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Effect of Bioregulators and Removal Method on Bloom Return and Fruiting in Cactus Pear

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Abstract It is well known that the removing of the spring growth (fruits, flowers and young cladodes) induces reflowering in cactus pear. On the other hand, previous works suggested the role of gibberellins to inhibit flower induction, but its implication in the reflowering potential is little known. The research was determined the implication of gibberellins on the degree of bloom return in cactus pear. Two days before complete removal of spring growth (realized at the full bloom stage), trees were sprayed with water (control), a solution of gibberellic acid (100 mg/l) and a solution of Alar (400 mg/l). In addition, two other treatments with a partial and progressive removal of the spring growth were performed to test the implication of the presence and absence of seeds of young fruits (source of synthesis of Gibberellins) on the reflowering phenomena. Treatments with gibberellic acid reduced significantly reflowering. The reduction was 50% in trees treated with 100 mg/l of GA3. Trees sprayed with the anti-gibberellins Alar showed a similar values with control. However, the highest reflowering rate and cumulative production occurred when a total and progressive removal of spring growth was performed over all the flowering period.

Keywords: Opuntia ficus-indica, gibberellic acid, anti-gibberellins, spring growth, cladodes, flowering

Introduction

The growth and development of plants are controlled in part by the hormonal balance. Among the growth regulators, gibberellins are known for their important role in the physiological and morphogenetic processes implicate in the reproductive and vegetative development of fruit species (Bernier *et al.*, 1981). In fact, the endogenous gibberellins synthesized by the seeds of the young fruits of the apple tree after fruiting have an inhibitory role of the floral induction and accentuate the alternate bearing behaviour. In addition, gibberellins have a key role on the inter-nodal elongation of the vegetative shoots in several fruit species (Bernier *et al.*, 1981; Buban and Faust, 1982).

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The cactus pear Opuntia ficus-indica is a long-domesticated cactus crop that is important in agricultural economies throughout arid and semiarid parts of the world (Nobel and Bobich, 2002; Griffith, 2004). The cactus pear products are valued for different purposes. Generally this specie is cultivated for their fruits, in several south-American countries and the Mediterranean basin, which present an important nutritional value (Inglese *et al.*, 2002; Griffith, 2004). The cladodes are considered a valuable product, which are used for human and animal nutrition (Sáenz-Hernandez *et al.*, 2002; Griffith, 2004).

The cactus pear growing under the Mediterranean climatic conditions, flourish at the end of spring and fruits reach maturity in summer. In the most commercial orchards, an autumnal production targeted and obtained by the removal of of flowers and cladodes of the first spring growth wave, which induce a second reproductive (reflowering) and vegetative growth (Barbera *et al.*, 1991). This cultural technique is frequently called “Scozzolatura” due to its Italian origin. Several studies have shown that reflowering in Opuntia ficus-indica is dependent on the removal time of the flowers and young cladodes. The reflowering intensity seems to be negatively correlated with the delay in the moment of the elimination of the spring growth (Aounallah *et al*., 2009; Barbera *et al.*, 1991, 1993; Inglese, 1998). In addition, the application of gibberellins, just after the removal of the spring growth, reduces the flower formation in cactus pear (Barbera *et al.*, 1993), On the other hand, a previous study finds that the flowers of summer growth grow from latent areoles (dormant buds) not differentiated (Aounallah *et al.*, 2009). These results suggest an important implication of endogenous gibberellins (GAs) synthesized by the seeds of the first young fruits of the spring growth set, before the application of the “Scozzolatura”, in the aptitude of Opuntia ficus-indica to reflowering. The aim of the present study was to determine the influence of exogenous application of GAs on the degree of return bloom in cactus pear, which can contribute to elucidate the implication of this hormone in the reproductive process of the cactus pear.

Materials and methods

Plant Material

The experiment was carried out in a commercial orchard located at Mraissa Cap Bon in north eastern of Tunisia characterized by a semi-arid climate. The orchard was planted by the ‘Gialla’ cultivar and trees were 10 years old and planted at a standard density of 500 trees per ha. Trees are irrigated and conducted under standard cultivation conditions.

Treatments and experimental design

A completely randomized design was adapted, with six replicates per treatment, for which thirty trees were selected with a uniform and similar initial yield and vigor. A control treatment (C), for which, all flowers, fruits and young cladodes of the spring growth were removed at the full bloom stage, without any application of GAs. Two other treatments with an application of Gibberellins and anti-Gibberellins were performed to test the influence of an increase and decrease of Gibberellins level on the reflowering potential of the cactus pear. The Gibberellins treatment (GA100) with GA3 at 100 mg/l and the anti-Gibberellins with Alar at 4 g/l, are applied two days after the total remove of the spring growth operated at full bloom stage. In addition, two other treatments, RM1 and RM2, with a partial and progressive removal of the spring growth were performed to test the implication of the presence and absence of seeds of young fruits set (source of synthesis of Gibberellins), before the application of the "Scozzolatura", on the reflowering phenomena. To ovoid ovules fecundation and seed formation, a treatment RM1 consists on the progressive removal of any flower opened before the full bloom stage was made. The RM2 treatment is equal to RM1, at the exception of keeping the two first fruits, per cladode, formed before until full bloom stage. .

Evaluations and data analysis

For each tree the number of flowers, fruits, and fertile and young cladodes for the spring and summer growths are recorded during two successive years. The reflowering rate is the ratio between the number of spring and summer flowers per tree. In addition the alternate bearing index is calculated by dividing the number of flowers per tree of each growth during the 2nd year by the 1st year.

Analysis of variance (ANOVA) was used to test differences among treatments. Means were compared by Tukey's test at $P<0.01$. All Statistical analysis was performed by the Statistic 8.0 software (Analytical Software, Tallahassee, USA).

Results

During two successive years, the punctual and total removal of the spring growth (Control) decreased the number of flowers per tree formed during the summer growth by 65%, when this elimination is applied at the full bloom stage (Fig. 1). This reduction of the reflowering potential is compounded by the application of exogenous gibberellins, reaching a decrease of 80% of the initial number flowers. The application of anti-gibberellins and the partial and progressive removal of spring growth, in which two fruits per cladode are saved (RM2), did not affect the reflowering potential of the plants in comparison with the control treatment. However, the progressive and total elimination of the young fruits (RM1) enhanced significantly the reflowering rate in comparison with the standard technique of elimination of spring growth (Control).

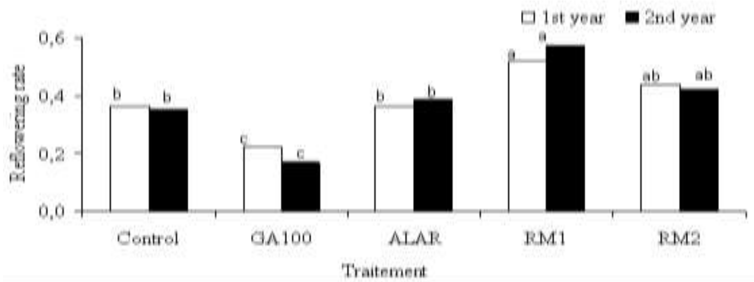

Figure 1. Reflowering rate of cactus pear for different treatments, during two successive years. Control: total elimination of flowers, fruits and cladodes during spring growth; GA100: application of gibberellic acid after the total remove of spring growth; Alar: application of an anti-gibberellins (Alar) after the total remove of spring growth; RM1: a total and progressive remove of spring growth; RM2: a partial and progressive elimination of spring growth. Different letters indicate significant differences at P<0.01 among treatments and years based on Tukey test

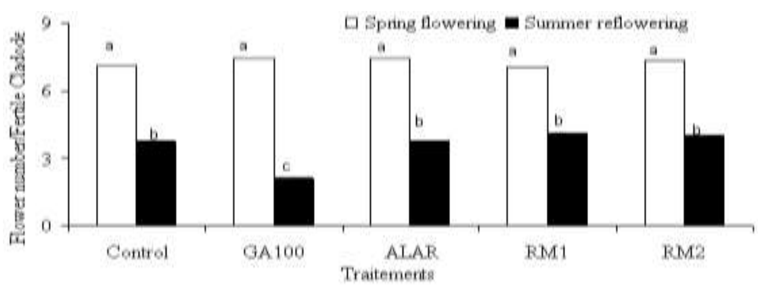

Figure 2. Flowers number per fertile cladode of cactus pear for different treatments. Control: total elimination of flowers, fruits and cladodes during spring growth; GA100: application of gibberellic acid after the total remove of spring growth; Alar: application of an anti-gibberellins (Alar) after the total remove of spring growth; RM1: a total and progressive remove of spring growth; RM2: a partial and progressive elimination of spring growth. Different letters indicate significant differences at P<0.01 among treatments and growth growths based on Tukey test. The values are the mean of two successive years per treatment.

The cladode fertility during the summer reflowering is negatively affected by all the type of used technique in eliminate the spring growth, including the use of the bioregulators. This decrease of cladode fertility is worsened by the application gibberellins GA3 (Fig. 2). In contrast with the flowers number per cladode, no improvement is observed in the fertility of cladodes of trees for which the total and progressive elimination of spring growth is applied, in comparison with the control treatment.

The number of fertile and young cladodes decreased for all treatments during the summer growth, including the Control (Fig. 3). Nevertheless, the magnitude of this reduction was great in the case of the young cladodes. The total and the progressive elimination of flowers and young cladodes (RM1) during the spring, was the unique treatment that enhance the number of fertile cladodes regarding to the punctual and total elimination of the spring growth (Control). These results, indicated that the best of reflowering rate of RM1 treatment, in comparison with the control, due to a higher number of fertile cladodes per tree and not to the number of flowers per fertile cladodes. The application of GA3 just after the removal of spring growth gave the highest reduction in the number of cladodes with flowers during the summer growth. For the vegetative development, at the exception of the GA100, all treatments showed a similar percentage of re-growth of young cladodes. In fact, the application of the exogenous gibberellins, improved the growth of the young cladodes during the summer reflowering.

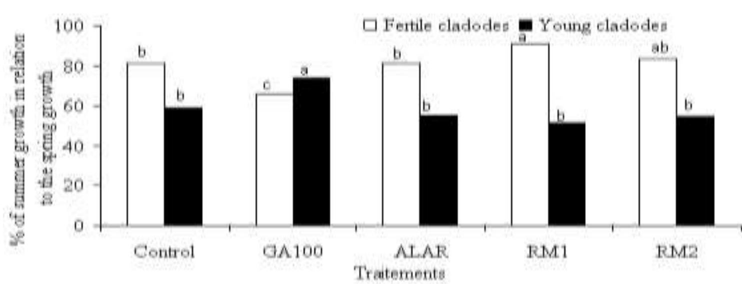

Figure 3. Percentage of fertile and young cladodes of the summer growth in relation to the spring growth for cactus pear. Control: total elimination of flowers, fruits and cladodes during spring growth; GA100: application of gibberellic acid after the total remove of spring growth; Alar: application of an anti-gibberellins (Alar) after the total remove of spring growth; RM1: a total and progressive remove of spring growth; RM2: a partial and progressive elimination of spring growth. Different letters indicate significant differences at P<0.01 among treatments within each type of cladodes based on Tukey test. The values are the mean of two successive years per treatment.

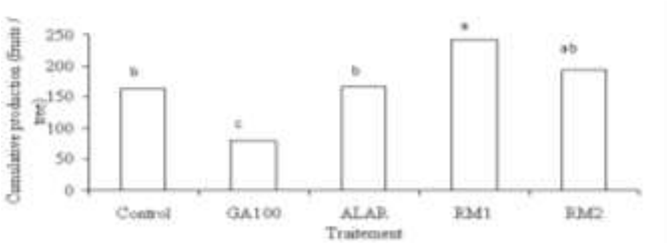

Figure 4. Cumulative fruit production per tree of cactus pear under different treatments, for two successive years. Control: total elimination of flowers, fruits and cladodes during spring growth; GA100: application of gibberellic acid after the total remove of spring growth; Alar: application of an anti-gibberellins (Alar) after the total remove of spring growth; RM1: a total and progressive remove of spring growth; RM2: a partial and progressive elimination of spring growth. Different letters indicate significant differences at $P<0.01$ among treatments based on Tukey test.

Cumulative production was only affected for GA100 and RM1 treatments in comparison with the Control. A reduction of 50% of the number of fruits per tree is observed after the application of gibberellins GA3 (Fig. 4.). In contrast, the progressive and total elimination of young fruits at full bloom stage (RM1), increase significantly the fruit production.

At the exception of the GA100, the other treatments had no affect the production regularity among the years in the cactus pear (Fig. 5). The application of GA3 induced a fluctuation of fruit production between two years.

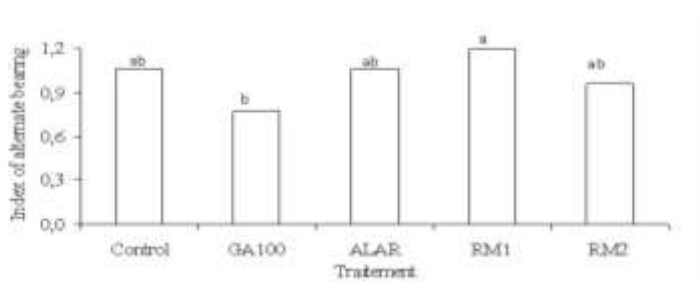

Figure 5. Index of alternate bearing for cactus pear under different treatments. Control: total elimination of flowers, fruits and cladodes during spring growth; GA100: application of gibberellic acid after the total remove of spring growth; Alar: application of an anti-gibberellins (Alar) after the total remove of spring growth; RM1: a total and progressive remove of spring growth; RM2: a partial and progressive elimination of spring growth. Different letters indicate significant differences at $P<0.01$ among treatments based on Tukey test.

Discussion

Gibberellins (GAs) affect flowering in a species-dependent manner: in long-day and biennial plants they promote flowering, whereas in other plants, including fruit trees, they inhibit it (Goldberg-Moller *et al*., 2013). This observation is confirmed in the present study for cactus pear. Cactus pear trees treated with gibberellins revealed an important reduction of their reflowering capacity.

In contrast to the GA3 application, the anti-gibberellins Alar not affects reflowering capacity and fruit production. Alar is an inhibitor of gibberellins biosynthesis and their application can reduce vegetative growth and enhance flowering intensity, as reported for other species (Dennis *et al*., 1970). The absence of the effect of Alar in the case of cactus pear, is may be due to the moment of their application. Mauk *et al*. (1990) and Omran and Semiah (2006) have been observed that the efficiency of an inhibitor of gibberellins biosynthesis depend on the moment of their application. A more detailed study using different gibberellins inhibitors and moment of their application will be necessary to better understand their influence on cactus pear reflowering and fruit production.

Progressive and total removal of spring growth was the only treatment which enhances reflowering intensity and fruit production in comparison with the control. This increase in reflowering intensity, may be due to the reduction in the effect of endogenous gibberellins biosynthesized by the seed of the young fruits, which considered to have an inhibitor effect on the reflowering intensity (Inglese *et al*., 1998). In fact, the progressive elimination of all young fruits formed before the moment of the "Scozzolaturra", reduced the biosynthesis of endogenous gibberellins.

All these results suggested that the floral induction of the summer reflowering in cactus pear depend on two conditions, the elimination of the spring flowers and cladodes and in an endogenous hormonal balance, when gibberellins play a key role.

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