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Development of parthenocarpous fruits in Acid Lime and Lemon

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Abstract

The methods of sexual propagation and condition of parthenocarpy are responsible for development of fruits in *Citrus* sp. This developmental process is followed by a growth pattern having an exponential initial phase which is dominated by cell division within the ovary wall and is accompanied by a phase of linearity taking place due to expansion of cell walls. The steady supply of carbohydrates is very essential to carry out the normal metabolic process under the regulation of underlying hormones in the fruits i.e. the action of auxins, gibberellins, cytokinins and abscisic acid. According to the recent case study reports, it has been found that certain genes have been identified which actively promote the biosynthesis mechanism of hormones, metabolism of carbohydrates, regulation of cell cycle etc. These hormones can be manipulated through various treatment combinations and cultural farming practices which lead to an enhancement in the process of growth and eventually fruit setting. The external GA_3 application helps in development of fruit setting in parthenocarpic fruits in *Citrus* sp. and auxins enables enlargement of fruits by improving the partitioning of assimilates and uptake of water. The treatments can be optimized and after thorough study of physiological, environmental and agronomic factors that influences the development of fruits.

Keywords: Propagation, parthenocarpy, Citrus, carbohydrates, cytokinins, abscisic acid

Introduction

Botanically, a citrus is a modified berry (hesperidium). The botany of the fruit is such that total 9 to 14 carpels are fused around the floral axis which forms the locules, where the juice vesicles or juice sacs and development of the seeds occur. The citrus fruit pericarp is differentiated structurally into three distinct layers having, the exocarp, the mesocarp and endocarp. The exocarp is the outermost portion of the fruit having an epidermal, hypodermal and parenchyma cells. The mesocarp consists of parenchymatous cells, intercellular spaces and a spongy tissue. The endocarp is the innermost layer of the pericarp, a part of locular membrane. It includes the epidermis and several parenchymatous cells. The ripening of the fruit, the mesocarp and exocarp detatches from endocarp and the exocarp is responsible for fruits characteristic colouration which varies from one species to another and also varieties. The growth and developmental pattern in citrus undergo an ovary growth and differentiation which leads to maturation and ultimately in the development of a matured fruit. The process of fruit setting begins during spring and it continues for six to nine months, which varies from species to cultivars. The entire development from flowering to maturation is called fruit set. In citrus, there is a restriction in the process of fertilization, which takes place due to homogenetic sterility where the pollen is not capable of fertilizing the flowers, of the same or different variety, which is referred to as self-incompatibility and cross-incompatibility, or due to gametic sterility. The presence of pollen tube growth inhibitors in the stigma/style can prevent the process of fertilization, which can be induced by environmental factors which causes an asynchronous development of the pollen tube and the ovule. The complete absence of the seeds occurs almost exclusively in triploid varieties. Homogenetic sterility induces facultative parthenocarpy in citrus. In this context, the incompatibility between pollen grains and receptive stigma is governed by a self-sterility gene with multiple alleles.

The development of parthenocarpic fruits in acid lime and lemon involves several physiological and biochemical processes.

Stage 1: Flower bud initiation and development

- Flower buds differentiate and develop under favourable environmental conditions.
- Floral organs, including the ovary, style, stigma and anthers, develop normally.
- The ovary contains ovules, which have the potential to develop into seeds following fertilization.

Stage 2: Anthesis and absence of fertilization

- Flowers open and undergo anthesis.
- In parthenocarpic cultivars, fruit development can occur without successful fertilization.
- Pollination may be completely absent or may occur without subsequent fertilization, depending on the type of parthenocarpy.

Stage 3: Hormonal stimulation of ovary growth

This is the most important physiological stage.

Fruit development is regulated by plant growth hormones:

- Auxins: Promote cell division and cell elongation in the ovary.
- Gibberellins (GA_3): Stimulate ovary growth and fruit enlargement.
- Cytokinins: Promote cell division during early fruit development.
- Abscisic acid (ABA): Influences fruit set and fruit drop, depending on its concentration and developmental stage.

In normal seeded fruits, fertilization stimulates the developing seeds to produce hormones that promote fruit growth. In parthenocarpic fruits, similar hormonal signals originate from the ovary or surrounding floral tissues without fertilization.

Stage 4: Fruit set and initial development

- The ovary begins to enlarge.
- Cell division and cell elongation occur in the developing pericarp.
- The fruit remains attached to the plant.
- The absence of fertilization does not necessarily prevent fruit set in naturally parthenocarpic cultivars.

Stage 5: Fruit enlargement

- The pericarp undergoes extensive cell enlargement.
- Juice vesicles develop within the endocarp.
- Organic acids, sugars and other metabolites accumulate.
- The fruit increases in size and develops characteristic citrus flavour.

Stage 6: Fruit maturation

- The fruit attains its characteristic shape, size and colour.
- Juice content increases.
- Peel colour changes depending on cultivar and environmental conditions.
- Fruits remain seedless or contain very few seeds due to the absence of successful fertilization.

4. Causes of Seedlessness in Parthenocarpic Lemon and Acid Lime

Seedlessness can result from different mechanisms:

1. Absence of fertilization: The ovary develops into a fruit without fusion of male and female gametes.
2. Failure of pollen germination: Pollen grains fail to germinate on the stigma.
3. Failure of pollen tube growth: Pollen tubes fail to reach the ovules.
4. Male sterility: Non-functional pollen prevents successful fertilization.
5. Female sterility: Ovules or embryo sacs are unable to participate successfully in fertilization.
6. Post-fertilization abortion: Fertilization occurs, but the developing embryo or seed aborts.
7. Hormonal regulation: Endogenous auxins and gibberellins stimulate fruit development independently of seed formation.



Fig. 1. Full fruit and parthenocarpic cross-sectional view of acid lime



Fig. 2. Cross-sectional view of parthenocarpic acid lime

For preventing the cross-pollination in citrus fruits, GA_3 (Gibberellic acid) can be applied before anthesis which significantly leads to an increase in the rate of abortion of ovule. It has been observed that, there is a specific reduction of the seeds with abortion rate of 26 % and 52

% when GA_3 was sprayed before two and seven days respectively. During the anthesis period, GA_3 stops the pollen tube growth and prevents the process of fertilization and formation of seeds (Mesejo *et al*., 2016). The application of copper sulphate ($CuSO_4.5H_2O$) also helps in inducing seedless fruits. When it is applied locally to the flower before pollination, it reduces the pollen germination and/or disrupts the pollen tube development leading to the prevention of pollen tubes from reaching the stigma. It is recommended to apply $CuSO_4.5H_2O$ to the entire tree when 60 % of the flowers are at anthesis stage. This treatment helps in the reduction of the number of seeds per fruit by 55-80% and increases the number of seedless fruits by 150-400 % depending on the year (Zhao *et al*. 2021).

Citrus varieties generally require successful pollination for fertilization, a process involving the transfer of pollen grains to the stigma, subsequent germination, and the growth of a pollen tube toward the ovules. These events typically reactivate ovary cell division, thereby promoting fruit and seed development. Nevertheless, numerous Citrus cultivars are capable of fruit set through parthenocarpy, bypassing fertilization. In such cases, genetic factors maintain elevated hormone levels in the ovary during anthesis and the early stages of fruit set. Fruit set patterns depend on cultivar, climate and flowering intensity with seeded varieties generally displaying higher fruit set ability than seedless ones, although substantial variability exists within seedless cultivars.

The advantages of parthenocarpic citrus fruits are that it reduces dependencies on pollinators, easy marketability of fruits and high consumer preference because there are no seeds, it helps in increasing the shelf-life of the fruits for better conservation due to reduced ethylene and are less susceptible to diseases (Zhou *et al*., 2018).



Fig. 3. Parthenocarpic acid lemon in bearing stages



Fig. 4. Longitudinal cross-sectional view of parthenocarpic lemon

Table 1. Differences between Normal and Parthenocarpic Citrus Fruits

Character	Normal seeded fruit	Parthenocarpic fruit
Fertilization	Occurs	Not required
Seed development	Usually, present	Absent
Ovary development	Stimulated by fertilization-associated signals	Stimulated independently of fertilization
Fruit set	Depends on successful reproductive processes and other factors	Can occur without fertilization
Commercial importance	Depends on cultivar and market	High where seedless fruits are preferred

Factors Affecting Parthenocarpic Fruit Development

1. Genetic constitution of the cultivar.
2. Endogenous hormonal balance.
3. Temperature during flowering and fruit set.
4. Relative humidity and water availability.
5. Nutritional status of the plant.
6. Pollination and fertilization conditions.
7. Application of plant growth regulators.

Significance in Horticulture

- Production of seedless or low-seeded acid lime and lemon fruits.
- Improved consumer preference and convenience.
- Potential improvement in commercial value.
- More consistent fruit production in cultivars with stable parthenocarpic ability.
- Reduced dependence on successful pollination and fertilization.

Conclusion

Parthenocarpic fruit development in acid lime and lemon is a genetically and physiologically regulated process in which the ovary develops into a mature fruit without fertilization. Endogenous plant hormones play a major role in

initiating and maintaining fruit growth, making parthenocarpy an important trait for developing commercially desirable seedless citrus cultivars.

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