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Bamboo Seeds as a Resource for the Future: A Review of Germination, Storage, Phytochemistry, and Biotechnological Applications

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Abstract— *Flowering and seed set is enigmatic in bamboos. Massive seeding is followed by death of the entire clump, and seeds also remain viable for a short span of time. This limitation restricts the utility of seeds for various purposes. The solution for this loss of viability can be obtained by improving seed storage methods, such as cryopreservation, to maintain viability over extended periods. Alternative approaches using in vitro techniques including somatic embryogenesis (micropropagation) followed by artificial seed production, as well as in vitro flowering with subsequent seed set, offer promising solutions. Seeds can be utilized for multiple applications through innovative, practical, and commercial approaches that address the unpredictable seeding behavior of bamboos. This review examines the current state of knowledge on bamboo seed germination, storage requirements, phytochemical composition, and biotechnological applications including micropropagation, somatic embryogenesis, artificial seeds, and in vitro flowering.*

Keywords— Bamboo seeds, Monocarpy, Somatic embryogenesis, Cryopreservation, Bamboo rice, Artificial seeds, In vitro flowering.

I. INTRODUCTION

Bamboos are monocarpic plants of the grass family (Poaceae). Flowering is cyclic in bamboos and manifested as transformation of the entire vegetative plant into inflorescence (Janzen, 1976; John and Nadgauda, 1999; Varmah and Bahadur, 2011). Seeds are produced in huge amounts (massive seeding) but lose viability within a short span of 2 to 3 months (Banik, 1994). Despite this limitation, seeds have potential for large-scale and inexpensive propagation naturally. The seeds can also be utilized for other purposes such as germplasm conservation and genetic improvement through biotechnological approaches (Nadgauda, 1999; Sharma et al., 2017), in addition to raising large-scale plantations both in vitro and in vivo. All these applications of seeds can be enhanced by increasing shelf life and preventing loss of viability within the short period after production.

There is limited information on uses of bamboo seeds (Kiruba et al., 2007), probably due to their scarcity resulting from limited viability. Seeds of bamboo species such as *Bambusa arundinacea* are collected and used as food grains (bamboo rice) by tribal communities of Kanyakumari district in Tamil Nadu, India (Kiruba et al., 2007). Bamboo seeds are nutritionally superior to rice and wheat (Rao et al., 1955). Bamboos are grouped under non-timber forest products, but they have transcended from 'poor man's timber' to 'the timber of the 21st century' (Singh et al., 2017).

Although bamboo is part of the grass family, which has been well studied in genomics, genome data for the subfamily Bambusoideae remains far from complete. Construction of bamboo genetic populations and genetic maps is difficult because bamboo flowering is unpredictable, with cycles ranging from 40 to 120 years (Sood et al., 2018). Research on methods to enhance viability of bamboo seeds can help address this paucity of genetic studies, particularly comparative genomic studies in bamboos. Full-length cDNA cloning and sequencing in bamboos has revealed close relationships with other Poaceae members including rice, wheat, and barley (Peng et al., 2010). This review aims to synthesize current knowledge on bamboo seed biology and explore potential applications for sustainable utilization of this valuable resource.

II. GERMINATION OF BAMBOO SEEDS

Bamboos are characterized by prolonged periods of flowering accompanied by massive seeding and subsequent death of the entire clump. Germination of seeds to produce saplings occurs with high percentage under shade within a few days of production (Sharma et al., 2017). Under in vitro conditions, plant growth regulators are known to affect the germination of seeds of various bamboo species (Singh and Nayyar, 2000; Gopichand and Sood, 2008; Sharma et al., 2016).

Seeds may be classified as orthodox or recalcitrant based on their germination characteristics. Orthodox seeds typically germinate within 2 to 24 days, while recalcitrant species such as *Melocanna* and *Ochlandra* exhibit shorter germination periods (Sharma et al., 2017). A third category of seeds exhibiting intermediate characteristics between orthodox and recalcitrant types has also been established (Ellis et al., 1990). Understanding these germination patterns is essential for developing effective propagation protocols for different bamboo species.

III. STORAGE OF BAMBOO SEEDS

Storage conditions significantly influence the viability of bamboo seeds, which is naturally limited to a short period (Banik, 1994). During storage, environmental factors including relative humidity and temperature play crucial roles in maintaining viability by affecting seed moisture content and consequently metabolic rate (Banik, 1994). Dried seeds stored at low temperatures in the range of 8 to 12°C have been found to remain viable for up to one year (Somen and Seethalakshmi, 1989; Midya, 1994).

More recently, Scherwinsk-Pereira et al. (2021) suggested the use of cryopreservation technology for long-term storage of bamboo seeds to maintain viability on an extended basis. Cryopreservation offers potential for preserving genetic resources from unpredictable flowering events and ensuring availability of germplasm for future research and propagation programs.

IV. PHYTOCHEMISTRY OF BAMBOO SEEDS

Bioactive compounds of plant origin are termed phytochemicals. Bamboo seeds have not been reported to contain toxic secondary compounds, unlike seeds of many tropical trees (Watt, 1889). Preliminary phytochemical analysis of bamboo rice from *Bambusa arundinacea* revealed the presence of tannins, phlobatannins, flavonoids, cardiac glycosides, reducing sugars, and phenols in aqueous extracts (Saravanamoorthy et al., 2016).

Bamboo rice is traditionally consumed by tribal populations of the Kanyakumari region in Tamil Nadu, India, for enhancing fertility (Kiruba et al., 2007). Alcoholic seed extracts of bamboo rice have shown the presence of flavonoids, tannins, phenols, quinones, sterols, carbohydrates, and amino acids (Thamizharasan et al., 2015). The extraction and analysis of phytochemicals in bamboo seeds is still in its infancy and requires further experimentation to fully characterize the bioactive compounds and their potential health benefits.

V. BIOTECHNOLOGICAL APPLICATIONS WITH BAMBOO SEEDS

Seeds are available only during the limited flowering periods in bamboos. Various biotechnological approaches have been developed to utilize seeds and seed-derived tissues for propagation, conservation, and genetic improvement of bamboo species.

5.1 Micropropagation Using Seed Explants:

Seed tissues have been widely used for micropropagation of bamboos. Examples include the use of embryonic axes of *Bambusa arundinacea* (Mehta et al., 1982) and *Bambusa bambos* var. *gigantea* (Kapoor and Rao, 2006), seed embryos of *Dendrocalamus farinosus* (Hu et al., 2011), zygotic embryos of *Bambusa vulgaris* (Rout and Das, 1994), inflorescence explants of *Bambusa oldhamii* (Yeh and Chang, 1986a) and *Bambusa beecheyana* (Yeh and Chang, 1986b), and pseudospikelets of *Bambusa balcooa* (Gillis et al., 2007). These approaches enable rapid multiplication of selected genotypes during limited seed availability windows.

5.2 Somatic Embryogenesis:

Natural seed formation in bamboos is a single-time occurrence in the life cycle and is followed by death of the entire clump. The use of biotechnological tools for production of somatic embryos from any available part of bamboo theoretically provides a solution to this limitation. Somatic embryogenesis allows for micropropagation and provides a source for developing genetically modified variants. Conventional breeding methods to induce hybrid vigor and obtain varieties with desired traits are almost impossible in bamboos due to long flowering cycles. Somatic embryogenesis opens a gateway for obtaining varieties with desired traits in this valuable resource.

An attempt at hybrid seed production using conventional breeding methods in bamboos was reported by Alexander and Rao (1968), marking the beginning of tissue culture research in bamboos. Seeds of hybrid bamboo (*Bambusa* × *Saccharum*) were germinated on sucrose-enriched medium (Alexander and Rao, 1968). Since naturally formed embryos are rare in bamboos, the importance of artificially generated seeds (somatic embryos) is immense, with advantages accruing as a substitute for natural embryogenesis or seed set.

Mehta et al. (1982) reported regeneration of plantlets of *Bambusa arundinacea* from somatic embryos. Subsequently, numerous scientific reports have documented production of somatic embryos in various bamboo species (reviewed by Singh et al., 2013). Godbole et al. (2002) achieved germination of somatic embryos and generation of plantlets in *Dendrocalamus hamiltonii*. While somatic embryogenesis has been achieved in various bamboos with sustainable success (reviewed by Singh et al., 2013), lab-to-land transfer rates still require improvement to enhance efficiency.

5.3 Artificial Seed Production:

Production of somatic embryos followed by their encapsulation with alginates generates artificial seeds. This technology holds promise for raising bamboo plantations (Singh et al., 2013) and mitigating shortage of this resource with multiple uses. Artificial seeds offer advantages including ease of handling, transport, and storage, as well as potential for large-scale propagation of elite genotypes.

5.4 In Vitro Flowering and Seed Set:

Flowering in bamboos is enigmatic and seeds are not produced regularly (John and Nadgauda, 1999). In vitro flowering followed by seed set can potentially help in understanding issues related to bamboo seeds and provide for ready availability of seeds at will. As early as 1990, Nadgauda et al. and Rao and Rao reported in vitro flowering in bamboos. According to Singh et al. (2013), despite considerable research in this area, it remains in its juvenile phase with no reports on practical and commercial exploitation. Further research is needed to achieve consistent and reproducible in vitro flowering and seed set that can be utilized for breeding and propagation programs.

VI. CONCLUSION

Bamboo seeds are available only for a short span of time during flowering events that occur at long, unpredictable intervals. Unlike seeds of other plants, bamboo seeds cannot be readily utilized and exploited, particularly for genetic studies and variety improvement programs. These limitations also restrict research on various aspects of bamboo biology and utilization.

In vitro techniques including somatic embryogenesis via micropropagation, artificial seed production, and in vitro flowering with subsequent seed set are practically possible and have been attempted on various scales to address these limitations, though with limited success to date. Further experiments are needed to obtain seeds through alternative methods and to improve research and development of bamboos for long-term sustainability. Cryopreservation offers potential for long-term storage of viable seeds and germplasm conservation. Phytochemical analysis of bamboo seeds reveals the presence of various bioactive compounds that warrant further investigation for potential health and nutritional applications. Continued research efforts combining conventional and biotechnological approaches will be essential for unlocking the full potential of bamboo seeds as a resource for the future.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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