

GRANULATION IN FLORIDA CITRUS

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Abstract. Granulation (also called crystallization or section drying) is a physiological disorder in citrus that results in reduced extractable juice and sometimes vesicle shriveling. While segments appear dry, the disorder is not caused by drying, but by gel formation within the vesicles. Though many citrus varieties may develop granulation (i.e., 'Valencia' orange, tangerines, and grapefruit), it was a particular problem in Florida 'Navel' oranges during the 2003 season. Many factors have been associated with the development of granulation in citrus, including advanced fruit maturity, large fruit, excessive tree vigor, severe mite damage, composition of the juice, and cool, dry, windy weather conditions. Tree water status and irrigation have also been reported to affect granulation with researchers reporting less granulation with less irrigation. During the 2003 navel orange season, the relatively high temperatures during bloom, low fruit set, and associated larger fruit likely played an important role in the excessive development of granulation in the fruit. Changing cultural practices (i.e., fertilization and irrigation) and use of rootstocks that encourage vigorous tree growth may have promoted the development of granulation,

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but specific data and their related impact on granulation in Florida are limited.

What is Granulation?

Granulation (also called crystallization or section drying) is a physiological disorder in citrus that results in reduced extractable juice and sometimes vesicle shriveling (Fig. 1). While segments appear dry, the disorder is not caused by drying, but by gel formation within the vesicles (Bartholomew et al., 1941). Freezing and sunburn cause injury that can be mistaken for granulation, but these events cause cellular col-



Fig. 1. Granulation of navel orange.

lapse and localized tissue death resulting in loss of juice and subsequent drying of sections, and not gel formation. Injury from freezing or sunburn can be separated from sound fruit based on fruit density and water content using optical sizers/graders that can calculate density based on fruit shape, or by the use of near infrared (NIR) absorption spectrometry or X-ray computed tomography (Grierson and Hayward, 1959; Miller, et al., 1988; Peiris et al., 1998). Even in granulated grapefruit, however, there is often a mixture of granulated vesicles and desiccated, collapsed vesicles that make definite distinction between granulation and vesicle desiccation difficult, but that allows possible separation of unmarketable fruit based on fruit density (Hwang et al., 1988).

Granulated vesicles within sections are discolored with a tough texture. The individual parenchyma cells within granulated vesicles have thickened walls with secondary wall formation in severe cases (Burns and Achor, 1989; Hwang et al., 1990). Such changes involve increased concentrations of various cell wall components (cellulose, hemicellulose, pectin, and lignin). Granulated vesicles also have elevated respiration, increased juice pH, and less soluble sugars and acids (Bartholomew et al., 1941; Burns, 1990; El-Zeftawi, 1978; Gilfillan and Stevenson, 1977; Sinclair and Jolliffe, 1961). Increased respiration is thought to fuel the various metabolic changes, especially changes in the cell wall (Burns, 1990). Other compositional changes are also evident within granulated tissue, with granulated juice vesicles containing 1.7 times the magnesium and more than twice the calcium content of normal vesicles (Sinclair and Jolliffe, 1961). It is thought that elevated levels of pectin and calcium result in the gel formation characteristic of granulated tissue.

Many citrus cultivars develop granulation such as 'Valencia' and navel orange (Bartholomew et al., 1941; El-Zeftawi, 1978; Gilfillan and Stevenson, 1977; Noort, 1969), tangerines (Nakajima, 1976), and grapefruit (Burns and Albrigo, 1997; Hwang et al., 1988). However, the disorder develops differently depending on the citrus species: in navel oranges, granulation often extends through the center of the fruit (Gilfillan and Stevenson, 1977; Noort, 1969); in grapefruit, it develops first at the stylar-end of the fruit (Burns and Albrigo, 1997); and in the other types, it develops first at the stem end (Bartholomew et al., 1941).

Possible Causes of Granulation

Though granulation has been shown to develop during storage in some citrus regions of the world (Gilfillan and Stevenson, 1977; Noort, 1969), in the United States it is considered to be a preharvest disorder (Smoot et al., 1971). However, even in the United States, the severity of the disorder can be enhanced during postharvest storage (Burns and Albrigo, 1997; Hwang et al., 1988). For example, Burns and Albrigo (1997) found that granulation developed faster in harvested 'Ruby Red' grapefruit stored at 21 °C, than in fruit left on the tree. In Florida grapefruit, Brown et al. (1998) found no effect of wax, fungicides, or storage temperature on the occurrence of the disorder after 16 weeks of storage.

Many factors have been associated with the development of granulation in citrus. The disorder is most commonly associated with large fruit and/or advanced fruit maturity (Awasthi and Nauriyal, 1972a; Bartholomew et al., 1941; Burns and Albrigo, 1997; Sinclair and Jolliffe, 1961; El-Zeftawi, 1973). Delayed harvest increases the risk of granulation with-

in the fruit. Production of large fruit is often associated with low fruit set which results in more plant resources (e.g., carbohydrates) available to each fruit for growth. Thus, delaying harvest of trees producing a small number of large fruit, should be avoided. Comparing alternate bearing cycles of citrus, El-Zeftawi (1973) reported more granulation during the light-bearing ("off") years, compared to the heavy-bearing ("on") years. Young trees often also experience greater levels of granulation (Awasthi and Nauriyal, 1972a; Bartholomew et al., 1941) possibly due to their rapid growth (vigor) and production of fewer, but larger fruit.

Growing location (i.e., higher levels in the coastal regions of California compared to the interior) and rootstock have been reported to influence the development of granulation (Awasthi and Nauriyal, 1972a; Bartholomew et al., 1941; El-Zeftawi, 1978), but results vary with growing region. Awasthi and Nauriyal (1972a) also reported that granulation was enhanced under shaded conditions, being highest in interior-canopy fruit and in fruit covered with black bags. In addition, granulation is associated more with late-bloom fruit (Bartholomew et al., 1941) than fruit from the main bloom.

Tree water status and irrigation have been reported to affect granulation with researchers reporting less granulation with less irrigation (Bartholomew et al., 1941). This effect appears to be independent of fruit size. In one block of severely granulated Florida 'Valencia' orange, 90% of fruit from trees receiving irrigation during drought periods developed at least some granulation, compared to only 72% of the fruit from unirrigated trees (Sites et al., 1951). Furthermore, in South African 'Navel' oranges, researchers reported that heavy late-summer rains enhanced granulation (Noort, 1969). Severe mite damage, and cool, dry, windy weather conditions have also been mentioned as possible causes of granulation (Browning et al., 1995).

As mentioned earlier, granulation is associated with lower sugar and acid levels within the fruit. Because many of the factors mentioned above relating to granulation also result in reduced internal sugar and/or acid content (e.g., late-bloom fruit, large fruit, high temperatures, increased fruit water content through irrigation or rain, shaded conditions, etc.), unusually low sugar and acid content may somehow provide a unifying mechanism for the development of granulation.

Florida 'Navel' Oranges this Season

While granulation often develops in late-season navel oranges, the 2003 Florida 'Navel' orange season experienced severe (50%, 75% or more) granulation relatively early (October) in the season. Orange growers and packers reported similar levels of granulation throughout the state and also in other cultivars. Even plantings of navel orange on sour orange rootstock, which growers associate with lower levels of granulation, developed severe problems.

Removing granulated fruit at the packinghouse can be difficult since there is no external sign of poor internal fruit quality. The gel formation associated with granulation does not in itself result in decreased fruit density compared to non-granulated fruit, rather, collapsed desiccated vesicles which are often intermixed with granulated vesicles (Hwang et al., 1988) do result in lower fruit density. Awasthi and Nauriyal (1972b) reported success in separating normal and granulated fruit based on density. In a recent evaluation in Florida, fruit were harvested in Oct. 2003 from two commercial navel

orange blocks and transported to the Citrus Research and Education Center in Lake Alfred, Fla. Fruit were run through a Colour Vision optical grader (Colour Vision Systems, Vero Beach, Fla.) at a speed of five cups per second. The grader was set to separate fruit into five density classes (<0.72, 0.72-0.77, 0.77-0.82, and >0.82 g/cm³). After the separated fruit were collected, they were cut at 0.64 cm (¼ inch) depths from the stem and categorized on the basis of granulation on a 0 (none) to 3 (severe) scale. ‘Navel’ oranges from one block (Fig. 2A) all had moderately severe to severe granulation (score of 2.25 to 2.95). Though fruit grouped in the lowest density classification (<0.72 g/cm³) were more granulated than the rest of the fruit, separation on a commercial scale would not be practical because of the severity of granulation even in the densest fruit. Granulation in the second block of navel oranges was less severe (Fig. 2B). While fruit in the least dense classifications still had moderately high granulation (score of 2.1 to 2.2), the densest fruit (>0.82 g/cm³) developed only slight granulation (score of 1.3) and may have been commercially salvageable for the fresh market. Besides fruit density, separation by size also served as useful grading criterion in removing granulated fruit, since large fruit are more granulated than small fruit. Using automatic sizing and grading equipment to sort for small-sized, high density fruit would result in the greatest chance of recovering non-granulated, packable fruit.

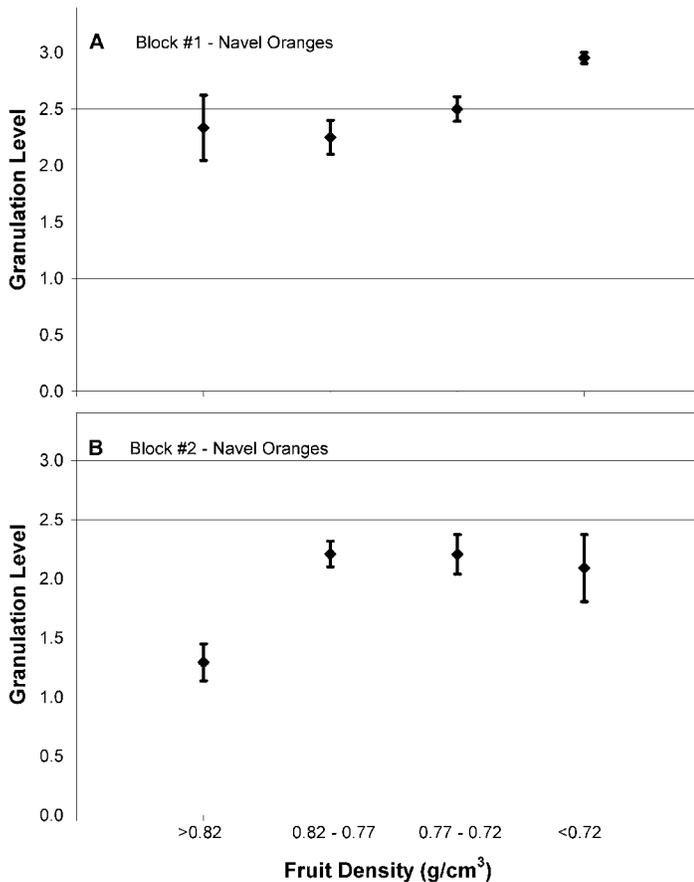


Fig. 2. Fruit density (g/cm³) versus level of granulation ¼ inch from the stem end in navel orange from two commercial blocks (“A” and “B”). Granulation was rated on a scale from 0 = none, to 3 = severe. Vertical bars represent ± standard error.

So what caused the unusually severe granulation in the 2003 Florida navel orange crop? There are likely many interacting factors, but low fruit set and subsequent fruit development were probably most important. Unlike the preceding 3 years that experienced relatively low levels of granulation (University of Florida/IFAS, 2004), in 2003 the Ft. Pierce February-March temperatures were much higher than the 29-year average of daily temperatures (National Climate Data Center, 1968-2003; Fig. 3). The 2003 navel orange bloom was compressed with a single peak around 10 Mar. 2003 in the Fort Pierce area. Stressful conditions around this date contributed to very low fruit set, large fruit size, and likely unusually vigorous vegetative growth. Though specific data are shown only for the Fort Pierce area, other citrus growing regions of the state experienced similar overall conditions.

The severity of high temperatures during February-March of 2003 is more evident when daily maximum temperatures are examined and compared to the 1998-2003 average temperatures (Fig. 4). Maximum temperatures in the Fort Pierce area were much higher during February-March of 2003 than the average and approached the highest maximums experienced during the middle of an average summer. Thus, the short bloom period and high temperatures in February and March likely stressed the trees. Seedless varieties, such as navel orange, are more sensitive to stress than seeded varieties and the high temperatures likely contributed to the relatively light fruit set and larger fruit which are associated with high levels of granulation (Bartholomew et al., 1941). In addition, though average temperatures during October-November of 2003 were similar to the 29-year average (Fig. 3), maximum daily temperatures during this same period tended to be above the 1998-2003 average (Fig. 4) and may have enhanced the development of granulation further. This does not rule out the possibility that changing in cultural practices (i.e., fertilization and irrigation) and use of rootstocks that encourage vigorous tree growth may have also promoted the development of granulation, but there are few data on the contribution of these factors to granulation of Florida citrus.

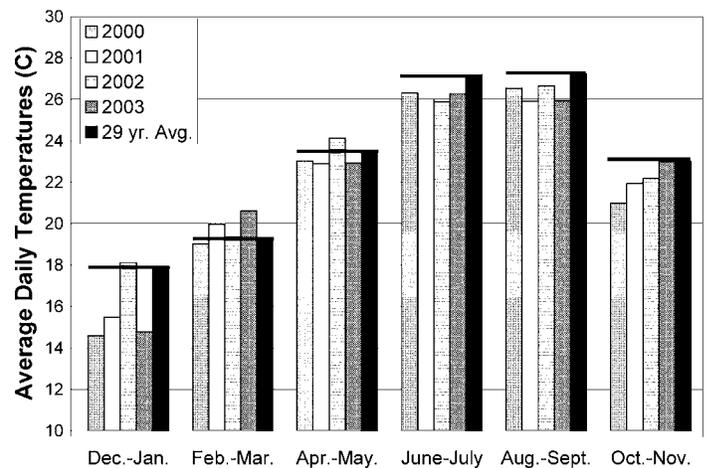


Fig. 3. Average temperatures in Fort Pierce, Fla. during 2-month periods between 2000 and 2003 (University of Florida/IFAS, 2004) compared with combined average temperatures for the same location and months over 29 years (National Climate Data Center, 1968-2003; emphasized by the horizontal lines). The “Dec.” values were from the previous year; e.g., “Dec.-Jan.” of 2000 averaged values over Dec. 1999 and Jan. 2000. “Dec.-Jan.” = floral induction; “Feb.-Mar.” = flower development; “Apr.-May” = Early fruit growth.

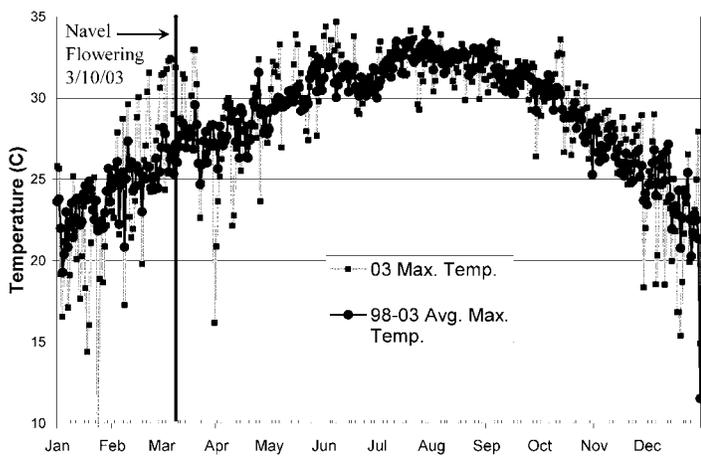


Fig. 4. Maximum daily temperatures in Fort Pierce, Fla. throughout the 2003 year compared with average maximum daily temperatures between 1998 and 2003 (University of Florida/IFAS, 2004). The vertical line represents the date of full bloom in the Fort Pierce, Fla. area.

Late-summer rains may have also enhanced granulation of navel oranges (Noort, 1969). During the 2003 Florida navel season, above average rainfall in the Fort Pierce area was experienced during the August-September (late summer-early fall) period (Fig. 5). Rainfall during the December-January period was slightly above the 29-year average, while during the rest of the 2003 season, rainfall was similar to or below the 29-year average.

Records for the 2003 navel orange season appear to be consistent with published reports associating excessive granulation with a light crop of large fruit and heavy late-summer rains. Though the navel bloom was earlier in 2004 compared to the 2003 season (27 Feb. 2004 vs. 12 Mar. 2003 in Fort Pierce), the fruit appear to be developing normally with greater numbers of fruit per tree than last year. In addition,

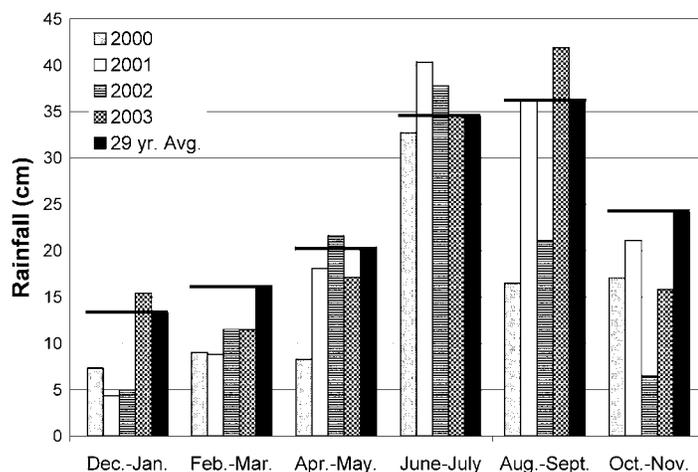


Fig. 5. Average rainfall in Fort Pierce, Fla. during 2-month periods between 2000 and 2003 (University of Florida/IFAS, 2004) compared with combined average rainfall for the same location and months over 29 years (National Climate Data Center, 1968-2003; emphasized by the horizontal lines). The "Dec." values were from the previous year; e.g., "Dec.-Jan." of 2000 averaged values over Dec. 1999 and Jan. 2000. "Dec.-Jan." = floral induction; "Feb.-Mar." = flower development; "Apr.-May" = Early fruit growth.

temperatures during March and April have been much lower than last year so that fruit growth is not as accelerated as it was last season. Thus, average fruit size is expected to be smaller this season compared to last season with less vegetative growth. Such conditions suggest that granulation will not be as severe this year as last. Further efforts to correlate environmental and crop characteristics with the risk of granulation may permit more accurate prediction of severe granulation. Ideally, such work would also be coupled with investigation of cultural practices such as reduced irrigation and control of vegetative vigor which may reduce granulation severity when fruit appear to be at risk.

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