Machine learning-based analysis of callus induction and biomass in *Lavandula x intermedia*

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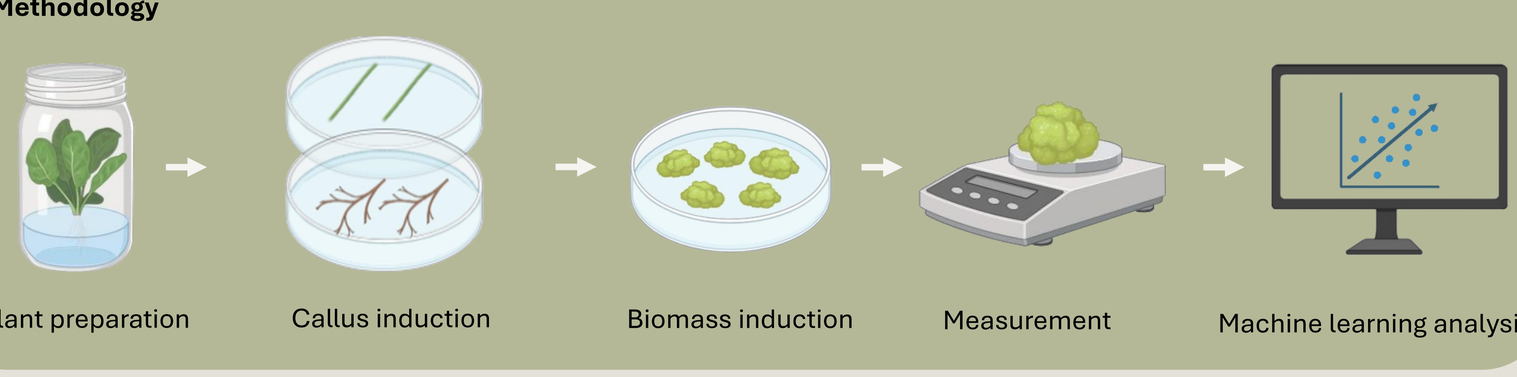
The genus *Lavandula* (Lamiaceae) is of significant industrial importance, globally cultivated for its essential oils and bioactive compounds, which are highly valued in the pharmaceutical, cosmetic and fragrance industries. While *Lavandula x intermedia* (lavadin) is preferred as a crop due to its superior biomass productivity and essential oil yield compared to *L. angustifolia*, its commercial potential is limited by significant phytochemical variability influenced by environmental and developmental factors.

Plant tissue culture offers a controlled platform to standardize metabolite production, yet optimizing these systems, particularly for Budrovka cultivar, remains challenging due to the complex, nonlinear interactions between explant origin, hormonal regulation and culture duration. Conventional optimization methods often fail to capture these intricate, high-order relationships. Consequently, integrating machine learning (ML) algorithms into tissue culture research provides a powerful approach to analyze high-dimensional data, predict optimal conditions, and enhance the efficiency and reproducibility of in vitro propagation systems. This study therefore aims to model the effects of explant type, plant growth regulator combinations and cultivation duration on callus induction and biomass production in *Lavandula x intermedia* var. Budrovka using supervised machine learning models.

Objectives

- To evaluate the effects of selected factors (explant type, plant growth regulators and cultivation time) on callus induction in *Lavandula x intermedia*.
- To apply machine learning models to predict callus formation and identify optimal cultivation conditions.

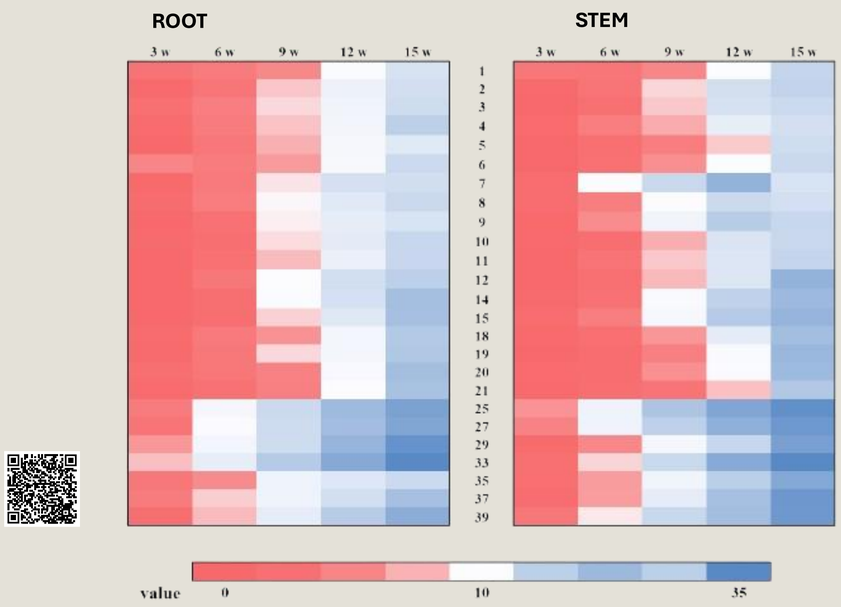
Methodology



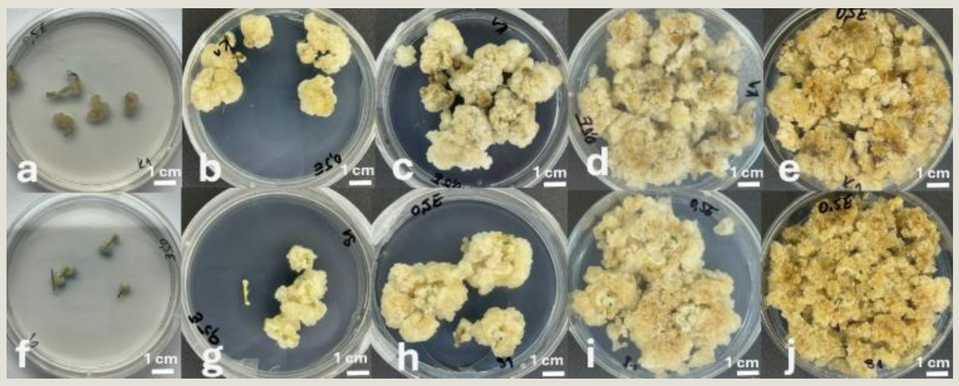
1 CALLUS INDUCTION

A total of 57 media were tested, of which regeneration was not observed in 25 treatments. Media eliciting any degree of adventitious roots or shoots were excluded to ensure reliable callus/specific biomass quantification.

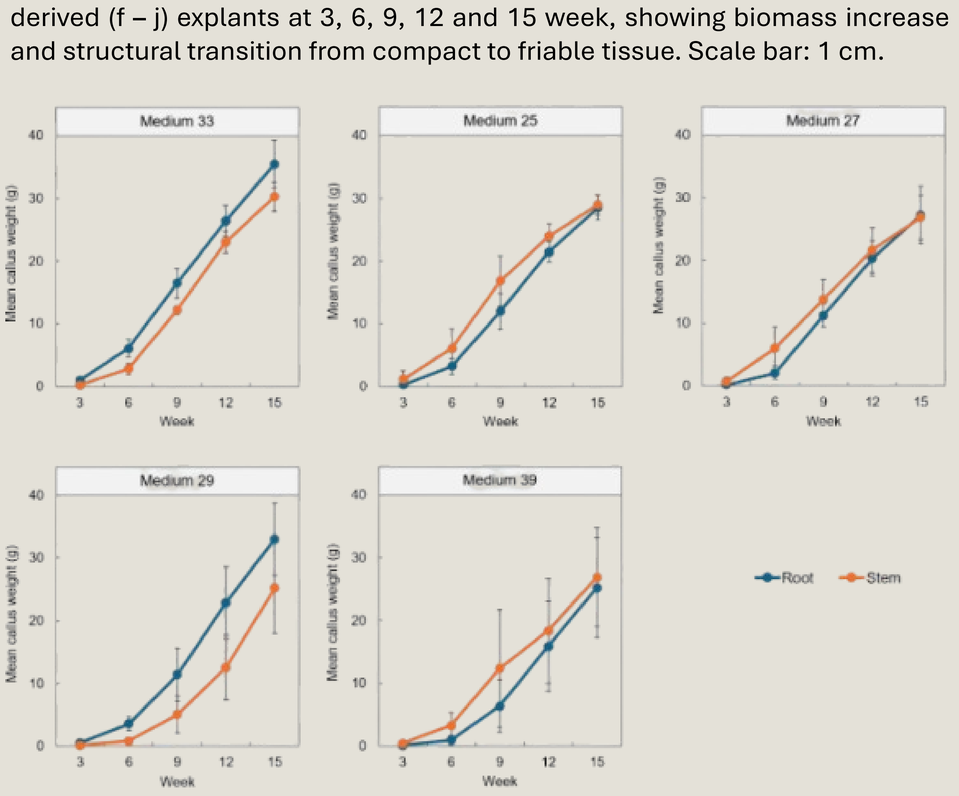
The attached QR code provides access to a complete list of all 57 tested media.



Heat map of fresh callus biomass accumulation in root-derived and stem-derived calli across 25 culture media.



Representative progression of callus growth in root-derived (a – e) and stem-derived (f – j) explants at 3, 6, 9, 12 and 15 week, showing biomass increase and structural transition from compact to friable tissue. Scale bar: 1 cm.



Callus biomass increased slowly until week 6, followed by rapid growth toward weeks 12-15, reaching up to 35 g fresh weight. High-performing media showed the strongest responses with root explants often achieving higher biomass at later stages.

2 MACHINE LEARNING

Machine learning was used to link culture conditions with callus response in *Lavandula x intermedia*.

Input data were used to train models predicting **callus induction** and **fresh weight.**

Different models were compared, and the best/performing one was used to identify optimal culture conditions for efficient callus prediction.

INPUTS

- Explant type (leaf, stem root)
- Plant growth regulators (different concentration and combination)
- Cultivation time

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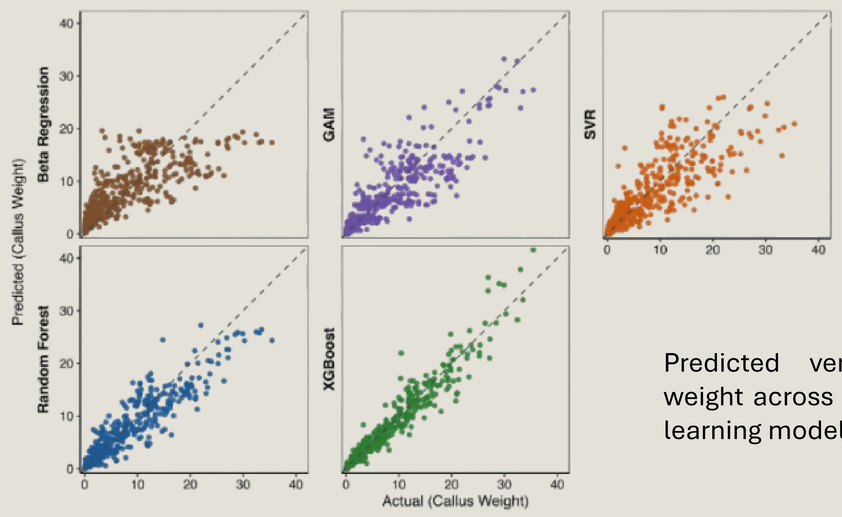
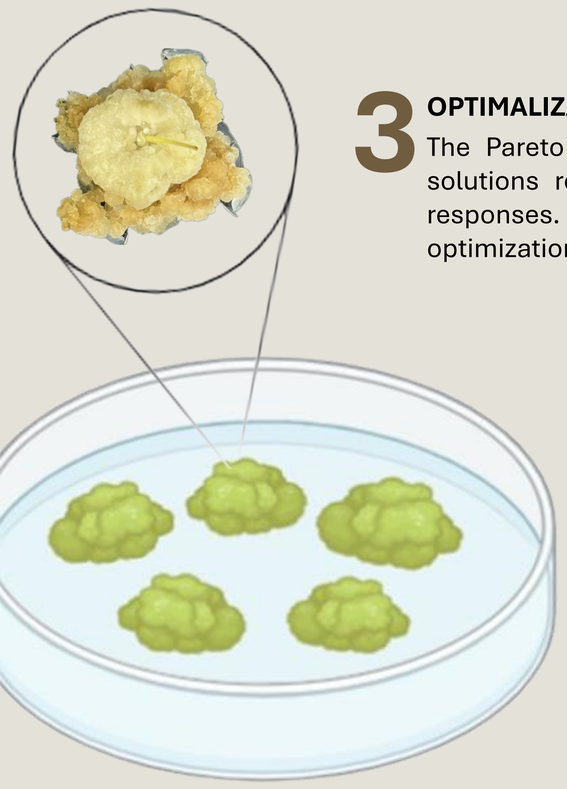
OUTPUTS

- Callus weight

A range of machine learning models was tested, and their performance was evaluated using statistical parameters (R^2, RMSE and MSE). Among the models shown, XGBoost and SVR achieved the highest accuracy.

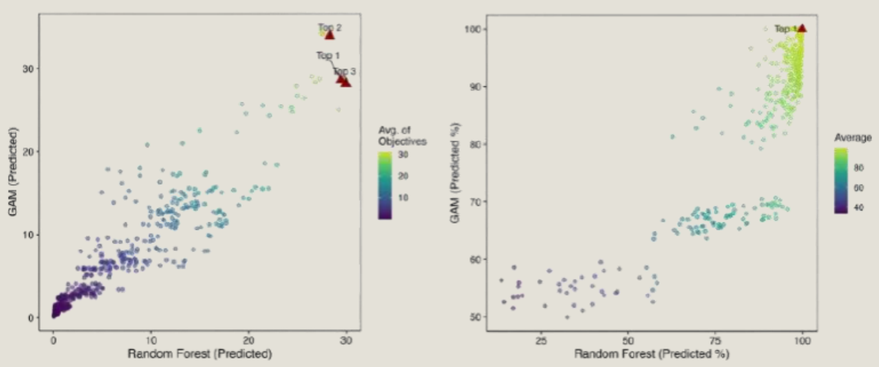


Predicted versus observed callus weight across statistical and machine learning models.



3 OPTIMALIZATION

The Pareto front shows the trade-off between callus biomass and induction. Top solutions represent optimal culture conditions with balanced high values of both responses. These results demonstrate the effectiveness of machine learning-based optimization for selecting optimal in vitro conditions.



Conclusion

Callus induction in *Lavandula x intermedia* is influenced by explant type, growth regulator composition and cultivation time. Machine learning models captured these relationships and enabled accurate prediction of callus induction and biomass. XGBoost and SVR showed the best performance. Integration of machine learning supports optimization of in vitro conditions.

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