EFFECT OF CLIMATE ON FRUIT DEVELOPMENT AND MATURATION

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Citrus is an evergreen, subtropical crop and low temperatures are the main factor restricting its geographical distribution. Frost and freezing temperatures damage the fruit and when lasting long enough, may kill the trees. Even at the milder, non-damaging range, temperatures present major limitations for vegetative growth as well as for fruit development and maturation. Little growth occurs in citrus tree organs below 13 °C (55 °F). However, in areas where temperatures rise above that minimum only for a relatively short summer period, both vegetative and reproductive development may be very much restricted.

Table 1 summarizes temperature, heat unit accumulation and rainfall data for several citrus growing areas around the world. Annual temperature averages tell, of course, only part of the story; monthly or even daily fluctuations reveal subtle changes which are also physiologically meaningful. The cumulative heat-unit method which is commonly used for prediction of harvest dates is also rather crude, since the response of fruit at different developmental stages to temperature varies considerably (Newman et al., 1967). Still, heat-unit data seem to correlate reasonably well with dates of fruit maturation (Reuther, 1973). Differences in date of maturation between 'early' and 'late' cultivars (e.g., Washington Navel and Valencia oranges) are believed to reflect differences in heat unit requirements - late cultivars require a larger sum of heat units. When the monthly increment of heat units is small, even seemingly slight differences between cultivars in heat unit requirements may result in considerable delay of maturation. Areas with low annual heat sums are forced to grow early ripening cultivars (Clementines, Satsumas).

While Table 1 shows the climatic data, Figure 1 demonstrates the ensuing differences in fruit development between a subtropical, cool dry location (Santa Paula, California) and a tropical location (Palmira, Colombia). Under the high temperatures prevailing in the tropics fruit development is fast and the fruit gets very large. In California fruit development is much slower. Fruit growth stops during cool winter months and resumes again at a low rate during spring, but the final size of fruit is considerably smaller than that attained in the tropics. The heat unit requirement for maturation of Valencia orange is fulfilled in tropical Colombia within 6.5 months, while in cool California about double this time is required. Correspondingly, tropical Valencia fruit remain 'mature and marketable' only for a short time, followed by rapid senescence. The California fruit, on the other hand, has an extended period of maturity during which the fruit may be harvested and marketed. Less extreme differences in heat-unit accumulation, such as found between mild, coastal and inner, desert-like locations (e.g., in Israel or California) are nonetheless sufficient to produce several weeks' delay in maturation dates (Herzog and Monselise, 1968; Reuther, 1973).

Table 1. Annual mean maximum, mean minimum, range and average temperatures, annual heat unit accumulation, annual rainfall and brief definition of climate in various citrus-growing regions.

Location	Latitude	Temperature (°C)				Heat Units	Rainfal l (mm)	Definition of climate
		Max.	Min.	Range	Average			
Rehovot, Israel	32° N	25.2	14.0	12.2	20.1	2595	580	Subtropical
Valencia, Spain	39.5° N	20.8	12.3	8.6	16.5	1626	397	Mediterranean, cool
Wakayama, Japan	34° N	21.3	11.8	9.5	16.6	1951	1808	Maritime, cool
Kerikeri, New Zealand	37° S	20.2	9.7	10.5	15.0	896	1656	Maritime, cool
Nelspruit, South Africa	25.5° S	26.7	13.7	13.0	20.2	2607	812	Semitropical
Orlando (Florida), USA	28.5° N	28.2	16.7	11.5	22.4	3465	1339	Semitropical
Santa Paula (California), USA	34.5° N	24.2	7.6	16.6	16.2	1258	317	Subtropical, cool-dry
Palmira, Colombia	3.5° N	29.9	18.0	11.9	23.9	3918	1010	Tropical

[1]Calculated as the annual sum of the (Average monthly temperature - 13) X (no. of days per month).
Compiled from data from Reuter (1973).
Conversion of °C to °F = °C x 1.8 + 32 = °F.

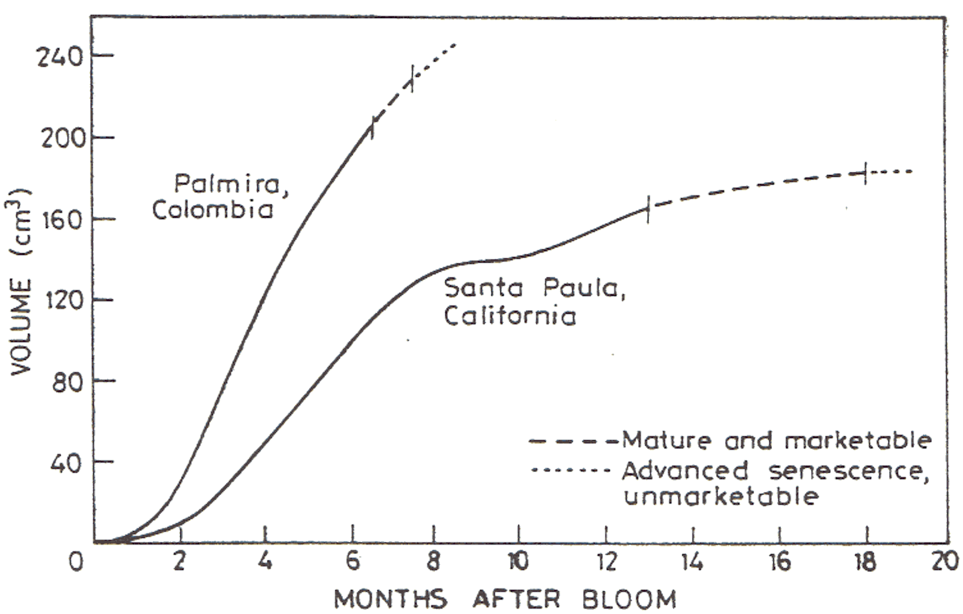

Figure 1. Schematic presentation of typical Valencia orange growth curves in two widely different climatic situations. In addition, periods of immaturity, market maturity and advanced senescence are approximated (modified from Reuther, 1973).

Climate affects fruit quality as well. Rind color is a major problem in the tropics - warm temperatures interfere with the loss of chlorophyll as well as with the build up of carotenoids. Thus, fruit in the tropics stay greenish and pale; oranges and mandarins, in particular, do not attain their attractive rind color. Cool temperatures, on the other hand, enhance the desired color changes. The autumn decline in air and soil temperatures marks the onset of color changes in subtropical regions (Young and Erickson, 1961). This view is supported by a large number of field observations and could also be simulated in controlled greenhouse experiments (Reuther, 1973).

Combinations of high temperature and high humidity result in tender, rapidly senescing fruit which has low storage potential and is highly susceptible to peel blemishes. A comparison between coastal and desert grown fruit in California has shown that the peel of fruit developing under the drier climate has a lower water content and is not so tender, presumably due to the hardening effect of moisture stress (Monselise and Turrell, 1959).

Internal quality is also affected by climate. Fruit developing in a hot, tropical climate tends to have a high total solids content, which is an advantage for the processing industry. Fruit developing under warm climates reach marketable sugar/acid ratios sooner than cooler locations. On the other hand, these fruits are low, often very low, in acid resulting in poor edible quality of low-acid cultivars. Thus, the somewhat cooler, subtropical areas are preferable for production of oranges and mandarins for the fresh fruit market.

Peel thickness and fruit shape is also affected by climate. Low average minimum winter temperatures resulted in thick-peeled, pyriform Marsh Seedless grapefruit developing during the following summer (Cohen et al., 1972), a phenomenon which still awaits a reasonable physiological explanation. The secondary thickening of the peel (Figure 2, Stage III,) is more pronounced under warm autumn temperatures (Kuraoka and Kikuki, 1961).

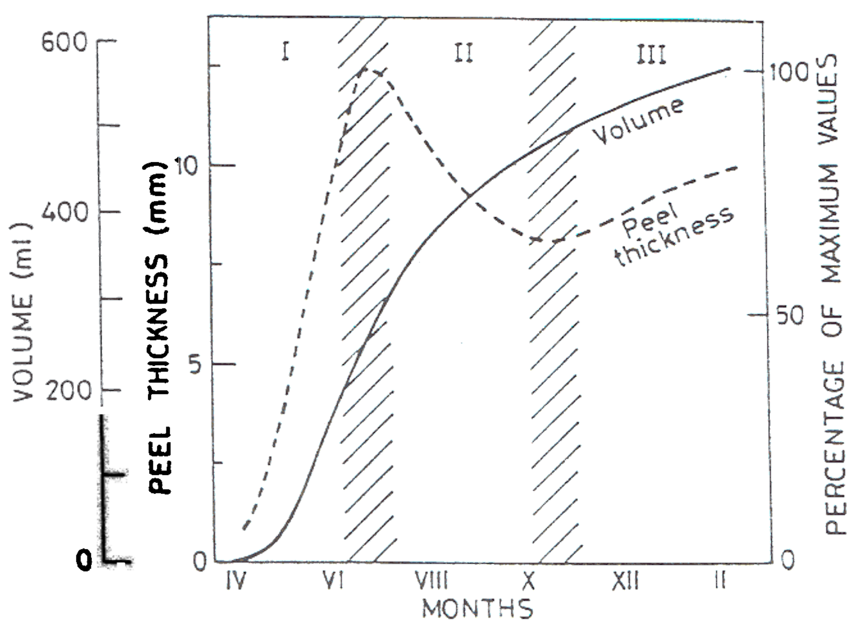

Figure 2. Fruit growth and development: growth in volume and peel thickness. I, II, III indicate developmental stages according to Bain (1958). Modified from Monselise (1986).

An extensive discussion of additional aspects of fruit development and maturation may be found in Spiegel-Roy and Goldschmidt (1996).

Temperature is the most important environmental factor affecting the citrus crop (Gat et al., in press) and, as such, must be carefully taken into account in productivity models.

Methods using the average daily or monthly temperature (e.g., the heat-unit system, see Table 1) often fail to express and quantify the effects of temperature, especially where large differences between daily maximum and minimum occur. The increasing computing abilities nowadays enable hourly based data processing.

A response-curve for fruit growth in grapefruit has been determined for a temperature range of 8-38°C (46-100°F), based on data taken from the literature. Effective Heat Unit (EHU) has been defined as one hour in which the optimum temperature (23°C or 73°F) is recorded. The daily accumulation of EHU (up to 24) directly relates to the response-curve, and is used to adjust the predicted fruit growth rate to the diurnal pattern of temperature (Bustan et al., 1996).

The EHU method takes into consideration the limiting effects of high temperature on fruit growth, which have been ignored by the common Daily Degree Days (DDD) method. The advantages of the EHU method will be demonstrated using fruit growth simulation and validation in two locations representing the mild, coastal region as against the hot, inner valleys in Israel.

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