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X-RAY SPECTROSCOPY AND ITS AGRICULTURAL APPLICATION

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ABSTRACT

Owing to its exceptional elemental analysis capabilities, X-ray spectroscopy is a potent analytical instrument that has transformed biological research. This method is essential for comprehending intricate biological processes and is used in the analysis of biological specimens. Applications include identifying trace elements in tissues, deciphering biomolecules' structural features, and learning about the workings of enzymes. Through comprehensive insights into the elemental composition and structural characteristics of biological samples, X-ray spectroscopy advances our understanding of nutrient physiology, phytotoxicity, heavy metal buildup, and adulterations in the field of agriculture.

KEYWORDS: Elemental analysis, Nutrient physiology, X- ray spectroscopy

INTRODUCTION

X-ray is a part of electromagnetic spectrum. X-rays have a wavelength in range of 10-5Å to 100 Å; conventional X-Ray spectroscopy is largely confined to approximately 0.1 Å to 25 Å. X-Ray spectroscopy is based upon measurement of emission, absorption, scattering, fluorescence and diffraction of electromagnetic radiation by atoms. It can be defined as short wavelength electromagnetic radiation produced by deceleration of high-energy or electronic transition of electrons in the inner orbitals of atoms. Transitions are used in X-ray spectroscopy for both absorption (XAS, X-ray absorption spectroscopy) and emission (XES, X-ray emission spectroscopy), where the former studies the transitions from the ground state to the excited state while the latter studies the decay process from the excited state. Synchrotron sources offer a spectrum of X-ray energies that are appropriate to most elements in the periodic table, especially those found in redox-active metallo-enzymes. Both techniques describe the chemical makeup and surroundings of atoms in molecules. The particular element being investigated is typically determined by the energy of the X-rays employed (Yano and Yachandra, 2009).

BRIEF HISTORY

In 1912, a pair of British physicists named William Henry and William Lawrence Bragg actually started using X-ray spectroscopy. They investigated the interactions between X-ray radiation and crystallographic atoms using spectroscopy. By the next year, their method known as X-ray crystallography had become the industry standard, and in 1915 they were awarded the Nobel Prize in Physics.

PRINCIPLE OF X-RAY SPECTROSCOPY

Materials can become ionised when they are exposed to high-energy, short-wavelength radiation, such as X-rays. An atom's inner shell electron jumps to a higher energy level when it is activated by a photon's energy. The energy it previously received from the excitation is released as a photon with a characteristic wavelength for the element when it returns to the low energy level (each element may have multiple characteristic wavelengths). Therefore, in modestly atomic number atoms, atomic X-rays released during electronic transitions to the inner shell states. Since each element has a distinct X-ray spectrum that may be used to identify it, these X-rays have distinctive energies linked to the atomic number.

X-Ray Spectroscopy is also based on Braggs law (1912) which states that The X-Rays appear to be reflected from the crystal only if the angle of incidence Ɵ satisfies the condition that

$$\sin\Theta = n\lambda / 2d$$

where where d is the inter planar distance of the crystal

n is an integer

λ is wavelength of X-radiation.

At all other angles, destructive interference occurs.

WORKING PRINCIPLE

The basic idea behind X-ray spectroscopy is that materials that are subjected to X-rays either produce or absorb secondary, or distinctive, X-rays. The elemental composition of the substance may be identified and analysed thanks to these secondary X-rays, which are specific to each element. This is a thorough breakdown of the operational principle:

Source: Primary X-rays are produced by an X-ray source, such as a synchrotron or X-ray tube. The substance under research is exposed to high-energy X-rays, which interact with its atoms.

Interaction with Atoms: Photoionization is a process by which the atoms can lose inner-shell electrons to the primary X-rays, which leaves vacancies in the inner shells of the atoms.

Emission of Characteristic X-rays: Electrons from higher energy levels (outer shells) descend to lower energy levels by releasing energy in the form of secondary X-rays, which helps fill the voids left by the ejected electrons. The energy difference between the two shells engaged in the transition is equivalent to the energy of these X-rays that are released.

Detection and Analysis: A suitable detector, such as a semiconductor detector, gas-filled detector, or crystal spectrometer, is used to detect the X-rays that are released. The distinctive X-rays' energy and intensity are measured by the detector. A spectrum is created when X-rays are detected; this is a visualization of the X-ray intensity vs energy. The typical X-ray energies of each element are distinct and show up as peaks in the spectrum. The spectral plot is later analysed using various softwares.

APPLICATION IN AGRICULTURE

X Ray spectroscopy has wide spectrum of uses in agriculture. Some of them are listed below:

- Elemental analysis of plants using X Ray spectrometry: Plant tissues can be analysed using X-ray spectroscopy in order to quantify the elements (As, Al, Co, Na, Sr, and Pb), micronutrients (Mn, Fe, and Zn), and macronutrients (P, K, Ca, Mg, and S) in plant samples using calibration curve methods. It can also be applied in the detection of heavy metals and trace elements. The physiology of nutrients and the toxicity of heavy metals in soil and plants are better understood as a result of these findings, which also present a chance to develop phytoremediation techniques (Margui et al., 2005).
- Elemental imaging and mapping of Plant tissues: The nondestructive nature of Micro-X Ray Fluoroscence (μ-XRF), a specialist X-ray spectroscopy technique, makes it useful for determining the spatial distribution of elements in a variety of biological samples.
- Plant physiology has utilised μ-XRF in particular to examine the distribution of elements in various plant components, including leaves, stems, roots, and seeds. The spatial distribution of zinc in primed common bean seeds and the chemical imaging of P, S, and Ca in soybean leaves infected with anthracnose were studied by Rodrigues et al., (2018).
- Real-time Monitoring: Farmers may now analyse plant health in the field in real-time, receiving rapid feedback on nutrient status and aiding in the optimisation of fertiliser application thanks to the development of portable XRF instruments.
- Detection of adulterations: Food product adulterants and pollutants are found using X-ray spectroscopy. To ensure that foods fulfil safety regulations before being consumed by consumers, it can, for example, detect the presence of heavy metals in grains, fruits, and vegetables.

- Verification of Nutrient Content: To make sure that food items meet quality standards and nutritional labelling requirements, X-ray absorption spectroscopy, or XAS, can be used to confirm the nutrients contained in the product (McLaughlin et al., 2011).
- Structure of insecticide can be determined via this technique.
- X Ray Spectroscopy can be used to detect DNA radiation damage.
- Structure of an element or a compound can be effectively determined.
- X-ray fluorescence (XRF) spectroscopy has been used to study tomato plant vigor, develop automatic weed control system and count the number of tiller in rice.

CONCLUSION

With the ability to precisely analyse the elements of soils, plants, and fertilisers, X-ray spectroscopy is a potent analytical tool in the agricultural industry. It improves knowledge of pollutant presence, soil composition, and nutrient distribution, which helps to maximise fertilisation techniques and raise crop yields. X-ray spectroscopy is essential to current farming and agricultural research because it supports increased agricultural output and environmental stewardship by enabling focused interventions and sustainable practices.

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