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Hairy root technology: a biotechnological platform for plant secondary metabolite production

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INTRODUCTION

Hairy roots developed after infection of plants with *Agrobacterium rhizogenes*, a symbiotic bacterium currently taxonomically renamed as *Rhizobium rhizogenes*, have been used for the production of economically valuable, diverse plant-based metabolites. *R. rhizogenes*, a gram-negative soil bacterium inhabiting near plant roots causes the 'hairy root syndrome', characterized by the development of non-geotropic branching roots at the site of infection. Hairy roots are fast growing, free from pathogen and herbicide contamination and genetically stable. Due to these properties, these have been considered as ideal systems for production of specialized macromolecules and secondary metabolites useful for both pharmaceutical and industrial applications.

What is hairy root technology

Hairy roots were discovered by Chilton in 1982 by Chilton and his co-workers (Chilton et al. 1982). *A. rhizogenes* harbours a Ri Plasmid that contains T-DNA carrying genes for hairy root formation. Once *A. rhizogenes* detects a wounded plant tissue, it activates its *vir* gene system, facilitated by phenolic compounds such as acetosyringone. The *vir* genes complex stimulates the excision and transfer of T-DNA from the bacteria into the plant genome via a type IV secretion system (T4SS). The T-DNA is transported to the nucleus where it gets integrated into the host genome. The T-DNA contains genes (*rolA*, *rolB*, *rolC*, and *rolD*) that induce hairy root phenotype by regulating plant hormonal balance by modulating auxin and cytokinin homeostasis. In addition, *aux1* and *aux2* genes are present which encode enzymes involved in auxin biosynthesis, increasing indole-3-acetic acid (IAA) levels to further enhance root development.

Advantages of hairy roots

Hairy roots have been used in plant regeneration, production of specialized metabolites, environmental remediation, biotransformation and production of recombinant proteins. Hairy root cultures offer several key benefits over traditional methods of metabolite production:

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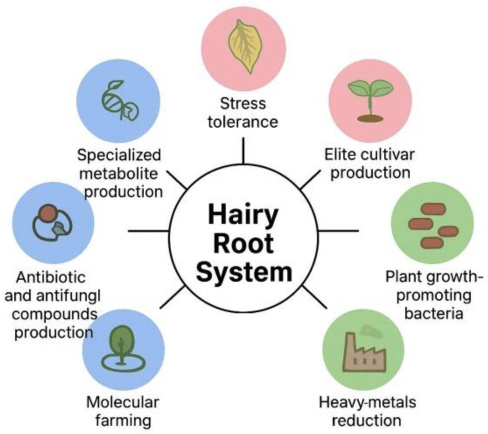
1. Hairy roots have a faster growth rate than normal roots in culture
2. Hairy roots have a hormone-independent growth pattern, i.e. they do not need plant growth regulators to multiply
3. The production of metabolites in hairy roots remains consistent over time
4. They produce equal or higher levels of compounds than the natural plant
5. They can be maintained under sterile, controlled conditions throughout the year

Hairy roots have been used for the production of a large number of secondary metabolites such as alkaloids, anthocyanins, flavonoids, ginsenosides, phenolics, stilbenes, lignans, and terpenoids. Hairy roots have also been used for the production of protein-based products such as vaccines, monoclonal antibodies, and therapeutic proteins.

Applications of hairy root technology



- *Plant secondary metabolite production*

Hairy root cultures have been established in many medicinal and aromatic plants to produce bioactive compounds such as alkaloids, flavonoids, terpenoids, phenolic compounds, and saponins. For example: *Catharanthus roseus* hairy roots are used to produce anti-cancer alkaloids like vincristine and vinblastine. Hairy roots have been induced in *Panax ginseng* for the production of ginsenosides, important for their tonic and antioxidant properties. Similarly, hairy roots in *Withania somnifera* (Ashwagandha) have been induced to produce withanolides, which have anti-stress and anti-inflammatory effects. The polyphenol curcumin used in the management of oxidative and inflammatory conditions has been induced in the hairy roots of *Atropa belladonna*. The production of Tanshinones, which have antioxidant activity, anti-inflammatory activity, cardiovascular effects, and antitumor activity has been increased using *Salvia miliorrhiza* hairy roots. Hairy root cultures have been induced in black carrots (*Daucus carota*), a major anthocyanin accumulator.

There are several other examples where hairy root cultures have been used for the production of secondary metabolites.

- *Phytoremediation*

Roots of plants are important for phytoremediation as they absorb contaminants from the soil and also help in phytotransformation, the metabolic degradation of the contaminant. Hairy roots have helped in supplementing this role as they increase the root biomass thereby increasing the contaminant uptake rate or they have been used to express a transgene in the hairy roots that assists in phytotransformation. For example, hairy root cultures of *Helianthus annuus* (sunflower) have been found to remove the antibiotics tetracycline and oxytetracycline from aqueous media. Similarly, *Armoracia rusticana* (horseradish) hairy roots have the ability to absorb acetaminophen. *Lycopersicon esculentum* hairy roots have shown to remove phenol from media in the presence of 5 mm hydrogen peroxide, while, hairy roots of *Brassica napus* have been used to phytoremediate 2,4-dichlorophenol (2,4-DCP).

- *Systems biology research*

Hairy roots are also valuable model systems for studying plant metabolic pathways. They serve as reliable models to investigate gene regulation, enzyme activity, and metabolic flux in the production of specific phytochemicals. Genetic engineering techniques can be used to insert or overexpress key biosynthetic genes, thereby boosting metabolite synthesis or enabling the production of novel compounds. Hairy roots can also be used to develop and test gene circuits. Two wood-related genes: Cinnamoyl-CoA Reductase1 (CCR1), a key lignin biosynthetic gene and IAA9A an auxin dependent transcription factor of the Aux/IAA family were edited using CRISPR/Cas9 Technology in Eucalyptus hairy roots. Similarly, steroid 16*α*-hydroxylase St16DOX gene was edited using CRISPR/Cas9 in potato, resulting in the generation of α-solanine-free hairy roots. In another study, overexpression of GmNAC15 in soybean hairy roots resulted in enhanced salt tolerance.

CONCLUSION

In summary, hairy root technology combines the benefits of plant genetic transformation, metabolic stability, and controlled culture conditions. The technology can be applied to rare, valuable, threatened, or endemic medicinal species for production of commercially valuable metabolites. Moreover, they can be used as tools for studying biosynthesis of plant-derived molecules and upscaling of bioproduction systems. By combining the advantages of *Agrobacterium rhizogenes*–mediated genetic transformation, stable growth, and high biosynthetic potential, hairy root cultures provide an excellent alternative to conventional cultivation and chemical synthesis. With further advances in metabolic engineering, and bioprocess optimization, hairy root technology will play a greater role in sustainable production and plant biodiversity conservation.

REFERENCES

Chilton MD, Tepfer DA, Petit A, David C, Casse-Delbart F, Tempé J (1982) *Agrobacterium rhizogenes* inserts T-DNA into the genomes of the host plant root cells. *Nature* 295: 432–434.

Morey KJ, Peebles CAM (2022) Hairy roots: An untapped potential for production of plant products. *Frontiers in Plant Science* 13:937095

Gutierrez-Valdes N, Häkkinen ST, Lemasson C, Guillet M, Oksman-Caldentey K-M, Ritala A, Cardon F (2020) Hairy root cultures—a versatile tool with multiple applications. *Frontiers in Plant Science* 11:33