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Review

Tissue Cultured Regeneration and Ecological Values in Major Bamboo Species

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Abstract

Objectives: The promising specific growth regulators are employed tissue culture of the bamboo species. The specific natural hardening mixture supports the acclimatization and adaptation of the protected cultivation. The bamboo species contribute to the carbon sequestration and stabilization of the environment.

Findings: The growth regulator 2, 4-D encourages callus induction and growth regulators NAA + TDZ, BAP + Kinetin + Gelrite, BAP + Kinetin + Coconut water + myo-inositol, NAA and TDZ impose plant regeneration in the Bambusa species. The growth regulator of 2,4-D, 2,4-D + Kinetin, 2,4-D + BA, 2,4-D + BAP and 2,4-D + NAA + BAP produces callus induction in the Dendrocalamus species. The growth regulator of TDZ, BA and IBA + Coumarin + Putrescine, BAP + GA3, NAA + Kinetin, BA + IBA, BA + Kinetin + NAA, NAA + Kinetin, Kinetin + IAA has facilitated shoot regeneration in the Dendrocalamus species with the specific period. The growth regulator of BA and TDZ; BAP + TDZ, IBA + Coumarin + Putrescine, BAP + GA3, NAA + Kinetin, BA + IBA, BA + Kinetin + NAA, NAA + Kinetin, Kinetin + IAA develops root regeneration with unambiguous time in the Dendrocalamus species. The growth regulator of BAP and Kinetin + BAP imposes shoot regeneration and IBA and IBA + Coumarin + sucrose conducts root regeneration in the edible bamboo. The natural hardening materials of cocopeat, vermicompost, perlite, cow dung, FYM, compost, soil & garden soil and humus soil, perlite, and FYM recommend in the acclimatization and adaptation of the Bambusa species and Dendrocalamus species respectively.

Novelty: The standard growth regulators and hardening mixtures impose tissue culture, acclimatization and adaptation in the bamboo species. The bamboo species involves in managing carbon sequestration, biogeochemical cycle and the environment.

Keywords: bamboo; tissue culture; growth regulators; hardening; carbon sequestration; climate

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Introduction

Bamboo is called 'green gold' and "poor man's timber", and is classified in the subfamily Bambusoideae of the Poaceae family. Bamboo is a woody evergreen perennial plant that consists of complex permanent tissues of phloem parenchyma, phloem fibre, and bast fibre (Science Daily, 2018). It has over 1000 species in the world in 20 species are the most popular. The common species grown at the global level are *Arundinaria*, *Bambusatra*, *Bambusa heterostachya*, *Bambusa nutaus*, *Bambusa oldhamii*, *Bambusa pervariabilis*, *Lingania chungii*, *Dendrocalamus hookeri*, *D. membranaceous*, *Gigantochloa balui*, *G. hasskarliana*, *Oxytenanthera*, *Lingania*, *Phyllostachys glauca*, *Schizostavhyum* and *Dendrocalamus brandisii* (Stephane, 2019). The commercial species of India are *Dendrocalamus Brandisii*, *Dendrocalamus giganteus*, *Dendrocalamus hamiltonii*, *Dendrocalamus strictus*, *Melocanna baccifera*, *Phyllostachys bambusoides*, *Bambusa pallida*, *Bambusa polymorpha*, *Bambusa taluda* and *Bambusa nutans* (Tripathi, 2018). The major bamboo producing countries are China, Brazil, Australia, Mexico, the USA, Venezuela, India, Colombia, Panama, Japan, Vietnam, Thailand, France, United Kingdom etc. (Canavan et al., 2016). India accounts for Second rank in bamboo production followed by China. The production of bamboo has been estimated at 3.23 million tonnes in India and the North-East states Manipur, Mizoram, Meghalaya, Nagaland, Sikkim Tripura and Arunachal Pradesh are the highest producer of bamboo (Samir, 2018; Rajesh *et al*., 2014).

The exploitation of the Bamboo species rises for the value addition product formation and income generation in the modern era. The bamboo raw material produces fibre; is used in building roads and bridges, preparing clothes, jewellery design, fuel consumption, textiles, utensils, table wares and furniture (Econation, 2018). Bamboo covers under non timber forest- it does not require external application of water and fertilizers. The Bamboo Fibre strain strength is 28,000 per square inch and the steel strain strength is 23,000 per square inch. The stress capacity of Bamboo is twofold than the Steel (Ahsan *et al*., 2011). The raw material of Bamboo applies in product manufacturing of several industry sectors like cup, baskets, nets, bags, mats, hats, lantern, pencils, match box, lampshades, fences, edible shoots, raw shoots, furnitures, crafts, woolen threads, clothes, bridges, jewellery, sheet, paper nappies, bone medicine, fibre, table wares, utensils, drugs, panel, floors and agricultural implements. The demand of bamboo has been rising in the global market (Avinash *et al*., 2020).

Conventional breeding is not given great achievement because of the non-vegetative phase and irregular flowering. It produces a huge amount of seeds after a long life cycle. Most of the seeds are non-viable (Meena et al., 2020). Thus, Complimentary methods involves in producing desired clones in the standard time period, are invitro culture techniques like micropropagation, auxiliary bud propagation, rhizogenesis, etc. are evolved in species improvement and Germplasm conservation in Bamboo (Kalpataru and Gogoi, 2013; Verma and Mishra, 2018). The plant tissue culture technique is useful to obtain large bamboo populations from desired species. The bamboo tissue culture was first experimented with by Alexander and Rao (1968) in *Dendrocalamus strictus*. Several methods like

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adventitious shoot bud methods, axillary bud and somatic embryogenesis were tested in the bamboo species **(Table 1).**

The conventional breeding method takes more periods for the crop improvement of the Bamboo. The scientists, researchers and professors counter male sterility problems, embryo disruptions and seed setting problems in the improvement of the Bamboo plant. The asexual propagation method such as offset cutting, and rhizome cutting produces cloned Bamboo plants but counters low phenotypic growth, low gene frequency, long flowering cycle, seed sterility, low seed viability, and bulk cutting problem (Bakshi *et al*., 2015). The morphological and reproductive growth of the Bamboo plant takes 40-60 years. The scientists, researchers and professors emphasize efficient biotechnological methods such as micropropagation, floral propagation, organogenesis and somatic embryogenesis for Bamboo plant improvement. The juvenile explants, zygotic embryo, seed, seedlings, nodal bud and nodal cutting successfully facilitate shoot and root regeneration and plant regeneration in the several species of the Bamboo (Brar *et al*., 2013). The carbon sequestrations, hardening durations and regeneration durations transit in the respective species of the Bamboo. The several species of Bamboo such as *Bambusa arundinacea*, *Bambusa atra*, *Bambusa balcooa*, *Bambusa bambos*, *Bambusa* bambos var. *gigantean*, *Bambusa edulis*, *Bambusa glaucescens*, *Bambusa nana*, *Bambusa nutans*, *Bambusa tulda*, *Bambusa ventricosa*, *Bambusa vulgaris*, *Dendrocalamus asper*, *Dendrocalamus giganteus*, *Dendrocalamus hamiltonii*, *Dendrocalamus hookeri*, *Dendrocalamus latiflorus*, *Dendrocalamus strictus*, *Guadua angustifolia*, *Thyrsostachys oliveri*, *Dendrocalamus membranaceus* successfully completed *invitro* plant regeneration through Plant tissue culture techniques (Preeti and Nikita, 2018).

The growth regulator is an imperative factor in the internal and external morphogenesis of plants. It functions naturally as well as synthetically for enhancing phases of growth in the plant (Anam *et al*., 2021). It governs the adverse as well as normal conditions. The growth regulators with or without combinations promote naturally morphological and anatomical growth in the plant through Gene regulations/Gene expressions discovered by eminent Scientist Jacob Monad (Ayman *et al*., 2021). The growth regulator maintains acclimatization and adaptation in the plant through the biosynthetic pathway (Jia *et al*., 2020). The growth regulators proliferate permanent and Meristematic tissues system in the plant through the biosynthetic pathway (So *et al*., 2015). The scientist, professor and expert formulate synthetic growth regulators for conducting tissue culture in the plants (Naeem *et al.*, 2019). The synthetic growth regulator is the key factor in the chemical compositions of the media (Hameg *et al*., 2020). The growth regulator induces callus and regenerates the plantlet. The combinations and non-combination of growth regulator facilitate callus induction and regeneration in plants (Momoko *et al*., 2013). The growth regulator with or without combinations with variable concentrations conducts callus induction and regeneration in the plants (Ming *et al*., 2019). The professional expert promotes callus induction and regeneration in the major Bamboo species (Shanwen *et al*., 2017).

The plant uptakes nutrients and water with the interventions of metabolic activities (Fabiane *et al*., 2018). The plant and seedlings are acclimatized and adapted to the open field

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with water and nutrient movement (Altaf *et al*., 2012). The growth and development of the plant are facilitated with the intervention of climatic factors, soil-water interactions and element movement (Heba *et al*., 2022). The developed tissue cultured plant is acclimatized and adapted to the standard soil ingredients and controlled climatic factors in the protected cultivations (Hazarika, 2003). Several soil mixtures such as cocopeat, vermicompost, perlite, cow dung, FYM, compost, soil and garden soil applies in the tissue cultured plants for growth enhancement and nutrient enrichment (Jaime *et al*., 2017). The controlled climatic factors of the protected cultivation are created acclimatization and adaptation in the tissue cultured plants (Budhindra *et al*., 2015). . The soil ingredients and controlled climatic factors are applied to the Bamboo species for the acclimatization and adaptation (Saloni *et al*., 2021).

The plant governs an imperative role in the maintenance of climatic factors (Kang *et al*., 2022). The bamboo sequesters variable carbon and has a different growing period (Corey, 2012). The plant provides habitat to the flora and fauna, forbids land degradation and maintains the soil system (Smith *et al*., 2015). The plant regulates the biogeochemical cycle and atmospheric cycle of the surroundings (Mirindi *et al*., 2018). The plant balances concentrations of carbon dioxide and temperature variations in the environment (Taub, 2010). The climatic factors conduct growth and development in the plant and maintain the climate cycle (Sharon and Siobhan, 2016). The plant harnesses the various sources of carbon and variable temperature and balances the environment (Xi *et al*., 2019). The species of Bamboo is the major plant kingdom, involves in balancing the sustainable environment (Akwada and Akinlabi, 2016). The species of Bamboo assimilates variable carbon concentrations from the surroundings and maintains the carbon cycle of the atmosphere (Xinzhang *et al*., 2019). The several species of Bamboo sequesters the carbon concentrations from the surrounding, and maintains carbon content and temperature in the environment (Qiu-Fang *et al*., 2020) **(Fig. 1).**

The plant growth regulator induces direct and indirect regeneration in Bamboo species to compensate for species loss and conservation. The standard growth regulator emerges Micropropagated plant in a specific time period. The cloned plant acclimatizes and adapts to protected cultivation with controlled climatic factors. The hardened plant grows in the barren and non-barren land for controlling climatic factors and maintaining the ecosystem. The acclimatized plant drives raw materials development and post-harvest product formation sustainably. The acclimatized plant involves carbon sequestration, biogeochemical cycle stabilization, and climate loss and constructs an evergreen ecosystem in the surrounding. With this background, the following objectives were taken discussed in the paper ie.,

i) Growth regulator interactions and Time taken in regeneration of Major Bamboo species,

ii) Mixture uses and Time taken in Hardening of Major Bamboo species,

iii) Ecological value of Major Bamboo species,

iv) Limitation & Multiple uses of Bamboo.

Materials and Methods

The information on tissue culture, hardening and ecology of bamboo species were collected from the referred journals from 1984 to 2022.

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i) Growth regulator interactions and Time taken in regeneration of Major Bamboo species

The growth regulators are an important factor in the chemical composition of media and tissue culture. It stimulates plant material for callus induction and regeneration. The combination or without combination growth regulators naturally enhances cell multiplication, growth & development in the plant (Abha *et al*., 2022). The growth regulators with or without combinations with variable concentrations are applied in the species of Bamboo for morphological and anatomical growth through Gene regulations (Meena *et al*., 2020). The specific explant cell and specific explant tissue create a stagnant/homeostasis state in the cell organelles system and transit metabolism and metabolic pathways in the immobilized nutrient media. The specific explant cell and specific explant tissue are induced callus with the intervention auxin growth regulator in the immobilized nutrient media. The callus contains Induced embryonic determined cells (IEDC Cells) to stimulate embryo formation. The callus containing IEDC cells inoculates into the Auxin: Cytokinin growth regulators ratio enriched media for the root and shoot regeneration. The repressor protein expresses the *IPT3 (ISOPENTENYL TRANSFERASE 3)*, *LOG1*, *LOG4*, *and LOG5 (LONELY GUY 1/4/5)* genes for the Shoot regeneration. The repressor protein expresses WOX5 (*WUSCHEL-RELATED HOMEOBOX 5*) and *SHR* (*SHORT ROOT*) genes for root regeneration (Fig. 2) (Siamak and Mohan, 2020). The standard growth regulator with or without combinations with variable concentrations is introduced by the Professors, Scientists and Researchers for the tissue culture of classified Bamboo species ie.,

1. *Bambusa* species

The centre of origin of *Bambusa balcooa* is India. The height of the *Bambusa balcooa* is 25 m, thick, and 150 mm in thickness, 35-42 years flower period, grows in the drought-resistant region, has high fibre strength and involve in industry construction (Krishnakumar *et al*., 2017). *Bambusa nutans* is distributed in India, Bangladesh, Myanmar and Thailand, is 600-1200 cm long, 40-70 mm diameter, 35 years flower period, applies in pole fencing, basket & mats preparation, paper development and cooking young shoots (Benton, 2015).

The solidified MS agar media containing 1 mg/L BAP was regenerated shootlet in 20-25 days and the developed shootlet was regenerated rootlet in 30-35 days in MS media containing 2 mg/l NAA from sterilized 1-1/2 year of nodal explant of *Bambusa nutans* wall ex. Munro of Jorhat, Assam (Kalpataru *et al*., 2014). The growth regulator of 1-1.5 mg/L BAP induces shoot regeneration and 3.5-4 mg/L induces root regeneration in *Bambusa balcooa*. The shoot regeneration was completed in 3 weeks and root regeneration in 15-20 days (Pratibha and Sarma, 2011). The cell division and cell proliferation are enhanced by the shoot length and shoot multiplication by the BAP in the *Bambusa balcooa*. The number of cells is enhanced by the NAA and the root organ is penetrated with the metabolic activity of NAA growth regulators. The combination of 4.4 µM BAP + 2.32 µM Kinetin + 0.2% w/v Gelrite and 6.6 µM BAP + 2.32 µM Kinetin + 2.5 % coconut water + 100 mg/L myo-inositol were facilitated shoot regeneration in 3 weeks (Divya and Sanjay, 2011). The kinetin conducts cell division and cell proliferation in nodal explant in *Bambusa balcooa* and BAP enhances the number of shoots in the *Bambusa balcooa.* The comprehensive interaction of growth regulators of BAP + Kinetin influences cell cycle and organ formation. The coconut water corporate in the cell division and myo-insitol stimulates explant material for conducting cell breaking. The tissue culture in Bamboo species is

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completed with growth regulator such as NAA, IAA, BAP, Kinetin and 2, 4-D (Anis *et al*., 2021). The hormonal interaction of 0.5 mg/L TDZ + 2 mg/L Kinetin were induced in the shootlet and the standard interaction of 1 mg/L IBA + 0.5 mg/L Kinetin + 0.1 g/L aconitase imposes root regeneration in the *Bambusa nutans*. The action of 1 mg/L NAA + 0.5 mg/L TDZ produces a somatic embryo in the *Bambusa balcooa*. The combination of TDZ + Kinetin conducts cell division, shoot elongation and shoot multiplication in the *Bambusa nutans*. The metabolic activity of 2,4-D induces callus induction in the plant material of *Bambusa nutans* (Hakan and Kerim, 2013). The individual growth regulators of 1 mg/L BAP emerged in multiple numbers of shoots in *Bambusa tulda* Roxb. in 5-6 weeks. The concentration ranges from 1-2.5 mg/L enhances shoot length and the number of shoots in Bamboo species. BAP and TDZ facilitate cell division, shoot elongation and shoot formation. The shoot regeneration is higher the with the TDZ growth regulator (Ajoy *et al*., 2022). The single growth regulator concentration of 4.4-26.44 μM BAP was developed shoot number and increased shoot length in *Bambusa balcooa* and the single combination of 2.69-32.26 μM NAA has emerged rootlet in the *Bambusa balcooa* in 35 days. The individual effect of BAP incurs cell division, shoot length elongation and shoot formation and the individual effect of NAA promotes cell division and root emergence in the Bamboo species (Saleh and Reza, 2021). The combination of 2 mg/L 2,4-D + Coconut water was induced embryogenic callus, the developed callus was imposed shoot regeneration in 2 weeks with 0.25 mg/L NAA + 0.25 mg/L TDZ and 1mg/L NAA + 0.5 mg/L TDZ in *Bambusa nutans*. The coconut water is endosperm and enrich with cytokinins, and has the feature of cell division, cell proliferation and cell multiplication. The growth regulators 2, 4-D have the character of callus induction. The mutual effect of TDZ+ NAA incurs cell division, cell proliferation and cell multiplication and TDZ has the action property of shoot elongation and shoot multiplication (Deependra *et al*., 2021).

The growth regulator 2, 4-D encourages callus induction in the *Bambusa* species. The combination of NAA + TDZ, BAP + Kinetin + Gelrite, BAP + Kinetin + Coconut water + myo-inositol and non-combination of NAA and TDZ imposes plant regeneration in the *Bambusa species*. The specific combination and non-combination growth regulators were found relevant findings in the Bambusa species with the precise time period (Venkatachalam *et al*., 2015).

2. *Dendrocalamus* species

Dendrocalamus strictus is cultivated in India, Nepal, Bangladesh, Myanmar and Thailand, Cuba, 6-18 m in height, 2.5-12 cm in diameter, every year flower period, is applied in house frames, rafters, tent poles, concrete reinforcement, walls, scaffolding and lance shafts (Suyog *et al*., 2015). *Dendrocalamus hamitonii* is grown in India, Sri Lanka, Bhutan, Nepal, Pakistan and eastern China, 15-18 m in height, 12-15 cm diameter, 3-4 years flower period, contributes to protecting tea plantation from windbreak, preparing houses & bridges construction, household utensils preparation, paper preparation, chair, basket & mats development, young shoots cooking, pickle formation (Abhishek *et al*., 2017). *Dendrocalamus asper* is planted in India, Sri lnaka, Southwest China, Southeast asia, 15-20 m in height, 3.5-15 cm diameter, 60 years flower period, used in young shoots cooking, spices preparation, building construction (Suresh *et al*., 2016). *Dendrocalamus sinicus* is the largest Bamboo in the world, 46 m in height, 37 cm diameter, less flower period, *recommends* in the preparation of furniture, construction and paper & pulp industry (Mukta *et al*., 2018).

The individual growth regulators of 2.5 mg/L BAP have emerged in multiple numbers of shoots in *Dendrocalamus stocksii* Munro in 5-6 weeks (Ajoy *et al*., 2022). The action of 1 mg/L BAP + 0.25 mg/L TDZ was produced shoot regeneration in 6 weeks and the combination of 5 mg/L IBA + 10 mg/L

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Coumarin + 75 mg/L Putrescine was imposed root regeneration in 3 weeks. The combined interaction of BAP + TDZ imposes cell proliferation, shoot elongation and shoot multiplication in *Dendrocalamus hamitonii* (Satyam *et al*., 2018). The *Dendrocalamus hamiltonii*, *Drepenostachyum falcatum* (hill bmaboo) or *Dendrocalamus asper* (edible bamboo) were facilitated callus induction in 4 weeks. The interaction of 9 µM 2,4-D + 2.85 µM NAA + 0.88 µM BAP was induced embryogenic callus by the *Dendrocalamus asper*. The NAA and BAP activity is restricted by 2,4-D and the activity of NAA and BAP conducts cell division, and cell proliferation in the explant material of *Dendrocalamus asper*. The compact callus develops with the incorporation of 2,4-D. The comprehensive interaction of 10 µM 2,4-D + 5 µM BAP were produced compact callus by the *Dendrocalamus falcatum*. The BAP conducts division in the cell and proliferation of the cell and 2,4-D induces callus induction in *Dendrocalamus falcatum*. The growth regulator combination of 4.4 µM BAP + 2.8 µM GA3 was merged somatic embryo in *Dendrocalamus falcatum*. The interaction of BAP + GA3 stimulates cell division, shoot proliferation and morphological growth in the *Dendrocalamus asper*. The cell division and shoot multiplication are promoted by the BAP; the morphological growth is executed by the GA3 with the growth regulator pathway. The variable concentrations of 10-50 µM BAP were produced shoot organ in *Dendrocalamus asper*, *Dendrocalamus hamiltonii* and *Dendrocalamus falcatum* for 4 weeks. The variable concentrations of BAP stimulate explant material for the shoot multiplication and shoot length elongation (Arya and Sarita, 2015). The hypocotyls explant of *Dendrocalmus sinicus* produced callus with the interference of growth regulator. The appearance of brown colour has appeared in the induction media and the addition of 400 mg/L of citric acid into the medium restricts the appearance of brown colour in the callus (Jin *et al*., 2021). The integression of 3 ppm TDZ was regenerated the shoot organ in the *Dendrocalamus asper* in 60 days. The action of TDZ initiates cell division, number of shoot lengths and shoot elongation. The activity of TDZ is higher than the GA (Gusmaity *et al*., 2020). The growth regulator interactions of 0 µM, 9 µM, 18 µM, 27 µM, 36 µM 2,4-D with 9 µM 2ip or 9 µM Kinetin was induced embryogenic callus from the *Dendrocalamus asper* in 30 days. The developed callus was introduced in 0 µM, 4.5 µM, 9 µM, 18 µM 2,4-D in combination with 9 µM cytokinins for regenerating plantlet in 39 days. The activity of kinetin facilitates cell differentiation, cell multiplication and the action of 2, 4-D induces callus in the *Dendrocalamus asper*. The interaction of 2,4-D + Cytokinins promotes shoot length elongation and shoot multiplication (Thiago, 2021). The single growth regulator of 1.5 mg/L BA and 1 mg/L BA was produced shoot regeneration in *Dendrocalamaus hamiltonii* in 3-5 weeks. 1mg/L IAA + IBA + NAA produced rootlet in the *Dendrocalamaus hamiltonii* in 3 weeks. The low concentrations of BA facilitate more shoot differentiation, shoot elongation and shoot multiplication. The activity of IAA + IBA + NAA imposes cell division and root development. NAA conducts cell differentiation and cell proliferation, IAA + IBA promotes root elongation and root multiplication (Abha and Sunila, 2021). The activity of 4 mg/L NAA + 2 mg/L Kinetin was imposed more shootlet multiplication in 15-20 days or the non-combination of 4 mg/L NAA was induced more root regeneration in *Dendrocalamus strictus*. The individual action of NAA facilitates cell differentiation and cell multiplication and the individual activity of Kinetin imposes cell division, shoot elongation and shoot formation (Shambhu *et al*., 2021). The interaction of 2,4-D + BA + NAA, 5 mg/L 2,4-D + 2 mg/L Kinetin + 4 mg/L IBA, 2,4-D + Kinetin were produced compact callus in *Dendrocalamus sericeus* Munro. The individual BA, interaction of BA + IBA, BA + Kinetin + NAA, 1 mg/L NAA + 2 mg/L kinetin, Kinetin + IAA were developed shootlet from the compact callus in *Dendrocalamus sericeus* Munro in 8 weeks. The combination of IBA + Kinetin, IBA + NAA, IAA and NAA, NAA + Kinetin have emerged rootlet in 2 weeks from the cultured shootlet of *Dendrocalamus sericeus* Munro (Duangruethai, 2021).

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The mature nodal seedlings of *Dendrocnlnmus strictus* have imposed *invitro* shoot and root multiplication. Multiple numbers of shoot were produced in MS media supplemented with coconut milk, kinetin and BAP from mature nodal seedlings. The half-strength MS liquid medium containing IBA was regenerated plantlets for 48 hours in dark conditions and the developed plantlets were transferred to the field for adaptation and acclimatization (Nadgir *et al*., 1984). 30-60 days old lateral branches of *Dendrocalamus hamitonii* were soaked in the stock solution for chemical sterilizations. The sterilized nodal explants of lateral branches were inoculated in MS media supplemented with 1 mg/l BAP + 0.25 mg/l TDZ for shoot regeneration was recorded in 6 weeks and the shootlet was inoculated in the MS media supplemented with 5 mg/L IBA + 10mg/l coumarin + 75 mg/l putrescine for root regeneration. The root regeneration was obtained in 3 weeks. The developed plantlet shifted into the shade-net house for 3 months of hardening (Ramasubbu and Chelladurai, 2020). The nodal shoot with axillary bud explants of *Dendrocalamus asper* (edible bamboo), *Drepenostachyum falcatum* (hill bamboo) and *D. hamiltonii* was produced in the MS media. The explants of nodal tissues and basal parts of leaves were developed into an embryogenic callus. MS medium supplemented with 20-30 µM 2,4-D and 2% sucrose were induced in Somatic embryos under dark conditions. MS media supplemented with 9µM 2,4-D + 2.85µM NAA + 0.88µM BAP medium induced callus 3-5 folds every 4 weeks in *Dendrocalamus asper*. The embryogenic callus was developed in MS media supplemented with 10 µM 2,4-D + 5µM BAP in *D. hamiltonii*. *Dendrocalamus falcatum* developed callus 2-3 folds on MS media containing 10µM 2,4-D + 0.88µM BAP. The somatic embryos were transformed into plantlets within 30 days on MS medium containing 4.4µM BAP and 2.8µM GA3 with a 70% conversion rate in *Dendrocalamus asper*. The somatic embryos were modified into plantlets on MS media containing 5µM BAP in *D. hamiltonii* and *D. falcatum*. *Dendrocalamus asper* produced consistently 14-16 fold shoots in 4 weeks subcultured cycle. *D. hamiltonii* and *D. falcatum* shoot multiplication was 6-10 in 4 weeks subcultured cycle. The regenerated shootlets were inoculated in the MS rooting media supplemented with 1.0-5.0 mg/l NAA or 5- 10mg/l IBA. The plantlet developed from somatic embryos and the regenerated plantlet was hardened and acclimatized and transferred in the field. Ornellas *et al.* (2017) cultured nodal explants of *Dendrocalamus asper* in MS basal medium containing or not Vitrofural and supplemented with BAP (5, 10, 15, 20 µM). Vitrofural decreased the culture contamination and promoted organogenic cultures. The concentrations between 15 and 20 µM BAP concentration increased cell proliferation and bud sprouting (Arya and Sarita, 2015). The MS medium supplemented with growth regulators and additives was introduced to callus through chemically sterilized hypocotyls of *Dendrocalamus sinicus*. The inclusion of citric acid @ 400 mg/L in the MS medium inhibited callus browning and callus was inoculated in the regeneration medium for plant regeneration (Mina and Mahboubeh, 2021). The good shoot regeneration in *Dendrocalamus asper* (Betung bamboo) was obtained with ¾ MS media + 3 ppm Thidiazuron (TDZ). The inclusion of TDZ into the MS media resulted in a maximum percentage of shoot number (80%) and its low concentration produced more leaves (Reza *et al*., 2014). The micropropagation of *Dendrocalamus asper* is one of the most widely cultivated commercial varieties of bamboo (edible type), dependent on germplasm selection, explants and micropropagation techniques (Mustaffa *et al*., 2021). This principle will be followed by both commercial breeders and molecular biologists in bamboo development.The single growth regulator of 2,4-D produces callus in the *Dendrocalamus* species and the interaction of 2,4-D + NAA + BAP, 2,4-D + BAP, 2,4-D + BA and 2,4-D + Kinetin develop callus in the *Dendrocalamus* species (Meral *et al*., 2016).

The single growth regulator of TDZ and BA has imposed shoot regeneration of the *Dendrocalamus* species (Hemant *et al*., 2012). The combined growth regulators of IBA + Coumarin +

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Putrescine, BAP + GA3, NAA + Kinetin, BA + IBA, BA + Kinetin + NAA, NAA + Kinetin, Kinetin + IAA have facilitated shoot regeneration in the *Dendrocalamus* species with the specific time period (Ahmet, 2014). The single growth regulator of BA and TDZ conducts root regeneration in the *Dendrocalamus* species and the combined growth regulators of BAP + TDZ, IBA + Coumarin + Putrescine, BAP + GA3, NAA + Kinetin, BA + IBA, BA + Kinetin + NAA, NAA + Kinetin, Kinetin + IAA develops root regeneration with unambiguous time in the *Dendrocalamus* species (Yuan *et al*., 2017).

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3. Edible bamboo

Bambusa tulda is covered in the Indian subcontinent, Indo-china, Tibet and Yunnan, 20 m in height, 5-10 cm diameter, 15-60 years flower period, extensively used in the paper pulp industry. *Melocanna baccifera* is cultivated in Bangladesh, Myanmar, India, and Thailand, 10-25 m in height, 1.5-15 cm diameter, 48 years flower period, uses in treating respiratory diseases, household utensils preparation, baskets, mats, handicrafts, wall plates, screens & hats preparation or young shoots cooking. Bambusa bamboos are grown in India, Bangladesh, Sri Lanka, Indochina, Seychelles, Central America, West Indies, Java, Malaysia, Philippines, 10-35 m in height, 2-3 cm diameter, extensively uses in ladder and bridges development. The demand for edible bamboo shoots *Bambusa tulda* and *Melocanna baccifera* are high in various Asian countries and the regeneration of bamboo plantlets is investigated because of the long and irregular bamboo flowering cycle and scarcity of bamboo seeds. The nodal shoots and seeds culture was applied to the edible mushroom species *Dendrocalamus asper* for plantlet regeneration (Goyal *et al.*, 2015). The axillary branch was induced shootlet. The nodal shoot explants were taken from juvenile primary and lateral branches and produced multiple shoots from axillary buds within 2 to 8 weeks on MS medium supplemented with 0.1-15 mg/l BA. The cultured seeds also produced multiple shoots (1-20) within 6 weeks on this medium and the multiple shoot differentiation was influenced by the concentration of BA in the medium. The *in vitro* generated shoots were excised and subcultured on MS + 3.0 mg/l BAP expressing a 15 to 20 fold rate of shoot multiplication. These shoots could be continuously multiplied for more than three years without loss of vigor. The nodal explants of the edible mushroom *Arundinaria callosa* were found successful for shoot multiplication in MS media supplemented with 13.3 µm BAP and 1 µm IBA. The half-strength MS media containing 25 µM IBA and 0.05 µM BAP promoted the best root induction (Sayanika and Sharma, 2009).

The efficient and reproducible protocol through the technique of forced axillary branching was developed for the edible bamboo species - *Bambusa bambos*. High-frequency multiple shoot induction was achieved from nodal segments of elite genotype in MS medium supplemented with 4.4 µM BAP and 1.16 µM Kinetin (Kn). The size of the explant and season greatly influenced the frequency of bud break. The best rooting response was observed on 9.80 µM of IBA. *In vitro* raised plants were successfully acclimatized and established in the field conditions where they exhibited normal growth. Genetic fidelity studies of DNA indicated no variations among the *in vitro* progenies. The molecular analysis confirmed that these plants were genetically similar and can be used as elite plants (Anand *et al.*, 2013). The effective axillary bud breaking was achieved in MS medium supplemented with 3 mg/L of BAP. Combining 2 mg/L of kinetin (Kn) with 3 mg/L of BAP had a synergistic effect for shoot multiplication in 45 days. Profuse production of dark-brown rhizome in *B. tulda* and abundant rooting for *M. baccifera* within 30 days was achieved in half-strength MS medium supplemented with 3 mg/L of IBA, 10 mg/L of coumarin, and 3% sucrose. The plantlet was acclimatized for 25 days in the greenhouse (Waikhom and Louis, 2014). *Invitro* cultures of *Bambusa balcooa* were achieved by using nodal segment as an explant (Waghmare *et. al.*, 2021). The maximum number of roots (6.34), highest root length (5.67) and more number of leaves (7.68) were obtained from MS basal medium containing 2.0 mg/L IBA. The well rootlet regenerated plantlets of *B. balcooa* were further hardened in soil: vermicompost: coco-peat as (1:1:1) proportion medium for primary hardening and riverbed sand: soil: farmyard manure as 1:1:1 proportion medium for secondary hardening. Of the total hardened plantlets, 90 % plantlets survived well after the secondary hardening stage.

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The growth regulator concentration of 0.1-15 mg/L BAP and 3 mg/L BAP have imposed shoot regeneration in 2-8 weeks and 6 weeks respectively. The higher concentrations of BAP retard the shoot multiplication and shoot regeneration in the edible bamboo. 13.3 µM BAP was introduced for shoot regeneration and 1 µM IBA has produced root regeneration in the *Arundinaria callosa*. The single growth regulator of BAP enhances shoot elongation and shoot multiplication in the *Arundinaria callosa* (Larekeng *et al.,* 2020). The interaction of 4.4 µM BAP + 1.6 µM Kinetin produced shoot regeneration in the *Bambusa bamboos*. The combination of Kinetin + BAP consecutively impacts the explant material of the *Bambusa bamboos* for the shoot elongation and shoot multiplication (Saikat *et al*., 2016). The combination of 2 mg/L Kinetin + 3 mg/L BAP has induced shoot regeneration in 45 days in *Bambusa tulda* and *Meloconna baccifera* (Waikhom and Louis, 2014). The root regeneration was initiated with 2 mg/L IBA in *Bambusa balcooa* (Malay and Amita, 2005). IBA has a property of root development in the explant of edible bamboo species.

The individual growth regulator of BAP contributes mostly to the shoot regeneration in the edible bamboo and the combined growth regulator of Kinetin + BAP imposes shoot regeneration in the edible bamboo (Nadra *et al*., 2015). The single regulator of IBA and comprehensive growth regulator of IBA + Coumarin + sucrose conducts more root regeneration in the edible bamboo (Bambang and Purwanti, 2017).

ii) Mixture uses and Time taken in Hardening of Major Bamboo species

The adoption of the plant in the soil compositions and atmospheric climatic factors is called acclimatization (Calleja-Cabrera *et al*., 2020). The acclimatization mechanism conducts in the protected cultivation and field trials for crop improvement. The adaptation and acclimatization of tissue cultured plants perform in the protected cultivation (Claudia *et al*., 2018). The tissue-cultured plants adapt to the soil texture with nutrient and climatic factors. The plant grows well with the incorporation of water and mineral influx (Sathiyavani *et al*., 2017). Several mixtures such as cocopeat, vermicompost, perlite, cow dung, FYM, compost, soil and garden soil apply in the soil and the soil mixtures are continuous transports into tissue cultured plants for nutrient enrichment and growth enhancement (Murukesan *et al*., 2020).

The chemical mixture recommends with variable concentrations in the bamboo species for the adaptation in the protected cultivation. The feasible concentrations of organic and inorganic chemicals apply to the soil for the acclimatization and adaptation of the Bamboo species (Fan *et al*., 2021). The feasible concentrations of chemical impacts the duration of acclimatization and adaptation in the bamboo species (Paulo *et al*., 2019). The possible concentrations of chemically enriched soil water are transported in the bamboo species for the natural adaptation in the relevant time duration (Kaushal *et al*., 2020).

1. *Bambusa* species

The developed plantlet of *Bambusa tulda* and *Dendrocalamus stocksii* were cultivated into the gunny bags containing the chemical mixture cocopeat + vermicompost + sand, soil rite, cocopeat, sand + perlite in the first phase hardening for 30-45 days. The adapted and acclimatized plant was transferred into the main bed containing sand + cow dung in the Shade-net house for the second stage of hardening. The cocopeat has water persistence property and maintains water requirements in the plant. The vermicompost has nutrient content property, distribute nutrient into the plant, and forbids abnormal symptoms or disorder in the plant. The

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perlite conveys potassium into the plant. The comprehensive interaction of chemical mixture acclimatizes bamboo species in the relevant time period and maintains the morphological and anatomical growth in the bamboo species (Mayowa and Joshua, 2018). The developed *Bambusa vulgaris* and *Bambusa bamboos* plant were transferred into the plastic cup containing sterilized cocopeat in the greenhouse nurture tissue cultured plantlet. The plantlet influxes adequate climate and nutrient factors for the primary hardening. The primary hardening plant was shifted into the polyhouse for providing high shelter of climatic factors and producing a field plant (Parth *et al*., 2019). The developed tissue cultured *Bambusa vulgaris* were hardened into the Shade-Net house for 20 days. The shade-net house mitigates the intensity of light and radiates a low wavelength of light into the house for maintaining plant health and system. The high light intensity creates necrosis and burns into the young plants. The relevant shifting interval of the plant impacts the growth and development of the bamboo plant (Giovanna *et al*., 2021). The mixtures of FYM + sand + soil (2:1:1) were imposed for 3-4 weeks for the hardening of *Bambusa balcooa*. The Farmyard manure has NPK property, soil improvement character and morphology & metabolic improvement in the plant. The sand provides silicon element to the soil for maintaining soil texture and soil property (Maria *et al*., 2018). The plantlet of *Bambusa bamboos* was acclimatized with a mixture of garden soil + sand + compost (1:1:1) for 5-7 days. The garden soil is more productive soil than the field soil. The soil-sand texture maintains moisture, the structure of the garden soil. The compost progresses the growth and physiology of the plant, and mitigates the time interval of the plant growth and development (Fang and Zhihui, 2015). The natural compositions of sterile cocopeat + vermicompost (3:1) were applied in the *Bambusa nutans* plantlet for acclimatizations and adaptations. The vermicompost provides NPK nutrients to the cocopeat and maintains moisture in the cocopeat. The natural mixture of vermicompost + cocopeat maintains and regulates growth and metabolism in the plant (Naseer and Shahid, 2018). The natural and chemical media of sand + soil + compost (40:10:50) + 250 gm/m3 fungicide was recommended into the *Bambusa tulda* and *Melocanna baccifera* plantlet for hardening. The compost transports nutrients and moisture in the sand and soil. The soil maintains physical and chemical properties with the incorporation of the compost (Christina *et al*., 2020). The fungicide restricts the habitat of pest populations and larval populations (Jochen *et al*., 2019). The fungicide manages soil health and plant health. The natural and chemical health media acclimatized with water potential, mineral nutrition, hormones and photosynthesis, and respiration for constructing a new plant in 3-4 weeks (Clarkson and Hanson, 2003).

The natural hardening materials cocopeat, vermicompost, perlite, cow dung, FYM, compost, soil and garden soil recommends for the acclimatization and adaptation of the *Bambusa* species (Yogeshwar *et al*., 2011). The hardening materials have water retention capacity, nutrient properties and soil & plant improvement. The proper transport of nutrients and water from the hardening materials in the tissue-cultured *Bambusa* species produces relevant duration (Abdoulaye *et al*., 2021).

2. *Dendrocalamus* species

The well-developed plantlet was shifted into the container containing cocopeat in the laboratory for 25-30 days primary stage of hardening. The initially acclimated plantlets shifted

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to the Net house for the secondary stage of hardening for 1-2 months. The cocopeat has water storage capacity and nutrient transport capacity. The cocopeat maintains the survival rate and metabolism in the plant. The micro-climate sustains growth and development or metabolism in the plant during the primary stage of hardening. The developing plantlet receives high intensity of climatic factors in the protected cultivation for creating juvenile to field trials plant (Bharat *et al*., 2019). The regenerated plantlet of Drepanostachyum luodianesev was acclimatized with humus soil + perlite in the greenhouse. The humus soil enriches with NPK nutrients and improves the tissue system, moisture content and metabolic system. The humus soil recovers nutrients and improves root penetration into the plant. The humus soil facilitates growth and development in the plant. The perlite clay mineral provides potassium elements; creating disease resistance, rigidity and sucrose-water molecule transport into the plant (Shuyan et al., 2018). The natural ingredients and, farmyard manure + soil (1:1:1) were applied in acclimatization and adaptation of Dendrocalamus strictus Nees. The bulky manure FYM improves nutrient and soil characteristics, supplies nutrients to the plant for promoting growth and development and metabolism (Xiaolin *et al*., 2020).

The hardening constituents of humus soil, perlite, and FYM utilize in the acclimatization and adaptation of the Dendrocalamus species. The species transports nutrient content, and water volume from the hardening materials. The tissue-cultured species regulates metabolism for regular growth and development (Hema *et al*., 2020). The tissue-cultured species receives regular controlled climatic factors for sustaining metabolism and growth or development at regular time intervals. Hardening is done gradually from high to low humidity and from low light intensity to high light intensity. (Ojo *et al*., 2018).

iii) Ecological value of Major Bamboo species,

Bamboo is a natural resource, that controls soil and environmental factors. It provides shelter to animals and humans and maintains ecology and the ecosystem. The bamboo regulates gas compositions, atmospheric cycle and the environment of the ecosystem. It regulates more carbon cycle and metabolism in the system. It sequesters variable carbon concentrations from the surroundings and maintains carbon concentrations point through the carbon cycle (Kang *et al*., 2022). The bamboo conducts carbon cycle metabolism for stabilizing the carbon concentrations and soil environment through the carbon cycle and biomass (Shiferaw *et al*., 2021). Bamboo maintains the industrial economic value and natural resources from the disaster. It forbids land degradation, and types of soil erosion provide resources in the industry for revenue generation (Rashmi *et al*., 2019)

The Bamboo biomass is contributed to the Charcoal wood/Biochar formation through the gasification process (Swapna *et al*., 2021). The released gas of the Bamboo has very less ash, alkali and Nitrogen or sulphur content (Parthasarathy *et al*., 2021). The latent heat of Bamboo is higher than in agricultural residues, grasses and straw (Nusirat *et al*., 2016). The net calorific value of bamboo is higher than other wood species like beech, spruce, eucalyptus and poplars and is in the range of 18.3-19.7 MJ/kg (Suniti *et al*., 2013). The bamboo utilizes for manufacturing value addition product formation. The exploitation of the resources rises in the Bamboo sector. The climatic factors and metabolism destabilize the environment (Ye *et al*., 2021). The scientists, professors and researchers involve biotechnological tools for the

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regeneration of species of bamboo, germplasm conservation and environment reformation (Verina and Julius, 2013). They conduct several research for evaluating the carbon sink efficiency and carbon storage in the species of bamboo for mobilizing the economic and environmental value (Chu and Liu, 2021). The bamboo sequesters 17 tonnes per ha per year of carbon and assimilates 2.5-3 gigatonnes of carbon dioxide per year from the surrounding (Seethalakshmi *et al*., 2009). The variable climatic factors like carbon, temperature and soil environment are regulated by the species of Bamboo (Subashree *et al*., 2020). The carbon sequestrations of the atmosphere and the growing are assimilated by the species of bamboo. The carbon sequestration of 29.96 mg/ha soil layer and 18.96 mg/ha atmosphere were assimilated by the *Schizostachyum pergracile* (Dhananjay *et al*., 2021).

1. *Bambusa* species

The carbon sequestration of 50.44 t/ha above-ground parts (culms, branches, leaves), 2.52 t/ha below-ground parts and 24.71 t/ha were assimilated by the 5 years old *Bambusa vulgaris* in the Bangladesh forest (Shawkat *et al*., 2015). The carbon sequestration of 115 t/ha and 71 t/ha above-ground parts were sunk by the *Bambusa vulgaris* and *Bambusa vulgaris var. vitata* in the Ghana forest (Martin *et al*., 2019). The total carbon sequestration (plant + soil) of 57.77 t/ha, 99.81 t/ha and 86.92 t/ha were stored by the 7 years old *Bambusa vulgaris*, 5 yrs old *Bambusa balcooa* and 4 yrs old *Bambusa nutans* in the Terai region of Uttarakhand forest (Kavita *et al*., 2020). The carbon sequestration of 27.79 mg/ha/year above-ground parts was assimilated by the *Bambusa tulda* in North East India (Angom and Suresh, 2021). The carbon sequestration of 13 mg/ha/year above-ground part was assimilated by the *Bambusa pallida* in the Indian forest (Singh and Kochhar, 2015). The carbon sequestration of 6 mg/ha/year of above-ground parts was trapped by the *Bambusa oldhami* in the Mexico forest (Castaneda-Mendoza *et al*., 2005). The total carbon sequestration of 29.70 t/ha above-ground parts was stored by the *Bambusa vulgaris* in the Cameroon forest (Barnabas *et al.*, 2020). The carbon sequestration of 19.46 mg/ha above-ground parts was trapped by the *Bambusa tulda* in the Mizoram forest (David, 2014). The carbon sequestration of 23.5 mg/ha/year of above-ground parts was aggregated by the *Bambusa arudinacea* in the Indian forest (Jia *et al*., 2016). The carbon sequestration of 81.1 mg/ha/year above-ground parts and 9 mg/ha/year below-ground parts and 57.1 mg/ha/year above-ground parts & 71.5 mg/ha/year below-ground parts were stored by the *Bambusa bamboos* and *Bambusa bulmeana* in the India and Philippines forest respectively (Julien *et al.*, 2020). The carbon sequestration of 23.4 mg/ha/year above-ground parts and 7.4 mg/ha/year below-ground parts were trapped by the *Bambusa burmanica* in the China forest (Arun *et al.*, 2015). The carbon sequestration of 29.5 mg/ha/year above-ground parts and 8.2 mg/ha/year below-ground parts were trapped by the *Bambusa chungii* in the China forest (Kumaraguru *et al.*, 2021). The carbon sequestration of 32.8 mg/ha/year above-ground parts and 2.0 mg/ha/year below-ground parts were sunk by the *Bambusa dolic bomerithalla* in the China forest (Chen *et al.*, 2018). The carbon sequestration of 25.7 mg/ha/year above-ground parts & 4.6 mg/ha/year below-ground parts and 48.4 mg/ha/year above-ground parts & 2.1 mg/ha/year below-ground parts were assimilated by the *Bambusa oldhami and Bambusa pachinesis* in the China & Mexico forest respectively (Blanca *et al.*, 2018). The carbon sequestration of 15.3 mg/ha/year above-ground part was sunk by the *Bambusa polymorpha* in the Myanmar forest (Navjot and Paul, 2010). The carbon

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sequestration of 35.7 mg/ha/year above-ground parts and 5.8 mg/ha/year below-ground parts were sunk by the *Bambusa rigida* in the China forest (Mujuru, 2014). The carbon sequestration of 25.5 mg/ha/year above-ground part was sinked by the *Bambusa sp.* in the Indian forest (Tian-Ming, 2014). The carbon sequestration of 70.7 mg/ha/year above-ground parts and 159.4 mg/ha/year below-ground parts were assimilated by the *Bambusa stenostachya* in the Taiwan forest (Sheikh *et al.,* 2022). The carbon sequestration of 21.7 mg/ha/year above-ground parts and 4.5 mg/ha/year below-ground parts were trapped by the *Bambusa textilis* in the China forest (Rojas *et al.,* 2013). The carbon sequestration of 23.5 mg/ha/year above-ground parts and 9.2 mg/ha/year below-ground parts were trapped by the *Bambusa tulda* in the Bangladesh, Myanmar, Philippines and India forests respectively (Koushik *et al.,* 2016). The carbon sequestration of 2.1 mg/ha/year above-ground parts and 3.4 mg/ha/year below-ground parts were trapped by the *Bashania fangian* in the China forest (Xuli *et al.,* 2017).

2. *Dendrocalamus* species

The carbon sequestration of 83.84 t/ha was assimilated by the 7 years old *Dendrocalamus strictus* in the Terai region of Uttarakhand (Yunyang *et al*., 2020). The carbon sequestration of 11.2 mg/ha/year of above-ground parts was assimilated by the *Dendrocalamus latiflorus* in North-East India (Wang, 2004). The carbon sequestration of 15.26 mg/ha/year of above-ground parts was stored by the *Dendrocalamus longispathus* (Huafang *et al*., 2021). The carbon sequestration of 13 mg/ha/year of above-ground parts was stored by the *Dendrocalamus strictus* in the Indian forest (Singh and Singh, 1999). The carbon sequestration of 24.34 t/ha above-ground parts was sunk by the *Dendrocalamus asper* in Majhera place of Uttarakhand forest, The carbon sequestration of 17 t/ha above-ground parts was sunk by the *Dendrocalamus asper* in Mehragaon place of Uttarakhand forest (Anjuli and Purwar, 2015). The carbon sequestration of 1.66 t/ha above-ground parts and 0.08 t/ha below-ground parts were sunk by the *Dendrocalamus strictus* in the Nepal forest (Dhruba and Jyoti, 2020). The carbon sequestration of 19.94 mg/ha/year of above-ground parts was aggregated by the *Dendrocalamus longispathus* (Rawat *et al*., 2018). The carbon sequestration of 163.28 mg/ha/year of above-ground parts was aggregated by the *Dendrocalamus giganteus* in the terai region of the eastern Himalayas (Surath *et al*., 2022). The carbon sequestration of 74.5 mg/ha/year of above-ground parts was sunk by the *Dendrocalamus asper* in the Philippines and Taiwan forests (Lantican *et al*., 2017). The carbon sequestration of 33.6 mg/ha/year above-ground parts and 3.9 mg/ha/year below-ground parts was sunk by the *Dendrocalamus giganteus* in China and Taiwan forest (Vaishali, 2018). The carbon sequestration of 53.1 mg/ha/year above-ground parts and 17.7 mg/ha/year below-ground parts were trapped by the *Dendrocalamus hamiltonii* in China forest (Rajesh *et al*., 2022). The carbon sequestration of 15.3 mg/ha/year above-ground parts and 7.1 mg/ha/year below-ground parts were trapped by the *Dendrocalamus membrance* in China forest (Ling *et al*., 2019). The carbon sequestration of 20.7 mg/ha/year above-ground parts and 7.4 mg/ha/year below-ground parts were trapped by the *Dendrocalamus strictus* in India and Myanmar forests (Kumar *et al*., 2022).

3. Other Bamboo Species

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The carbon sequestration of 22.10 mg/ha/year above-ground parts, 4.85 mg/ha/year below-ground parts and 53.25 mg/ha/year soil strata were trapped by the *Schizostachyum pergracile* in Manipur forest (Amrabati and Pratap, 2016). The carbon sequestration of 10.94 mg/ha/year was trapped by the *Phyllostachys pubescens* in the North-East forest (Sujarwo, 2016). The carbon sequestration of 9.89 mg/ha/year was sunk by the *Phyllostachys maikinoi* in the North-East forest (Uttam *et al.*, 2021). The carbon sequestration of 13 mg/ha/year was assimilated by the *Phyllostachys bambusoi* in Japan forest (Isagi *et al.*, 1997). The carbon sequestration of 8 mg/ha/year was assimilated by the *Phyllostachys maikinoi* in the Taiwan forest (Yen and Lee, 2011).

The carbon sequestration of 7 mg/ha/year was assimilated by the *Phyllostachys pubescens* in China forest (Zhang *et al.*, 2014). The five-year-old bamboo *Bixa orellana* and *Khaya senegalensis* were sunk carbon 23.9-13.2 t/acre, 71-334 t/acre and 71-334 t/acre in Tamil Nadu forest (Boomiraj *et al.*, 2021). The carbon sequestration of 33.18±13.21 mg/ha/year above-ground parts (culms, branches, leaves) and 22.22±24.66 mg/ha/year above-ground parts were assimilated by the *Phyllostachys pubescens* and *Phyllostachys maikinoi* in Taiwan forest respectively (Yi and Tian, 2021). The carbon sequestration of 12.68 mg/ha/year above-ground part was sunk by the *Melocanna baccifera* in the Mizoram forest (Venkateswara, 2009). The carbon sequestration of 71.19 t/ha/year above-ground part was stored by the *Schizostachyum lumampao* in Cuyambay forest, Tanay forest, Rizal forest and Philippines forest (Zohreh *et al*., 2017). The carbon sequestration of 9.89 mg/ha/year above-ground part was trapped by the *Phyllostachys maikinoi* in the Taiwan forest (Dar-Hsiung and Tsai-Huei, 2015). The carbon sequestration of 5.1 mg/ha/year above-ground parts (culms, branches, leaves) and 1.9 mg/ha/year below-ground parts were assimilated by the *Acidosasa edulis* in China forest (Lin *et al*., 2017). The carbon sequestration of 23.7 mg/ha/year above-ground parts and 10.9 mg/ha/year below-ground parts were assimilated by the *Arundinaria fargessi* in China forest (Gilbert *et al*., 2018). The carbon sequestration of 68.4 mg/ha/year above-ground parts and 12.8 mg/ha/year below-ground parts were assimilated by the *Arundinaria alpina* in Ethiopia and Kenya forest (Urgesa, 2019). The carbon sequestration of 14.7 mg/ha/year above-ground parts and 4.1 mg/ha/year below-ground parts were assimilated by the Bamboo in the forest of China, Laos, Myanmar, Thailand and Vietnam forest (Bauters, 2018). The carbon sequestration of 2.6 mg/ha/year above-ground parts and 0.6 mg/ha/year below-ground parts; 5.6 mg/ha/year above-ground parts and 6.1 mg/ha/year below-ground parts were trapped by the *Bashania fargesii* and *Chimonobambusa quadrangularis* in the China forest respectively (Brigitte *et al*., 2017). The carbon sequestration of 80.8 mg/ha/year above-ground parts and 6.5 mg/ha/year above-ground parts were trapped by the *Chusquea culeou* and *Chusquea tenuiflora* in the Chile forest respectively (Amy and Victoria, 2011). The carbon sequestration of 33.5 mg/ha/year above-ground parts and 26.5 mg/ha/year below-ground parts; 4.4 mg/ha/year above-ground parts and 10.9 mg/ha/year below-ground parts were trapped by the *Fargesia scabrida* and *Fargesia spathacea* in the China forest respectively (John *et al*., 2015). The carbon sequestration of 10.9 mg/ha/year above-ground parts and 1.9 mg/ha/year below-ground parts, 1.3 mg/ha/year below-ground parts were trapped by the *Fargesia spathacea* and *Gelidocalamus stellatus* in the China forest respectively (Guolong *et al*., 2019). The carbon sequestration of 1.9 mg/ha/year above-ground parts and 1.3 mg/ha/year below-

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ground parts; 73.4 mg/ha/year aboveground parts were trapped by the *Gigantochloa apus* and *Gigantochloa levis* in the Indonesia and Philippines forest respectively (Vismaya, 2021). The carbon sequestration of 20.9 mg/ha/year above-ground parts was trapped by the *Gigantochloa* sp. in the Indonesia and Thailand forest respectively (Sheila, 2021). The carbon sequestration of 69.9 mg/ha/year above-ground parts and 7.5 mg/ha/year below-ground parts; 5.1 mg/ha/year above-ground parts were trapped by the *Guddua angustifolia* and *Guddua weberbaueri* in the Boliva, Colombia, Ecuador forest and Brazil forests respectively (Tomas *et al*., 2017). The carbon sequestration of 29.9 mg/ha/year above-ground parts and 16.9 mg/ha/year below-ground parts; 10.4 mg/ha/year above-ground parts and 8.2 mg/ha/year below-ground parts were trapped by the *Neosinocalamus affinis* and *Oligostachyum oedognatum* in the China forest respectively (Kaibo *et al*., 2017). The carbon sequestration of 5.6 mg/ha/year above-ground parts was trapped by the *Phyllostachys atroviginata* in the China forest (Xu *et al*., 2018). The carbon sequestration of 31.2 mg/ha/year above-ground parts and 13.4 mg/ha/year below-ground parts were trapped by the *Phyllostachys bambusoides* in Japan and South Korea forest (Choonsig *et al*., 2018). The carbon sequestration of 33.2 mg/ha/year above-ground parts and 14.8 mg/ha/year below-ground parts were trapped by the *Phyllostachys edulis* in China, Korea, Japan and Taiwan forest (Yangguang *et al*., 2018). The carbon sequestration of 20 mg/ha/year above-ground parts and 35.6 mg/ha/year below-ground parts were sunk by the *Phyllostachys heteroclada* in the China forest (Wang *et al*., 2013). The carbon sequestration of 24.7 mg/ha/year above-ground parts and 69.2 mg/ha/year below-ground parts and 42.2 mg/ha/year above-ground parts and 59.0 mg/ha/year below-ground parts were sunk by the *Phyllostachys maikinoi* and *Phyllostachys meyeri* in Taiwan and China forest respectively (Sharma *et al*., 2021). The carbon sequestration of 14.5 mg/ha/year above-ground parts and 12.2 mg/ha/year below-ground parts and 28.2 mg/ha/year above-ground parts and 15.1 mg/ha/year below-ground parts were sunk by the *Phyllostachys nidularia* and *Phyllostachys nigra* in South Korea and China forest respectively (Lv *et al*., 2020). The carbon sequestration of 6.8 mg/ha/year above-ground parts and 3 mg/ha/year below-ground parts and 68.1 mg/ha/year above-ground parts and 117.1 mg/ha/year below-ground parts were sunk by the *Phyllostachys praecox* and *Phyllostachys rutila* in China forest respectively (Yin *et al*., 2011). The carbon sequestration of 16 mg/ha/year above-ground parts and 41.5 mg/ha/year below-ground parts and 17.3 mg/ha/year above-ground parts and 11.6 mg/ha/year below-ground parts were sunk by the *Phyllostachys viridis* and *Phyllostachys amarus* in China forest respectively (Viktor, 2012). The carbon sequestration of 20 mg/ha/year above-ground parts and 7.8 mg/ha/year below-ground parts and 32.4 mg/ha/year above-ground parts and 34.4 mg/ha/year below-ground parts were sunk by the *Phyllostachys viridis* and *Pseudosasa amabilis* and *Pseudosasa usawai* in China forest respectively (Meta *et al*., 2015).

Carbon sequestration and carbon storage are involved in the species of Bamboo. The species of Bamboo assimilates carbon stock and carbon sequestration with the involvement of the carbon cycle; also maintain the soil and temperature of the surrounding with the interference of the cycle (Kumari *et al*., 2020; Hatfield and Dold, 2019). The species of Bamboo positively impacts several factors for maintaining the environment ecosystem ie.,

i) Soil ii) Carbon iii) Temperature

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i) Soil

The species of bamboo maintains an edaphic factor with the soil layer. The species of Bamboo forbids the land degradation of 6 m^2, and maintains the habitat and biogeochemical cycle of the soil layer. Bamboo improves the physical and chemical properties of the soil. The bamboo species reforms the nutrient and properties of the poor soil. The bamboo species grow well in acid soil with low base saturation and gravel content soil, retards in alkaline, shallow, calcareous soil with gravel content. It recovers the clay content, soil depth, total Nitrogen, soil organic matter and cation exchange capacity in the soil. The species of Bamboo assimilates more NPK nutrient content in the upper soil horizon than in the low soil horizon. The average nitrogen assimilation rate of 333.77 kg/ha, 332.20 kg/ha, 319.25 kg/ha, 319.45 kg/ha, 331.47 kg/ha, 324.30 kg/ha and 315. 87 kg/ha are managed by the *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides* respectively in the upper soil horizon of the Himachal Pradesh hill. The average phosphorus assimilation rate of 44.08 kg/ha, 43.67 kg/ha, 39.57 kg/ha, 40.27 kg/ha, 44.42 kg/ha, 41.43 kg/ha and 39.22 kg/ha are transported by the *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides* respectively in the upper soil horizon of the Himachal Pradesh hill. The average potassium assimilation rates of 319.52 kg/ha, 318.39 kg/ha, 314.11 kg/ha, 315.55 kg/ha, 316.89 kg/ha, 315.49 kg/ha and 314.19 kg/ha are transported by the *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides* respectively in the upper soil horizon of the Himachal Pradesh hill (Yourmila and Bhardwaj, 2017; Rohit *et al.,* 2021). The bamboo involves the Calcium exchange and Magnesium exchange from the soil layer. The calcium exchange of 818.63 mg/kg, 817.57 mg/kg, 811.03 mg/kg, 811.61 mg/kg, 817.81 mg/kg, 811.88 mg/kg and 811.77 mg/kg are transported by the *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides* respectively in the upper soil horizon of the Himachal Pradesh hill. The Magnesium exchange rate of 626.49 mg/kg, 625.88 mg/kg, 618.04 mg/kg, 619.04 mg/kg, 625.56 mg/kg, 619.99 mg/kg and 617.57 mg/kg are transported by the *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa tulda, Phyllostachys aurea, Dendrocalamus strictus, Melocanna baccifera, Phyllostachys bambusoides* respectively in the upper soil horizon of the Himachal Pradesh hill (**Nongdam, and Leimapokpam, 2014**).

ii) Carbon

The anthropogenic activity disturbs the environmental system and rises carbon concentrations in the environment. The carbon availability is nearly 3 times more than the above-ground parts and 2 times more than the atmospheric carbon. The carbon emission from the soil is 7-9 times more than anthropogenic activity carbon (Sam *et al*., 2021). The carbon rate emission per year is 4.3% per year, which is higher than China's (Wang *et al*., 2020). The carbon storage of above-ground terrestrial habitat is about to 86% and 73% soil carbon of the earth (Vashum and Jayakumar, 2012). The bamboo is an imperative Agroforestry tree for the edaphic and ecology. The bamboo covers one quarter in tropical regions and one-fifth in sub-

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tropical regions (Partey *et al*., 2017). The bamboo involves in combating the carbon cycle, soil carbon and carbon sequestration. The bamboo contributes to stabilizing the carbon concentrations in the soil and the environment of the temperate as well as tropical region regions. The species of bamboo sinks more carbon content during the vegetative growth phase (Yiping *et al.,* 2010). The species of bamboo sequesters carbon from the above-ground parts and below-ground parts. The *Annona reticulata* and *Annona squamosa* sinks 83.1 kg/ha and 73.5 kg/ha carbon in the University campus, Aurangabad, Maharashtra, India (Chavan and Rasal, 2012). The species of bamboo assimilates 18.93-23.55 mg/ha/year on average in North-East India (Gera and Chauhan, 2012). The species of bamboo harvests after 5-7 years of a short interval. The leaves of bamboo species fall between 12-18 months and the abscission of leaves of Bamboo species sequesters 1.5-5 mg carbon per ha. The leaves, sheath and branches fall after 72 months and store 4.7 mg of carbon per ha (Zheng *et al*., 2020). The species of bamboo transfers inorganic carbon into molecular carbon dioxide through the atmospheric carbon cycle. The molecular carbon dioxide utilizes in the system metabolism. The waste and dead material such as leaves, stems, and sheath, contains biochemical matters that are decomposed into organic matter through the biogeochemical cycle and produces nutrients such as C, H, O, N through the mineralization process. The species of bamboo translocates carbon and another nutrient from the soil for the growth and development or compensates for the nutrient of the soil (Wojciech and Sławomir, 2020).

iii) Temperature

Human destructs forest populations for fulfilling desired resources. The destruction of forests impacts global warming, rainfall and temperature. It creates a high temperature and less rainfall in the surrounding. The raising temperature impacts in growth and yield of the Bamboo (Deborah *et al.,* 2022). The forest loss mitigates the carbon cycle and increases the carbon content in the surrounding. It impacts the albedo, evapotranspiration and canopy roughness of the plants. Deforestation causes the transition in light intensity and temperature. It raises the humidity in the environment and mitigates aeration in the surrounding. The concentrations of nitrogen oxide raise the quantity of methane and lead in the atmosphere. The concentrations of ozone and methane affect the biochemical cycle (Hanqin *et al.*, 2015).

Bamboo is an imperative forest resource for mitigating climatic factor transition and ecological balance. The reforestation of bamboo species balances ecology and ecosystem. The species of bamboo declined by 75% soil erosion. It maintains climatic factor two montane temperature and pine plantations or 6 times tropical deciduous forest. The *Scizostachyum pergracile* sinks 220 mg carbon/ha/year for establishing stable climatic factors. The mature bamboo forest sinks 15 tones of carbon/ha/year for balancing the environment. The species of bamboo maintains a 5-20 °C average temperature, 1000-2000 mm rainfall and pH of 4.5-7 in the environment (Kohei *et al*., 2017). The species of bamboo declines the intensity of light and restricts the incidence of ultraviolet light. The reforestation of bamboo species mitigates surrounding temperature and increases humidity and microbial activity in the soil (Ed-Haun *et al*., 2019). The restoration of bamboo species transforms the temperature and microclimate of the surrounding. The *Bambusa vulgaris*, *Bambusa oldhamii* and *Bambusa tuldoides* declines wind speed and temperature and raise the humidity of the forest shelter (Peter, 2015). The

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species of Bamboo mitigates the intensity of light and temperature and evapotranspiration in the forest (Evandro *et al*., 2020).

The bamboo species maintain a 2-3 °C lower temperature in full sun (Yigardu *et al*., 2016). The temperature of 26.7 °C, 32.9 °C and 29 °C were found at 8.00, 12.00 and 16.00 O'clock respectively. The species of bamboo maintains the temperature of the soil and air (Boostma, 1976) **(Fig. 3)**.

Limitations

Propagation of bamboo in general, and that of tissue culture in particular, has certain limitations compared to other crops (Sharbati *et al*., 2012). Propagations through seeds are limited due to the long flowering cycle (up to 120 years), seed sterility and short seed viability. Infrequent and unpredictable flowering events coupled with peculiar monocarpic behaviour i.e. flowering once before culm death, and extensive genome polyploidization are additional challenges for this woody group. The vegetative propagation by cuttings, offsets and rhizomes is also inadequate to cope with the demand for planting stock due to large propagule size, limited availability, seasonal dependence, low multiplication rate and rooting percentage. The woody bamboo takes 100 years a long time to flower, and the flowering time of the bamboo cannot be predicted for each generation. The use of controlled tissue culture systems allows investigation into the mechanism of bamboo flowering and facilitates selective breeding (Jin-Ling *et al*., 2017). The higher level of contaminations, variability in the sprouting of buds, insufficient multiplication rates and difficulty in rooting are found in bamboo tissue culture. The development of competent callus and long-term maintenance of competent callus and efficiency of plantlet regeneration are prime issues of bamboo tissue culture (Muralidharan, 2017). The regenerated Bamboo plantlet is acclimatized in the protected cultivation and laboratory room with soil led chemical mixtures for 3-5 months, the acclimatized plantlets are incompetent to field trial for the crop improvement (Mengjie *et al*., 2017).

4. Multipurpose uses of Bamboo

The raw materials of Bamboo are involved in the production of household handicrafts, furniture, bamboo-ply, laminated boards, flooring, roofing sheets, fencing industry, food, charcoal, vinegar, beverages, natural pesticides, toiletries, construction work, furniture, utensils, fibre and paper, charcoal. The young shoots are used in preparing value-added products for consumption purposes and the young leaves are consumed by the animal. The fibrous sheaths are chopped into pieces and are consumed in curry or soup with fish or meat and pickle.

The aerial shoot of Bamboo riches in high protein, less fat, moderate dietary fibre, amino acids, selenium, potassium, antioxidants and minerals for a healthy heart. The young shoots of Bamboo are applied in the preparation of fermented shoots, pickles, bamboo beer, bamboo cookies, Soft drinks, bamboo wine, and canned products of the world. The shoot covers 18 amino acids and 96% moisture.

The raw material of Bamboo is applied in the post-harvest product preparations such as bamboo salt, bamboo vinegar, and bamboo extracts involves in controlling diabetes and cholesterol levels. The secondary metabolites are extracted from the aerial shoot for the treatment of hypertension, sweating, paralysis, antioxidant activities and anti-inflammatory effects. The morphological parts of *Bambusa arundinacea* involve in antiinflammatory, antiulcer, anti-diabetic, anti-oxidant, anthelmintic, astringent

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activity, ringworm, bleeding gums, arthritis, antileprotic and anticoagulation activities haemoptysis, of chronic inflammatory conditions, rheumatoid arthritis. The pyrolyzate is extracted from the shoot for treating the nervous system from oxidative stress, anti-apoptotic effects, and ischemic injury treatment. The young shoots of *Bambusa bamboos* are enhanced appetite, extracted metabolite from the buds treats estrogenic activity, antifertility activity and birth control, cancer prevention properties, and reducing blood pressure. The chemical is isolated from the leaves of *Bambusa bamboos* for curing common bacterial diseases.

The morphological portion of the plant is synthesized silica, choline, betaine, cyanogenetic glycosides, albuminoids, oxalic acid, reducing sugar, resins, waxes, benzoic acid, arginine, cysteine, histidine, niacin, riboflavin, thiamine, protein, gluteline, lysine, methionine, a proteolytic enzyme, nuclease, urease with the involvement of the metabolism. The beneficial organic molecules such as oxalic acid, reducing sugar, resins, waxes, HCN, and benzoic acid are developed with the incorporation of the metabolism. Several amino acids such as arginine, cysteine, histidine, isoleucine, leucine, lysine, methionine, phenylamine, threonine, valine, tyrosine, niacin, riboflavin and thiamine are synthesized in the shoot system for the structural building. The leaf generates glutamine, lysine, methionine, betaine, choline, a proteolytic enzyme, nuclease, and urease for the system activities (Hossain *et al*., 2015).

Conclusions

The interaction of specific growth regulators is involved in callus induction and plant regeneration in the bamboo species. The concentrations of growth regulators influence callus induction and regenerations in the bamboo species with the incorporation of tissue culture methods. The tissue culture of bamboo plants involves the restoration of forest resources and maintaining edaphic and climatic factors. The tissue-cultured bamboo specie conserves germplasm, sinks carbon and stable the climatic factors. The suitable hardening mixture involves the acclimatization and adaptation of the bamboo species with relevant duration for the new plant development. The development of Bamboo species reforms the environment and biogeochemical cycle.

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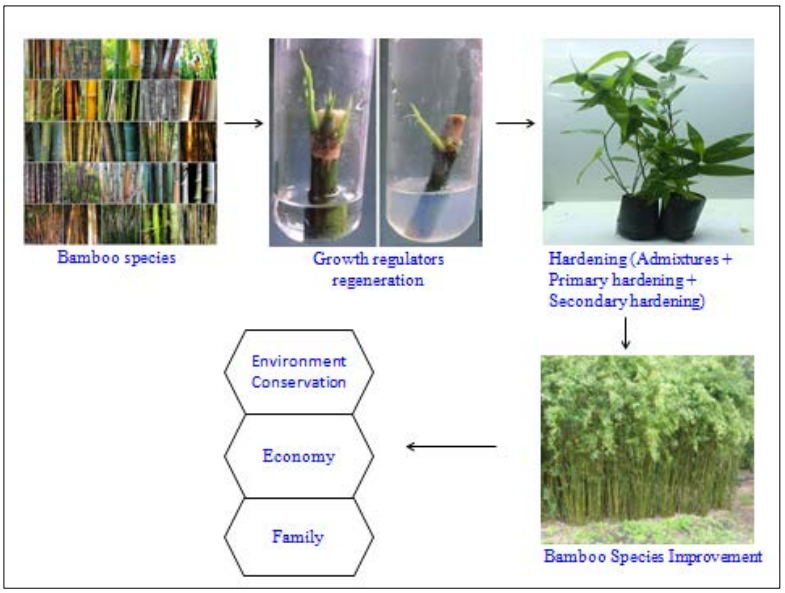

Fig. 1: Micropropagation and Ecosystem values of Bamboo species

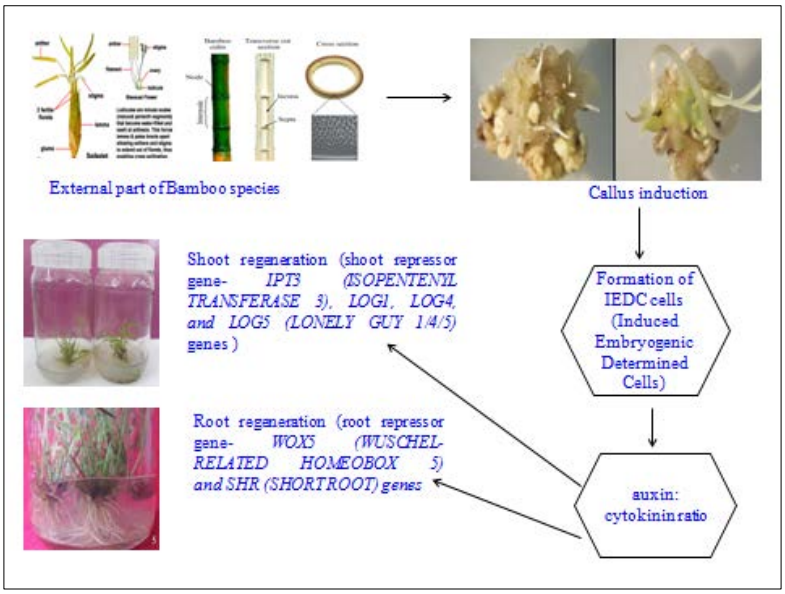

Fig. 2: Gene Regulations in Regeneration of Bamboo species (Ye *et al*., 2017)

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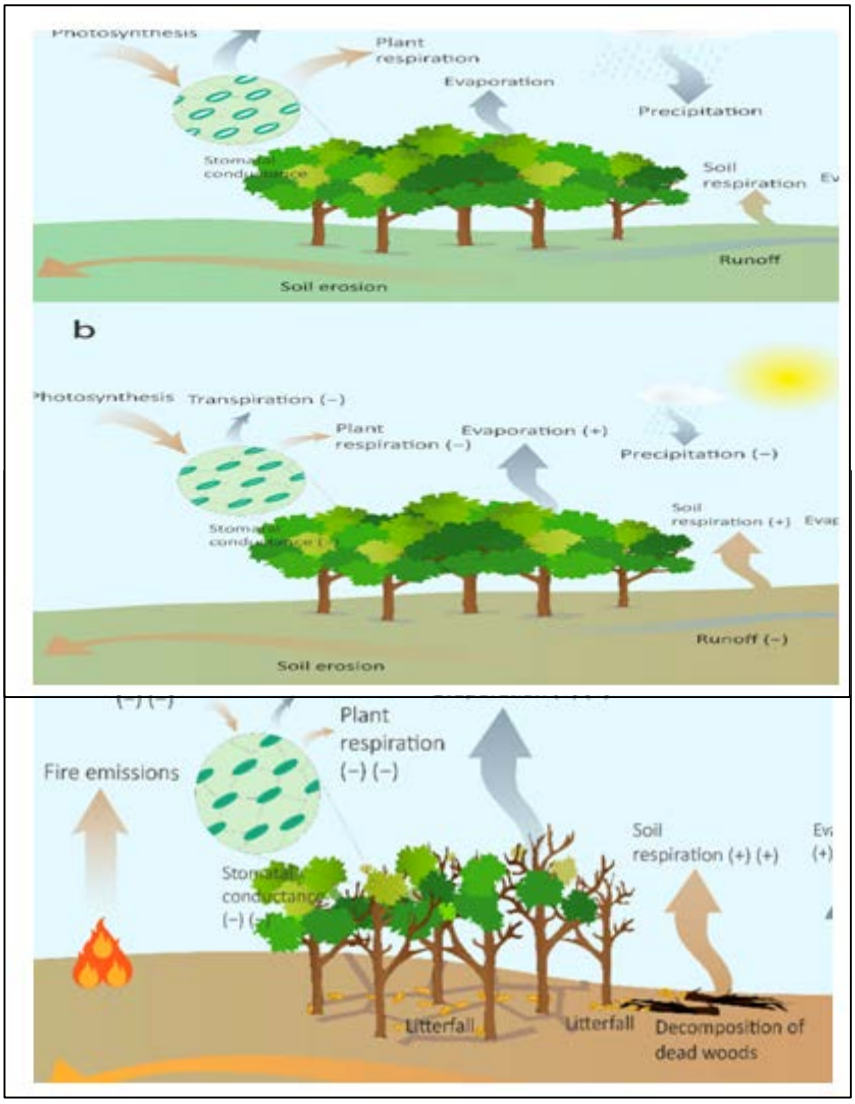

Fig. 3: Carbon cycle and carbon sequestration in Forest (Xiao *et al*., 2021)

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Table 1: Growth regulators and Durations in regeneration of Major Bamboo species

Sl. No.	Bamboo species	Regions	External plant	Growth regulators (S- Shoot, R- root)	Durations of Regeneration (S-shoot, R- root)	References
	***Bambusa* species**					
1	*Bambusa nutans* wall ex. Munro	Jorhat	1-1/2 year of nodal explant	Shoot- 1 mg/l BAP Root- 2 mg/l NAA	Shoot- 20-25 days Root- 30-35 days	Kalpataru *et al*., 2013
2	*Bambusa balcooa*	Jagirod, Assam	nodes containing axillary buds	Shoot- 1-1.5 mg/L BAP Root- 3.5-4 mg/L	Shoot- 3 weeks, Root- 15-20 days	Pratibha and Sarma, 2011
3	*Bambusa balcooa*	Gual Pahari, Haryana	nodal segments	Shoot- 4.4 µM BAP + 2.32 µM Kinetin + 0.2% w/v Gelrite and 6.6 µM BAP + 2.32 µM Kinetin + 2.5 % coconut water + 100 mg/L myo-inositol	Shoot- 3 weeks	Divya and Sanjay, 2011
4	*Bambusa nutans*			Shoot- 0.5 mg/L TDZ + 2 mg/L Kinetin		
5	*Bambusa tulda*	TNB College campus Bhagalpur, Bihar	nodes containing axillary buds	Shoot- 1 mg/L BAP	Shoot- 5-6 weeks	Ajoy *et al*., 2022
6	*Bambusa balcooa*	Saptari district, Nepal	nodal segments	Shoot- 4.4-26.44 µM BAP	Shoot- 35 days	Meena *et al*., 2021

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7	*Bambusa nutans*	Thailand and India	nodal shoot segment	Shoot- 0.25 mg/L NAA + 0.25 mg/L TDZ; 1mg/L NAA + 0.5 mg/L TDZ	Shoot- 2 weeks	Deependra *et al*., 2021
	***Dendrocalamus* species**					
8	*Dendrocalamus stocksii* Munro	TNB College campus Bhagalpur, Bihar	nodes containing axillary buds	Shoot- 2.5 mg/L BAP	Shoot- 5-6 weeks	Ajoy *et al*., 2022
9	*Dendrocalamus hamitonii*	Rain Forest Research Institute, Jorhat	single nodal cuttings	Shoot- 1 mg/L BAP + 0.25 mg/L TDZ Root- 5 mg/L IBA + 10 mg/L Coumarin + 75 mg/L Putrescine	Shoot- 6 weeks Root- 3 weeks	Satyam *et al*., 2018
10	*Dendrocalamus asper*, *Dendrocalamus hamiltonii* and *Dendrocalamus falcatum*	Arid Forest Research Institute, Jodhpur	Nodal segments containing single axillary bud	Shoot- 10-50 µM BAP	Shoot- 4 weeks	Arya and Sarita, 2015
11	*Dendrocalamus asper*	Hasanuddin University, Makassar	nodal shoot segment	Shoot- 3 ppm TDZ	Shoot- 60 days	Gusmaity *et al*., 2020

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12	*Dendrocalamus asper*	Pardinho, Brazil	Young inflorescence (pre-anthesis stages)	Shoot- 0 µM, 4.5 µM, 9 µM, 18 µM 2,4-D + 9 µM cytokinins	Shoot- 39 days	Thiago, 2021
13	*Dendrocalamaus hamiltonii*	LNMU Darbhanga; Bihar	single nodal segment	Shoot- 1.5 mg/L BA and 1 mg/L BA, Root- 1mg/L IAA + IBA + NAA	Shoot- 3-5 weeks Root- 3 weeks	Abha and Sunila, 2021
14	*Dendrocalamus strictus*	IGKV, Raipur	single nodal segment	Shoot- 4 mg/L NAA + 2 mg/L Kinetin Root- 4 mg/L NAA	Shoot- 15-20 days	Shambhu *et al*., 2021
15	*Dendrocalamus sericeus* Munro	Thailand	nodal segments	Shoot- 1 mg/L NAA + 2 mg/L kinetin	Shoot- 8 weeks Root- 2 weeks	Duangruethai, 2021
	Edible bamboo					
16	*Arundinaria callosa*	Bishnupur District of Manipur	nodal shoot explants	Shoot- 0.1-15 mg/l BA	Shoot- 2 to 8 weeks	Sayanika and Devi, 2009
17	*B. tulda* and for *M. baccifera*	Botanical Survey of India (BSI), Kolkata	nodal segments containing axillary buds	Shoot- 2 mg/L of kinetin (Kn) + mg/L of BAP Root- 3 mg/L of IBA, 10 mg/L of coumarin, and 3% sucrose	Shoot- 45 days Root- 25 days	Waikhom and Louis, 2014

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Table 2: Natural Mixture uses and Time taken in Hardening of Major Bamboo species

Sl. No.	Bamboo species	Hardening Mixtures	Hardening Duration	References
	***Bambusa* species**			
1	*Bambusa balcooa*	FYM + sand + soil (2:1:1)	3-4 weeks	Maria *et al*., 2018
2	*Bambusa bamboos*	garden soil + sand + compost (1:1:1)	5-7 days	Fang and Zhihui, 2015
3	*Bambusa nutans*	sterile cocopeat + vermicompost (3:1)		Naseer and Shahid, 2018
4	*Bambusa tulda* and *Melocanna baccifera*	sand + soil + compost (40:10:50) + 250 gm/m^3 fungicide	3-4 weeks	Christina *et al*., 2020
	***Dendrocalamus* species**			
5	*Drepanostachyum luodianesev*	humus soil + perlite		Shuyan *et al*., 2018
6	*Dendrocalamus strictus* Nees.	sand, farm yard manure + soil (1:1:1)		Xiaolin *et al*., 2020

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Table 3: Carbon Sequestration of Major Bamboo species					
Sl. No.	**Bamboo species**	**Regions**	**Carbon Sequestration (t/ha; mg/ha/year)**		**References**
	***Bambusa* species**		**Above ground parts (culms, branches, leaves)**	**Below ground parts**	
1	5 years old *Bambusa vulgaris*	Bangladesh forest	50.44 t/ha	24.71 t/ha	Shawkat *et al*., 2015
2	*Bambusa vulgaris*	Ghana forest	115 t/ha		Martin *et al*., 2019
3	*Bambusa vulgaris var. vitata*	Ghana forest	71 t/ha		Martin *et al*., 2019
4	7 years old *Bambusa vulgaris*	terai region of Uttarakhand forest	57.77 t/ha		Kavita *et al*., 2020
5	5 yrs old *Bambusa balcooa*	terai region of Uttarakhand forest	99.81 t/ha		Kavita *et al*., 2020
6	4 yrs old *Bambusa nutans*	terai region of Uttarakhand forest	86.92 t/ha		Kavita *et al*., 2020
7	*Bambusa tulda*	North East India	27.79 mg/ha/year		Angom and Suresh, 2021
8	*Bambusa pallida*	Indian forest	13 mg/ha/year		Singh and Kochhar, 2015
9	*Bambusa oldhami*	Mexico forest	6 mg/ha/year		Castaneda-Mendoza *et al*., 2005
10	*Bambusa vulgaris*	Cameroon forest	29.70 t/ha		Barnabas *et al*., 2020
11	*Bambusa tulda*	Mizoram forest	19.46 mg/ha		David, 2014
12	*Bambusa arudinacea*	Indian forest	23.5 mg/ha/year		Jia *et al*., 2016
13	*Bambusa bamboos*	India forest	81.1 mg/ha/year	9 mg/ha/year	Julien *et al.*, 2020
14	*Bambusa bulmeana*	Philippines forest	57.1 mg/ha/year	71.5 mg/ha/year	Julien *et al.*, 2020
15	*Bambusa burmanica*	China forest	23.4 mg/ha/year	7.4 mg/ha/year	Arun *et al.*, 2015
16	*Bambusa chungii*	China forest	29.5 mg/ha/year	8.2 mg/ha/year	Kumaraguru *et al.*, 2021
17	*Bambusa dolic bomerithalla*	China forest	32.8 mg/ha/year	2.0 mg/ha/year	Chen *et al.*, 2018
18	*Bambusa oldhami*	China forest	25.7 mg/ha/year	4.6 mg/ha/year	Blanca *et al.*, 2018
19	*Bambusa pachinesis*	Mexico forest	48.4 mg/ha/year	2.1 mg/ha/year	Blanca *et al.*, 2018
20	*Bambusa polymorpha*	Myanmar forest	15.3 mg/ha/year		Navjot and Paul, 2010
21	*Bambusa rigida*	China forest	35.7 mg/ha/year	5.8 mg/ha/year	Mujuru, 2014
22	*Bambusa sp.*	Indian forest	25.5 mg/ha/year		Tian-Ming, 2014

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23	*Bambusa stenostachya*	Taiwan forest	70.7 mg/ha/year	159.4 mg/ha/year	Sheikh *et al.*, 2022
24	*Bambusa textilis*	China forest	21.7 mg/ha/year	4.5 mg/ha/year	Rojas *et al.*, 2013
25	*Bambusa tulda*	Bangladesh, Myanmar, Philippines and India forest	23.5 mg/ha/year	9.2 mg/ha/year	Koushik *et al.*, 2016
26	*Bashania fangian*	China forest	2.1 mg/ha/year	3.4 mg/ha/year	Xuli *et al.*, 2017
	Dendrocalamus species				
27	7 years old *Dendrocalamus strictus*	Terai region of Uttarakhand	83.84 t/ha		Kavita *et al*., 2020
28	*Dendrocalamus latiflorus*	North-East India	11.2 mg/ha/year		Wang, 2004
29	*Dendrocalamus strictus*	Indian forest	13 mg/ha/year		Singh and Singh, 1999
30	*Dendrocalamus asper*	Majhera place of Uttarakhand forest	24.34 t/ha		Anjuli and Purwar, 2015
31	*Dendrocalamus asper*	Mehragaon place of Uttarakhand forest	17 t/ha		Anjuli and Purwar, 2015
32	*Dendrocalamus strictus*	Nepal forest	1.66 t/ha	0.08 t/ha	Dhruba and Jyoti, 2020
33	*Dendrocalamus giganteus*	terai region of eastern himalayas	163.28 mg/ha/year		Surath *et al*., 2022
34	*Dendrocalamus asper*	Philippines and Taiwan forest	74.5 mg/ha/year		Lantican *et al.*, 2017
35	*Dendrocalamus giganteus*	China and Taiwan forest	33.6 mg/ha/year	3.9 mg/ha/year	Vaishali, 2018
36	*Dendrocalamus hamiltonii*	China forest	53.1 mg/ha/year	17.7 mg/ha/year	Rajesh *et al*., 2022
37	*Dendrocalamus membrance*	China forest	15.3 mg/ha/year	7.1 mg/ha/year	Ling *et al*., 2019
38	*Dendrocalamus strictus*	India and Myanmar forest	20.7 mg/ha/year	7.4 mg/ha/year	Kumar *et al*., 2022
	Other Bamboo Species				
39	*Schizostachyum pergracile*	Manipur forest	22.10 mg/ha/year	4.85 mg/ha/year	Amrabati and Pratap, 2016
40	*Phyllostachys pubescens*	North-East forest	10.94 mg/ha/year		Sujarwo, 2016

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41	*Phyllostachys maikinoi*	North-East forest	9.89 mg/ha/year		Uttam *et al.*, 2021
42	*Phyllostachys bambusoi*	Japan forest	13 mg/ha/year		Isagi *et al.*, 1997
43	*Phyllostachys maikinoi*	Taiwan forest	8 mg/ha/year		Yen and Lee, 2011
44	*Phyllostachys pubescens*	China forest	7 mg/ha/year		Zhang *et al.*, 2014
45	*Phyllostachys pubescens*	Taiwan forest	33.18±13.21 mg/ha/year		Yi and Tian, 2021
46	*Phyllostachys maikinoi*	Taiwan forest	22.22±24.66 mg/ha/year		Yi and Tian, 2021
47	*Melocanna baccifera*	Mizoram forest	12.68 mg/ha/year		Venkateswara, 2009
48	*Schizostachyum lumampao*	Cuyambay forest, Tanay forest, Rizal forest and Philippines forest	71.19 t/ha/year		Zohreh *et al.*, 2017
49	*Phyllostachys maikinoi*	Taiwan forest	9.89 mg/ha/year		Dar-Hsiung and Tsai-Huei, 2015
50	*Acidosasa edulis*	China forest	5.1 mg/ha/year	1.9 mg/ha/year	Lin *et al.*, 2017
51	*Arundinaria fargessi*	China forest	23.7 mg/ha/year	10.9 mg/ha/year	Gilbert *et al.*, 2018
52	*Arundinaria alpina*	Ethiopia and Kenya forest	68.4 mg/ha/year	12.8 mg/ha/year	Urgesa, 2019
53	Bamboo	China, Laos, Myanmar, Thailand and Vietnam forest	14.7 mg/ha/year	4.1 mg/ha/year	Bauters, 2018
54	*Bashania fargesii*	China forest	2.6 mg/ha/year	0.6 mg/ha/year	Brigitte *et al.*, 2017
55	*Chimonobambusa quadrangularis*	China forest	5.6 mg/ha/year	6.1 mg/ha/year	Brigitte *et al.*, 2017
56	*Chusquea culeou*	Chile forest	80.8 mg/ha/year		Amy and Victoria, 2011
57	*Chusquea tenuiflora*	Chile forest	6.5 mg/ha/year		Amy and Victoria, 2011
58	*Fargesia scabrida*	China forest	33.5 mg/ha/year	26.5 mg/ha/year	John *et al.*, 2015
59	*Fargesia spathacea*	China forest	4.4 mg/ha/year	10.9 mg/ha/year	John *et al.*, 2015
60	*Fargesia spathacea*	China forest	10.9 mg/ha/year	1.9 mg/ha/year	Guolong *et al.*, 2019
61	*Gelidocalamus stellatus*	China forest	1.3 mg/ha/year		Guolong *et al.*, 2019
62	*Gigantochloa apus*	Indonesia forest	1.9 mg/ha/year	1.3 mg/ha/year	Vismaya, 2021

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63	*Gigantochloa levis*	Philippines forest	73.4 mg/ha/year		Vismaya, 2021
64	*Gigantochloa* sp.	Indonesia and Thailand forest	20.9 mg/ha/year		Sheila, 2021
65	*Guddua angustifolia*	Boliva, Colombia, Ecuador forest and Brazil forest	69.9 mg/ha/year	7.5 mg/ha/year	Tomas *et al*., 2017
66	*Guddua weberbaueri*	Boliva, Colombia, Ecuador forest and Brazil forest	5.1 mg/ha/year		Tomas *et al*., 2017
67	*Neosinocalamus affinis*	China forest	29.9 mg/ha/year	16.9 mg/ha/year	Kaibo *et al*., 2017
68	*Oligostachyum oedognatum*	China forest	10.4 mg/ha/year	8.2 mg/ha/year	Kaibo *et al*., 2017
69	*Phyllostachys atroviginata*	China forest	5.6 mg/ha/year		Xu *et al*., 2018
70	*Phyllostachys bambusoides*	Japan and South Korea forest	31.2 mg/ha/year	13.4 mg/ha/year	Choonsig *et al*., 2018
72	*Phyllostachys edulis*	China, Korea, Japan and Taiwan forest	33.2 mg/ha/year	14.8 mg/ha/year	Yangguang *et al*., 2018
73	*Phyllostachys heteroclada*	China forest	20 mg/ha/year	35.6 mg/ha/year	Wang *et al*., 2013
74	*Phyllostachys maikinoi*	Taiwan forest	24.7 mg/ha/year	69.2 mg/ha/year	Sharma *et al*., 2021
75	*Phyllostachys meyeri*	China forest	42.2 mg/ha/year	59.0 mg/ha/year	Sharma *et al*., 2021
76	*Phyllostachys nidularia*	South Korea forest	14.5 mg/ha/year	12.2 mg/ha/year	Lv *et al*., 2020
77	*Phyllostachys nigra*	China forest	28.2 mg/ha/year	15.1 mg/ha/year	Lv *et al*., 2020
78	*Phyllostachys praecox*	China forest	6.8 mg/ha/year	3 mg/ha/year	Yin *et al*., 2011
79	*Phyllostachys rutila*	China forest	68.1 mg/ha/year	117.1 mg/ha/year	Yin *et al*., 2011
80	*Phyllostachys viridis*	China forest	16 mg/ha/year	41.5 mg/ha/year	Viktor, 2012
81	*Phyllostachys amarus*	China forest	17.3 mg/ha/year	11.6 mg/ha/year	Viktor, 2012
82	*Phyllostachys viridis* and	China forest	20 mg/ha/year	7.8 mg/ha/year	Meta *et al*., 2015

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83	*Pseudosasa usawai and Pseudosasa amabilis*	China forest	32.4 mg/ha/year	34.4 mg/ha/year	Meta *et al*., 2015