Data-Driven System for Vertical Farming and Milk Quality Prediction: A Framework for Investigating the Impact of Microgreens in Dairy Nutrition

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Introduction

Precision milk-component pricing and the growing demand for premium-quality dairy products place renewed focus on smart feed design.

To quantify this potential before launching costly in-vivo trials, we assembled two, independently validated building blocks:

Machine-learning (ML) estimator – Trained on 25 000 commercial milk-record pairs, the multi-output model predicts casein concentration and somatic cell count (SCC) from routinely monitored milk traits (fat, protein, lactose, urea, conductivity, etc.).

Sensor-rich growth chamber – A custom vertical-farm module equipped with PAR, CO_2, temperature, humidity and EC sensors, delivering microgreen batches with repeatable nutrient profiles at <4 kWh kg^{-1} DM.

Our working hypothesis is that these two assets can be wired into a closed loop: fixed-composition microgreens are blended into the basal ration at graded inclusion levels, the ML estimator forecasts the resulting casein yield and SCC trajectory.

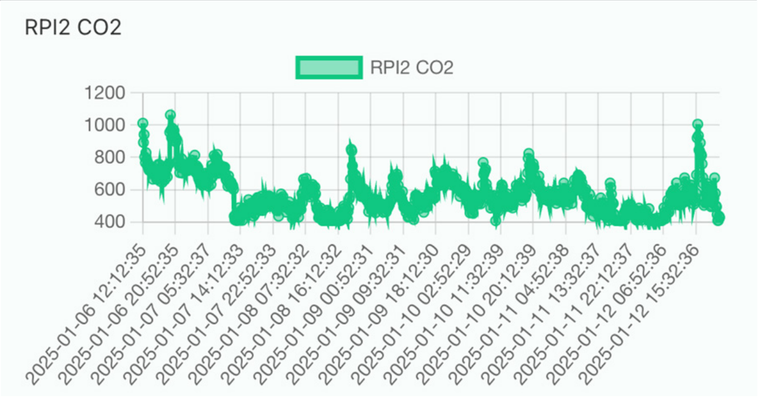
Materials and Methods

Crop-production platform

A purpose-built, cloud-connected vertical-farm chamber supplies the microgreens.

Lighting – Programmable ePAR LED array (400–750 nm) with six independently dimmable channels enables bespoke light recipes and light programs. Power draw is continuously modulated to maintain a target PPFD of 250–300 µmol m^{-2} s^{-1} at canopy height.

Climate & hydroponics – Recirculating deep-water culture with automatic pH and EC regulation keeps the nutrient solution stable; a thermostated air loop plus mist cooling clamp the vapour-pressure deficit at 0.9 kPa.



The measured microgreen nutrient profile is merged with a library of conventional forages (maize silage, alfalfa haylage) and concentrates (soybean meal, ground maize). Microgreens replace these ingredients in 5 percentage-point steps from 0 % to 40 % of dietary dry matter while the remaining ration is re-balanced to stay isoenergetic.

SSC and casein estimation from easily measurable milk constituents:

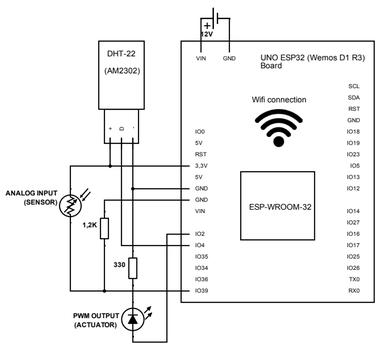
- Baseline: multiple linear regression (scikit-learn).
- Advanced: feed-forward neural network (TensorFlow/Keras) with two hidden layers (64-64 neurons, ReLU activations) and an Adam optimiser (learning-rate 0.001, 100 epochs, batch 32).

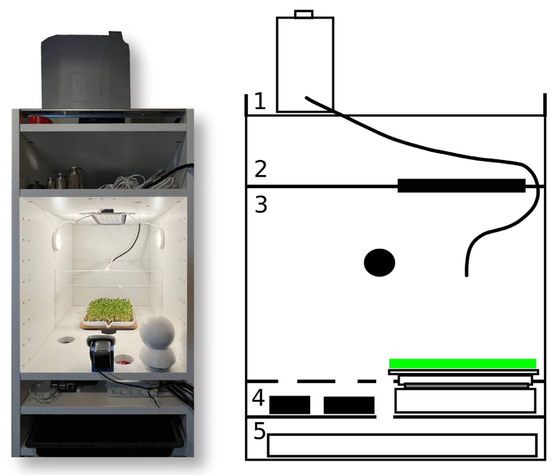
Both models were fitted to 25 000 monthly milk–feed records collected over three years from three Hungarian Holstein herds (80 % train, 10 % validation, 10 % test). Target variables were total protein, casein, log-transformed SCC and milk oleic-acid concentration.

Results

Cross-validation yielded R^2 = 0.86 and RMSE = 0.12 g 100 g^{-1} for casein; R^2 = 0.79 and RMSE = 0.18 for log-SCC. The neural-network marginally out-performed linear regression (ΔRMSE ≈ 4 %), especially at high microgreen inclusion (> 25 % DM).

Trait	Linear regression	Neural network	ΔRMSE
Milk protein (%)	R^2 = 0.86, RMSE = 0.12	R^2 = 0.92, RMSE = 0.08	−33 %
Casein (%)	R^2 = 0.84, RMSE = 0.11	R^2 = 0.91, RMSE = 0.07	−36 %
Log-SCC	R^2 = 0.64, RMSE = 0.24	R^2 = 0.79, RMSE = 0.18	−25 %
Oleic acid (g 100 g^{-1})	R^2 = 0.75, RMSE = 0.015	R^2 = 0.88, RMSE = 0.010	−33 %



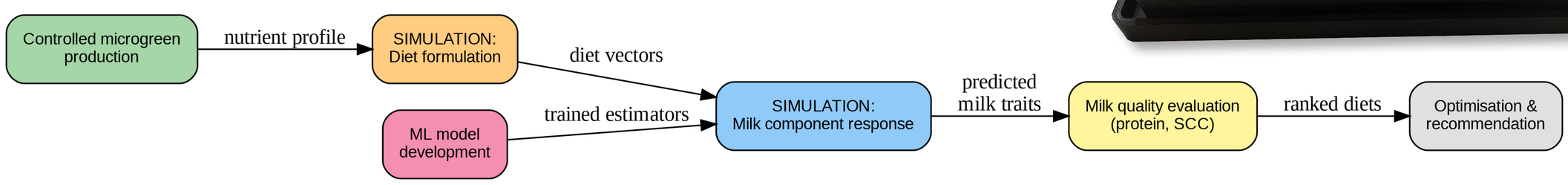


The feed-forward neural network consistently out-performed multiple linear regression, capturing non-linear diet–milk relationships across all four target variables.

Results of the simulated microgreen inclusion (0–40 % of dietary DM):

Milk protein: 3.25 ➔ 3.60 % (+11 %)
Casein: 2.55 ➔ 2.95 % (+16 %)
Log-SCC: 5.25 ➔ 5.05 (≈ −20 000 cells mL^{-1})
Oleic acid: 0.28 ➔ 0.32 g 100 g^{-1} (+14 %)

The above results came from the most profitable ration (+30 % microgreens).



Conclusion

We now possess every functional element required for a closed-loop, precision-nutrition system: (i) a low-energy vertical-farm chamber that reproducibly delivers microgreens of known nutrient density, and (ii) a rigorously validated machine-learning model that converts feed profiles into quantitative milk-quality predictions.