POLLINATION AND RELATED FACTORS AFFECTING FRUIT QUALITY

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Most of Florida's citrus is marketed as processed juice. Even so, the fresh fruit market is also highly important. Fruit quality for the juice markets involves juice color and factors involved in flavor, such as total soluble solids, acidity, the ratio of soluble solids to acids and juice content. Certain factors such as limone and narigen in the juice as well as various other flavor components play a role but are usually not factors influenced by grower production practices and are not included in this paper. Fresh fruit quality involves not only juice quality but fruit size, rind texture and thickness, rind blemishes and color, and seed content. Pollination and related factors play a small role in affecting juice quality but it's the influence on fruit size and seed content that are of greatest importance and which will be reviewed here.

THE SEXUAL PROCESS

There are many kinds of plants, some which are reproduced by seed and others which are not. Ferns, mosses, lichens and fungi are examples of plants not producing seeds. Citrus belongs to the seed bearing plants that produce seeds within the matured ovary of the flowers, the fruits. Seeds are a result of the sexual process in which pollen from the male sex organ of the plant, the stamen, is transferred to the stigmatic surface of the female sex organ, the pistil. This transfer of pollen is called pollination and it is a major step in the sexual process. Following pollination, the pollen germinates; i.e., it forms a pollen tube which grows down the style, a slender stalk connecting the stigmatic surface at the pistil's apex and the ovary, which is the lower part of the pistil. The pollen tube ultimately penetrates the embryo sac in the ovules in the ovary and discharges two sperm or male nuclei. One sperm unites with the egg cell and develops into the embryo of the seed. The other fuses with the two endosperm nuclei in the embryo sac to produce endosperm that nourishes the growth of the embryo. . The importance of this sequence of events is that each step (pollination, pollen tube growth, sexual fertilization and seed development) triggers the production of growth regulators which have an influence on fruit set and development. It would be misleading to suggest that science has identified all of the growth regulators involved and their respective roles. Even so, there is sufficient evidence from work with citrus and other fruit to establish the relationship of the sexual process to fruit set, growth and quality as a valid principle.

SEED CONTENT

Fruit species, such as peach, tomato and citrus vary in seed content, peach having one seed, and tomato numerous seeds. Citrus is intermediate in seed content. Within the genus Citrus seed content can vary considerably, the 'Tahiti' lime being virtually seedless while 'Duncan' grapefruit has 50 or more seeds. Certain seedy varieties, such as 'Pineapple', have about 15 seeds. Most so-called commercially seedless varieties of orange ('Hamlin', 'Valencia') and grapefruit ('Marsh' and 'Redblush') have 0-6 seeds. The lack of seeds in 'Tahiti' lime is due to sterile (nonfunctional) pollen and ovules. Commercial seedlessness in 'Hamlin' and 'Valencia' oranges and grapefruit is due to very low level of fertile ovules. However, they have an appreciable amount of viable pollen. ' Marsh' and' 'Redblush' have low levels of pollen and ovule fertility.

Since high levels of ovule (female) sterility is common in all commercially seedless oranges and grapefruit, there is no way to increase seediness appreciably. Even though placing extremely large quantities of viable pollen by hand on some commercially seedless varieties, such as 'Valencia' oranges, will slightly increase seed content, the effect is hardly noticeable in the field where bees, the

pollinating agents for citrus, transfer relatively limited amounts of pollen. The above is important because fruit quality of commercially seedless fruit is not reduced by a higher seed content when grown adjacent to varieties with large amounts of viable pollen. Several mandarin hybrids ('Orlando', 'Minneola', 'Robinson', 'Nova' and 'Sunburst') grown in Florida are sexually self-incompatible. Such varieties have viable pollen and fertile ovules. There is a chemical inhibitor in the style, however, that reduces pollen tube growth so much the style abscisses (falls off) before the pollen tube can enter the ovary and bring about fertilization. Therefore, no seeds are produced. Since sexual fertilization is normally needed for fruit set, such varieties should theoretically not set fruit. Some varieties, however, have the capacity for setting fruit without sexual fertilization. The capacity of a variety to set and mature fruit without sexual fertilization is termed parthenocarpy. The above mandarin hybrids are only weakly parthenocarpic. Thus, many of their seedless fruits fall under conditions of physiological stress, primarily drought, that would not cause seedy fruit to drop. One mandarin hybrid, 'Page', is strongly parthenocarpic and tolerates more stress without shedding fruit. By providing pollenizer varieties with sexually compatible, pollen good yields are obtained; however, the resulting fruit is seedy and fresh fruit quality is thereby reduced.

Fortunately, the U.S. market is adjusted to seedy mandarin types. 'Murcott' and 'Temple', for example, have long been quite profitable as fresh fruit. So was the 'Dancy' tangerine when it was important. On the other hand, 'Parson Brown' and 'Pineapple' sweet orange, 'Duncan' and 'Foster Pink' grapefruit all fell out of favor as commercially seedless substitutes became available. Florida's attitude toward seediness is somewhat difficult to understand. A mutant seedless 'Temple' became available several years ago but has not been planted commercially to any extent. 'Fallglow', a seedy, self-fruitful mandarin hybrid, has just been released. The USDA has also recently released three moderately seedy sweet oranges. Admittedly the latter are primarily for processing; however, it is desirable to have seedless type oranges so they can also be marketed fresh. European markets do not like seeds. Europeans have gone to considerable efforts to locate seedless, high yielding strains of 'Clementine', a self-incompatible mandarin type. Their 'Valencia', blood and navel oranges are all commercially seedless. California also has limited their fruit production to seedless type varieties with minor exceptions. The seedless 'Unshiu' oranges of Japan, called satsuma mandarins elsewhere, predominate in that country.

FRUIT SIZE AND SHAPE

Fruit size is highly important in the U.S. fresh fruit market, particularly in the case of mandarin types which are mostly relatively small fruits to start with. The seedy 'Dancy' tangerine often suffered what was called economic abandonment in years when excessively heavy crop loads resulted in such small fruit it could not be marketed. Even small fruited 'Hamlin' suffers on the fresh market when grown on 'Cleopatra' mandarin, which induces small fruit sizes. Both excessively large and small grapefruit sizes can be problems. Within a variety seedless fruits are generally smaller than seedy ones. This is true even for commercially seedless varieties such as 'Valencia'; i.e., those fruits with a few seeds will average a larger size than those that are seedless. In seedy varieties, such as 'Pineapple', those fruits with the fewest seeds will on the average be smaller than those with the maximum number of seeds.

It is in the sexually self-incompatible mandarin hybrids, however, where seeds play a large, important role in determining fruit size. The range of seed per fruit of 'Orlando' tangelo, for example, can be 0-45 in groves planted with a proper pollenizer variety. Research has shown there is a highly significant linear relationship between seeds and fruit size; i.e., for every increase of a seed there is a corresponding stepwise increase in size (Fig. 1). This has been demonstrated in several experiments.

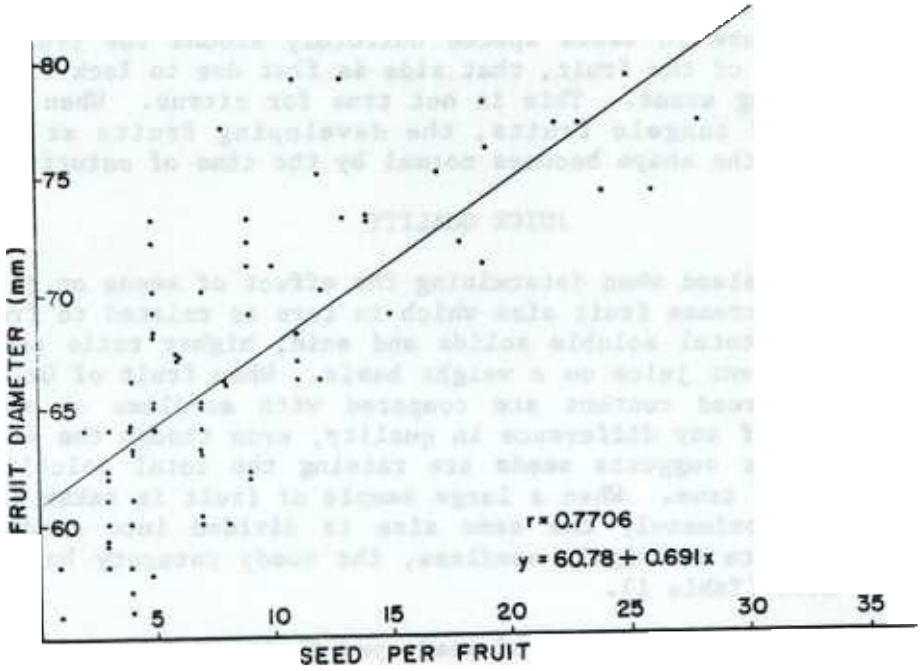

Fig. 1. Influence of seed number on fruit diameter of Orlando tangelo. Solid line is calculated regression line showing a highly significant linear relationship; i.e., a stepwise increase of diameter occurs with unit increase of seeds.

One can see from Fig. 1, however, that factors other than seeds play a large role in determining fruit size because all of the points, each of which represents a fruit, do not fall on the calculated regression line. Such factors are crop load, irrigation, tree vigor and rootstock. It is important to understand that while cross-pollination of self-incompatible varieties is important in assuring an adequate crop, it can be excessive and result in setting seedy fruits that are smaller than seedless fruit produced on a tree with a lighter crop load. Excessive cross-pollination results from use of too many highly effective pollenizer trees. Large numbers of 'Orlando' trees used as a pollenizer for 'Robinson' has at times resulted in excessive crops, smaller fruit and devastating limb breakage.

Another problem arises with 'Page' which would unquestionably be a fine commercial variety were it not for its small fruit size. Proper cross-pollination and the resulting seeds increase fruit size, but not enough. Moreover, it is highly parthenocarpic and thereby sets many seedless fruits even when cross-pollination is provided. This is because bees don't visit every flower and some that aren't visited produce small seedless fruit.

This influence of seeds on fruit size is not limited to citrus. For example, seeds have a direct, positive effect on passion fruit size. This fruit has so many seeds, the required cross-pollination needed for maximum seed content and fruit size is not always attained. Moreover, it is apparent that seed development, rather than pollination or sexual fertilization itself, is responsible for the later stages of fruit enlargement. Where the embryos or immature seeds of peaches are killed by low temperatures, the fruit remains extremely small even though it persists until maturity.

Fruit shape is affected by seeds in some fruit species. For example, long tapering pear fruit, called rat-tailed fruit, are formed when seedless. Rat-tailed watermelons have been shown to develop when an insufficient number of bee visits and

thereby inadequate pollen results in few or no seeds in the stem end of the fruit. Apple fruits normally have 10 seeds spaced uniformly around the fruit. If seeds fail to form on one side of the fruit, that side is flat due to lack of the hormonal stimulation of developing seeds. This is not true for citrus. When seeds fail to develop on one side of tangelo fruits, the developing fruits at times appear off-shaped at first but the shape becomes normal by the time of maturity.

JUICE QUALITY

It is easy to be mislead when determining the effect of seeds on juice quality. This is because seeds increase fruit size which in turn is related to fruit quality. Large fruit have lower total soluble solids and acid, higher ratio and more juice per fruit but lower percent juice on a weight basis. When fruit of Orlando tangelo with moderate to high seed content are compared with seedless or near seedless fruit, there is little if any difference in quality, even though the seedy fruit is distinctly larger. This suggests seeds are raising the total soluble solids and acid content and this is true. When a large sample of fruit is taken from a single tree and fruit of approximately the same size is divided into seedless or near seedless, and intermediate to highly seedless, the seedy category has higher total soluble solids and acid (Table 1).

Table 1. The influence of mean number of seeds per fruit on Brix and acid values of juice of 'Orlando' tangelo.

Experiment No.	No. seeds per fruit			
	0-5		5-25	
	Brix	acid	Brix	acid
1	10.2	.65	10.7	.69
2	10.5	.60	10.9	.65
3	10.6	.63	10.9	.67

All fruits in an experiment were of essentially the same size.

POLLEN SOURCE

A direct influence of pollen on fruit size and quality is called metaxenia. One of the few examples of this is the date where pollen source affects the sugar content and size of fruit.

In order to evaluate pollen source on size of 'Orlando' tangelo, several pollen sources were hand applied, using sufficient quantities of pollen to ensure maximum fruit set and a high seed content. Each pollen variety was applied to flowers on a small area of the outer canopy of the tree to eliminate effect of position on the tree. Pollen source had no effect on fruit size. Seed content was essentially similar (Table 2).

Table 2. Influence of pollen source on number of seeds/fruit and fruit diameter of 'Orlando' tangelo[1,2,3]

Pollen Source (variety)	Seeds/fruit	Fruit dia. (mm)
Hamlin	28.5	87.3
Pineapple	28.6	88.8
Valencia	28.4	87.8
Duncan	29.0	88.2
Dancy	29.4	87.0
Temple	29.1	87.0

1. Table values are the means obtained from experiments in 3 separate years and represent several hundred fruit.
   Hand pollination transferred large quantities of pollen, hence the large, relatively uniform seed numbers.
3 Use of several other pollen sources has given similar results.

REDUCING SEED CONTENT

Selections of naturally occurring seedless mutations has been the most common way of producing seedless varieties. 'Marsh' and 'Redblush' grapefruit are good examples of this. The selection of a seedless 'Temple' mandarin is a more recent example. Also, good yielding selections of 'Clementine', a self-incompatible low yielding mandarin hybrid have been made in Spain and Moroccco.

It is at least possible that careful search over a number of years would bring forth selections of self-incompatible mandarin hybrids grown in Florida that would produce high yielding crops of parthenocarpically produced citrus fruit, however, little or no effort is being made in that direction.

Irradiation of both seeds and buds have produced seedless selections of seedy varieties. This work, which is being done in Florida by the USDA at Orlando, has considerable promise.

Girdling trees in blocks of 'Orlando', 'Minneola', 'Robinson' and 'Nova' without pollenizer trees has greatly increased yields of parthenocarpically set seedless fruit. Fruit size was good but not as large as when seeds were produced through cross-pollination. Yields of seedless navel orange were also increased in this manner. Girdling consisted of a single cut (no removal of bark) around the trunk and through the bark, using a hook-bladed knife. The degree of success was related to several factors. Only vigorous trees, such as relatively young ones, responded well. As trees aged and vigor decreased, the increase of yield disappeared. Also, trees suffering heavy leaf loss due to freeze damage did not set fruit well despite the presence of flowers. However, young fruiting age Orlando trees responded well for 9 consecutive years. Proper time of girdling is from full bloom to two-thirds petal fall but some success was obtained even at complete petal fall. A careful and complete girdle must be made. Citrus laborers doing the girdling have not consistently done an adequate job. Girdling is no longer commercially used in Florida because of the difficulty of crawling under hundreds of trees.

Gibberellic Acid (GA) applied at the rate of 10-15 ppm in full bloom has increased yields of seedless fruits of several self-incompatible varieties in blocks of trees without pollenizers for cross-pollination. Applications are made as an aqueous spray that wets the canopy well. The material is systemic and research has shown GA is effective when applied by hand to either foliage or flowers alone or to both.

At concentrations above 15 ppm a relatively heavy amount of leaf drop occurs. Fortunately only the older leaves fall, many of which would have dropped normally during the bloom but at a slower rate. Even so, 15 ppm is the maximum to use on tangelos. Even then a slightly heavier leaf drop than is normal may occur for a short time.

There are two other undesirable side effects. First the normal development of orange peel color is slightly delayed. Such fruit will, however, respond to ethylene degreening. Second, and most important, fruit size is decreased. In some cases with 'Robinson' and 'Nova' the decrease in fruit size has offset the increase in fruit numbers to the point there was no increase in fruit yield measured as boxes of fruit per tree. The greatest commercial success has been obtained with the large-fruited 'Minneola' tangelo which can tolerate the reduction in fruit size. A comparison of the sizes of fruits resulting from cross-pollination, girdling and GA respectively is presented in Fig. 2.

On the positive side, the small fruit set with GA has a higher percentage of juice per fruit on a weight basis than either seedy fruit or seedless fruit set through girdling. Also, the GA-induced fruit have a smoother peel.

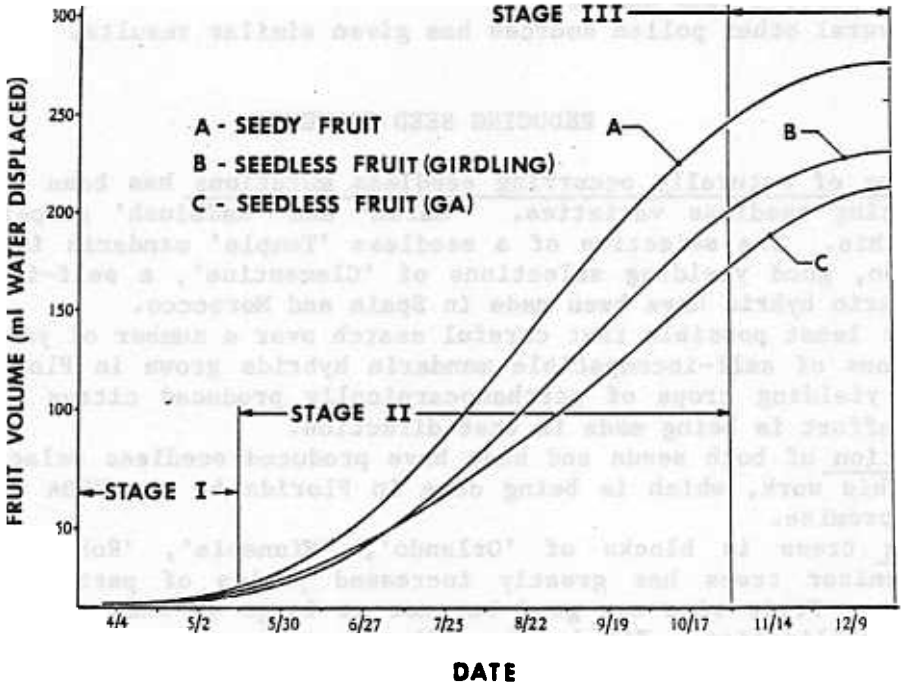

Fig. 2. Growth curves of Orlando tangelo fruits induced by cross-pollination (seedy fruit), girdling (seedless fruit) and GA (seedless fruit) respectively.