THINNING EFFECTS ON CITRUS YIELD AND FRUIT SIZE

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Abstract

Thinning is performed in Citrus to increase fruit size and thus to enhance the market value of the crop. Fruit count is reduced and crop yield may be either unchanged or markedly reduced depending on the thinning procedure used.

The sink strength of the fruitlets, which determines fruitlet growth rate, is largely determined during the early stages of development. It may be increased reducing flower formation through the application of gibberellic acid during the winter rest period. In some cultivars this reduction in flower number results in an increase in the size of the ovaries and a faster early fruitlet growth rate. Also, the application of a synthetic auxin at flower opening increases selectively in most cultivars the sink strength of some of the ovaries. In both cases, the final number of fruits set is reduced in an indirect way and final fruit size is increased. Crop yield is not affected significantly.

A significant proportion of the developing fruitlets is shed within two weeks due to auxin-induced ethylene synthesis when an appropriate auxin is applied before the end of June drop. This fruitlet thinning reduces intersink competition and increases the fruitlet growth rate and final fruit size whenever fruit growth is limited by metabolite supply. This ethylene-induced abscission always results in a reduction in yield.

From the direct effect of some auxins on the sink strength of the fruitlets, an increase in fruit size without affecting crop yield may be obtained when the auxin application is timed at the end of June drop when fruitlet shedding has ended and is hardly affected by auxin-induced ethylene synthesis. Although this system of application offers potentially some advantages considerable expertise is needed to time-out precisely these applications which must be performed in a range of a few days. A slightly earlier application may cause a significant thinning, while a delayed application has only a minor effect on fruitlet growth and final fruit size. The effect of these applications on fruitlet growth may be weak in heavily fruit loaded trees.

The comparative advantages and pitfalls of the different strategies to increase fruit size in Citrus are briefly discussed.

1. Introduction

The importance of fruit size as a parameter of quality of citrus fruits has incresed markedly in recent times to a point that the income obtained from small-sized fruits is often lower than the production and handling costs. Fruit size has become as important as yield in the determination of the profitability, and an economic premium is usually obtained through the increase in fruit size even at the expense of a reduction in crop yield. To this aim, several techniques have been

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used including hand thinning (Zaragoza et al., 1992), chemical and/or hormone thinning (Hirose, 1981; Ortolá et al., 1991), and the application of synthetic auxins to enhance fruitlet growth (Coggins and Hield, 1968; Monselise, 1979; Wilson, 1983). The practical use of these techniques is not without drawbacks. Although thinning has been succesfully used in Satsuma mandarin in Japan for many years (Iwahori, 1990), in some cultivars it may result in an excessive crop loss which may offset the benefits derived from the increase in fruit size (Galliani et al., 1975; Goldschmidt and Monselise, 1977). On the other hand, the application of synthetic auxins to enhance fruitlet growth has resulted often in too erratic results probably by an improper timing of the applications.

In the present report, we summarize our present knowledge on the way as fruit size is regulated and the different methodologies available to increase it through the application of plant growth regulators. Understanding the mechanism of action of the applied bioregulators shall ensure more reliable results from their application.

2. The determination of fruit size

Fruitlet growth rate and final fruit size is determined and may be limited by the sink strength of the developing fruitlets and by metabolite supply. These two parameters are not independent but are related in a sometimes subtle way. A shortage in metabolite supply during the early stages of fruitlet development may impair irreversibly the sink strength of the fruitlets and reduce fruit growth at later stages of development when metabolite supply may not be a limiting factor any longer. Conversely, the presence of strong sinks may attract most of the available metabolites and in this way starve the weakest sinks leading to a reduction in their growth rate and sometimes to their abscission.

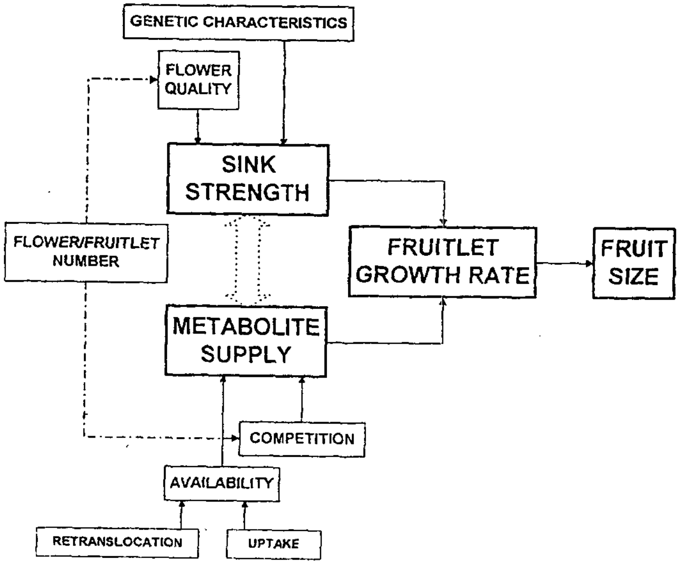

Figure 1. Factors which determine fruitlet growth rate and final fruit size. Adapted from Guardiola (1988).

Some of the factors affecting the parameters which determine fruit size may not be manipulated by the grower (i.e. the genetic characteristics depend on the cultivar) or may be optimized through standard cultural practices such as fertilization, irrigation, tillage and pruning. Under optimal management conditions, metabolite supply is mainly determined by intersink competition and may be manipulated through the removal of a part of the developing fruitlets (thinning). The sink strength of the fruitlets depends on flower quality, a parameter which is related to flower number and is also amenable to manipulation. Further, the sink strength of the fruitlets may be also affected in a direct way.

For these purposes, plant bioregulators are being or may be used, and the different approaches are discussed below. To be effective, the application of the plant bioregulators should be performed during the early stages of fruit development. From the kinetic analysis of fruitlet growth (Guardiola, 1988; Van Rensburg et al., 1996) and from the correlations in fruit size during several stages of development, it seems that in most cases a period of limitation in supply occurs at the end of the physiological shedding of fruits (June drop). Final fruit size is largely determined at this time (Praloran et al., 1981; Guardiola et al., 1988).

3. Flowering and fuit size

An inverse relationship between fruit count per tree and final fruit size has been reported repeteadly (Galliani et al., 1975; Goldschmidt and Monselise, 1977; Guardiola, 1988) and is the basis for the use of thinning as a standard technique to increase fruit size. However, the statistical analysis of these relatioships showed that fruit count, which is determined at the end of June drop, accounts for less than 50% of the variability in fruit size. Further, it was shown that a significant part of this variability is determined at the time of flowering (Guardiola, 1988; 1992).

Table1. The combined effect of 2,4-D applications and the reduction in flower number on yield and fruit size in Esbal clementine. A 20 ppm GA_3 spray was performed in early December to inhibit flower formation. The auxin 2,4-D (20 ppm) was sprayed at full bloom. From García-Luis and Guardiola (unpublished results).

Treatments	Fruit count (thousands/tree)	Mean fruit weight (g)	Crop yield (kg/tree)
High flower number (1.77 flowers/node)			
Untreated	2.07	59.6	80
2,4-D treated	1.45	67.7	76
Low flower number (0.18 flowers/node)			
Untreated	1.28	67.5	68
2,4-D treated	1.21	77.7	80
(SE)	(0.19) P=0.05	(2.7) P=0.01	(9.1) NS

The inverse relationship between flower number and final fruit size may result from the smaller use of metabolites in flower formation and during the early fruitlet growth when flower number is low (Guardiola et al., 1984a; 1984b), which should result in an increase in supply and a reduced intersink competition, but also the quality of the flowers has a decissive influence. A reduction in flower number results in a higher proportion of leafy inflorescences (Guardiola, 1981a; 1997), and the fruit borne on these inflorescences is of a bigger final size than fruit borne on leafless inflorescences (Guardiola and Lázaro, 1987; Erner, 1988). Further, ovary size at anthesis is inversely related to flower number (Guardiola et al., 1984a; García-Luis et al., 1988). A bigger ovary size results in a faster initial growth of the fruitlets with a parallel increase in fruitlet shedding in such a way that the rate of dry matter accumulation in the remaining fruitlets remains constant during the last part of the June drop (Guardiola, 1988). Over a wide range of flower number this parameter has no influence on crop yield, and a reduction in flower number results in a reduction in the number of fruits set and finally harvested and an increase in fruit size (García-Luis, 1994). For some navel orange cultivars, a maximal crop value is obtained when flower number is close to 0.2 flowers per node. A further reduction in flower number results in a reduction in yield (Guardiola, 1992).

The application of gibberellic acid as a full coverage spray at a concentration between 10 and 20 ppm during the winter rest period markedly reduces flower formation and has proved useful to increase fruit size in some highly flowering cultivars. In Table 1 the response of the small fruited Esbal clementine is shown. Reducing the number of flowers from 1.77 to 0.18 flowers per node increased fruit size by 13%. In addition, the size of these fruits could be further increased through the application of an appropriate auxin.

4. Auxin effects on fruit development

The application of synthetic auxins to developing citrus fruits results in several direct effects on fruit development which affect fruitlet behaviour both in a direct way and through the changes in assimilate partitioning in the tree. The main aspects of the auxin effects are shown in the flow chart diagram depicted in figure 2, in which both the direct and the indirect effects caused by the application of auxins are presented.

In general terms, the application of an auxin has four primary effects on fruitlet development:

a) A transient reduction in fruitlet growth rate. As discussed elsewhere (Guardiola, 1996) this effect is a general response to the application of auxins, particularly when performed during the earlier stages of fruitlet development (Guardiola et al.,1993). This effect may result in a final reduction in fruit size.

b) A direct effect on fruitlet abscission, which may potentially result in a delay of fruitlet abscission and/or an increase in set. This effect is only shown when ethylene synthesis is low or prevented (see below).

c) An increase in fruitlet abscission which is mediated through the auxin-induced ethylene synthesis by fruit. This additional abscission results in a reduction in late intersink competition and an increase in final fruit size. This abscission occurs between 2-3 weeks after the application of the auxin, and the natural shedding of fruitlets results accelerated by the application (Hirose, 1981; Ortolá et al., 1997).

d) An increase in the sink strength of the developing fruitlets, an effect which is measurable several days after the transient reduction in growth. This increase in sink strength results in a faster growth of the treated fruits until maturation (Guardiola and Lázaro, 1987; Ortolá et al., 1988; Agustí et al., 1994). Therefore, the difference in weight between treated and untreated fruits increases with time to become maximal at harvest. When the auxin is applied before June drop, the increase in fruitlet growth rate causes an increase in fruitlet abscission which is unrelated to auxin-induced ethylene synthesis. As discussed above, this effect results in an increase in final fruit size without affecting significantly crop yield.

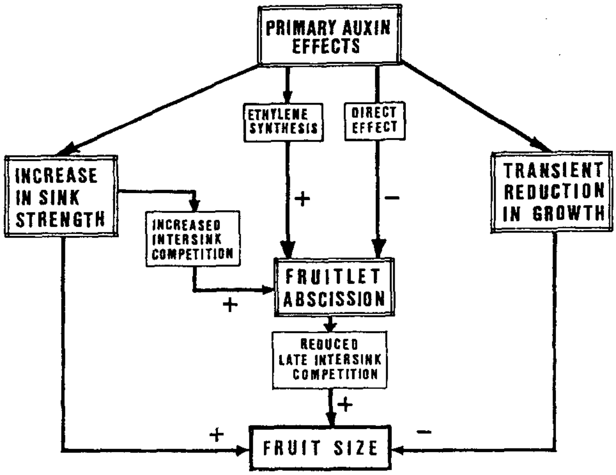

Figure 2. Diagram showing the primary effects of synthetic auxins on fruitlet abscission and growth rate, and the influence on final fruit size. Adapted from Guardiola (1988)

There are marked differences among the available auxins to elicit the above described effects. The relative importance of each one of these effects depends on the nature and concentration of the auxin applied, on the stage of development of the fruitlet at the time of auxin application, the citrus cultivar, and the status of the tree, an aspect linked probably to carbohydrate availability (Ortolá et al., 1997). The auxin 2,4-D, at the concentrations recommended, has no significant effect on ethylene synthesis and has no direct thinning effect. Most of the available auxins, on the contrary, induce ethylene synthesis and cause a significant thinning when applied before the end of June drop (Ortolá et al., 1997). An increase in the fruit strength of the fruitlets is obtained for most citrus cultivars when the application of an appropriate auxin is performed from flowering up to shortly after the end of June drop. Beyond this point the sensitivity of the fruitlets decreases markedly and the effect on final fruit size is smaller if any (Guardiola and Lázaro, 1987; Vanniere et al., 1987; Vanniere and Arcuset, 1989; Agustí et al., 1994). Satsuma mandarin shows a different behaviour, and an increase in sink strength is only obtained when the auxins are applied towards the end of fruitlet abscission. Further, this mandarin has a weak response to 2,4-D (García-Luis and Guardiola, unpublished results) in contrast to the sensitivity of most citrus cultivars.

A judicious selection of the auxin used and the conditions of the application may enhance the importance of the desired effect, and therefore we may define the auxin application refering to the main effect sought. It must be stressed, however, that a complete separation of effects is not always feasible. Further, the conditions of the applications must be determined for each cultivar, as in some cases marked differences in responsiveness have been found.

5. Auxins as fruit thinners

Since fruit count is inversely related to fruit size, this parameter may be increased through the reduction in the number of developing fruits (thinning). Fruit thinning always results in a reduction in crop yield, but when performed with auxins this reduction is smaller than predicted from the relationships between fruit count and yield. One reason is that, when appropriately timed, the auxins thin selectively the smaller fruits from the tree. Further, thinning results in an increase in the size of the remaining fruits, which compensates in part for the reduction in yield due to the reduction in fruit count.

Thinning by auxins results from the auxin-induced ethylene synthesis. To be most effective thinning must be performed from two weeks before June drop until mid drop. At an earlier date the selective effect of thinning is not shown and the biggest fruitlets are shed. Beyond June drop the fruit becomes largely insensitive and can be hardly thinned. Within some limits an early thinning is more effective to increase fruit size than a late thinning. This is a distinct advantage of auxin-induced versus hand thinning. Hand thinning can only be performed, and at a considerably higher cost, after June drop, a circumstance which reduces its effectiveness to increase fruit size (Zaragoza et al., 1992; Table 6).

Table 2. The effect of the timing of NAA applications on thinning, fruit size and crop value in Satsuma mandarin. (In brackets expressed as a percentage of the control values). (From Ortolá et al., 1991).

Parameter (per tree)	Treatments		
	Untreated	NAA (June 16)	NAA (July 11)
Fruit number	885	582 (66)	874 (99)
Mean fruit weight (g)	67	84 (125)	71 (106)
Crop yield (Kg)	56	48 (86)	61 (109)
Small size fruit (Kg) (< 55 mm)	30	15 (50)	30 (100)
Large size fruit (Kg) (> 55 mm)	25	33 (132)	31 (124)

Thinning is justified on overloaded trees which produce a significant amount of unmarketable fruit and risk to enter into an alternate bearing habit. In regular bearer trees with a lower crop load the benefits obtained through thinning may be offset by the loss in yield. Further, some of the reported increases in fruit size may not be due to the reduction in competition brougth about by thinning but to the direct effect of the auxin on the sink strength of the fruit, and similar effects on fruit size may be obtained without any thinning. This situation is demonstrated in the experiment reported in Table 2 comparing the effect on fruit size in Satsuma mandarin of a thinning NAA application (applied on June 16 during the physiological fruit drop) and that of a later application (performed on July 11) which does not thins fruit (see below). The amount of large fruit produced was similar in both cases despite the 34% thinning of fruit caused by the early NAA application. A similar conclusion may be drawn from Hirose (1981) results on this same cultivar. This author showed that for a similar amount of thinning final fruit size was bigger when performed with NAA, which increases the sink strentgh of the fruitlets, than when performed with Figaron, which has no effect on the sink strength.

Incidentally, table 2 shows one of the most common pitfalls found in many reports on thinning, which merely show the mean fruit weight. The much higher mean fruit weight for the thinned (84 g) than for the unthinned (71 g) trees does not reflect an increase in fruit size but merely the selective thinning of the smaller fruits, a response which itself does not increase the crop value. Reports should show the sizing of the fruit best expressed in Kg per tree rather than on per cent frequency. In this way, the economic return of the application may be easily calculated.

6. The use of auxins as fruit growth enhancers

The direct effect of some auxins on the sink strength of the developing fruitlets was demonstrated in the early 50's by Stewart and coworkers, but the attempts to exploit this response to increase fruit size in the absence of thinning is quite recent (Guardiola, 1981; Guardiola and Lázaro, 1987; Vanniere et al., 1987).

To this aim, the auxin application is performed after the physiological fruitlet drop, at a time the fruit is not sensitive to ethylene-induced abscission. The increase in fruitlet growth rate results in an increase in final fruit size when fruit load is not too high. When fruit load is excessive, fruitlet growth is limited by metabolite supply and the response to these auxin applications is weak (García-Luis, 1985). Further, as there is no reduction in fruit count crop yield should be increased.

Table 3 . The effect of an application of 2,4,5-T (10 ppm) at the end of June drop on yield and fruit size in Fino Clementine and Owari Satsuma. (From Guardiola, 1996).

Cultivar and treatments	Fruit count (thousands tree^{-1})	Mean fruit weight (g)	Crop yield (Kg tree^{-1})
Fino Clementine			
Untreated	2.04	55.7	113
2,4,5-T treated	1.71*	61.4**	109^{NS}
SE	0.07	0.5	4.2
Owari Satsuma			
Untreated	1.99	70.4	138
2,4,5-T treated	1.69^{NS}	75.7**	127^{NS}
SE	0.12	1.3	8.2

NS, * and **. Non significant and significant at P = 0.95 and 0.99 respectively in the paired comparison to the untreated controls.

In practice, an increase in yield is rarely found. The sensitivity of the fruitlets to applied auxins is lost rapidly after the end of drop, and the applications are usually performed at slightly earlier dates, during the last days of June drop, which results in some thinning. Typical results obtained with this technique are shown in Table 3 for satsuma and clementine mandarins. There is a small reduction in fruit count which in many cases is below the statistical significance, which is compensated by the increase in fruit size, and crop yield is not affected.

These initial observations performed on small-fruited mandarins have been extended recently to other citrus cultivars and the conditions for the application of this technique have been determined for many of them. As mentioned above the response obtained depends critically on fruit load. Also, there are marked differences among auxins to elicit a growth response from the fruitlets. Further, considerable expertise is needed to time out the auxin applications. A too late application is largely ineffective while too early ones may cause an undesirable thinning. Under optimal conditions, the results on fruit size are comparable to those obtained through thinning.

7. The response to the applications at flowering

An increase in fruit size resulting from the application of the synthetic auxin 2,4-D at flowering was reported for oranges and grapefruits by Stewart and coworkers in the 50's, but this research was not pursued and the response was considered to be too erratic for practical use. We have pursued this research in our laboratory and found that at lower application rates (17 to 20 ppm) than initially used the application of 2,4-D at flowering results in a reliable thinning of several mandarins and hybrids (Duarte et al., 1996). Further work confirmed a similar response for oranges and grapefruit. At variance with the thinning effect reported above, this thinning is unrelated to auxin-induced ethylene synthesis but results from the initial faster growth of the developing fruitlets. As discused above, this competition-induced thinning does not result in a reduction in crop yield. and the reduction in fruit count is compensated by the increase in fruit size (Table 4).

Table 4. The effect of the time of a 2,4-D (20 ppm) application on yield and fruit size in Esbal clementine. (From Duarte et al., 1996).

Treatment and date of application	Fruit count (thousands tree^{-1})	Mean fruit weight (g)	Crop yield (Kg tree^{-1}) Total	Crop yield (Kg tree^{-1}) Marketable
Untreated (control)	1.83	46	84	52
2,4-D at flowering	1.30	61	80	69
2,4-D 2 weeks AFB	1.31	58	76	65
2,4-D 6 weeks AFB	1.59	55	88	72
SE	0.09	1.6	5.4	4.6
Significance (F value)	0.01	0.01	NS	0.05

As compared to other systems of fruit size manipulation reported, the application at flowering has some distinct advantages. Perhaps the most relevant one is that the time of application is not critical and may be performed at any time from flowering up to at least 6 weeks after full bloom, not to mention that 2-4,D is the cheapest of all the available auxins. As a limitation it should be remarked that for an unknown reason some cultivars seem to respond poorly to this application at flower opening.

8. Concluding remarks

Increasing fruit size through auxin applications has been for a long time an open possibility for citrus growers. This technique was not popular in the near past as the results were considered unreliable or, at least, considerable expertise was deemed necessary to succeed with their use. With the increasing influence of fruit size on market prices and the better understanding of the mechanism of action of the auxins leading to consisting and reliable results the time has come to exploit the advantages obtained from their use. A further increase in fruit weight may be obtained in highly flowering cultivars through the reduction in flower number (Table 1), but our preliminary trials indicate that some cultivars do not respond in the same way. Some of the techniques described do not involve a direct thinning effect as an immediate consequence of the application of the plant bioregulator, but some thinning occurs at a later date from the changes induced in assimilate partitioning in the tree. Only occasionally has been reported that the increase in the sink strength of the developing fruitlets has resulted in a small increase in crop yield. Crop yield seems to be limited by the characteristics of the tree, and any increase in fruitlet growth rate is paralleled by a reduction in final set.

Table 5. Advantages (+) and pitfalls (-) for the different strategies for the use of synthetic auxins to increase fruit size in Citrus. (From Guardiola, 1996).

1. THINNING PART OF THE DEVELOPING FRUITLETS
   - There is always a reduction in yield.
   - Response depends on temperature and fruit load.
   + Advisable when non-marketable small fruits are expected.
   + It may correct alternate bearing

2. INCREASING THE SINK STRENGTH OF THE FRUITLETS
   - Considerable expertise is needed to time the applications.
   - Response may be weak on overloaded trees.
   + Total yield either is not affected or is slightly reduced.

3. APPLICATION OF AUXINS AT/SHORTLY AFTER ANTHESIS
   - Not all cultivars are equally responsive.
   + Easy to apply and to time the applications.
   + No significant effect on total yield.

Table 6. The comparative effectiveness of several thinning procedures in Esbal clementine. Auxin treatments were 2,4-D (17 ppm) at flowering and/or 2,4-DP (50 ppm) at the end of drop. All non-marketable fruit were hand thinned by mid July, 3 months before harvest. Data on a per tree basis. (García-Luis and Guardiola, unpublished results).

Thinning procedure	Final set (fruit number)	Hand thinned fruit (number)	Harvest data		
			Crop yield (Kg)	Fruit number	Fruit weight (g)
2,4-D	1632	400	85	1232	68.3
2,4-DP	1649	390	85	1259	68.1
2,4-D+2,4-DP	1516	240	88	1276	69.1
Hand-thinned	1986	865	67	1121	60.2
(SE)	(107)		(5.1)		(2.1)

As presented above there are three different basic mechanisms of auxin action, and each one has advantages and pitfalls (Table 5). The most appropriate technique shall be determined by cultivar sensitivity and the general status of the tree, and in many cases similar results are obtained with different techniques (Table 6) and the choice may be left to the grower preference or be based in economic considerations. In our preliminary trials we could not find any distinct advantage from the combined action of two auxin applications. These results contrast with the marked additive effect reported above for the application of an auxin in combination with flower reduction (Table 1).

In any case there is not a best technique or auxin, and auxin applications can not substitute for basic failures in cultural practices.

9. References

Agustí,M., V.Almela, M.Aznar, M.El-Otmani & J.Pons, 1994. Satsuma mandarin fruit size increased by 2,4- dichlorophenoxypropionic acid butylglycol ester. HortScience 29:279-281.

Coggins,C.W.Jr. & H.Z.Hield, 1968. Plant growth regulators. In W.Reuther, L.D.Batchelor & J.Webber (eds). The Citrus Industry, vol 2:371-389. Univ. of California.

Duarte,A.M.M., D.T.G.Trindade & J.L.Guardiola, 1996. Thinning of Esbal clementine with 2-4,dichlrophenoxyacetic acid. Influence on yield, fruit size and fruit quality. Proc. Int. Soc. Citriculture (in the press).

Erner,Y., 1989. Citrus fruit set: carbohydrate, hormone and leaf mineral relationships. In C.J.Wright (ed.) Manipulation of Fruiting, 233-242. Butterworth and Co.

Galliani, S.,S.P.Monselise & R.Goren, 1975. Improving fruit size and breaking alternate bearing in Wilking mandarins by etephon and other agents. HortScience 10.68.

García-Luis, A., 1987. Limitaciones en el uso de reguladores del desarrollo en agricultura. In J.L.Guardiola and C..Monerri (eds.) Fisiología Vegetal 85. Universidad Politécnica. Valencia.

García-Luis; A., 1994. The physiology of flowering in Citrus. Nogyo oyobi Engei 69:689-696.

García-Luis, A., F.Fornés & J.L.Guardiola, 1988. Competition and fruitlet abscission in satsuma mandarin. Proc. 6th Int. Citrus Congress: 485-490.

Goldschmidt, E.E. and S.P.Monselise. 1977. Physiological assumptions toward the development of a Citrus fruiting model. Proc. Int. Soc. Citriculture, 1:668-672.

Guardiola, J.L., 1981a. Flower initiation and development in Citrus. Proc. Int. Soc. Citriculture 1:242-246.

Guardiola, J.L. 1981b. Aumento del tamaño del fruto en Satsuma y Clementinas. Problemas y perspectivas. Levante Agrícola-Vergel 230:67-68.

Guardiola, J.L. 1988. Factors limiting productivity in Citrus. A physiological approach. Proc. 6th Int. Citrus Congress, 1:381-394.

Guardiola, J.L. 1992. Fruit set and growth. In L.C.Donadio (ed.), Second International Seminar on Citrus. Univ. of Bebedouro, Brasil, pp 1-30.

Guardiola, J.L. 1996. Synthetic auxins and citrus fruit size. Strategies of use and mechanism of action. Proc. Int. Soc. Citriculture (in the press).

Guardiola, J.L., 1997. Competition for carbohydrates and fruit set. In S.H.Futch and W.J.Kender (eds.) Citrus Flowering and Fruiting Short Course. Univ. of Florida. Gainesville.

Guardiola, J.L., F.García-Marí & M.Agustí, 1984a. Competition and fruit set in the

Washington navel orange. Physiol. Plantarum 62:297-302.

Guardiola, J.L., J.González-Ferrer & M.Agustí, 1984b. Fruiting pattern and the retranslocation of reserves in the Navelate and the Washington navel oranges. Proc. Int. Soc. Citriculture:194-200.

Guardiola, J.L. and E.Lázaro. 1987. The effect of synthetic auxins on fruit growth and anatomical development in Satsuma mandarin. Sci. Hortic. 31:119-130.

Guardiola, J.L., V.Almela and M.T.Barrés. 1988. Dual effects of auxins on fruit growth in Satsuma mandarin. Sci. Hortic. 34:228-237.

Guardiola, J.L., M.T.Barrés, C.Albert and A.García-Luis. 1993. Effects of exogenous growth regulators on fruit development in Citrus unshiu. Ann. Bot. 71:169-176.

Hirose, H., 1981. Development of chemical thinners of commercial use for Satsuma mandarin in Japan. Proc. Int. Soc. Citriculture 1:256-260.

Iwahori, S., 1990. Present research trends and accomplishment of citriculture in Japan. Proc. Int. Citrus Symposium:14-24.

Monselise, S.P., 1979. The use of growth regulators in citriculture: a review. Sci. Hortic. 11:151-162.

Ortolá, A., C.Monerri & J.L.Guardiola, 1988. Direct stimulation of fruit size in Satsuma mandarin by the application of naphtalene acetic acid. Actas Hortic. 1:22-27.

Ortolá, A.G., C.Monerri and J.L.Guardiola. 1991. The use of naphtalene acetic acid as a fruit growth enhancer in Satsuma mandarin; a comparison with the fruit thinning effect. Sci. Hortic. 47:15-25.

Ortolá, A., C.Monerri & J.L.Guardiola, 1997. Fruitlet age and inflorescence characteristics affect the thinning and the increase in fruitlet growth rate induced by auxin applications in Citrus. Acta Hortic.(in the press)

Praloran, J.C., G.Vullin, C.Jacquemond & D.Despierre, 1981. Observations sur la croissance des clementines in Corse. Fruits 36:755-767.

Van Rensburg, P., P.Shung-Shi, A.García-Luis, F.Fornés and J.L.Guardiola. 1996. Improving crop value in Fino clementine mandarin with plant growth regulators. Proc. Int. Soc. Citriculture (in the press).

Vanniere, H., C.Jacquemond and G.Vullin. 1987. Amélioration du calibre des clémentines: techniques expérimentées in Corse. Comp. Rendu CLAM, Chania, Greece, July 1987.

Vanniere, H. & P.Arcuset, 1989. Ameloration du calibre des Clementines en Corse par l'emploi du dichlorprop. Fruits 44:393-400.

Zaragoza, S., I.Trenor, E.Alonso, E.Primo-Millo & M.Agustí, 1992. Treatments to increase the final fruit size on satsuma Clausellina. Proc. Int. Soc. Citriculture 2:725-728.