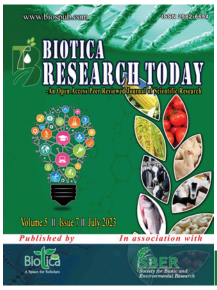

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Strategy Related to Speed Breeding in Fruit Crops: Reduction in Juvenility

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Abstract

Horticulture crops have traditionally required long-term breeding programmes for the development of new varieties, primarily due to their perennial nature and long juvenile phase. Speed breeding offer a promising solution to accelerate the generation advancement process, resulting in the rapid release of new varieties with desirable traits. This incorporates various breeding methods such as FasTrack breeding using genetically engineered tree flowering genes, tissue culture techniques, marker-assisted selection (MAS), genomic selection and induced mutation breeding. Whereas, strategy related to speed breeding includes various cultural practices such as, grafting, application of plant bio-regulators, soil solarization and utilize dwarfing rootstocks. The shortened breeding cycle facilitated by speed breeding allows for faster release of new fruit varieties and meeting the increasing demand for horticultural products for the growing population. In this article, we will discuss the speed breeding techniques and strategies that play a crucial role in enhancing the efficiency of fruit crop breeding.

Keywords: Biotechnology, FasTrack breeding, Shortened breeding cycle, VIGS

Introduction

With increasing population day by day, the global food security is becoming a major issue. The environment changes occurring at a rapid rate is forcing the rich genetic diversity towards extinction. The insufficient pace of advancements in several critical crops poses a challenge in meeting future demands, primarily due to the prolonged generation time of crop plants, which hinders progress. However, the revolutionary technique of speed breeding has emerged as a global game-changer by effectively minimizing the generation time, thus expediting breeding protocols and research programs aimed at enhancing crop varieties. Speed breeding, an innovative and highly promising methodology inspired by the US National Aeronautics and Space Administration (NASA) promises to boost the development of new crop varieties by mushrooming hope of food security. Speed breeding is a cutting-edge approach that has emerged recently to expedite the breeding process of fruit crops. As the global demand for superior varieties continues to rise, it becomes increasingly crucial to shorten the prolonged juvenile phase of fruit crops, enabling faster breeding cycles and more efficient fulfillment of market demands. This strategy revolves around manipulating plant growth conditions to hasten reproductive development and reduce the time required for plants to attain maturity.

Through the optimization of factors like temperature,

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light intensity and photoperiod, speed breeding creates an optimal environment that stimulates early onset of flowering and fruiting. Consequently, breeders can rapidly assess and choose favorable traits in fruit crops, such as disease resistance, fruit quality and yield, without enduring the extended wait for plants to reach reproductive maturity. Moreover, by integrating advanced techniques like tissue culture and genetic markers, speed breeding can further amplify the efficacy of trait selection and genetic enhancement.

Juvenility

Juvenility refers to the initial developmental stage of fruit crops during which plants are incapable of flowering. This reduction in the juvenile period is important for breeders and growers as it enables them to accelerate the breeding process, generate new cultivars more rapidly and increase the efficiency of fruit crop production. The juvenile period extends from seed germination till the plants acquire the ability to flower. There are two main types of juvenility: true juvenility, characterized by compact growth, low lignification and small, thick leaves; and pseudo juvenility, characterized by rapid shoot growth, long internodes and small, thick leaves with low lignification. By implementing various techniques such as tissue culture, genetic manipulation and environmental control, the juvenile period can be shortened, allowing fruit crops to reach the flowering stage earlier.

Importance of Reducing Juvenility

Reducing juvenility in fruit trees is a desirable goal for several reasons. Firstly, it allows for the acceleration of the breeding cycle. By minimizing the time it takes for a fruit tree to reach maturity and produce viable offspring, breeders can more quickly evaluate and select promising new varieties. Furthermore, reducing juvenility enables orchard owners to establish profitable orchards at an earlier stage. Instead of waiting for several years for the trees to mature and bear fruit, they can start harvesting and selling produce sooner. With shorter generation times, researchers and scientists can rapidly introduce and test novel traits and characteristics in fruit trees. This expedites the process of developing cultivars that are better adapted to changing environmental conditions, consumer preferences and market demands.

Strategy to Reduce Juvenility

Cultural Method

Grafting

Grafting is a technique widely used in horticulture to reduce plant height and shorten the vegetative phase, ultimately promoting an early transition to the reproductive phase. Various examples demonstrate the effectiveness of grafting in achieving these goals. For instance, when mandarin is grafted onto *Citrus jambhiri* rootstock, it yields more flowers compared to grafting onto sweet orange or acid lime. In the case of kinnow mandarin, grafting onto troyer citrange induces precocity in bearing, leading to earlier fruit production. Oriental persimmon grafted onto Hachiya cv. rootstock exhibits increased flower production at an early stage. Similarly, in grapes, the use of dogridge and 110R rootstocks results in larger and bolder berries. Additionally, *Ziziphus nummularia* and *Ziziphus lotus* serve as effective rootstocks in reducing juvenility and promoting a precocious nature and early fruit maturity in ber trees. Overall, grafting offers valuable benefits in achieving an early reproductive phase and enhancing fruit production in various plant species.

Dwarfing Root Stock and Inter-Stock

By grafting the scion onto a dwarfing rootstock, the overall growth of the plant is controlled, resulting in earlier flower and fruit production. Inter-stocking involves using an intermediate variety between the rootstock and scion, which can possess early flowering or fast growth (Table 1) characteristics. This promotes early maturation and reduces the duration of the juvenile phase. Both approaches contribute to shorter juvenile periods, enabling more efficient fruit production, faster variety development and increased crop productivity.

Table 1: Important dwarfing rootstock and inter-stock used for impart precocity in fruit crops

Fruit species	Dwarfing Rootstock
Apple	B.9, B.10, G.16, G.41, G.65, Ottawa 3, P.2, P.22, Supporter 1, Supporter 4
Apricot	Hybrid P- 2308, *Prunus beyesiyi*
Ber	*Zizyphus nummularia*
Cherry	Gisela 10, colt, charger, Rubira
Citrus	Flying Dragon, Trifoliate Orange and its hybrids, F&A 418, 23, 24 *(Troyer citrange × Cleopatra mandarin*)
Guava	Pusa Srijan
Mango	Royal Special. ST-9, Kurukkan, Olour, Vellaikolumban (for Alphonso only), Rumani (Dashehari), Anupam (As interstock), Khom, Creeping, Latra, Totapari Red Small, Saigon 119, Piva
Peach	Prunus beyesiyi, Krymsk 1 (Chinese Bush Cherry × Myrobalan Plum), Siberian C
Plum	Pixy, St. Julien 2,3, Plumina, Jaspi
Pear	Pyrodwarf

Soil Solarization

Soil solarization is an agricultural practice that involves covering the soil with plastic film, resulting in several benefits. One of the advantages is the increase in soil temperature, which helps in controlling soil-borne pathogens and weed seeds. Additionally, soil solarization aids in water conservation by reducing evaporation and improving water penetration into the soil. The elevated soil temperature also enhances plant nutrient absorption, leading to improved growth and productivity. Solar energy transmitted through the plastic film contributes to an increase in soil temperature, promoting trunk diameter expansion and positively impacting the flowering index. Overall, soil solarization offers multiple advantages for crop production and can contribute to improved agricultural outcomes.

Irrigation

Irrigation strategies play a significant role in reducing the juvenile period in fruit crops. Proper and timely irrigation can provide the necessary water and nutrients for optimal plant growth, maintaining the C/N ratio of the plant which facilitating the transition from the vegetative stage to the reproductive phase. Adequate soil moisture levels ensure that plants receive sufficient hydration, allowing them to develop robust root systems and establish faster. This promotes overall plant growth, shortens the juvenile period and enhances the chances of early flowering and fruiting.

Chemical Method

Plant Growth Regulators

The use of PGRs as a method for shortening juvenility and/or promoting flowering has been widely adopted as a general tool for reducing the length of the breeding cycle (Table 2). Inside modern greenhouses, bree ders carefully apply PGRs to their plants to induce flowering earlier than nature intended.

Table 2: Plant growth regulators used for enhancing precocious flowering in fruit crops

Sl. No.	Crop	PGR	Concentration	Stage of application
1	Pineapple	Ethephon	100 ppm	40 leaves stage
2	Mango	Ethephon	10,000 ppm	Before floral induction
3	Citrus	CCC	5,000 ppm	After 3 years
4	Mango	CEPA	1,000 ppm	40 months old, seedling

Biotechnological Method

Genetic Factors Controlling Floral Initiation

Use of the LEAFY (*LFY*), FRUITFULL (*FUL*), APETELA1 (*AP1*), AGAMOUS (*AG*), TERMINAL FLOWER (*TFL1*) and SQUAMOSA (*SQUA*) genes initiates the process of flowering during the initial phase of the juvenility.

Gene Silencing

Reduce juvenility or vegetative growth maintenance factors. Down-regulation of MdTFL gene is having antisense expression in Apple.

Over-Expression of Genes

LFY, the FT gene in Apple and the *CsFT* gene in Sweet orange play significant roles in the development of floral meristems. To induce early flowering, transgenic apple trees were created by introducing a gene from silver birch (*Betula pendula*). The resulting transgenic F1 apple seedlings were obtained through a cross between the transgenic line T1190 cv. Pinova and the wild apple species *Malus fusca*. Notably, the occurrence of flowers was observed for the first time once the height of the seedling reached approximately 40 cm.

Using the rapid flowering characteristic, breeders are employing a yearly generation cycle by crossing early flowering transgenic progeny with superior cultivars or wild counterparts that exhibit favorable traits such as resistance to key apple pathogens like apple scab and fire blight. This technology holds significant potential in other perennial plants, including citrus and pear, where genetic modifications have been implemented to achieve early flowering (Matsuda *et al.*, 2009). Poncirus plants that have been genetically modified to express the *CiFT* gene, which is a homolog of the FLOWERING LOCUST gene, exhibited early flowering. Additionally, Carrizo seedlings that were engineered to consistently over-express the floral-regulatory genes LEAFY (*LFY*) or APETALA1 (*AP1*) from Arabidopsis produced fertile flowers and fruits in their initial year, leading to a significant reduction in the juvenile phase.

Use of Virus Induced Gene Silencing (*VIGS*)

McGarry *et al.* (2017) conducted research on the application of the Virus-Induced Gene Silencing (VIGS) system in apple breeding. In this system, flowering is triggered by introducing an Apple latent spherical virus (ALSV) into seedlings, which carries a gene responsible for flowering (FT) from *Arabidopsis thaliana*. Notably, ALSV does not cause disease symptoms, does not spread horizontally to other trees and vertical transmission of the virus through seeds occurs at very low rates. Since the utilization of VIGS does not involve the creation of genetically modified (GM) cultivars, it can serve as a valuable breeding tool.

FasTrack Breeding

This technology introduces a novel approach to accelerate the enhancement of germplasm and cultivars of tree fruits and other crops with long generation cycles. Tree fruits such as plum, apricot and cherry typically require a minimum of three years and sometimes more than seven years, to reach the flowering and fruiting stage. To address this issue, a fast-track breeding system has been developed utilizing a genetically engineered (GE) tree flowering gene, known as the Early, Continual Flowering (ECF) Gene. By incorporating this gene into the genetic makeup of a parent plum line through genetic engineering techniques, the resulting trees exhibit early and continuous flowering and fruiting cycles, enabling the "FasTrack" breeding process to be conducted within controlled environments like greenhouses or screen houses (Srinivasan *et al.*, 2012). Each tree has the potential to become a new cultivar or an enhanced variety, serving as a valuable resource for ongoing breeding efforts using conventional methods.

Conclusion

In conclusion, the strategy of speed breeding in fruit crops offers a promising approach to reduce juvenility and accelerate the breeding process. Speed breeding techniques expedite the achievement of homozygosity and enable efficient assessment of pre-existing or genetically modified lines, including gene-edited crops and transgenic crops. Additionally, it facilitates the identification of suitable rootstocks or inter-stocks in diverse fruit crops, exploration of cultural techniques and adoption of novel biotechnological methodologies. Use of genomics and genetic mappings helps in the shortening the life cycle of the plant. It will be a way towards accelerating crop improvements by reducing the amount of time, space and resources invested. The reduction in juvenility attained through speed breeding holds immense potential for fruit crop breeders, empowering them to develop novel varieties at an accelerated pace.

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