatments on parthenocarpic fruit development in 'Deveci' and 'Ankara' pear cultivars. Acta Horticulturae 1094, 373-382.

Pasa, M.D., B. Carra, C.P. da Silva, M.N. Ciotta, A.F. Brighenti, and A.J. Pereira. 2017a. Early spring application of Aminoethoxyvinilglycine (AVG) increases fruit set and yield of ‘Rocha’ pears. Revista Brasileira De Fruticultura 39(4).

Pasa, M.S., C.P. SILVA, B. Carra, A.F. Brighenti, A.L.K. SOUZA, and J.L. Petri. 2017b. Thidiazuron (TDZ) increases fruit set and yield of ‘Hosui’ and ‘Packham’s Triumph’ pear trees. Anais da Academia Brasileira de Ciências 89(4), 3103-3110.

Shackel, K., D. Ramos, L. Schwankl, E. Mitcham, S. Weinbaum, R. Snyder, W. Biasi, and G. McGourty. 1999. Effect of water and nitrogen on pear size and quality. Good Fruit Grower 50, 34-34.

Silva, J.B., A.G. Neto, D. Pazzin, J.C. Fachinello, and C.L. Giacobbo. 2010. Fruit set of pear fruits 'Garber' in the different fruiting organs regarding quadrant, pruning, girdling, bending and chemical treatments. Acta Horticulturae 872, 289-294.

Toselli, M., C. Zavalloni, B. Marangoni, M. Tagliavini, D. SCUDELLARI, and G. Andreini. 1998. Effetto dell’epoca di concimazione azotata e dei trattamenti di calcio sulla qualità delle pere conference. Frutticoltura, Bologna 9, 45-48.

Vercammen, J. 2014. Comparison of different planting systems for 'Conference'. Acta Horticulturae 1058, 37-43.

Vercammen, J. and A. Gomand. 2008. Fruit set of 'Conference': a small dose of gibberellins or Regalis. Acta Horticulturae 800, 131-138.

Vercammen, J., A. Gomand, and D. Bylemans. 2015. Improving the fruit set of 'Conference' with gibberellins or Regalis. Acta Horticulturae 1094, 257-264.

Warnier, O. 2000. Quelle est l’intérêt d’une pollinisation croisée en Conférence. Fruit Belge 484, 47-50.

Webster, A. 2002. Factors influencing the flowering, fruit set and fruit growth of European pears. Acta Horticulturae 596, 699-709.

Yarushnykov, V.V. and M.M. Blanke. 2007. Alleviation of frost damage to pear flowers by gibberellin. Acta Horticulturae 732, 659-663.

Zhang, C., K. Tanabe, F. Tamura, A. Itai, and M. Yoshida. 2007. Roles of gibberellins in increasing sink demand in Japanese pear fruit during rapid fruit growth. Plant Growth Regulation 52(2), 161-172.

Zhang, C., K. Tanabe, F. Tamura, K. Matsumoto, and A. Yoshida. 2005. 13C-photosynthate accumulation in Japanese pear fruit during the period of rapid fruit growth is limited by the sink strength of fruit rather than by the transport capacity of the pedicel. J. Exp. Bot. 56(420), 2713-2719.

Table 1. List of experiment number, year, location, and treatments performed for the different fruit set trials. Note that GA_3 (gibberellic acid) dose refers to active ingredient, whereas for GA_{4+7} plus BA (Promalin®) refers to the commercial product. Petal fall (H) (Fleckinger, 1964) plus 7, 14, or 21 days after.

Experiment #	Year	Location	Treatments
1	2010	Gimenells	GA_3 1 g·ha^{-1} at H+7
			GA_3 1 g·ha^{-1} at H+14
			GA_3 1 g·ha^{-1} at H+21
			GA_3 2 g·ha^{-1} at H+7
			GA_3 2 g·ha^{-1} at H+14
			GA_3 2 g·ha^{-1} at H+21
			Untreated control
2	2011	Gimenells	GA_3 2 g·ha^{-1} at H+7
			GA_3 2 g·ha^{-1} at H+14
			GA_3 2 g·ha^{-1} at H+21
			GA_3 1 g·ha^{-1} at H+7 & H+14
			GA_3 1 g·ha^{-1} at H+14 & H+21
			GA_3 2 g·ha^{-1} at H+7 & H+14
			GA_3 2 g·ha^{-1} at H+14 & H+21
			GA_{4+7}+BA 500 mL·ha^{-1} at H+7
			GA_{4+7}+BA 500 mL·ha^{-1} at H+14
			GA_{4+7}+BA 500 mL·ha^{-1} at H+21
			GA_{4+7}+BA 500 mL·ha^{-1} at H+7, H+14 & H+21
			Untreated control
3	2012	Gimenells	GA_3 2 g·ha^{-1} at H+7
			GA_3 2 g·ha^{-1} at H+14
			GA_3 2 g·ha^{-1} at H+21
			GA_{4+7}+BA 250 mL·ha^{-1} at H+7
			GA_{4+7}+BA 250 mL·ha^{-1} at H+14
			GA_{4+7}+BA 250 mL·ha^{-1} at H+21
			GA_{4+7}+BA 500 mL·ha^{-1} at H+7
			GA_{4+7}+BA 500 mL·ha^{-1} at H+14
			GA_{4+7}+BA 500 mL·ha^{-1} at H+21
			Untreated control
4	2013	Tornabous, Puigverd d'Agramunt, Bellpuig & Castellnou de Seana	GA_{4+7}+BA 500 mL·ha^{-1} at H+7
			GA_{4+7}+BA 500 mL·ha^{-1} at H+14
			GA_{4+7}+BA 500 mL·ha^{-1} at H+21
			GA_{4+7}+BA 500 mL·ha^{-1} at H+7, H+14 & H+21
			Untreated control

Table 2. Average monthly maximum and minimum temperature (ºC) and relative humidity (RH, %) in 2010-2013, and mean ± SD over all four years in Gimenells, Spain.

	Tmin (ºC)				Tmax (ºC)				RH (%)						
Month	**2010**	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**	**Mean±SD Tmin (ºC)**	**Mean±SD Tmax (ºC)**	**Mean±SD RH (%)**
January	1.5	-0.6	-1.0	0.4	9.2	8.5	9.9	10.4	79.2	84.8	81.8	80.3	0.1 ± 1.1	9.5 ± 0.9	81.5 ± 2.5
February	0.6	1.0	-3.4	0.8	10.9	14.3	12.4	12.4	73.2	73.5	51.9	68.0	-0.3 ± 2.1	12.5 ± 1.4	66.6 ± 10.2
March	3.3	4.5	3.1	4.8	15.3	16.4	19.4	16.0	67.8	71.9	55.7	70.5	3.9 ± 0.9	16.8 ± 1.8	66.5 ± 7.4
April	7.1	8.6	6.8	6.2	20.2	23.4	18.8	18.9	67.4	66.3	62.9	65.3	7.2 ± 1.0	20.3 ± 2.1	65.5 ± 1.9
May	9.5	11.4	11.6	7.7	22.9	26.9	26.3	20.5	61.0	62.0	59.1	65.7	10.0 ± 1.9	24.1 ± 3.0	61.9 ± 2.8
June	13.6	14.3	15.5	12.4	28.0	28.7	31.2	27.2	62.1	57.7	52.5	59.0	14.0 ± 1.3	28.8 ± 1.7	57.8 ± 4.0
July	18.2	16.0	16.3	17.7	33.5	30.2	31.3	32.7	54.3	55.8	56.5	58.4	17.1 ± 1.1	31.9 ± 1.5	56.2 ± 1.7
August	16.2	17.6	18.3	16.5	31.3	32.5	33.8	30.2	58.0	58.5	54.8	63.1	17.1 ± 1.0	32.0 ± 1.5	58.6 ± 3.4
September	13.0	14.2	13.1	12.8	26.5	29.8	27.2	27.5	65.6	63.2	63.5	65.6	13.3 ± 0.6	27.8 ± 1.4	64.5 ± 1.3
October	8.0	9.1	9.7	10.5	20.8	23.3	22.1	23.8	70.3	69.1	75.3	70.6	9.3 ± 1.1	22.5 ± 1.4	71.4 ± 2.7
November	3.0	8.0	4.9	4.2	14.2	15.5	14.4	14.9	75.4	86.0	83.1	69.9	5.0 ± 2.1	14.7 ± 0.6	78.6 ± 7.3
December	-0.2	1.6	0.8	-0.4	9.2	11.3	11.3	7.4	76.5	80.2	80.2	87.3	0.5 ± 0.9	9.8 ± 1.9	81.1 ± 4.5

Table 3. Number of flower clusters per tree (Flower #), fruit set (final fruit number/flower cluster), yield (kg/tree), fruit weight (g), percentage of yield >60 mm, percentage of yield >65 mm, and return bloom for each combination of GA_3 dose and time (7, 14, or 21 days after petal fall) on 'Conference' pear trees (Experiment 1). Note that GA_3 (gibberellic acid) dose refers to active ingredient (1g·ha^{-1} or 2 g·ha^{-1}). Petal fall (H) (Fleckinger, 1964). Return bloom was measured the following spring, by counting the total number of flower clusters per tree. Grey bars represent variable value. Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). [NS]Nonsignificant at $P \leq 0.05$.

Hormone	Dose	Time	Treatment	Flower #	Fruit set	Yield (kg)	Fruit weight (g)	Yield >60 mm (%)	Yield >65 mm (%)	Return bloom
GA_3	1 g			336	48 B	22 B	145 A	75 A	55	175
	2 g			342	56 A	26 A	138 B	71 B	50	168
	P			NS	0.0071	0.0161	0.0386	0.0208	NS	NS
		H+7		339	52 B	24 A	143 A	75 A	54 AB	136
		H+14		338	64 A	27 A	132 B	67 B	46 B	163
		H+21		340	41 C	20 B	149 A	77 A	57 A	215
		P		NS	<0.0001	0.0005	<0.0001	<0.0001	0.0048	NS
			Control	349	40 C	21 B	158 A	81 A	64 A	193
			GA_3 1 g at H+7	335	44 BC	22 B	152 AB	79 A	61 AB	138
			GA_3 1 g at H+14	338	58 AB	25 AB	135 BC	69 BC	48 BCD	182
			GA_3 1 g at H+21	337	42 C	20 B	147 AB	77 AB	55 ABCD	204
			GA_3 2 g at H+7	345	60 A	27 AB	135 BC	71 ABC	46 CD	132
			GA_3 2 g at H+14	339	69 A	30 A	129 C	64 C	45 D	144
			GA_3 2 g at H+21	344	40 C	20 B	151 AB	77 AB	59 ABC	226
			P	NS	<0.0001	0.0003	<0.0001	<0.0001	0.0002	NS

Table 4. Number of flower clusters per tree (Flower #), fruit set (final fruit number/flower cluster), yield (kg/tree), fruit weight (g), percentage of yield >60 mm, percentage of yield >65 mm, and return bloom for each combination of GA_3 or GA_{4+7} + BA dose and time (7, 14, or 21 days after petal fall) on 'Conference' pear trees (Experiment 2). Note that GA_3 (gibberellic acid) dose refers to active ingredient ($1 g \cdot ha^{-1}$ or $2 g \cdot ha^{-1}$), whereas for GA_{4+7} + BA (Promalin®) refers to the commercial product ($500 mL \cdot ha^{-1}$). Petal fall (H) (Fleckinger, 1964). Return bloom was measured the following spring, by counting the total number of flower clusters per tree. Grey bars represent variable value. Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). [NS]Nonsignificant at $P \leq 0.05$.

Hormone	Dose	Time	Treatment	Flower #	Fruit set	Yield (kg)	Fruit weight (g)	Yield >60 mm (%)	Yield >65 mm (%)	Return bloom
GA_3	1 g			143	206	36	123	60	36	113
	2 g			137	223	36	120	58	33	122
	P			NS	NS	NS	NS	NS	NS	NS
	1 g	H+7 & H+14		141	216	37	123	59	36	110
		H+14 & H+21		144	197	34	122	60	36	116
		P		NS	NS	NS	NS	NS	NS	NS
	2 g	H+7		138	230	37	119	55	33	122
		H+14		140	232	38	118	54	30	135
		H+21		138	211	34	126	60	34	134
		H+7 & H+14		137	230	37	115	53	29	145
		H+14 & H+21		137	208	35	124	61	37	102
		P		NS	NS	NS	NS	NS	NS	NS
GA_{4+7}+BA	500 mL	H+7		139	258 AB	37	109 BC	50 A	27 AB	133
		H+14		140	251 AB	42	124 A	60 A	37 A	123
		H+21		150	230 B	41	120 AB	56 A	31 A	111
		H+7 & H+14 & H+21		135	350 A	43	97 C	35 B	16 B	90
		P		NS	0.0107	NS	0.0001	0.0001	0.0022	NS
			Control	138	171 B	34 A	146 A	72 A	47 A	113
			GA_3 1 g at H+7 & H+14	141	216 B	37 A	123 BC	59 AB	36 AB	110
			GA_3 1 g at H+14 & H+21	144	197 B	34 A	122 BC	60 AB	36 AB	116
			GA_3 2 g at H+7	138	230 B	37 A	119 BC	55 B	33 AB	122
			GA_3 2 g at H+14	140	232 B	38 A	118 BC	54 B	30 BC	135
			GA_3 2 g at H+21	138	211 B	34 A	126 B	60 AB	34 AB	134
			GA_3 2 g at H+7 & H+14	138	236 B	37 A	115 BC	54 B	29 BC	145
			GA_3 2 g at H+14 & H+21	137	208 B	35 A	124 BC	61 AB	37 AB	102
			GA_{4+7}+BA 500 mL at H+7	139	258 AB	37 A	109 CD	50 B	27 BC	133
			GA_{4+7}+BA 500 mL at H+14	140	250 B	42 A	124 BC	60 AB	36 AB	124
			GA_{4+7}+BA 500 mL at H+21	150	230 B	41 A	120 BC	56 B	31 ABC	111
			GA_{4+7}+BA 500 mL at H+7 & H+14 & H+21	135	350 A	43 A	97 D	35 C	16 C	90
			P	NS	<0.0001	0.027	<0.0001	<0.0001	<0.0001	NS

Table 5. Number of flower clusters per tree (Flower #), fruit set (final fruit number/flower cluster), yield (kg/tree), fruit weight (g), percentage of yield >60 mm, percentage of yield >65 mm, and return bloom for each combination of GA_3 or GA_{4+7} + BA dose and time (7, 14, or 21 days after petal fall) on 'Conference' pear trees (Experiment 3). Note that GA_3 (gibberellic acid) dose refers to active ingredient (2 g·ha^{-1}), whereas for GA_{4+7} + BA (Promalin®) refers to the commercial product (250 mL·ha^{-1} or 500 mL·ha^{-1}). Petal fall (H) (Fleckinger, 1964). Return bloom was measured the following spring, by counting the total number of flower clusters per tree. Grey bars represent variable value. Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). [NS]Nonsignificant at $P \leq 0.05$.

Hormone	Dose	Time	Treatment	Flower #	Fruit set	Yield (kg)	Fruit weight (g)	Yield >60 mm (%)	Yield >65 mm (%)	Return bloom
GA_3	2g	H+7		131	161	24	119 AB	51	29	294
		H+14		132	143	24	128 A	58	35	252
		H+21		130	140	21	116 B	48	26	283
		P		NS	NS	NS	0.0476	NS	NS	NS
GA_{4+7}+BA	250 mL			131	144	22	123	52	29	250
	500 mL			128	158	23	120	51	26	264
	P			NS	NS	NS	NS	NS	NS	NS
		H+7		130	143	22	127	56	32 A	255
		H+14		129	160	22	115	46	22 B	235
		H+21		130	151	23	123	52	28 AB	281
		P		NS	NS	NS	NS	NS	0.0413	NS
			Control	127	133	21	131 A	60	35 A	270
			GA_3 2 g at H+7	130	161	24	119 A	51	29 A	295
			GA_3 2 g at H+14	132	143	24	128 A	58	35 A	254
			GA_3 2 g at H+21	129	140	20	116 A	48	26 A	284
			GA_{4+7}+BA 250 mL at H+7	131	122	20	131 A	60	35 A	264
			GA_{4+7}+BA 250 mL at H+14	130	160	22	113 A	44	21 A	241
			GA_{4+7}+BA 250 mL at H+21	131	145	22	124 A	52	30 A	252
			GA_{4+7}+BA 500 mL at H+7	127	163	24	122 A	53	29 A	254
			GA_{4+7}+BA 500 mL at H+14	128	154	22	117 A	48	23 A	233
			GA_{4+7}+BA 500 mL at H+21	128	157	24	121 A	51	27 A	317
			P	NS	NS	NS	0.0355	NS	0.0494	NS

Table 6. Number of flower clusters per tree (Flower #), fruit set (final fruit number/flower cluster), yield (kg/tree), fruit weight (g), percentage of yield >60 mm, percentage of yield >65 mm, and return bloom for each combination of GA_{4+7} + BA applied at 500 $mL \cdot ha^{-1}$ of commercial product (Promalin®) at 7, 14, or 21 days after petal fall (H) (Fleckinger, 1964) on 'Conference' pear trees in four different sites (Experiment 4). Return bloom was measured the following spring, by counting the total number of flower clusters per tree. Grey bars represent variable value. Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). ^{NS}Nonsignificant at $P \leq 0.05$.

Site	Treatment	Flower #	Fruit set	Yield (kg)	Fruit weight (g)	Yield >60 mm (%)	Yield >65 mm (%)	Return bloom
Bellpuig	Control	397	35 C	21 B	158 A	84 A	61 A	250 A
	GA_{4+7}+BA at H+7	393	66 AB	26 AB	103 B	44 B	22 B	167 B
	GA_{4+7}+BA at H+14	420	66 AB	27 AB	99 B	37 B	16 B	140 B
	GA_{4+7}+BA at H+21	409	61 B	26 AB	109 B	46 B	23 B	165 B
	GA_{4+7}+BA at H+7 & H+14 & H+21	414	91 A	28 A	78 C	15 C	5 C	71 C
	P	NS	<0.0001	0.0334	<0.0001	<0.0001	<0.0001	<0.0001
Castellnou de Seana	Control	313	46 C	21 C	150 A	80 A	59 A	181 A
	GA_{4+7}+BA at H+7	301	73 BC	23 BC	109 B	50 B	28 B	114 BC
	GA_{4+7}+BA at H+14	290	89 AB	25 AB	101 B	39 B	20 BC	113 BC
	GA_{4+7}+BA at H+21	345	69 BC	24 BC	105 B	41 B	20 B	130 B
	GA_{4+7}+BA at H+7 & H+14 & H+21	304	115 A	28 A	83 C	19 C	7 C	83 C
	P	NS	<0.0001	0.0009	<0.0001	<0.0001	<0.0001	<0.0001
Puigverd d'Agramunt	Control	377	29 C	14 B	139 A	72 A	47 A	195 A
	GA_{4+7}+BA at H+7	358	69 B	21 A	90 B	25 B	7 B	148 AB
	GA_{4+7}+BA at H+14	366	65 B	19 AB	82 BC	15 BC	4 B	127 AB
	GA_{4+7}+BA at H+21	383	61 B	19 AB	84 B	17 B	5 B	147 AB
	GA_{4+7}+BA at H+7 & H+14 & H+21	373	94 A	23 A	67 C	3 C	0 B	78 B
	P	NS	<0.0001	0.0018	<0.0001	<0.0001	<0.0001	<0.0001
Tornabous	Control	388	39 B	21	140 A	73 A	55 A	182 AB
	GA_{4+7}+BA at H+7	388	50 B	21	109 BC	47 B	28 B	204 A
	GA_{4+7}+BA at H+14	375	57 AB	23	108 BC	45 B	26 B	139 AB
	GA_{4+7}+BA at H+21	398	50 B	22	113 B	47 B	27 B	170 AB
	GA_{4+7}+BA at H+7 & H+14 & H+21	385	76 A	26	95 C	27 C	12 C	129 B
	P	NS	0.0009	NS	<0.0001	<0.0001	<0.0001	0.0140