

# Real-Time Detection of Turmeric Adulteration with Metanil Yellow using a Miniaturized NIR Sensor and AI techniques

## Authors

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## INTRODUCTION

Products like spices are among the most targeted foods in the European Union for fraudsters, since the spice market exemplifies complex and globalized supply chains. Turmeric is a widely used spice famous for its vivid color, unique flavor, and purported health advantages. Its medicinal properties in addressing various health issues have sparked a surge in global demand for it, raising concerns about the spice industry's integrity. The most common adulterants of turmeric, added for financial gain, are synthetic, non-authorized azo dyes, particularly **Metanil Yellow (MY)**.

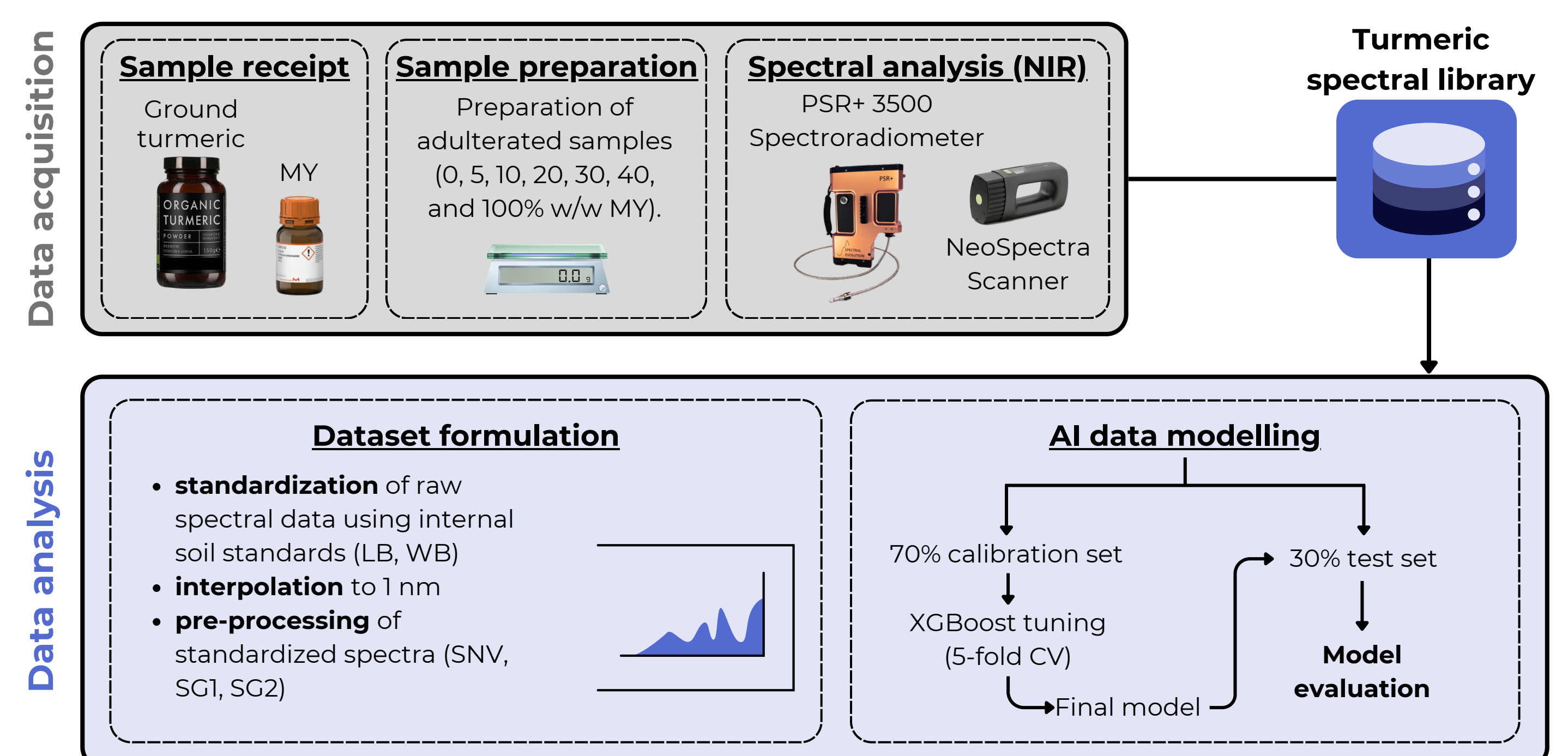
To tackle eventual malpractices concerning the turmeric supply chain, this study addresses the exploration of a **rapid, cost-efficient, and non-destructive method** utilizing a **miniaturized Fourier transform near-infrared (FT-NIR) (1350 – 2500 nm) sensor** coupled with **Artificial Intelligence (AI) techniques** to detect the presence of MY in turmeric.

## MATERIALS & METHODS

The methodological approach is divided into **two key phases (Figure 1)**.

The first phase, **data acquisition**, involved obtaining pure samples of commercial 100% organic ground turmeric and the adulterant dye (C<sub>18</sub>H<sub>14</sub>N<sub>3</sub>NaO<sub>3</sub>, Tokyo Chemical Industry Co., Ltd.) in powder form. These were then mixed to create adulterated turmeric samples at different classes (0, 5, 10, 20, 30, 40, and 100% w/w MY). The reflectance spectra of all samples (100) were recorded utilizing both the reference instrument (PSR+ 3500 Spectroradiometer) and the portable miniaturized device (NeoSpectra Scanner).

The second phase, **data analysis**, comprised several steps. The raw spectral data were standardized based on the spectral signatures of internal soil standards (Lucky Bay - LB and Wylie Bay - WB). Following this, interpolation and pre-processing of the standardized spectra, including the Standard Normal Variate (SNV) transform, first- and second-derivative of the absorbance (SG1 and SG2, respectively) were carried out too. The XGBoost algorithm was used to classify the spectral samples into the corresponding adulteration classes. Each model was tuned using 5-fold CV in the calibration set (70%) and evaluated in an independent test set (30%).

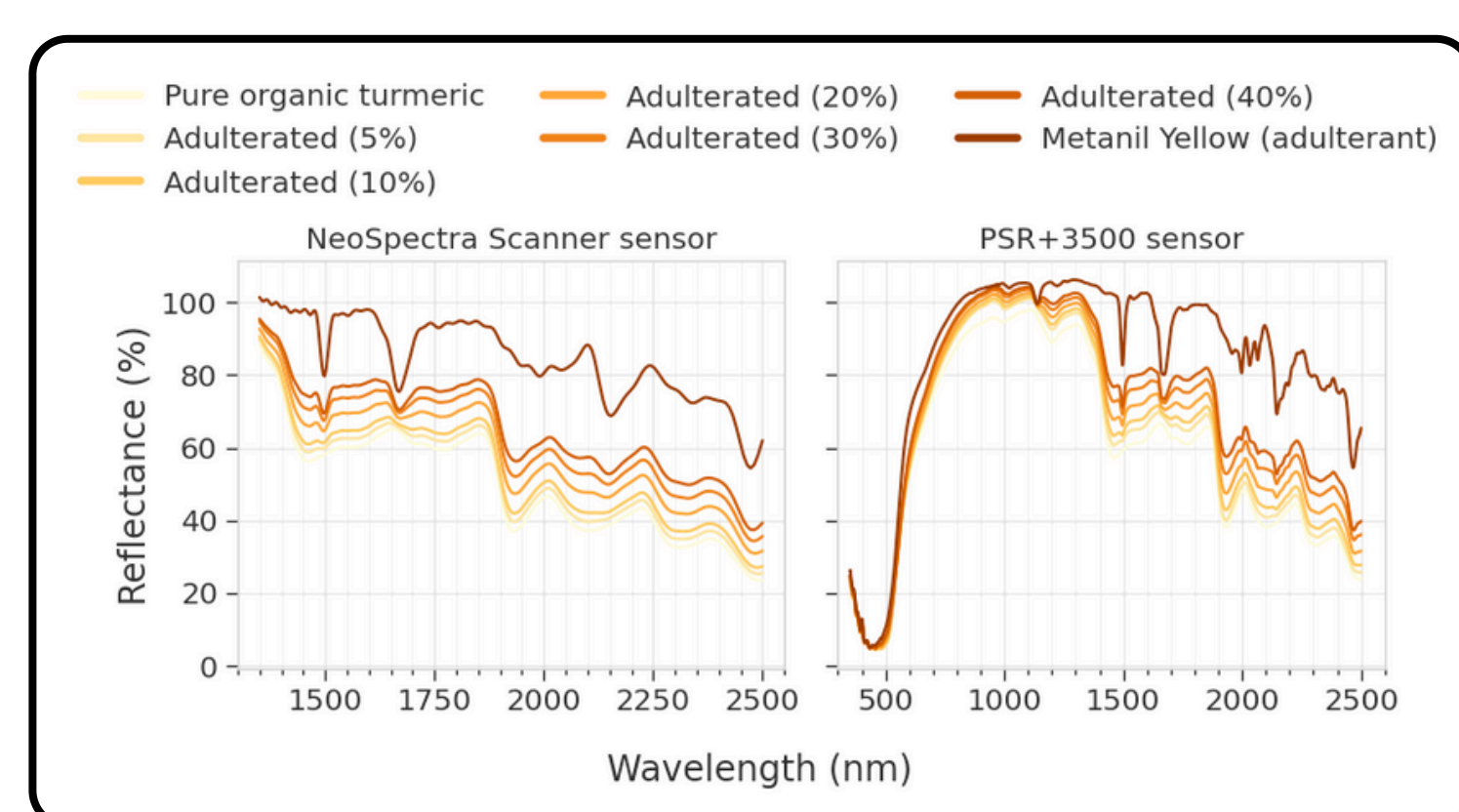


**Figure 1.** Flowchart of the methodological approach for the spectral analysis of turmeric adulteration.

## RESULTS

The infrared reflectance spectra of NeoSpectra Scanner and PSR+ 3500 sensors are illustrated in **Figure 2**, showcasing the characteristics of the pure sample (ground turmeric), the adulterant (MY), and the adulterated samples.

As adulteration increases, a notable shift is observed in the spectral reflectance of the adulterant, characterized by an elevated albedo. Specific absorption bands at **~1500, 1820, and 2300 nm** in the adulterant become more pronounced in the adulterated spectra, as the adulteration level increases.



**Figure 2.** The effect of the adulteration level on the mean reflectance spectra of both sensors.

This trend suggests a **direct correlation between the level of adulteration and the alteration of spectral properties**, providing valuable insights into the nature of the adulterants and their impact on material reflectance.

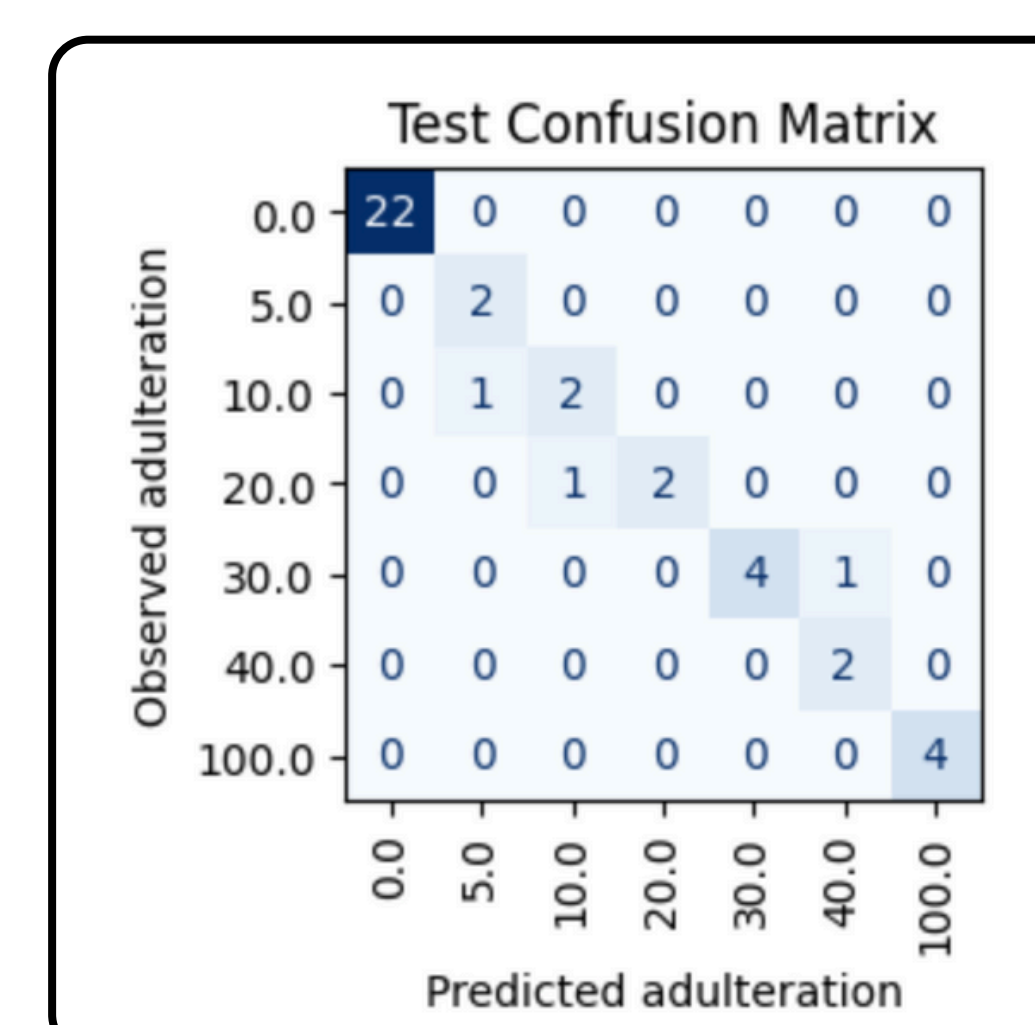
The classification results in the independent test set presented in **Table 1** demonstrate the efficacy of our approach in identifying adulterated samples.

Marginal variations exist between NeoSpectra and PSR+ 3500 devices, with PSR+ 3500 sensor exhibiting slightly higher accuracy rates.

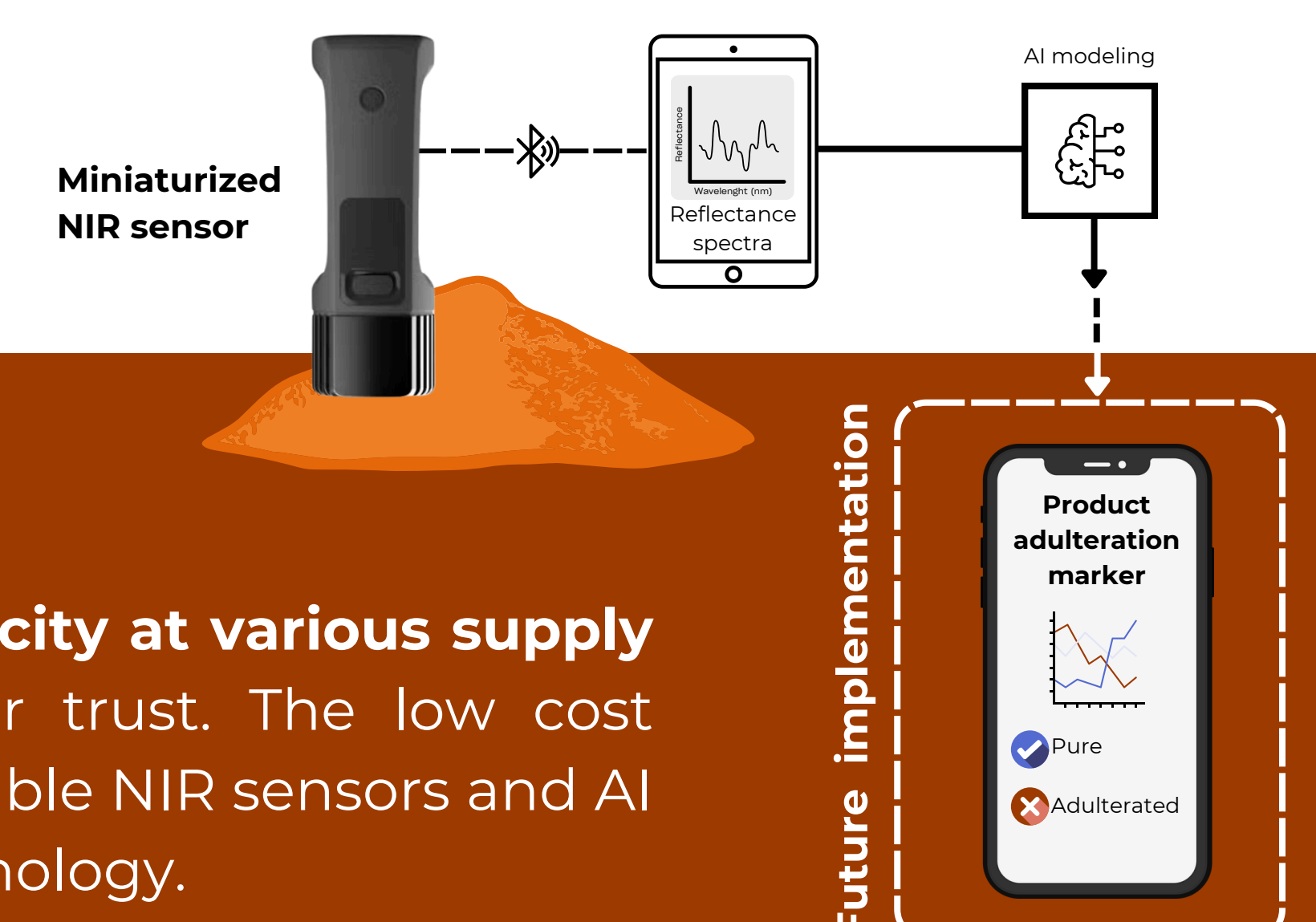
**Table 1.** Classification accuracy and Cohen's  $\kappa$  in the independent test set.

sensor	NeoSpectra Scanner		PSR+ 3500	
	accuracy	$\kappa$	accuracy	$\kappa$
Reflectance	0.90	0.86	0.98	0.93
Reflectance + SNV	0.88	0.82	0.96	0.93
Absorbance + SG1	0.88	0.82	0.98	0.97
Absorbance + SG2	0.93	0.89	1.00	1.00

The best results are obtained when employing the second derivative of absorbance spectra as a pre-processing step. Our analysis shows that all three pre-processing methods predict adulteration with **over 90% accuracy**, confirming the robustness of this spectroscopic technique in differentiating genuine from adulterated samples.



**Figure 3.** Confusion matrix for the model developed from NeoSpectra and the Absorbance + SG2.



## CONCLUSIONS

The proposed approach represents a promising **non-destructive solution for on-site testing of turmeric authenticity at various supply chain stages**, enhancing transparency and accountability in the spice industry and strengthening consumer trust. The low cost miniaturized sensor exhibited similar accuracy levels as the higher-end spectrometer. In the future, integrating portable NIR sensors and AI modeling into a **user-friendly platform or app** potentially facilitates the widespread adoption of the developed technology.

## SELECTED LITERATURE

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