Identification and Analysis of Meat Species Using Laser Induced Breakdown Spectroscopy (LIBS): A Review

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Abstract. The high price of beef and its processed products has led to many cases of adulteration with pork, resulting in issues related to halal food assurance. Therefore, it is crucial to conduct identification and analysis of the types of meat used in order to maintain food halalness. One of the methods currently advancing in the identification and analysis of meat types is Laser-Induced Breakdown Spectroscopy (LIBS). The aim of this study is to determine the capability of Laser-Induced Breakdown Spectroscopy (LIBS) in identifying and analyzing various types of meat. The study results indicate that the Laser-Induced Breakdown Spectroscopy (LIBS) method is capable of identifying and analyzing meat types with simple sample preparation and accurate outcomes compared to other methods such as Real Time-PCR, Enzyme-Linked Immunosorbent Assay (ELISA), Electronic Nose System, Fourier-transform infrared spectroscopy (FTIR), and Raman spectroscopy. The Laser-Induced Breakdown Spectroscopy (LIBS) method can be combined with various chemometric methods such as PCA, PLS, and MSC. Laser-Induced Breakdown Spectroscopy (LIBS) can identify and analyze various types of meat with an accuracy of up to 100% in shrimp and clams mixed sample. In conclusion, the combination of LIBS and chemometric methods demonstrates promising results in identifying and analyzing meat types.

Keywords: meat identification, meat analysis, Laser-Induced Breakdown Spectroscopy

INTRODUCTION

The consumption of meat stands as an integral facet of a nutritionally balanced diet, cherished by consumers for its intrinsic nutritional value and gustatory appeal. Projections for the forthcoming decade indicate a
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prospective amplification in the global meat supply, predicated upon evolving dietary preferences rooted in considerations of health, nutrition, and culinary choices. Throughout the forecasted timeframe, there is an anticipation of a 2% rise in the global average per capita meat consumption, extending from the baseline period of 2020-2022 to the year 2032 [1]. Beef, as one of the most consumed meat, in the coming decade, it is anticipated that worldwide consumption will reach 51 million metric tons [1]. In fact, the awareness of society to consume more animal protein resulting in the increase of beef product price. Due to its affordability and relatively similar characteristics to beef [2], pork, which is forbidden for Muslim consumption, is often adulterated with beef [3]. In response to burgeoning consumer expectations pertaining to the security of beef product authenticity, both the meat industry and scientific communities are actively investigating alternative methodologies to safeguard of beef authentication [4].

Various common methods have been reported for the purpose of identifying meat species (Table 1). One frequently employed approach is Real-Time Polymerase Chain Reaction (PCR), which has been utilized to identify meat types in several processed meat products, including beef bologna, pork bologna, and chicken sausages [5]. However, it should be noted that employing the PCR method necessitates specialized equipment and incurs high costs. Apart from PCR, the dielectric sensing system method can also be employed to identify meat types in both fresh meat and processed meat products. Previous studies have employed the microwave dielectric sensing system method to classify meat types using samples of beef, chicken, and pork fat [6]. However, the result shows a relatively similar variations in reflection coefficients observed in chicken and beef fat. These results underscore limitations in the system's capability to distinct all meat types effectively, thereby diminishing its effectiveness in meat and product identification. Additionally, this method involves a complex system, challenging calibration procedures, low spatial resolution outcomes, and high system costs [7].

Another method that has also been reported in the identification of types of meat is the Enzyme-Linked Immunosorbent Assay (ELISA). The analyzed samples included rat meat, beef, chicken, and pork, with the aim of observing the differences between rat meat and the other three meat samples [8]. The results of this research indicate that rat meat can be identified and differentiated from beef, chicken, and pork samples. However, the analysis is only sensitive to cooked meat; low accuracy was found for raw rat meat samples [9]. This constitutes a significant weakness, given that raw meat mixtures can occur. Another method that can be utilized for the detection of meat types is the Electronic Nose System. Therefore, it is crucial to conduct accurate and rapid testing to identify and analyze various types of meat to determine if there is any adulteration with other meats, particularly pork.

Table 1. Various methods for meat species identification

<table>
<thead>
<tr>
<th>Ref</th>
<th>Method</th>
<th>Sample</th>
<th>Result</th>
<th>Limitations</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5]</td>
<td>Real-Time PCR</td>
<td>Chicken sausages, beef bologna, and pork bologna</td>
<td>The beef bologna contains 84.49% beef, the pork bologna contains 92.8% pork, and the chicken sausage contains 95.14% chicken meat.</td>
<td>Requiring specialized equipment as well as high costs</td>
<td>A wide range of detection [10] and The ability of multiplexing [11]</td>
</tr>
<tr>
<td>[6]</td>
<td>Microwave Dielectric Sensing System</td>
<td>Beef fat, chicken fat, and pork fat</td>
<td>Pork fat demonstrates distinct tendencies when compared to the fat of chicken and beef</td>
<td>The complexity of the system, it challenging calibration, low spatial resolution, and high cost [7]. Some types of meat tend to be difficult to distinguish.</td>
<td>Swift processing and non-destructive sampling</td>
</tr>
<tr>
<td>[12]</td>
<td>Optimized electronic nose system (OENS)</td>
<td>Minced beef and minced pork</td>
<td>The detection of beef and pork has an accuracy of approximately 98.10%.</td>
<td>A considerable amount of time is required for the calibration process. [13].</td>
<td>A small sample size with high sensitivity</td>
</tr>
<tr>
<td>[8]</td>
<td>Enzyme-Linked Immunosorbent Assay (ELISA)</td>
<td>Rat meat, beef, chicken meat, and pork.</td>
<td>The type of meat can be detected with a limit of detection (LOD) of 0.01 µg/L.</td>
<td>The accuracy for the raw meat samples is insufficient.</td>
<td>High precision and good accuracy for well-cooked meat [9].</td>
</tr>
</tbody>
</table>
A rapidly advancing method for this purpose is Laser-Induced Breakdown Spectroscopy (LIBS). Due to its rapid, simple, and accurate, LIBS has been used along with c Multivariate Data Analysis (MVDA) in a variety of food products for various purposes. In meat and meat products, LIBS has been used for detection of adulteration [18-23]. Laser-Induced Breakdown Spectroscopy (LIBS) serves as a valuable tool for identifying meat species by analyzing the elemental composition of minerals within the protein. The process begins with laser ablation, where a high-energy laser beam is directed at the meat sample, generating a plasma plume containing ions, atoms, and molecules. As the plasma emits light during cooling, the characteristic spectral lines reveal information about the minerals present, such as calcium and phosphorus, and the proteins composed of elements like carbon, nitrogen, oxygen, and sulfur. These elements contribute to the unique fingerprints of each meat species. Through advanced data analysis and calibration against a database of known species, LIBS can accurately identify different meat types based on their elemental composition. This study focuses on recent investigations regarding the potential application of LIBS in the identification of meat products. Therefore, the purpose of this paper is to evaluate the capabilities of LIBS in identifying and analyzing meat and its processed products.

**FUNDAMENTAL ASPECT OF LASER-INDUCED BREAKDOWN SPECTROSCOPY**

**Basic principle of Laser-Induced Breakdown Spectroscopy**

Laser-Induced Breakdown Spectroscopy (LIBS) is a spectroscopy technique based on the interaction between a laser beam and a sample. In LIBS, a high-energy laser pulse is focused on the sample, leading to the formation of a plasma plume [24]. This plasma emits characteristic light, which is then analyzed to determine the elemental composition of the sample. Laser-Induced Breakdown Spectroscopy (LIBS) initiates with the delivery of a high-energy laser pulse onto the sample [25]. This intense burst of energy induces rapid heating and vaporization of the sample, generating a plasma plume comprised of ions, electrons, and neutral species. As the plasma returns to a lower energy state, it emits light that carries distinct spectral lines corresponding to the elemental composition of the sample [26]. The emitted light is then collected and directed through a spectrometer, which disperses it into its constituent wavelengths. The resulting spectrum is analyzed to identify and quantify the elements present in the sample. LIBS, with its capability for rapid and in situ elemental analysis across various materials, finds applications in fields such as environmental monitoring, geological exploration, material science, and even planetary exploration [27-29].

In Laser-Induced Breakdown Spectroscopy (LIBS), the primary sampling techniques involve focusing a high-energy laser beam onto the surface of the sample, inducing ablation and the formation of a plasma plume [30]. This technique is known as bulk sampling and is widely employed for the elemental analysis of solid or liquid samples. As the laser interacts with the sample, the resulting plasma emits light with characteristic spectral lines corresponding to the elements present. The versatility of LIBS allows for the analysis of a diverse range of samples, making it a valuable tool in scientific research and various applications [27-29], including meat species identification. In addition to these primary sampling techniques, LIBS offers flexibility in its application to different sample states. For instance, it can be adapted for depth profiling [31-33] by varying the laser parameters, allowing researchers to analyze elemental composition at different layers within a material. Moreover, LIBS can be employed for stand-off analysis [34-36], where

| [14] Fourier Transform Infrared Spectroscopy (FTIR) | Beef, lamb, and chicken, pork. | The accuracy reaches 81.25% for pure samples, and for mixed samples, this model demonstrates a predictive accuracy of 72.2%. | Information regarding the compounds or individual components within the complex mixture cannot be extracted [15]. | The process involves simple measurement, non-destructive techniques, and rapid analysis [16]. |
| [17] Raman spectroscopy | Beef, deer, and lamb. | The accuracy rates achieved were 80% for Partial Least Squares Discriminant Analysis (PLS-DA) and 92% for Support Vector Machine (SVM). | Fluorescence signal arises at energies below excitation, often causing disruptions in sample analysis [15]. | The analysis does not indicate the presence of any water disturbance. [15]. |
the laser is directed at a distance from the sample. This feature is particularly beneficial for scenarios where direct contact with the sample is challenging or hazardous, such as in remote sensing applications or in the analysis of objects in hostile environments [37, 38]. The adaptability of LIBS in sample handling and its capability for remote analysis contribute to its widespread use across scientific disciplines and industrial sectors. As technology advances, ongoing research aims to refine and expand the capabilities of LIBS, further enhancing its utility in diverse analytical applications.

**Experimental setup of Laser-Induced Breakdown Spectroscopy**

In the standard configuration of a LIBS (Laser-Induced Breakdown Spectroscopy) setup, a comprehensive ensemble of components collaborates to facilitate precise and insightful analyses. This setup includes a pulsed laser, a focal lens, a sample holder, collection lenses, a spectrometer, a time delay generator, and a computer. While various laser systems, such as CO2 and Excimer, offer adaptability, the Nd:YAG laser stands out as a popular choice [39], operating at its fundamental wavelength (1,064 nm) or one of its harmonics (532, 355, or 266 nm) [40], typically in the nanosecond range. Among the critical laser parameters, the excitation wavelength significantly influences the interaction between the laser and the material surface [41]. LIBS systems exhibit a diverse range of laser pulse durations, spanning from femtoseconds to microseconds. The choice of pulse duration impacts the resulting spectra, with femtosecond lasers ceasing interaction before plasma formation and microsecond lasers delivering a considerable amount of pulse energy to excite species in the plasma.

The plasma emission, a pivotal aspect of LIBS, is captured by a spectrometer, often employing a broad-range polychromator and a detector such as a charge-coupled device (CCD) [42] and an intensified charge-coupled device (ICCD) [43]. The spectrometer's resolution plays a crucial role in defining the quality of a LIBS measurement [44], allowing for the separation of consecutive emission lines without the need for intricate processing. The time delay generator plays a fundamental role in the LIBS setup, ensuring synchronization between the laser and the spectrometer through electrical pulses spanning from nanoseconds to milliseconds [45]. Fine-tuning the delay time enables the optimization of the signal-to-noise/background ratio, enhancing the precision of quantitative analyses. While a sample holder is optional [46], it proves beneficial for adjusting optics, enabling consistent placement of samples at the same distance relative to the laser focus. Notably, LIBS can be applied directly to the sample, even in its original location, but a sample holder streamlines the process, facilitating optical adjustments.

A notable advancement in LIBS methodology involves the utilization of a second pulse to enhance signal quality [47]. In double-pulse LIBS (DP-LIBS), the first pulse ablates a fraction of the sample surface and creates a plasma, while the second pulse re-excites the plasma, enhancing the signal-to-noise ratio [48]. DP-LIBS systems may utilize a single laser emitting two consecutive pulses or two independent lasers emitting pulses. The inter-pulse delay, typically a few microseconds, must be short enough to re-excite the plasma during its lifetime. Recent developments in LIBS system setups aim to enhance repeatability and sensitivity. Proposals include resonance laser excitation, spark discharge excitation, microwave excitation, plasma confinement in an external magnetic field, and plasma confinement in a microchamber, as reviewed [43]. These advancements contribute to the evolving landscape of LIBS technology, offering potential avenues for further refinement and innovation. In scenarios where a specific element is not detected in soil sample analyses by the utilized LIBS system, experimental configurations incorporating the aforementioned advancements may be considered. This adaptive approach underscores the dynamic nature of LIBS methodology and its capacity for continuous improvement and customization in response to specific analytical challenges.

**IDENTIFICATION OF VARIOUS TYPES OF MEAT USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS)**

Sample preparation and analysis employ Laser-Induced Breakdown Spectroscopy (LIBS)

Laser-Induced Breakdown Spectroscopy (LIBS) has been employed for both qualitative and quantitative analysis of elemental composition across various types of distinct samples [49], including meat samples [18]. Sample preparation for LIBS analysis can be done in various ways. Bilge et al., 2016 reported sample preparation with the following process: A selection of beef, chicken, and pork meat are prepared. Subsequently, all the fat in the samples is manually removed.
The lean, fat-free meat samples are then ground using a 3 mm plate grinder. The process of mixing the beef, pork, and chicken meat samples is carried out utilizing minced meat to enhance homogeneous mixing efficiency. In this quantitative study, chicken thighs, pork meat, and beef are employed at concentrations ranging from 10% to 50%. The minced meat samples are subsequently dried in an oven at a temperature of 105°C for a duration of 2 hours. For solvent extraction, 25 grams of dried minced meat are placed within filter paper and extracted using hexane in a Soxhlet extractor for a period of 4 hours. Once the dried samples have been prepared, they are milled into a powdered form using a laboratory mill. The powdered samples are sieved through a 180 mesh sieve. The final step involves shaping the dried samples into pellets using a Specac pellet press machine. These pellets can then be subjected to analysis using Laser-Induced Breakdown Spectroscopy (LIBS) to identify the type of meat. Other studies have reported sample preparation without the formation of pellets, but instead utilizing a sample freezing process [19]. Frozen meat and offal samples were chosen for two primary purposes. One of these reasons was to ensure a uniform sample structure (consistent height and hardness) for LIBS measurements, as the focusing quality significantly influences the results. Consequently, all samples were prepared to have nearly identical forms, minimizing potential losses in signal quality. The second rationale was to reduce the liquid water content, aiming to enhance the LIBS signal. Another study did not undergo the sample formation process into pellets or sample freezing [23]. The preparation reported as following process: fresh meat were sliced into pieces measuring 40 mm × 20 mm × 10 mm, and efforts were made to eliminate the fat portion as much as possible during the slicing procedure to prevent its interference with the spectral signal during the experiment. Various methods can be employed in sample preparation, highlighting the advantage of using LIBS that is not confined to a single preparation method. This is highly beneficial as the research can be adjusted to the suitable preparation method.

**Meat species identification using Laser-Induced Breakdown Spectroscopy (LIBS)**

Laser-Induced Breakdown Spectroscopy (LIBS) is a sophisticated technique employed for the identification of a sample's elemental composition. The process initiates with the delivery of a brief yet intense laser (Q-switched Nd:YAG laser) pulse to the sample, inducing the formation of a high-energy plasma on the sample's surface. This plasma, characterized by its extremely high temperature, generates elemental emission as it cools down. The emitted light carries a unique spectral fingerprint for each element present in the sample. A light collector gathers this emitted light, and a spectrometer disperses it into individual wavelengths, akin to a prism. The resulting emission spectra are then subjected to thorough analysis.

Several studies reported LIBS spectral data on samples of various types of meat. Sezer at al., reported the LIBS spectra result on beef, chicken, and pork sample [18]. The spectra obtained revealed the presence of various elements and organic compounds in the meat, including macro elements (K, Na, Ca, Mg), micro elements (Fe, Zn), and organic compounds (C, H, O, N). By focusing on protein markers, the study successfully identified different meat species based on differences in elemental composition. While similar spectral patterns were observed for beef, chicken, and pork, the intensity of the spectra varied, indicating unique elemental and protein composition for each meat type. The study emphasized the dominance of K, Ca, and Mg elements in the LIBS spectra, with higher intensity compared to Zn and Fe. Previous study report the same result that shows a different intensity of LIBS spectra among six sample (shrimp, chicken, beef, scallop, pig liver, and a mixed of shrimp and scallop sample) [50]. The result show that Mg, K, and Na included as macro element, while organic compound detected are C, H, O, N and molecular bonds (C-N). The differences in the concentration of these elements in the meat samples were reflected in the spectral intensity of their LIBS spectra. This variation in spectral intensity provided the basis for effectively discriminating between the different meat species. The results of LIBS spectra of offal adulteration in beef samples also showed similar results. Spectra of beef kidney, liver, heart, lung, and spleen samples were analyzed in the study. The most prominent bands in the spectra were identified, showing significant elemental concentration differences among the samples. Specifically, differences in the bands for Na, Ca, K, and Mg were observed. These differences in elemental composition allowed for successful discrimination of the offal samples [19]. The use of LIBS on meat species identification not only for raw meat but also processed one. A study utilized LIBS spectra to identify macro and micro elements (K, Ca, Mg, Na, Zn, Fe) and organic elements (C, O, N) in salami and fermented sausage (beef, chicken, and pork) sample. Differences in peak intensity among these elements were crucial for distinguishing and classifying the sample [51]. Specifically, variations in intensity for elements, including K, Ca,
and Mg played a more significant role in differentiation compared to sodium, zinc, and iron. This approach successfully separated meat samples based on their elemental composition.

LIBS spectra can be used to distinguish meat species based on peak intensity because different meat species exhibit unique elemental compositions [52]. LIBS works by using laser pulses to generate a plasma from the sample, and the emitted light spectrum is analyzed to identify the elements present. In the context of meat analysis, macro elements (such as K, Na, Ca, Mg) and micro elements (such as Fe, Zn) contribute to the spectral signature. The peak intensity in the LIBS spectra corresponds to the abundance of specific elements in the sample [44]. Since different meat species have distinct elemental compositions, the intensity of peaks related to these elements will vary between species. By analyzing these variations in intensity, researchers can identify and distinguish different meat species. For example, if the LIBS spectra of chicken, beef, and pork show differences in the intensity of peaks related to elements like potassium (K), calcium (Ca), and magnesium (Mg) [18, 19, 21, 22, 50], it indicates unique elemental compositions for each type of meat. These differences in peak intensity serve as a fingerprint for each meat species, allowing for accurate identification through LIBS analysis.

Analyzing LIBS spectra for meat identification requires the adept application of Multivariate Data Analysis (MVDA) [53]. LIBS generates intricate spectra with numerous peaks representing different elemental components in a sample. MVDA techniques such as principal component analysis (PCA) or partial least squares (PLS) step in to untangle this complexity by reducing data dimensionality [54]. The variability inherent in meat samples, arising from differences in composition and sources, is effectively navigated through MVDA, aiding in discerning patterns and key features within the spectra. MVDA also proves invaluable in revealing correlations and interactions between spectral bands [55], shedding light on the contributions of specific elements or compounds to distinct peaks. Additionally, these techniques play a crucial role in noise reduction, sifting through the data to enhance signal quality. Ultimately, MVDA empowers the creation of models that classify and predict meat types based on their unique spectral signatures, akin to crafting a recipe for accurate identification by discerning the essential ingredients within the spectral mix. By comparing the observed spectral lines with a known database of elemental spectra, scientists can identify and quantify the elements within the sample. The intensity and position of the spectral lines offer insights into the concentration of each identified element, making LIBS a powerful tool for meat species identification.

Table 2. Identification of meat types using Laser-Induced Breakdown Spectroscopy (LIBS).

<table>
<thead>
<tr>
<th>Ref</th>
<th>Method</th>
<th>Sample</th>
<th>Multivariate Data Analysis</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>[18]</td>
<td>LIBS</td>
<td>Beef, chicken, and pork.</td>
<td>PCA and PLS</td>
<td>Coefficients of determination of 0.994 for pork adulterated beef and 0.999 for chicken adulterated beef</td>
</tr>
<tr>
<td>[19]</td>
<td>LIBS</td>
<td>Beef (meat), liver, kidneys, heart, lungs, and spleen</td>
<td>PCA and PLS</td>
<td>The LOD (Limit of Detection) is 3.8% in relation to the given mixed sample</td>
</tr>
<tr>
<td>[50]</td>
<td>LIBS</td>
<td>Shrimp, chicken, beef, clams, pork liver, and a composite sample of shrimp and clams</td>
<td>Multiplicative Scatter Correction (MSC) and K-Nearest Neighbor (KNN)</td>
<td>The level of identification of the six types of meat increased from 94.17% to 100%, and the prediction coefficient of variance decreased from 5.16% to 0.56%.</td>
</tr>
<tr>
<td>[21]</td>
<td>LIBS</td>
<td>Beef, chicken, and pork.</td>
<td>PCA and PLS</td>
<td>The Limit of Detection (LOD) for the mixture of beef and chicken, as well as pork, is determined to be 2.84% and 3.89%, respectively</td>
</tr>
<tr>
<td>[22]</td>
<td>LIBS</td>
<td>Sausages and salami</td>
<td>PCA and PLS</td>
<td>The Limit of Detection (LOD) for the mixture of chicken and pork in beef sausages is 3.68% and 3.83% for the myofibril fraction, whereas in smoked beef, it is 3.80% and 3.47% for the sarcoplasmic fraction.</td>
</tr>
</tbody>
</table>
| [23] | LIBS and Raman spectroscopy | Beef, lamb, and pork.      | Back Propagation Neural Network (BPNN) | LIBS-Raman Accuracy: 99.42%  
LIBS Accuracy: 92.67%  
Raman Accuracy: 93.92% |
Various studies on Laser-Induced Breakdown Spectroscopy (LIBS) have been reported to be capable of identifying types of meat with a high of accuracy, as demonstrated in Table 2. Bilge et al, report a study that aimed to utilize laser-induced breakdown spectroscopy (LIBS) for the identification of meat species and assess its potential as a rapid, in-situ method for discriminating between various types of meat [18]. In this research, pork, beef, and chicken samples were gathered from diverse sources and converted into pellets for LIBS measurements. The acquired LIBS spectra were analyzed using chemometric methods, specifically principal component analysis (PCA) and partial least square (PLS). The PCA method, combined with the obtained spectra, achieved a good discrimination with an 83.37% rate, effectively distinguishing between the different meat species. On the other hand, the PLS method provided determination coefficients and limit of detection values for adulteration, demonstrating its effectiveness in quantitatively detecting meat adulteration. The results showed that the PLS method could accurately determine the adulteration ratio, with coefficients of determination (R²) of 0.994 for pork adulterated beef and 0.999 for chicken adulterated beef, along with corresponding limit of detection values. A good R² value is also indicated by the study reported by Veliglou et al, which is 0.947 [19]. The study aimed to use laser-induced breakdown spectroscopy (LIBS) and multivariate data analysis to distinguish edible animal offal from beef and determine adulteration ratios based on elemental compositions. Samples, including beef and various offal types, were obtained from a local slaughterhouse in Tekirdag, Turkey. The sample preparation differs from Bilge et al, who formed samples into pellets, while this study freezes the samples for analysis using LIBS. This study also employed the same multivariate analysis (PCA and PLS). The research not only calculated R² but also LOD to determine the sensitivity of the method used. The obtained LOD reached 3.8% for offal adulteration using PLS.

Veliglou et al, also report another sample but with more diverse samples and different multivariate analysis (MVA) [50]. The aim of the study was to improve the accuracy and stability of meat species identification using laser-induced breakdown spectroscopy (LIBS) by eliminating the spectra scatter effect. The sample used in this research not only tereserial, but also aquatic animal (shrimp, chicken, beef, clams, pork liver, and a composite sample of shrimp and clams) that was formed into pellet. The method involved the use of multiplicativ scatter correction (MSC) as a spectral pretreatment method for scatter correction, and the corrected spectra were identified based on the K-nearest neighbor (KNN) model. The results showed that after the processing of MSC, the identification rate of the six kinds of meat pellets improved significantly. The test set accuracy and the coefficient of variance were used to evaluate the accuracy and stability of meat identification. The average coefficient of variance decreased from 5.16% to 0.56%, indicating improved stability. The relative position of each spectrum and their average spectrum was calculated, showing that the repeatability of meat species recognition improved significantly.

Another study reported the combination of LIBS with Raman spectroscopy for identifying samples of beef, lamb, and pork [23]. The objective of this research is to develop a method for identifying and classifying meat tissue based on the combination of LIBS-Raman spectroscopy and comparing its accuracy with LIBS and Raman alone. The samples used for detection were three types of meat (beef, lamb, and pork). The results of LIBS-Raman showed the highest classification accuracy of up to 99.42%. Furthermore, the results indicated that the accuracy of LIBS (93.92%) was superior to that of the Raman method (92.67%). The accuracy results using Raman were similar to a previously reported study, with accuracies of 80% (PLSDA) and 92% (SVM). Therefore, it is evident that the best accuracy is achieved using LIBS. Previous research has also been conducted to enhance the accuracy and stability of meat species identification using LIBS combined with Multiplicativ Scatter Correction (MSC). The meat used in this study included shrimp, chicken, beef, clams, pork liver, and a mixed sample of shrimp and clams. The results of this research demonstrated an improved accuracy and stability in identifying meat species using LIBS and MSC. The identification percentage of shrimp and clams mixed sample increased from 94.17% to 100%, and the prediction coefficient of variation decreased from 5.16% to 0.56%. In addition to beef samples, various beef organ parts such as liver, kidney, heart, lungs, and spleen have also been reported. Organ samples from cattle were mixed with beef to identify both. The obtained results showed a LOD value of 3.8% in that mixed sample [19].

Table 3. The value of the sensitivity of the pH optical sensor to variations in the concentration of phosphate buffer
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<table>
<thead>
<tr>
<th>Multi-element analysis: LIBS is capable of detecting and analyzing the main elements and trace elements in food samples with good precision and accuracy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick analysis: LIBS provides rapid analysis for food samples, making it suitable for sample applications with large quantities.</td>
</tr>
<tr>
<td>Simple sample preparation and the use of a small quantity of samples High spatial resolution on the target and the analysis results show high accuracy.</td>
</tr>
<tr>
<td>Matrix effects: Food samples often possess complex and non-homogeneous matrices, which can influence the accuracy and reproducibility of LIBS analysis.</td>
</tr>
<tr>
<td>Calibration requirements: LIBS necessitates calibration for accurate quantification of elemental concentrations.</td>
</tr>
</tbody>
</table>

Based on the reported use of LIBS in meat type identification, it can be observed that LIBS offers several advantages (Table 3). LIBS has the capability to detect and analyze main elements and trace elements in food samples with precision and accuracy [56]. The sample preparation is straightforward and can be analyzed quickly, making LIBS suitable for analyzing large quantities of samples. The analysis results using LIBS provide real-time outcomes, with high spatial resolution on the target and good accuracy. Behind the advantages of utilizing LIBS analysis, there are certainly some drawbacks of LIBS that also need to be acknowledged and minimized. Calibration requirements become a limitation in LIBS analysis due to the highly complex chemical structure of food. Consequently, it is challenging to prepare standard samples that are suitable for the actual food samples. This complicates the acquisition of an accurate calibration curve and quantitative results. Furthermore, the effects of sample matrices disrupt the analyte spectrum, thereby further complicating the calibration process. To address these limitations, correction factors can be employed along with the calibration curve in certain cases, as demonstrated [56].

**THE CHALLENGE OF ANALYZING TYPES OF MEAT USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) IN THE FUTURE.**

Meat identification and analysis using Laser-Induced Breakdown Spectroscopy (LIBS) is a promising method to ensure the authenticity of halal meat. However, several challenges and recommendations need to be considered in the future development of halal meat analysis using LIBS. Here are some of them:

1. **Appropriate reference standards:**
   It is important to have accurate reference standards in halal meat analysis using LIBS. This involves creating a comprehensive LIBS database with characteristic spectra for various types of halal and non-halal meats. Strong collaboration efforts among researchers, food experts, and halal supervisory authorities are required to gather this data.

2. **Non-destructive testing:**
   Developing non-destructive LIBS techniques is crucial, hence the analyzed meat can still be used after testing. This will allow for broader testing and ensure the integrity of the analyzed meat.

3. **Portability:**
   The development of portable LIBS devices will enable easy and fast halal meat analysis in the field, such as in meat processing plants or retail stores. This will help reduce analysis costs and time.

4. **Multi-component testing:**
   LIBS can also be expanded to identify more than one parameter in halal meat analysis, such as detecting forbidden residues or the use of non-halal additives. Further research is needed to expand the application of LIBS in testing other important components in halal meat.

Although meat identification and analysis using LIBS holds promise, there are several challenges that must be overcome to enhance the accuracy, validity, and usability of this technology. By focusing on continuous research, collaboration among stakeholders, and the development of improved technology, LIBS can become a powerful tool in ensuring the authenticity of halal meat in the future.

**CONCLUSION**

The research focused on the identification and analysis of different types of meat has yielded several noteworthy findings. Among the array of methods available for this purpose, spectroscopy has stood out as a prominent approach. Within spectroscopy, Laser-Induced Breakdown
Spectroscopy (LIBS) has emerged as a rapidly evolving technique with significant potential. Notably, LIBS has demonstrated its superiority in accuracy compared to alternative methods like FTIR and Raman Spectroscopy. An intriguing aspect of LIBS is its compatibility with various chemometric methods, including but not limited to Principal Component Analysis (PCA), Partial Least Squares (PLS), and Multiplicative Scatter Correction (MSC). This compatibility further enhances its utility in the identification and analysis of diverse meat species. Perhaps the most striking conclusion is the exceptional precision exhibited by Laser-Induced Breakdown Spectroscopy (LIBS) in this domain. The accuracy achieved in identifying and analyzing various types of meat using LIBS has been observed to reach an impressive 100% for shrimp and clams mixed sample. These findings collectively underscore the immense potential of LIBS as a cutting-edge tool for accurate and comprehensive meat analysis.

REFERENCE


