

CLIMATIC EFFECTS ON FLOWERING, FRUIT SET AND QUALITY OF CITRUS – A REVIEW

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Abstract. Weather and genetics have the strongest impact on reproductive response of citrus. Flowering is primarily determined by the amount of cool temperatures and/or drought as well as previous crop load and amount of year-old flush. Citrus in many locations in the Americas responds to both cool temperatures and drought in establishing the flowering level for the next season. Some major factors involved in regulation of fruit set are temperatures, evapotranspiration balance against available soil moisture, and competition with growth amongst fruit and vegetative flush. Competing crop load, temperatures and available soil moisture determine fruit size. Fruit quality is determined by temperatures, soil moisture, nutrition and crop load. Climatic patterns (El Nino Southern Oscillations) influence fruit production and quality through the weather that is produced. The important stages of fruit development mentioned above and their regulation are discussed. The potential to have a unifying model that predicts the level and date of flowering and the effect of temperatures and water availability on fruit set and size are discussed also.

Introduction

For an earlier, more comprehensive review of climatic effects on citrus see Reuther (1973). This review emphasizes climatic factors since, by and large, climate is very important to reproductive growth of citrus, and usually we have little control over climatic effects and must learn to live with them. Different types of citrus (oranges, mandarins, grapefruit, lemons, limes) are clearly suited to different climates (long term weather), particularly in relationship to expected fruit quality. Even within a species, cultivars differ in their suitability to a specific climate. In spite of this, there is still a similar behavior of citrus to weather (short-term climatic variation) stimuli for flowering, fruit set and most quality characteristics. Because of this, it should be possible to provide a unifying model for most behavior if enough data is available to represent all of the weather variability over a given region. This would be an appropriate endeavor for a region such as the Americas because of the climatic variability between and within citrus growing areas in the region and climate's importance to productivity and quality for utilization.

A basic understanding of the behavior of citrus in relation to reproductive growth is a prerequisite to developing a unifying model of this behavior. It is best approached by phenology stage as each stage of reproductive growth has its own controlling factors, but each stage leads to the next and many aspects of the next phase are somewhat regulated by the previous stage. For example, the extent of flowering is regulated by many factors including last year's crop load, but it in turn partially determines how many of the flowers can set and become mature fruit, with fewer percentage of the flowers and fruitlets setting the more flowers there are. Application of climatic variation to citrus reproductive development in Florida is embodied in an expert system (Albrigo, et al. 2002). This program conceptualizes phenological development into a weather driven time course with other important factors, best timing of production practices and counteractive steps that can be applied to partially overcome adverse weather events.

Flowering

The flowering process in citrus consists of several discrete phases: flower bud induction, bud differentiation, and anthesis. The induction process is associated with environmental factors and results in the commitment of meristematic cells to form reproductive structures. Under subtropical conditions, citrus flowering occurs primarily during the spring following the inductive winter season (Furr and Armstrong, 1956, García-Luis *et al.*, 1995a; Monselise and Halevy, 1964). During winter, low-temperature conditions cause the inactivity of buds while inducing them to be able to flower (Moss, 1969, Reuther *et al.*, 1973). As hours of low temperature accumulate, spring bud sprouting shifts from vegetative (with no flowers) to mixed (flowers and leaves) to mostly reproductive (leafless with at least one flower) (Moss, 1969). As for flower intensity, greater accumulation of hours of low temperature increases floral induction, thus increasing number of flowers per tree, number of flowers per node, and sprouting (Poerwanto and Inoue, 1990; Valiente and Albrigo, 2004). The most effective temperatures for induction appear to be in the 10 to 15 °C range (Moss, 1969; Valiente and Albrigo, 2004).

Although winter low temperatures increase citrus flowering (Furr *et al.*, 1947; Moss, 1969), the effects of natural winter temperatures on flowering intensity had not been quantified. This is particularly important in Florida, where winter-time accumulation of hours of inductive temperatures [below 20 °C (Moss, 1976)] can vary from 712 to 1474 hr per year [(analysis of Florida's historical climatological data (Valiente, 2001))] and may explain the great variability in flowering intensity from year to year. Strong correlations of hours of low temperatures with flowering intensity were obtained from recent studies in Florida (Valiente and Albrigo, 2004). Intermittent warm periods during the winter following low temperature flower bud induction periods initiate differentiation of induced flower buds resulting in waves of flowering under Florida conditions (Valiente and Albrigo, 2002).

On the other hand, flowering in tropical climates is the result of water stress induced flower buds and growth and flowering proceed as a rainy season begins (Cassin *et al.*, 1969). At least 45 to 60 days of water stress are required to induce an economic level of flowering in a tropical climate (Cassin *et al.*, 1969; Borroto *et al.*, 1977; Lovatt, *et al.*, 1988), while more than 70 continuous days of water stress may be detrimental to tree health and productivity (Cassin *et al.*, 1969). In contrast, thirty days of continuous low temperature induction results in a moderate flowering level, and 45 days or more with low temperatures usually results in good flowering (Moss, 1969). In intermediate climates, neither the optimum low temperature nor the ideal drought stress induction level is usually met. We do not know the overall effect on flowering when both drought stress and low temperatures suitable for flower bud induction occur but each may last less than the desired time, like some winters in Brazil. Data from Brazil (Albrigo *et al.*, 2004) and growth chamber studies in Florida have begun to evaluate flower bud induction with partial fulfillment of climatic stress by a combination of cool temperatures and drought. More studies are needed to determine the combined effect of these two factors on overall flowering intensity. This is particularly important for climates like those in many of the citrus producing areas of Central America.

Other important factors determining the level of flowering are crop load and availability of buds of the appropriate age to flower. The presence of fruit located at the apex of branches has an inhibitory effect on the sprouting of new shoots and on the expression of the nature (vegetative or reproductive) of basipetal lateral buds (García-Luis *et al.*, 1986; Goldschmidt and Monselise, 1972; Koshita *et al.*, 1999; Moss, 1969; Reuther, 1973). The presence of fruit does not exert a strong inhibitory effect on the growth of shoots from neighboring branches. Fruit diminishes the proportion of buds that are able to sprout on the spring growth (García-Luis *et al.*, 1995b). The inhibitory effect of crop load on sprouting and on vegetative and reproductive development seems to be related to hormonal changes (mainly GA) and carbohydrate competition

(Goldschmidt et al., 1985). In Florida, fruit on 2 to 3 cm branches decreased flowering intensity about 42% compared to no fruit (Valiente and Albrigo, 2004).

Bud age and position along the shoot also interact with climate and affect bud sprouting and flowering. Only buds younger than one year old contribute significantly to spring growth (Guardiola *et al.*, 1977). Once the shoots are mature, the proportion of buds sprouting in spring decreases with increasing bud age. García-Luis *et al.* (1995) reported that summer shoots developed more vegetative buds than generative buds, but in Florida summer flush produces three times more flowers per shoot than spring ones, and buds towards the apex of shoots were more easily induced than basal buds (Valiente and Albrigo, 2004). Also, Guardiola (1981) reported that younger buds of spring flush produced more flowers than older buds and this occurred on both spring and summer shoots in the Florida study (Valiente and Albrigo, 2004).

Once induced, the release of the stress by higher temperatures triggers growth (Cassin et al., 1969), provided that other conditions such as available soil moisture are not limiting. In citrus, the differentiation of floral organs begins at the first stages of bud swelling and sprouting. The time of initiation of differentiation varies by citrus cultivar and environmental conditions (Abbott, 1935). Floral differentiation involves the anatomical and morphological transition of vegetative to floral meristems. Anthesis occurs after the induction and differentiation processes have been completed, usually when warmer springtime conditions exist (Lovatt *et al.*, 1984, Lord and Eckard, 1985).

Ambient temperature not only has a direct effect on induction and differentiation but also affects flowering date and intensity (Cassin *et al.*, 1969; García-Luis *et al.*, 1992). Flowering (initiation of differentiation to full bloom) in high temperature tropical climates can occur in less than 24 days (Cassin *et al.*, 1969), while at much as 4 to 5 months are required in a much cooler Mediterranean climate (Lord and Eckard, 1985). In Florida over 20 years, the time for flower bud development to full bloom ranged from 54 to 88 days (Valiente and Albrigo, 2002). High temperatures during floral differentiation and expansion shorten development time and advance date of anthesis (Moss, 1973; Guardiola, 1997a Valiente and Albrigo, 2002), but higher temperatures during sprouting also are reported to increase inflorescence leafiness and to inhibit flowering (Moss, 1976) and date of flowering (Valiente and Albrigo, 2002).

A temperature model for date of flowering has been developed for Florida (Valiente and Albrigo, 2002), but it is not known if it is applicable in other climates. Its usefulness may be limited, particularly if drought stress occurs during part of the flower bud differentiation period.

Fruit set

Fruit set is regulated primarily by number of flowers, additional competition with flush and other fruitlets, temperatures and available moisture balanced against evaporative demand. Generally, fruit set increases as more flowers are available, but the % set decreases, particularly at very high levels of flowering. This is primarily from competition, which begins between the flowers and may also include competition with the spring flush (Guardiola, 1997b). At high levels of flowering typical of navel oranges (Erickson and Brannaman, 1960) and probably many mandarin cultivars (Guardiola, 1977), many flowers are too weak or not fully developed and fall off the tree without opening. Further competition continues as the fruit enlarge. Both carbohydrate and possibly nutritional competition contribute to the typical drop waves that occur during and after flowering (Ruiz and Guardiola, 1994, Albrigo, 2002).

Very high temperatures during bloom and for the following 2 to 3 months result in excessive fruit drop (Moss, 1973; Brewer *et al.*, 1977). The progress of the drop waves is also accelerated. If soil moisture is limited, excessive fruit drop occurs until the second drop wave is over (May-June

for a spring bloom) (Koo, 1967). After these 2 drop waves are completed, the fruit are very resistant to further drop at least until near harvest (Erickson and Brannaman, 1960).

These earlier studies all dealt with typical spring blooms in Mediterranean Subtropical climates. The effects of intermediate climates (tropical-subtropical) and tropical climates on fruit set have scarcely been reported. Further, the performance of second blooms as regarding fruit set has not been reported. Is the first bloom crop load sufficient to constitute another competition factor? Is the weather sufficiently different after a second bloom compared to after the first bloom to result in a completely different potential for fruit set. How much of a factor is post bloom fruit drop (Peres et al., 2000) compared to detrimental weather factors acting directly on fruit set. All of these potential variables make fruit set in intermediate and tropical climates much more complicated than in a lower winter temperature, single bloom inducing regime with a Mediterranean climate.

Fruit size

Fruit size is primarily regulated by number of competing flowers and fruitlets, temperatures, particularly during early development and available soil moisture through most of fruit development. Canopy leaf area to fruit numbers is probably a factor also. All of these factors have a larger influence earlier than later in fruit development.

Although citrus is not as sensitive as some other fruit crops to competition from other fruit as a factor in determining fruit size, there is still an effect, particularly in cooler climates such as California, Spain or South Africa. This is reflected in the fruit growth's sensitivity to nutritional balance between N and K in these climates (DuPlessis and Koen, 1988). In warmer, more humid climates, fruit size is often acceptable even with a large crop. This is because the higher temperatures from bloom through the first half of fruit development in the tropical climates increase the rate of fruit growth (Reuther and Ríos-Castaño, 1969). This period covers the cell division and major cell enlargement phase of fruit growth (Bain, 1958). In the cooler spring climates of Mediterranean areas, higher temperatures during the first stage of fruit growth can significantly increase fruit size (Marsh, et al., 1999). Ideal temperatures for enhancement of fruit growth rate appear to be in the 20 to 25 °C range, with both lower and higher temperatures reducing growth rate (Reuther, 1973). Good soil moisture availability during stages 1 and 2 also is important to fruit growth rate (Taylor and Furr, 1937). Even later in fruit development (Summer to early Fall for Spring bloom fruit), heavy irrigation or rains can lead to larger fruit at harvest (Sites *et al.*, 1951).

Because citrus crop load is usually not very heavy in a tropical climate while temperatures are favorable for a good growth rate, fruit size problems are likely to be from sizes being too large. Quick expansion of fruit and prolonged maintenance of green color often make it difficult to distinguish between fruit of different blooms for proper timing of harvests. Flowering and fruit expansion characteristics need to be understood in relationship to fruit maturation and anticipated quality to maximize harvested quality in intermediate to tropical climates.

Fruit quality

Each *Citrus* species and cultivar has an expected internal and external quality when grown under ideal management and weather conditions for that cultivar. These expectations differ enough that at least one type of citrus is ideally suited to a given Subtropical to Tropical climates, while others often are not. The suitability of a cultivar to a given climate is mostly

related to the species selection in its area of origin (Reuther, 1973) and secondarily to special characteristics of some cultivars.

Limes are native to Southeast Asia and, as such, do well in a tropical climate. They are expected to stay green and have a good acid level. Lime fruit start with very high acidity levels that can withstand the degradation of acidity that high temperatures cause (Kurihara, 1969). High temperatures retard the degradation of chlorophyll and thus the fruit stay green (Reuther, 1973).

Because it is a fruit with high acidity and bitter principles that are reduced by high temperatures, grapefruit also do well in a tropical or a warmer, humid subtropical (intermediate subtropical, Reuther, 1973) climate. Grapefruit probably originated in the Caribbean Tropics as a pummelo hybrid (Bowman and Gmitter, 1990). The fact that color change only requires loss of green to expose natural yellows also makes it a suitable citrus for warmer climates.

Lemons might fit this tropical scenario also, but the tree is too vigorous and thorny in a tropical or even intermediate climate. Fruit quality as we expect it is very satisfactory in a Mediterranean climate. The area of origin is thought to be the eastern Himalayan regions of India (Davies and Albrigo, 1994).

Oranges require cool temperatures during later stages of development in order to have good color development and to preserve acidity from the lower levels that usually occur in cultivars of this fruit. Oranges originated in cooler climates, probably in Central China, and they were most likely selected for lower acidity as that suits the palate of Asian people. These color and internal quality characteristics are difficult to maintain in a tropical climate and in many years in intermediate climates (Reuther, 1973; Albrigo (1990).

Mandarins carry these color and acidity characteristics to even more of an extreme and usually do the poorest as far as fruit set (seedless management cultivars) and quality are concerned when grown in a tropical climate. Under higher temperature growing conditions typical of tropical and many intermediate climates, the resulting internal fruit quality is usually very insipid, with moderate sugars and very low acidity particularly if the high temperatures persist late into fruit development. Externally, the fruit are usually too green and unattractive when grown in a hot climate.

General effects of warmer climates on citrus fruit development are as follows: regarding internal quality, high temperatures accelerate fruit growth, the fruit has less time to accumulate soluble solids, and the high respiration rate leads to use of carbohydrates in respiration, which further reduces available sugars for accumulation in the fruit. The high respiration rate may lead to faster turnover of acids (Purvis, 1983) with resulting rapid dissipation of acidity level at higher temperatures (Kurihara, 1969; Reuther, 1973). In Florida, there is a significant relationship between fall temperature and rate of acidity decline (Fig. 1). Faster maturation, due to higher temperatures in the tropics not only leads to lower soluble solids than in intermediate climates and lower acidity than in all cooler climates but also leads to early juice loss (Reuther and Ríos-Castaño, 1969). More section drying also occurs with low acidity and soluble solids content (Burns and Albrigo, 1997) and earlier maturation and other-wise poorer internal quality (Reuther, 1973). External quality also is affected by tropical climates through larger size, smoother surfaces, but poorer color if loss of green and enhancement of orange pigments is desirable (Reuther and Ríos-Castaño, 1969). More external waxes are deposited on the surface of oranges grown in a cool, dry climate compared to a warm, humid one (Albrigo, 1973) which results in less weight loss after harvest (Fig. 2). Generally, better fresh external quality occurs in cooler fall and winter climates, while better juice quality occurs in intermediate climates that have moderate winters and higher humidity (Reuther, 1973).

Year to year variation in weather in a given climatic zone can lead to significant fruit quality variation. In the Southeastern USA, El Niño Southern Oscillations (ENSO) cause large differences in winter temperatures and rainfall (Hansen *et al.*, 1998). In turn this may lead to significant differences in soluble solids content of citrus fruit (Albrigo, 1993) (Table 1). This effect may be because of changes in winter temperatures from warmer to colder years in an ENSO cycle. In warmer winters, photosynthesis may be higher (Possingham and Kriedemann, 1969), thereby producing more sugars for accumulation in the fruit. In cooler winters the reverse can happen. This effect may be more pronounced in Valencia fruit that develop and mature over a time period that includes 2 winters in Florida. Juice content also is affected by these cycles. The overall effect on soluble solids per box may be as much as 0.9 kg per 40.8 kg fresh wt from low to high solids years (Albrigo, 1990).

There is some evidence that the climate of Brazil also is influenced by ENSO cycles, but little information is available about how much impact these weather cycles may have there or on citrus production in other areas in the Americas. Since seasonal temperatures and rainfall can be influenced, both flowering and fruit development also may be affected in many growing areas. These possibilities should be studied further in more citrus growing areas of the Americas, and probably other areas of the world.

Literature Cited

- Albrigo, L.G. 1973. Some parameters influencing development of surface wax-Citrus fruits. Proc. 1st Int. Soc. Citriculture 1973, Vol. 3:107-115.
- Albrigo, L.G. 1990. Climatic influences on seasonal variation of Florida "Valencia" orange pounds solids. XXII Congress Internl. Soc. Hort. Sci. 1. Oral; 645(Abst. 2413)
- Albrigo, L.G. 1993. Multi-year production cycles of 'Valencia' orange soluble solids per fresh weight coincide with El Nino events. HortScience 28(5):484 (Abst. 256).
- Albrigo, L.G. 2002. Foliar uptake of N-P-K sources and urea biuret tolerance in citrus. Proc. Int. Symp. Foliar Nutrition of Perennial Fruit Plants. Acta Hort. 594:627-633.
- Albrigo, L.G., J.I. Valiente and H.W. Beck. 2002. Flowering expert system development for a phenology based citrus decision support system. Acta Hort. 584:247-254
- Albrigo, L.G, J.I. Valiente and C. Van Parys de Wit. 2004. Influence of drought and winter temperatures on year-to-year citrus fruit set and yield variation in Sao Paulo, Brazil. Proc. Int. Soc.Citriculture, p. 263-267.
- Abbott, C.E. 1935. Blossom-bud differentiation in citrus trees. Amer. J. Bot. 22:476-485.
- Bain, J.M. 1958. Morphological, anatomical and physiological changes in the developing fruit of 'Valencia' orange *Citrus sinensis* (L.) Osbeck. Aust. J. Bot. 6(1):1-24
- Borroto, C.G. and A.M. Rodríguez. 1977. The effect of water stress and presence of fruit of previous harvest on flowering and fruit set of 'Valencia' oranges in Cuba. Proc. Int. Soc. Citriculture 3:1069-1073.
- Bowman, K.D. and F.G. Gmitter, Jr. 1990. Caribbean forbidden fruit: Grapefruit's missing link with the past and to the future. Fruit Varieties J. 44:41-44/
- Brewer, R.F., K. Opitz, F. Aljibury and K. Hench. 1977. The effects of cooling by overhead sprinkling on "June Drop" of navel oranges in California. Proc. Int. Soc. Citriculture 1977, Vol. 3:1045-1048.
- Cassin, J., J. Bourdeaut, A. Fougue, V. Furon, J.P. Gaillard, J. LeBourdelles, G. Montagut and C. Moreuil. 1969. The influence of climate upon blooming of citrus in tropical areas. Proc. First Int. Citrus Symp. 1:315-323.

- Davies, F.S. and L.G. Albrigo. Citrus, 254 pp, CAB International Press, Wallingford, UK.
- DuPlessis, S.F. and T.J. Koen. 1988. The effect of N and K fertilization on yield and fruit size of Valencia. Proc. Sixth Internl. Citrus Cong. Vol 2:663-672.
- Erickson, L.C. and B.L. Brannaman. 1960. Abscission of reproductive structures and leaves of orange trees. J. Amer. Soc. Hort. Sci. 75:222-229.
- Furr, J.R. and W.W. Armstrong. 1956. Flower induction in Marsh grapefruit in the Coachella Valley, Calif. Proc. Amer. Soc. Hort. Sci. 67:176-182.
- García-Luis, A., V. Almela, C. Monerri, M. Agustí, and J.L. Guardiola. 1986. Inhibition of flowering in vivo by existing fruits and applied growth regulators in *Citrus unshiu*. Physiol. Plant. 66:515-520.
- García-Luis, A., M. Kanduser and J.L. Guardiola. 1995. The influence of fruiting on the bud sprouting and flower induction responses to chilling in *Citrus*. J. Hort. Sci. 70:817-825.
- García-Luis, A., M. Kanduser, P. Santamarina and J.L. Guardiola. 1992. Low temperature influence on flowering in *Citrus*. The separation of inductive and bud dormancy releasing effects. Physiol. Plant. 86:648-652.
- Goldschmidt, E.E., N. Aschkenazi, Y. Herzano, A.A. Schaffer and S.P. Monselise. 1985. A role for carbohydrate levels in the control of flowering in citrus. Sci. Hort. 26:159-166.
- Goldschmidt, E.E. and S.P. Monselise. 1972. Physiological assumptions towards the development of a citrus fruiting model. Proc. Intl. Soc. Citricult. 2:668-672.
- Guardiola, J.L. 1981. Flower initiation and development in citrus. Proc. Intl. Soc. Citricult. 2:242-246.
- Guardiola, J.L. 1997a. Overview of flower bud induction, flowering and fruit set, p. 5-21. In: S.H. Futch and W.K. Kender (eds.). Citrus flowering and fruit short course. Citrus Research and Education Center, Lake Alfred, Fla.
- Guardiola, J.L. 1997b. Competition for carbohydrates and fruit set., p. 43-72. In: S.H. Futch and W.K. Kender (eds.). Citrus flowering and fruit short course. Citrus Research and Education Center, Lake Alfred, Fla.
- Guardiola, J.L., M. Agustí and F. García-Mari. 1977. Gibberellic acid and flower bud development in sweet orange. Proc. Intl. Soc. Citricult. 2:696-699.
- Hansen, J.W., A. Irmak and J.W. Jones. 1998. El Niño – Southern Oscillation influences on Florida crop yields. Proc. Soil Crop Soc. Fla. 57:12-16.
- Koo, R.C.J. 1967. Importance of moisture control in citrus groves. Citrus World, September 1967; pp13, 16.
- Kurihara, A. 1969. Fruit growth of Satsuma orange under controlled condition. I. Effects of preharvest temperature on fruit growth, color development, and fruit quality in Satsuma orange. Bul. Hort. Res. Sta. Japan Ser. A, No. 8:15-30.
- Koshita, Y., T. Takahara, T. Ogata and A. Goto. 1999. Involvement of endogenous plant hormones (IAA, ABA, GAs) in leaves and flower bud formation of satsuma mandarin (*Citrus unshiu* Marc.). Sci. Hort. 79:185-194.
- Lovatt, C.J., S.M. Streeter, T.C. Minter, N.V. O'Connell, D.L. Flaherty, M.W. Freeman and P.B. Goodell. 1984. Phenology of flowering in *Citrus sinensis* [L.] Osbeck cv. Washington navel orange. Proc. Intl. Soc. Citricult. 1:186-190.
- Marsh, K.B., A.C. Richardson and E.A. McCrae. 1999. Early- and mid-season temperature effects on the growth and composition of satsuma mandarins. J. Hort. Sci. & Biotech. 74:443-451.
- Monselise, S.P. and A.H. Halevy. 1964. Chemical inhibition and promotion of citrus flower bud induction. Proc. Amer. Soc. Hort. Sci. 84:141-146.
- Moss, G.I. 1969. Influence of temperature and photoperiod on flower induction and inflorescence development in sweet orange (*Citrus sinensis* L. Osbeck). J. Hort.

- Sci. 44:311-320.
- Moss, G.I. 1973. The influence of temperature during flower development on the subsequent fruit-set of sweet orange (*Citrus sinensis*) 'Washington Navel.' Hort. Res. 13:65-73.
- Moss, G.I. 1976. Temperature effects on flower initiation in sweet orange (*Citrus sinensis* L. Osbeck). Aust. J. Agric. Res. 27:399-407.
- Peres, N.A.R., N.L. Souza and L.W. Timmer. 2000. Postbloom fruit drop in Brazil and Florida: Occurrence and control by fungicides. Proc. Intl. Soc. Citricult. IX Congr. 2000:1051-1052.
- Poerwanto, R. and H. Inoue. 1990. Effects of air and soil temperatures on flower development and morphology of satsuma mandarin. J. Hort. Sci. 65:739-745.
- Possingham, J.V. and Kriedemann. 1969. Environmental effects on the formation and distribution of photosynthetic assimilates in citrus. Proc. First Citrus Symp. Vol 1:325-332
- Purvis, A.C. 1983. Effects of film thickness and storage temperature on water loss and internal quality of seal-packaged grapefruit. J. Amer. Soc. Hort. Sci. 108:562-566.
- Reuther, W. 1973. Climate and citrus behavior, p. 280-337. In: W. Reuther (ed.). The Citrus Industry. Vol. III. Univ. of Calif. Press, Davis.
- Reuther, W., E.M. Nauer and L. Summers. 1973. Effects of seasonal temperature regimes on development and maturation of citrus fruits. Proc. Intl. Soc. Citricult. 3:63-71.
- Reuther, W. and D. Ríos-Castaño. 1969. Comparison of growth, maturation and composition of citrus fruits in subtropical California and tropical Columbia. Proc. First Internl. Citrus Symp. Vol 1;277-300.
- Ruiz, R. and J.L. Guardiola. 1994. Carbohydrate and mineral nutrition of orange fruitlets in relation to growth and abscission. Physiol. Plant. 90:27-36.
- Sites, J.W., H.J. Reitz and E.J. Deszyck. 1951. Some results of irrigation research with Florida citrus. Proc. Fla. State Hort. Soc. 64:71-79.
- Taylor, C.A. and J.R. Furr. 1937. Use of soil-moisture and fruit-growth records for checking irrigation practices in citrus orchards. USDA Cir. 426; 23pp.
- Valiente, J.I. 2001. Timing and intensity of flowering of sweet orange [*Citrus sinensis* (L.) Osbeck] as a function of local weather factors and crop under central Florida conditions. PhD Diss., Dept. of Hort. Sci., Univ. of Fla.
- Valiente, J.I. and L.G. Albrigo. 2002. Modeling flowering date of sweet orange [*Citrus sinensis* (L.) Osbeck] trees in Central Florida based on historical weather records. Proc. Internl. Soc. Citricult. 1:186-190.
- Valiente, J.I. and L.G. Albrigo. 2004. Flower bud induction of sweet orange trees [*Citrus sinensis* (L.) Osbeck]: Effect of low temperatures, crop load, and bud age. J. Amer. Soc. Hort. Sci. 129 (in press).

Table 1. Soluble solids (kg SS per 40.8 kg fresh wt.) of 'Valencia' oranges in Florida. Average of 5 years in each December-January mean temperature and accumulated rainfall range.

Winter weather type	Mean Dec-Jan. T °C	Avg. Accumul. Rain cm	SS kg / 40.8 kg FWt
Lower T	15.7	9.4	2.7
Medium T	16.5	13.4	3.0
Higher T	18.5	18.2	3.2

Fig. 1. Effect of fall monthly average maximum temperature on the rate of acidity decline, data from several years plotted against maximum monthly temperature.

Fig. 2. Surface wax concentration on fruit from 3 orchards in a cool, dry climates (Central California (o) and Arizona (*)) and 3 orchards from a warmer, more humid climate (Florida (+) and the wax effect on postharvest weight loss.