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A Sustainable Approach in Plant Tissue Culture Using Waste-Derived Nutrients

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Plant tissue culture is an extensively used method of biotechnology, mainly for micropropagation, conservation, and crop improvement. still, in plant tissue culture synthetic nutrient media increases product cost and raises sustainability concerns. Recent investigation has explored organic based waste- derived materials as potential nutrient sources due to its composition of sugars, minerals, and bioactive composites. This composition has the potential to develop cost-effective, eco-friendly and sustainable methods in tissue culture and the applicability of opted waste- derived materials such as coconut water, banana peel, sugarcane molasses, and whey in sustainable biotechnology, along with their advantages, limitations, and future prospects.

Introduction

Plant tissue culture involves the *in vitro* cultivation of plant cells, tissues, or organs under sterile and controlled conditions. It is widely used for rapid multiplication of disease-free plants, conservation of germplasm, and crop improvement. A nutrient medium contained macronutrients, micronutrients, vitamins, a carbon source, and plant growth regulators is necessary for growth and development (George, Hall, & De Klerk, 2008).

The Murashige and Skoog (MS) medium is the most widely used formulation; however, its dependence on purified chemical components increases cost and limits accessibility in low-resource settings. Environmental concerns associated with synthetic inputs have encouraged interest in sustainable alternatives, including nutrient sources derived from agricultural and food wastes (Gavrilescu & Chisti, 2005). Recent advances in sustainable agriculture highlight the potential of natural extracts from agricultural waste, fruits, and algae as nutrient-rich, eco-friendly alternatives for plant growth. Substances like coconut water, banana peel extract, and seaweed gel offer essential bioactive compounds, making them promising substitutes for synthetic components in plant tissue culture. (Rao, S. 2025).

In this context, this article explores the use of waste-derived nutrients as substitutes for synthetic components in plant tissue culture media. It aims to evaluate their effectiveness in supporting plant growth while assessing their economic and environmental advantages, thereby contributing to the development of sustainable and eco-friendly cultivation practices.

Waste-Derived Nutrients: Concept and Sources

Waste-derived nutrients are the materials obtained from agriculture, food, or plant-based wastes that contain useful organic compounds such as carbohydrate, minerals, and other bioactive substances.

Banana peel has been a rich source of a nutrient-rich biomass, that containing carbohydrates, minerals (especially potassium), and phenolic compounds (Emaga et al., 2007). The composition of coconut water is sugars, amino acids, minerals, and biologically active compounds such as cytokinins, which contribute to its biological activity (Yong et al., 2009). Sugarcane molasses is considered as a by-product of sugar processing and is extensively recognized as a rich source of sucrose and fermentable sugars, widely used in biotechnological fermentation processes (Gavrilescu & Chisti, 2005). Whey is a dairy industry by-product, contains lactose, proteins, and minerals and is mostly used in microbial and industrial bioprocessing (Bhuvanendran, et al., 2024).

Significance in Plant Tissue Culture

Coconut water is extensively used as an organic substitute in plant tissue culture media due to its biochemical composition, in which sugars, amino acids, minerals, and cytokinins are included, act as a stimulant of biological activities in plant systems (Yong et al., 2009). Organic supplementation, including fruit extracts, are commonly recognized in plant tissue culture as a supplement that may enhance morphogenesis when added to basal nutrient rich media (George, Hall, & De Klerk, 2008). Other waste materials such as banana peel, molasses, and whey are mainly characterized for their nutritional composition and industrial or bioprocessing applications, and their direct application in plant tissue culture media remains in development without established protocols.

Advantages of Waste-Derived Nutrients

Waste-derived materials has potential of reduction in cost due to their minimum economic value and wide availability. Their use also aids environmental sustainability by decreasing organic waste accumulation and promoting recycling (Gavrilescu & Chisti, 2005). In addition, their biochemical composition such as sugars, minerals, and organic compound indicates potential utility as supplementary nutrient sources in biological systems.

Challenges and Limitations

Sources and processing conditions varies and this is a limitation of waste-derived materials (Gavrilescu & Chisti, 2005). The inhibitory compounds (pheholics) presence may affect biological systems, if not properly processed (George, Hall, & De Klerk, 2008). There is other challenge of microbial contamination due to high organic content, necessitating rigorous aseptic conditions. Lack of standardized preparation methods further limits consistency and large-scale application.

Future Prospects

Future investigations should emphasize on standardization of extraction and processing methods for waste-derived materials along with their integration with minimal synthetic media components (George, Hall, & De Klerk, 2008). Advances in fermentation and bioprocessing technologies could enhance nutrient availability and minimising inhibitory compounds (Gavrilescu & Chisti, 2005). Waste-derived nutrient systems represent a promising avenue in sustainable biotechnology though further validation for large-scale application is required. Future research should explore a wider range of natural extracts and their combinations to enhance plant growth. While also evaluating the long-term genetic stability of plants cultured using natural extract-based media to ensure consistency and reliability. Collaboration with industry stakeholders is essential to develop scalable, commercially viable production systems for broader application (Rao, S. 2025)

Conclusion

Waste-derived nutrients represent a promising sustainable approach for plant tissue culture by utilizing renewable organic resources and reducing environmental impact. However, current research supports their role mainly as supplementary components rather than full replacements of conventional tissue culture media. With further optimization and standardization, they may contribute to cost-effective and eco-friendly plant tissue culture approach.

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