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Synthetic Seed: Production and Applications

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INTRODUCTION

Synthetic seed technology represents a significant advancement in plant biotechnology, offering an innovative approach to plant propagation and conservation. It involves the encapsulation of somatic embryos or other plant propagules, such as shoot buds, within a protective and nutrient-enriched hydrogel matrix—most commonly calcium alginate—forming artificial seeds capable of developing into complete plants. This technique facilitates the clonal propagation of elite genotypes while ensuring high levels of genetic uniformity. Moreover, Synthetic seed technology supports long-term storage, easy handling, and direct field sowing, making it a cost-effective and efficient method for the large-scale production of transgenic and hybrid cultivars. Consequently, it holds great potential for enhancing agricultural productivity and germplasm conservation.(Bajaj et al., 1993).

This technique is well suited for large-scale plant production. Synthetic seeds are defined as artificially encapsulated somatic embryos, shoot buds, cell aggregates, or any other tissue that can be used for sowing as a seed and that possess the ability to convert into a plant under in vitro or ex vitro conditions and that retains this potential also after storage. Earlier, synthetic seeds were referred only to the somatic embryos that were of economic use in crop production and plant delivery to the field or greenhouses (Gray, et al., 1991).

Synthetic seed technology has become a valuable advancement in plant biotechnology, particularly for micropropagation, mass multiplication, and germplasm conservation of important plant species. This method involves the encapsulation of somatic embryos or other tissue culture–derived propagules, such as shoot tips and nodal segments, in a protective hydrogel coating, usually calcium alginate, to produce artificial seeds.

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These synthetic seeds function as effective propagules for **plant regeneration** under both laboratory and field conditions, while maintaining genetic uniformity among the regenerated plants. Furthermore, the technique contributes significantly to efficient **storage management** by enabling both short-term and long-term preservation of viable propagules. Therefore, synthetic seed technology offers a reliable approach for crop improvement, propagation of seedless or difficult-to-propagate plants, and long-term conservation of plant genetic resources.

Methodology

Healthy in vitro-derived explants (e.g., shoot tips, nodal segments, or somatic embryos) are selected from actively growing cultures. The explants are suspended in a sterile sodium alginate solution (2–4% w/v) prepared in liquid Murashige and Skoog (MS) medium. (Murashige T and Skoog F, 1962).

The alginate-coated explants are then dropped gently into a calcium chloride ($CaCl_2$) solution (50–100 mM) using a sterile pipette. This results in instantaneous formation of calcium alginate beads through ion exchange, encapsulating the explants. The beads are allowed to polymerize for 20–30 minutes for proper hardening. (Redenbaugh et al., 1986)

After complexation, the beads (synthetic seeds) are rinsed 2–3 times with sterile distilled water to remove excess calcium ions. The encapsulated propagules are then cultured on MS medium (with or without plant growth regulators) under controlled environmental conditions (25 ± 2°C, 16/8 h photoperiod). (Rai et al., 2009)

Applications:

Synthetic seed technology has several important applications in plant biotechnology and agriculture. It is widely used for **micropropagation and large-scale multiplication** of elite, hybrid, transgenic, and disease-free plant varieties. This technology is especially useful for the propagation of **seedless or difficult-to-seed plants**, such as banana, grapes, and many ornamental species, where conventional seed propagation is not possible or less effective. Another major application is **germplasm conservation**, as encapsulated propagules can be stored for short-term and long-term periods, including under cryopreservation conditions, without significant loss of viability.

Synthetic seeds also play an important role in the **conservation of rare, endangered, and medicinal plant species** by facilitating their preservation and regeneration. In addition, they allow **easy handling, storage, transportation, and exchange** of plant material between laboratories and research institutions. The technology further supports **direct field sowing and plant regeneration** under both in vitro and ex vitro conditions, ensuring genetic uniformity

Vegetative propagation is very much beneficial because of the capability of long term storage. Synthetic seeds have many diverse applications in agriculture (Redenbaugh *et al*., 1990; Redenbaugh, 1993). A similar system could be developed in other crops although the specific commercial applications will undoubtedly differ. In plant breeding programs of cross pollinating species, this technology might provide an alternative way to store germplasm instead of a field or greenhouse nursery. Synthetic seeds also offer the opportunity to store genetically heterozygous plants or other plants with unique gene combination that cannot be maintained by conventional seed production due to genetic recombination that occurs at each generation of seed increase.

Tab 1: Table showing list of plant species in which encapsulation technology is used to produce synthetic seed with references.

Plant	Propagule used for encapsulation	References
Actinidia deliciosa (Kiwifruit)	SBs	Piccioni and Standardi,1995
Arachis hypogaea (Groundnut)	SEs	Onay *et al.*, 1996
Asparagus cooperi	SEs	Ghosh and Sen,1994
Betula pendula (Birch)	SBs	Piccioni and Standardi, 1995
Brassica campestris (Mustard)	SBs	Arya *et al.*, 1998
Camellia japonica L.	SEs	Janeiro *et al.*,1997
Cratagus oxyacatha (Hawthorn)	SBs	Piccioni and Standardi,1995
Cymbidium giganteum (Orchid)	PLBs	Corrie and Tandon,1993
Daucus carota (Carrot)	SEs	Kitto and Janick, 1982, 1985
Dendrobium wardiunum (Orchid)	PLBs	Sharma *et al.*, 1992
Eucalyptus citriodora (Eucalyptus)	SEs	Muralidharan and Mascarenhas, 1995
Geodorum densiflorum (Lam) Schltr. (Orchid)	PLBs	Datta *et al.*, 1999
Medicago sativa (Alfalfa)	SEs	Redenbaugh *et al.*, 1984
Morus indica (Mulberry)	SBs	Bapat, 1993
Musa (Banana cv. Basrai)	SBs	Ganapathi *et al.*, 1992
Phaius tankervillae (Orchid)	PLBs	Malemngaba *et al.*, 1996
Picea ahies (Norway spruce)	SEs	Gupta *et al.*, 1987
Picea glauca (White spruce)	SEs	Attree *et al.*, 1994
Picea glauca Engelmanni (Interior spruce)	SEs	Lulsdorf *et al.*, 1993

Fig 2: (A) Artificial seeds encapsulated with sodium alginate; (B) Germination of somatic embryo; (C) Ruptured beads showing sprouting of shoots
(Source Plant Tissue Culture Totipotency to Transgenic AGROBIOS)

and true-to-type plants. Therefore, synthetic seed technology is considered a valuable tool for crop improvement, sustainable agriculture, and plant genetic resource management.

Advantages and Disadvantages of Synthetic Seeds:

Synthetic seeds enable large-scale clonal propagation of elite genotypes with high uniformity and facilitate easy handling, storage, and transport compared to conventional in vitro methods (Redenbaugh et al., 1986). They are particularly useful for recalcitrant species and allow short-term germplasm conservation, while encapsulation provides protection and can include nutrients or growth regulators (Rai et al., 2009). Another key advantage is the prevention of desiccation. In natural conditions, somatic embryos and propagules can easily lose moisture and fail to survive; however,

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protective coatings help maintain adequate hydration and viability. Additionally, synthetic seeds are particularly valuable for propagating seedless or difficult-to-seed plant species, such as grapes, where conventional seed-based propagation is not feasible. Overall, this technology ensures better survival, protection, and efficient propagation of plants.(Faisal et al., 2019)

However, limitations include low and genotype-dependent conversion rates, reduced viability during storage due to desiccation sensitivity, risk of contamination, and higher cost with technical requirements. Additionally, somaclonal variation may occur when somatic embryos are used (Murashige & Skoog, 1962).

Future Prospective:

In the future, synthetic seeds are expected to play a significant role in the conservation of germplasm, especially through the application of cryopreservation methods. Both hydrated calcium alginate-coated and desiccated polyethylene glycol-based artificial seeds can be employed for this purpose, while partial desiccation before cryopreservation may further enhance their survival and regeneration efficiency.

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