Near-Infrared Spectroscopy in Food

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Abstract

As technology continues to advance, Near-Infrared Spectroscopy (NIRS) has emerged as a crucial, non-destructive analytical tool for rapid, precise, and cost-effective food analysis. Operating within the 780–2500 nm spectral range, it detects and quantifies key components such as moisture, protein, fat, and carbohydrates by analyzing molecular vibrations. Its versatility has led to widespread applications across food sectors, including meat, dairy, grains, and beverages, offering high-speed, multi-component analysis that enhances quality assurance and process control. While challenges such as calibration requirements and complex data interpretation persist, the ongoing integration of advanced technologies ensures that NIRS will continue to play a pivotal role in promoting efficiency, precision, and sustainability in the food industry.

1. Introduction

Near-infrared spectroscopy (NIRS) is an analytical technique utilizes the near-infrared region of the electromagnetic spectrum typically from 780 nm to 2500 nm. NIRS Measures composition of materials by detecting light absorption and reflection. It is non-destructive, fast and requires minimal sample preparation for identification of moisture, protein, fat and carbohydrates. NIR is widely used in the agriculture and food industry for non-destructive qualitative and quantitative analysis of raw materials, in-process materials and finished products

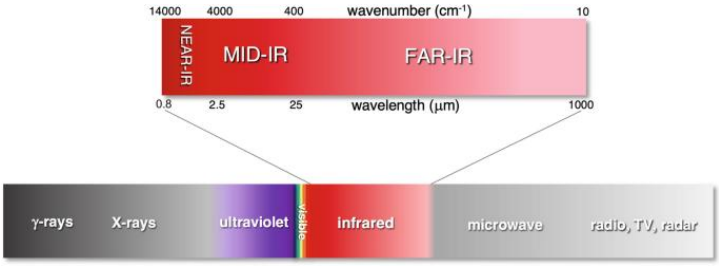

Fig 1. NIR light spectrum

1. Working principle of near infra-red spectroscopy (NIRS)

NIR spectroscopy utilizes the spectral range from 780 to 2500 nm and provides information about the vibration behavior of bonds. The NIR spectrum records the response of molecular bonds such as -CH, -NH, -OH, and -SH functional groups. These are subjected to vibrational energy changes when irradiated by NIR frequencies. These special bonds play an important role in extracting information to analyze chemical structures. The energy absorption occurs when molecules vibrate or is translated into an absorption spectrum within the NIR spectrometer.

Phenomena of light interaction

1. Transmission
2. Reflectance
3. Transflectance

2. Important spectral ranges in food analysis

- Water content: The 1400-1450 and 1940 nm range is effective for analyzing moisture and water content
- Protein content: The 2050–2250 nm range, linked to N-H bond, is used for protein analysis
- Carbonyl groups in fats and oils: The 2100-2200 nm range, associated with carbonyl stretching vibrations, is used for analyzing carbonyl groups in fats and oils
- Carbohydrate/ Polysaccharides: The range around 2050-2100 nm associated with O–H band of polysaccharides

3. Comparison with different spectroscopy

- Minimal sample preparation
- High-speed analysis
- Penetration depth and bulk analysis
- Simultaneous multi-component analysis
- Safe and non-ionizing radiation
- Compatibility with chemometric analysis
- Cost-effective and low maintenance

4. Applications in food industry

- Meat
- Fruits and vegetables
- Grain and grain products
- Dairy products

- Oils
- Fish and fish products
- Beverages

5. Case studies

Tian *et al.* (2021) identifies total phenolic content of whole wheat flour using near-infrared spectroscopy and chemometrics.

- His findings show peaks gets at 1428-1470nm (7000-6800 cm^{-1}) attributed to O– H of phenolic hydroxyl groups and C–H combination of aromatic structures shows the presence of phenols in wheat flour
- The sharp peak at around 1923nm (5200 cm^{-1}) was associated with O–H stretch/ bend of polysaccharides overlapping with water peaks and peak at around 2083 (4800 cm^{-1}) for polysaccharide.
- Original spectra, multiplicative scatter correction, second derivative and MSC + second derivative gives R^2 values 0.78, 0.87,0.93 and 0.95 respectively.
- Sample processed with multiplicative signal correction (MSC) and second derivative (SD) shows higher coefficient of correlation (R^2) value and provides most preferable results with unknown samples

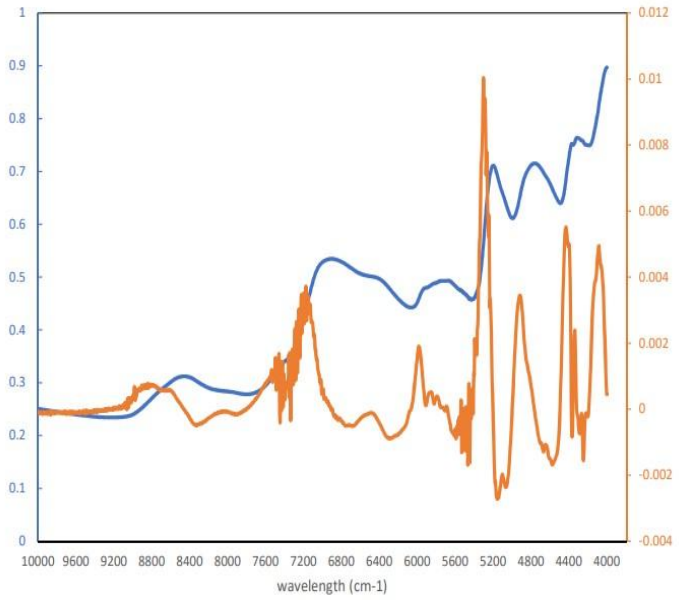

Fig. 2. Comparison of averaged spectrum of the original spectra set and averaged spectrum of pre-processed spectra set

- Abu-Khalaf and Hmidat (2020) examined visible/near infrared (VIS/NIR) spectroscopy in optical sensor for evaluating olive oil quality.
- This was the 1st study to employ the 400–1100 nm range of vis/NIR for quantifying quality parameters and classifying olive oil groups
- Six bands (peaks at 450.5, 532, 601, 673, 932 and 977 nm) in the VIS/NIR region have been observed
- Their finding showed that extra virgin and virgin had higher absorption than lampante and ordinary virgin in almost all the range of spectra
- Also, it was found that the VIS/NIR spectroscopy was able to identify some quality parameters (*i.e.* acidity and peroxide) with good accuracy (free acidity ≤ 0.8%., ≤ 2%≤ 3.3%, > 3.3% respectively)
- The coefficients of correlation (R^2) for acidity and peroxide were 0.88 and 0.83 for different types of oil

6. Challenges and limitations

- NIR measurements are not highly selective, so chemometric techniques are needed for further data processing
- NIR spectra often contain numerous extraneous peaks, making data interpretation challenging
- Accurate, robust prediction equation require large sample sets to account for variations in physical and chemical properties
- Multiple calibration equations are needed for different sample types
- High costs are involved in creating NIR equations, though calibrations can be shared across instruments to reduce expenses

7. Conclusion

NIR spectroscopy is a non-destructive, rapid and cost-effective method for analyzing the chemical composition, moisture content, fat, protein and other essential quality parameters in food. NIR spectroscopy's ability to simultaneously monitor multiple properties in real-time enhances process control and strengthens quality assurance in food production. With the integration of chemometrics, NIR spectroscopy is becoming an essential tool in food analysis, enabling more precise and comprehensive quality assessment. As technology advances, NIR

spectroscopy will gain even greater importance in the food industry, enhancing quality control, efficiency and sustainability

8. References

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