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APPLICATION OF SPECTROSCOPIC TECHNIQUES (NIR AND RAMAN) IN THE NON-DESTRUCTIVE INSPECTION OF MEAT AND MILK: ADVANCES FOR THE SAFETY AND QUALITY OF PRODUCTS OF ANIMAL ORIGIN

APLICAÇÃO DE TÉCNICAS ESPECTROSCÓPICAS (NIR E RAMAN) NA INSPEÇÃO NÃO DESTRUTIVA DE CARNE E LEITE: AVANÇOS PARA A SEGURANÇA E QUALIDADE DE PRODUTOS DE ORIGEM ANIMAL

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ABSTRACT

Objective: To review the advances and applications of NIR and Raman spectroscopic techniques in the non-destructive inspection of meat and milk, highlighting their relevance to Veterinary Medicine, food safety and fraud prevention. The adulteration of food of animal origin represents a growing challenge for inspection services, requiring fast, sensitive and sustainable analytical methods. This review was based on scientific articles, dissertations, and theses published between 2010 and 2024, which address the use of near-infrared (NIR) spectroscopy and Raman spectroscopy in food, with an emphasis on integration with chemometric tools. The results demonstrate that NIR is effective in predicting the centesimal composition of meat and milk, while Raman spectroscopy has high specificity for wet matrix analysis. The association of these techniques with multivariate methods, such as PCA and PLS-DA, allows the detection of adulterations with an accuracy greater than 90%. The miniaturization of spectrometers and the use of portable equipment make these technologies applicable in real time in routine sanitary inspection. It is concluded that spectroscopy, combined with chemometrics, represents a strategic innovation for the quality control of products of animal origin, reinforcing the role of the veterinarian in ensuring food safety.

Keywords: Food spectroscopy. Non-destructive inspection. Chemometrics. Fraud detection. Food security.

RESUMO

Objetivo: Revisar os avanços e aplicações das técnicas espectroscópicas NIR e Raman na inspeção não destrutiva de carne e leite, destacando sua relevância para a Medicina Veterinária, segurança alimentar e prevenção de fraudes. A adulteração de alimentos de origem animal representa um desafio crescente para os serviços de inspeção, exigindo métodos analíticos rápidos, sensíveis e sustentáveis. Esta revisão foi baseada em artigos científicos, dissertações e teses publicados entre 2010 e 2024, que abordam o uso da espectroscopia no infravermelho próximo (NIR) e da espectroscopia Raman em alimentos, com ênfase na integração com ferramentas quimiométricas. Os resultados demonstram que a NIR é eficaz na predição da composição centesimal da carne e do leite, enquanto a espectroscopia Raman apresenta alta especificidade para análise de matriz úmida. A associação dessas técnicas com métodos multivariados,

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como PCA e PLS-DA, permite a detecção de adulterações com acurácia superior a 90%. A miniaturização dos espectrômetros e o uso de equipamentos portáteis tornam essas tecnologias aplicáveis em tempo real na inspeção sanitária de rotina. Conclui-se que a espectroscopia, aliada à quimiometria, representa uma inovação estratégica para o controle de qualidade de produtos de origem animal, reforçando o papel do médico veterinário na garantia da segurança alimentar.

Palavras-chave: Espectroscopia de alimentos. Inspeção não destrutiva. Quimiometria. Detecção de fraudes. Segurança alimentar.

RESUMEN

Objetivo: Revisar los avances y aplicaciones de las técnicas espectroscópicas NIR y Raman en la inspección no destructiva de carne y leche, destacando su relevancia para la Medicina Veterinaria, la seguridad alimentaria y la prevención del fraude. La adulteración de alimentos de origen animal representa un desafío creciente para los servicios de inspección, que requieren métodos analíticos rápidos, sensibles y sostenibles. Esta revisión se basó en artículos científicos, disertaciones y tesis publicadas entre 2010 y 2024, que abordan el uso de la espectroscopia de infrarrojo cercano (NIR) y la espectroscopia Raman en alimentos, con énfasis en la integración con herramientas quimiométricas. Los resultados demuestran que el NIR es eficaz para predecir la composición centesimal de la carne y la leche, mientras que la espectroscopia Raman presenta una alta especificidad para el análisis de matriz húmeda. La asociación de estas técnicas con métodos multivariantes, como PCA y PLS-DA, permite la detección de adulteraciones con una precisión superior al 90%. La miniaturización de los espectrómetros y el uso de equipos portátiles hacen que estas tecnologías sean aplicables en tiempo real en la inspección sanitaria de rutina. Se concluye que la espectroscopia, combinada con la quimiometría, representa una innovación estratégica para el control de calidad de productos de origen animal, reforzando el papel del veterinario en la garantía de la seguridad alimentaria.

Palabras clave: Espectroscopía de alimentos. Inspección no destructiva. Quimiometría. Detección de fraude. Seguridad alimentaria.

INTRODUCTION

The adulteration of foods of animal origin, such as meat and milk, represents one of the main concerns of modern health inspection. Fraudulent practices, such as the addition of water, salts, collagen, carrageenan and starches, aim to increase the commercial value of products, harming their nutritional composition and putting the health of consumers at risk (Nunes, 2015). These behaviors violate ethical and legal standards, challenging quality control and traceability systems along the production chain.

To face this scenario, the use of non-destructive, fast and highly sensitive analytical methods, capable of detecting fraud with precision, has been intensified. Among the techniques, near-infrared (NIR) spectroscopy and Raman spectroscopy stand out, both employed in the qualitative and quantitative evaluation of the composition of foods of animal origin (Ferreira, 2013; Brunetti & Stanke Filho, 2024).

Near-infrared spectroscopy is sensitive to chemical bonds such as O–H, N–H, and C–H, present in proteins, lipids, and water, and is efficient in predicting the proximate composition of meat and milk (Ferreira, 2013). On the other hand, Raman spectroscopy, which uses inelastic scattering of light, provides high molecular specificity and is little influenced by the presence of water, making it perfect for wet matrices such as raw milk and fresh meat (Brunetti & Stanke Filho, 2024). The two techniques become even more robust when combined with chemometrics, using multivariate models such as PCA (Principal Component Analysis) and PLS-DA (Partial Least Squares Discriminant Analysis) that are capable of categorizing and predicting adulteration with high accuracy (Nunes, 2015).

Technological progress, which includes the reduction of the size of NIR and Raman spectrometers, has enabled their direct use in industrial contexts and in field verifications, favoring faster and more effective quality control (Ferreira, 2013). These technologies are in line with the responsibilities of the veterinarian, according to the Regulation of Industrial and Sanitary Inspection of Products of Animal Origin (RIISPOA), being essential to ensure food safety and safeguard the health of the population (Nunes, 2015).

Therefore, this work aims to review the advances and applications of NIR and Raman spectroscopic techniques in the non-destructive inspection of meat and milk, with emphasis on their relevance to Veterinary Medicine and fraud prevention.

METHODOLOGY

This study is a narrative review of the literature, whose purpose was to compile and critically analyze the main advances in the use of near-infrared (NIR) spectroscopy and Raman spectroscopy in the non-destructive inspection of foods of animal origin, with emphasis on the identification of fraud and the evaluation of the quality of meat and milk. The research was carried out from already published academic works, including scientific articles, dissertations and theses accessible in respected databases, such as Scopus, Web of Science, PubMed, ScienceDirect and Google Scholar. Institutional repositories, such as the Digital Library of Theses and Dissertations (BDTD), as well as directly available academic resources, which discuss specific uses of spectroscopic techniques in the food industry, were also analyzed.

Priority was given to studies published between 2010 and 2024, written in Portuguese, English, or Spanish, and that presented experimental data or consistent reviews on the application of NIR or Raman spectroscopy in the analysis of fresh meat, raw milk, dairy products, and food supplements. Studies that integrate these techniques with multivariate analysis methods, such as principal component analysis (PCA) and partial least squares discriminant analysis (PLS-DA), have received special attention, since such combinations have demonstrated greater sensitivity and specificity in the classification of adulterated samples.

During the analysis of the selected materials, sources that addressed foods of plant origin in an exclusive way were disregarded, studies whose main focus was not spectroscopy or that presented a lack of practical data or experimental validation. The methodological approach adopted allowed not only the characterization of the state of the art on the subject, but also the identification of the advantages, limitations and technological trends associated with the use of spectroscopy in the routine of veterinary inspection and in the guarantee of food safety.

RESULTS AND DISCUSSIONS

Spectroscopic techniques employed in the analysis of food of animal origin have shown significant progress in terms of analytical accuracy, speed and ability to identify fraud. Near-infrared (NIR) spectroscopy is notable for its speed, lack of destruction, and sensitivity to the molecular structure of food (Nunes, 2015). Ferreira (2013) evidenced the effectiveness of NIR in the evaluation of complex foods such as soybean and

quinoa, presenting coefficients of determination (R2) above 0.80 for proteins, lipids and moisture, in addition to mean errors of less than 1%, even without prior sample preparation.

This technique becomes even more solid when combined with chemometrics, particularly through PLS. Brunetti and Stanke Filho (2024) evidenced this synergy when using infrared spectroscopy to determine creatine in food supplements, even in the face of interference from other compounds. The authors emphasized that NIR has high sensitivity to functional groups such as -CH, -NH and -OH, making it appropriate for the evaluation of animal products, such as meat and milk.

In addition, Nunes (2015) developed chemometric models to identify fraud in fresh beef, employing mid-infrared spectroscopy (MIR), along with total attenuated reflectance (ATR) and physicochemical information. The writer studied 43 real samples collected by the Federal Police and 12 control samples, using the principal component analysis (PCA) and PLS-DA models, respectively. The PLS-DA model that combines spectral and physicochemical data proved to be the most effective, correctly classifying all control samples and identifying adulterated ones with only four false negatives, demonstrating an accuracy of over 90%.

Nunes (2015) also studied the purges (liquid expelled after thawing) of 51 samples that were adulterated in a controlled manner with water, sodium tripolyphosphate, collagen, carrageenan and maltodextrin, as well as water. The MIR spectroscopy used in the purges made it possible not only to detect adulteration, but also to identify the type of adulterant used. The models created demonstrated high precision and specificity, highlighting the use of variables chosen through the VIP scores.

On the other hand, Raman spectroscopy, despite being less studied in Brazil, has shown its efficiency in identifying fraud in milk and processed meats. According to Hoffmann (2023), the method has high selectivity in the detection of specific chemical components, being little affected by water - a crucial attribute for the analysis of wet matrices. Petersen, Yu, and Lu (2021) proved the ability of portable Raman spectrometers to identify adulterations in dairy products with tolerance limits of less than 1%.

Brunetti and Stanke Filho (2024) also highlighted the complementarity between NIR and Raman in the evaluation of food supplements, such as creatine, noting that the

two methodologies provide different sensitivities for the existing functional groups. This combined method emphasizes the possibility of employing hybrid strategies in the verification of animal feed.

In addition to analytical efficiency, a crucial factor is the portability of contemporary devices. The reduction in the size of NIR spectrometers has made it possible to carry out analyses directly on the production line, in slaughterhouses, dairies or even in mobile units. Beć, Grabska, and Huck (2022) highlight that these devices, in addition to working with a digital connection, provide an agile response and low operating cost, in line with the principles of sustainability and health surveillance.

The combination of spectroscopic techniques with chemometric methods, such as PCA, PLS-DA, SIMCA and SVM, improves the classification and prediction of samples, even making it possible to identify counterfeits at early levels. These models also benefit from the removal of irrelevant variables and the choice of pertinent variables through VIP scores, which enhances understanding and reduces analysis time (Ferreira, 2013; Nunes, 2015).

Therefore, NIR and Raman spectroscopy, integrated with chemometrics, constitutes a significant advance for Veterinary Medicine and sanitary inspection systems. Its applications enable not only the rapid identification of fraud, but also the strengthening of quality control systems, contributing to food safety, traceability and consumer confidence.

FINAL CONSIDERATIONS

NIR and Raman spectroscopy, coupled with chemometric tools, represents a significant advance in the non-destructive inspection of animal foods. Both techniques demonstrate high efficiency in detecting adulteration and predicting quality parameters, with advantages such as speed, sustainability, and portability. The application of these technologies in the routine of veterinarians and inspection services strengthens food safety, increases product reliability and contributes to transparency in the production chain. Investing in its implementation and technical training is essential to modernize sanitary control systems and effectively combat food fraud.

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