

FEASIBILITY STUDIES OF OPTICAL SPECTROSCOPIC SENSING IN AGRI-FOOD APPLICATIONS

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FEASIBILITY STUDIES OF OPTICAL SPECTROSCOPIC SENSING IN AGRI-FOOD APPLICATIONS

by

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Submitted

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**Dedicated to my family for their unconditional love, support,
and encouragement**

Certificate

This is to certify that the dissertation titled “**Feasibility studies of optical spectroscopic sensing in agri-food applications**”, being submitted by **Diksha Garg** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of bonafide research work carried out by her. She has worked under my guidance and supervision and has fulfilled the requirements, which to my knowledge, have reached the requisite standard for the submission of this dissertation. The results contained in this dissertation have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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Abstract

Food products consist of different organic and inorganic substances that are highly sensitive and susceptible to being affected by variations in the product's internal and external environments. Alteration of food quality results due to the action of microorganisms, food enzymes, chemical reactions, and physical changes. The consumption of food with altered quality may cause serious negative impacts on the consumer's health as well as industrial market relations. Thus, food quality assessment is of critical importance to preclude public health issues and monetary losses to the Government. Conventional methods of food quality testing employed in the present food industry are mostly invasive, time-consuming, and require special sample treatment. Consequently, most of these cannot be adapted into a field-deployable platform for the same. On the other hand, optical spectroscopic techniques have shown great potential in studying the different aspects of food products as a rapid, non-destructive, label-free, and non-contact means of quality assessment. However, the applicability of a particular spectroscopic tool depends on several factors. Thus, prior knowledge of feasibility is important for the judicious selection of targeted optical techniques with aligned applications in order to obtain optimal details about the sample.

Therefore, the present dissertation explores the feasibility of two specific optical spectroscopic techniques, namely, Raman and Terahertz (THz) spectroscopy, towards developing a successful model for rapid food assessment. While THz spectroscopy is based on the absorption of the resonant frequencies lying in the THz region, Raman spectroscopy is related to the inelastic scattering of the excitation radiation from the molecules. These techniques are complementary in nature and their simultaneous implementation may provide broad information about the intermolecular and intramolecular interactions. These are essentially related to the compositional and structural parameters, and hence, to the authenticity and quality of the food product. In the

present dissertation, different classes of food products were analyzed to investigate the applicability of these spectroscopic techniques on the basis of the factors examined in corresponding experiments: these include identification, quantification, moisture measurement, adulteration, and spoilage detection. Our results demonstrate that their selectivity and specificity are limited by system parameters and physical characteristics of the sample, suggesting the need for some improvements and modifications in terms of instruments and data processing to implement them in the food industry.

सार

खाद्य उत्पादों में विभिन्न कार्बनिक और अकार्बनिक पदार्थ होते हैं जो उत्पाद के आंतरिक और बाहरी वातावरण में भिन्नता से प्रभावित होने के लिए अत्यधिक संवेदनशील और अतिसंवेदनशील होते हैं। सूक्ष्मजीवों, खाद्य एंजाइमों, रासायनिक प्रतिक्रियाओं और भौतिक परिवर्तनों की क्रिया के कारण भोजन की गुणवत्ता में परिवर्तन होता है। परिवर्तित गुणवत्ता वाले भोजन की खपत से उपभोक्ता के स्वास्थ्य के साथ-साथ औद्योगिक बाजार संबंधों पर गंभीर नकारात्मक प्रभाव पड़ सकता है। इस प्रकार, सार्वजनिक स्वास्थ्य के मुद्दों और सरकार को मौद्रिक नुकसान को रोकने के लिए खाद्य गुणवत्ता मूल्यांकन महत्वपूर्ण है। वर्तमान खाद्य उद्योग में नियोजित खाद्य गुणवत्ता परीक्षण के पारंपरिक तरीके ज्यादातर आक्रामक, समय लेने वाले हैं, और विशेष नमूना उपचार की आवश्यकता होती है। नतीजतन, इनमें से अधिकांश को एक फील्ड-डिप्लॉयेबल प्लेटफॉर्म में नहीं बदला जा सकता है। दूसरी ओर, ऑप्टिकल स्पेक्ट्रोस्कोपिक तकनीकों ने गुणवत्ता मूल्यांकन के तीव्र, गैर-विनाशकारी, लेबल-मुक्त और गैर-संपर्क साधनों के रूप में खाद्य उत्पादों के विभिन्न पहलुओं का अध्ययन करने में काफी संभावनाएं दिखाई हैं। हालांकि, किसी विशेष स्पेक्ट्रोस्कोपिक उपकरण की प्रयोज्यता कई कारकों पर निर्भर करती है। इस प्रकार, नमूने के बारे में इष्टतम विवरण प्राप्त करने के लिए संरक्षित अनुप्रयोगों के साथ लक्षित ऑप्टिकल तकनीकों के विवेकपूर्ण चयन के लिए व्यवहार्यता का पूर्व ज्ञान महत्वपूर्ण है।

इसलिए, वर्तमान शोध प्रबंध तेजी से खाद्य मूल्यांकन के लिए एक सफल मॉडल विकसित करने की दिशा में दो विशिष्ट ऑप्टिकल स्पेक्ट्रोस्कोपिक तकनीकों, अर्थात् रमन और टेराहर्ट्ज़ (THz) स्पेक्ट्रोस्कोपी की व्यवहार्यता की पड़ताल करता है। जबकि THz स्पेक्ट्रोस्कोपी THz क्षेत्र में गुंजयमान आवृत्तियों के अवशोषण पर आधारित है, रमन स्पेक्ट्रोस्कोपी अणुओं से उत्तेजना विकिरण के अप्रत्यास्थ बिखरने से संबंधित है। ये तकनीक प्रकृति में पूरक हैं और उनका एक साथ कार्यान्वयन इंटरमॉलिक्युलर और इंट्रामोल्कुलर इंटरैक्शन

के बारे में व्यापक जानकारी प्रदान कर सकता है। ये अनिवार्य रूप से संरचनागत और संरचनात्मक मापदंडों से संबंधित हैं, और इसलिए, खाद्य उत्पाद की प्रामाणिकता और गुणवत्ता के लिए। वर्तमान शोध प्रबंध में, संबंधित प्रयोगों में जांचे गए कारकों के आधार पर इन स्पेक्ट्रोस्कोपिक तकनीकों की प्रयोज्यता की जांच के लिए खाद्य उत्पादों के विभिन्न वर्गों का विश्लेषण किया गया था: इनमें पहचान, मात्रा का ठहराव, नमी माप, मिलावट और खराब होने का पता लगाना शामिल है। हमारे परिणाम प्रदर्शित करते हैं कि उनकी चयनात्मकता और विशिष्टता सिस्टम मापदंडों और नमूने की भौतिक विशेषताओं द्वारा सीमित हैं, जो खाद्य उद्योग में उन्हें लागू करने के लिए उपकरणों और डेटा प्रसंस्करण के संदर्भ में कुछ सुधार और संशोधन की आवश्यकता का सुझाव देते हैं।

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