

Use of visible and NIR spectroscopy from beef classification based on farming intensification degree

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Why is this important?

European beef production is anything but uniform, ranging from extensive grass-fed suckler herds to intensive feedlot systems fattening young cattle. Such variety of farming systems, shaped by geography, climate, and economics, translate into a continuum of intensification degree rather than discrete categories for European beef farms. This variability translates into distinct quality grades, creating opportunities for market differentiation but also increasing the risk of frauds. For this reason, reliable analytical tools are increasingly needed to ensure authenticity and maintain consumer trust in the sector.

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What was done?

In this study, the INTAQT project evaluated the ability of different spectral devices combined with chemometric models to classify beef samples into intensification classes.

A total of 497 beef samples from Switzerland, France, Spain, Italy and the United Kingdom (UK) were analysed using three different spectral devices, including two portable; the FlameNIR (in the restricted NIR range 935-1665 nm) and the IndiGo Vis (in the visible range), and one benchtop device - NIRS™ DS2500 (in the whole Vis/NIR spectral range). Samples were categorised into six different classes (referred to as classes, Class0 to Class5 along the manuscript), based on the level of intensification of the farms, as previously reported by Caumette et al. (2026). Two dataset split approach were tested. The first approach defined the individual animal as the experimental unit (Animal-split approach), while the second accounted for the farm effect by defining the farm as the experimental unit (Farm-split approach).

Main results

Different spectral devices and dataset split approach (influence of the farm)

- For all three devices, the model built on the dataset using the Animal-split demonstrated comparable metrics in calibration but higher in validation than the model built using the Farm-split.
- The three devices showed comparable performances when using the Animal-split, reaching a balanced accuracy of 0.87 for FlameNIR, and 0.89 for both IndiGo and NIRS™ DS2500. With the Farm-split approach, the balanced accuracy of the model lowered to 0.74 for FlameNIR, 0.79 for IndiGo and 0.85 for NIRS™ DS2500.
- Overall, the classification model based on spectral data collected through the NIRS™ DS2500 device showed the highest performances and robustness in validation.

Difference of sensitivity for different classes

- **Class0** showed the highest number of correctly classified samples, representing the most distinct class in the dataset in terms of characteristics of slaughtered animals. This was characterized by suckler cows fattened before culling (up to 9 years of age) in French farms, supplied medium-high concentrate levels. Misclassification occurred mainly toward Class3.
- **Class3**, characterized by UK yearlings fattened until 28 months on grasslands with a moderate level of concentrate input, showed good sensitivity and relative stability among devices and splitting approaches. Although the model captured some spectral peculiarities for this class, indiscriminate misclassification with all the other classes was observed.
- **Class5** showed lower sensitivity but lower variability among split approaches and devices. This was represented by animals fattened in indoor feedlots (Italy, Spain and Switzerland) until 14 months of age, and with the highest proportion of concentrates and maize silage supplementation. Due to this characteristic, Class5 was probably distinguished by a specific spectral signature associated to the elevated high energy feed inputs.
- **Class1** and **Class2** were highly misclassified each other. These two classes shared a common biological background: both comprised animals raised exclusively at pasture in Swiss grasslands, without any concentrates, and differing exclusively in genetic type, slaughter age and weight of fattened animals. This proximity was somewhat reflected in the classification performance.
- **Class4** showed moderate to good precision. Across all models, a consistent proportion of samples from this class were misclassified as Class5. Class4 comprised animals from Swiss farms where animals were fattened indoor until 16 months of age with a median medium to high supplementation of concentrates and maize silage. This class was characterized as the one more sensitive to the farm effect and it could be supposed that, at the farm-level, spectral variations related to the farm effect may have overwhelmed the presence in spectral signal related to the grade of intensification.

Benefits for practitioners

Implementation of spectral based classification systems for beef farms intensification using tools can:

- As a reagent-free technique, spectroscopy aligns with green analytical chemistry principles, limiting chemical waste and reducing operator exposure to the solvents typically required in conventional wet-chemistry protocols.
- For producers working with grasslands-based beef systems, robust spectral-based classification models offer an objective tool to substantiate authenticity claims and support market positioning against more competitive products from intensive systems.
- In portable format, spectral instruments allow practitioners to perform on-site checks directly at critical points along the chain, as farm, abattoir, or point of sale, without depending on external laboratory turnaround.
- The spectral technique lends itself to integration within traceability systems, giving practitioners a practical means of documenting product history alongside compositional verification.

Practical recommendations

Fast and low-cost portable devices could offer the potential to acquire spectral measurements directly on-site, for example, on carcasses during grading or at processing facilities. Such an approach could substantially reduce time, costs, and analytical effort, while introducing innovation into authentication systems for the beef industry.

Limitations and future opportunities

When the farm is considered as the experimental unit of the model (Farm-split approach), the classification performance decrease, suggesting the driving influence of specific farm characteristics. To mitigate this effect, future studies should refine the experimental design by increasing the number of farms included in each intensification class and Country: a more balanced and representative distribution of farms across calibration and validation sets would improve the robustness of the model and provide a more reliable assessment of classification performance. Accordingly, future studies would benefit from including farms representing different production systems within more restricted geographical areas other than from different Countries, ensuring a balanced representation in both dimensions.

Key message

Combining Vis/NIR spectroscopy with CovSel-LDA chemometrics can effectively detect beef composition differences linked to farming intensification level. Classification accuracy fell when farms, rather than individual animals, were used as the experimental unit, confirming that farm-specific characteristics (management, feed sources, environment) strongly influence spectral profiles, and that the Farm-split provides a more realistic benchmark for real-world authentication, where samples typically come from previously unseen farms. The best classification results were consistently obtained for classes with the most distinct animal and management characteristics, such as culled suckler cows versus young beef, or exclusively grass-fed versus concentrate-supplemented systems. Misclassification concentrated among classes sharing similar age, feeding intensity or genetic background, particularly among animals fattened indoors under comparable concentrate and maize-silage regimes, reflecting the real continuum of European farming practices rather than a technical shortcoming.