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Research
Animal Nutrition and Feed Science—Review

Molecular Structure of Feeds in Relation to Nutrient Utilization and Availability in Animals: A Novel Approach

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ABSTRACT

The invention and development of new research concepts, novel methodologies, and novel bioanalytical techniques are essential in advancing the animal sciences, which include feed and nutrition science. This article introduces a novel approach that shows the potential of advanced synchrotron-based bioanalytical technology for studying the effects of molecular structural changes in feeds induced by various treatments (e.g., genetic modification, gene silencing, heat-related feed processing, biofuel processing) in relation to nutrient digestion and absorption in animals. Advanced techniques based on synchrotron radiation (e.g., synchrotron radiation infrared microspectroscopy (SR-IMS) and synchrotron radiation X-ray techniques) have been developed as a fast, noninvasive, bioanalytical technology that, unlike traditional wet chemistry methods, does not damage or destroy the inherent molecular structure of the feed. The cutting-edge and advanced research tool of synchrotron light (which is a million times brighter than sunlight) can be used to explore the inherent structure of biological tissue at cellular and molecular levels at ultra-high spatial resolutions. In conclusion, the use of recently developed bioanalytical techniques based on synchrotron radiation along with common research techniques is leading to dramatic advances in animal feed and nutritional research.

1. Introduction

The invention and development of new research concepts, novel methodologies, and novel bioanalytical techniques are essential in advancing the animal sciences, which include feed and nutrition science [1]. Common and conventional wet chemistry methods are often used for nutritional analysis and feed evaluation. However, wet chemistry methods usually destroy the inherent molecular structure of the feed during preparation for lab digestion and analysis processing [1–3] because these wet analytical methods include heavy applications of harsh chemicals. These chemicals often destroy or alter the native or original inherent molecular structure of the feed, and often generate artifacts that affect feed and nutrition evaluation [1–2].

Recently developed advanced synchrotron radiation infrared microspectroscopy (SR-IMS) is a fast, noninvasive, and direct bioanalytical technology [4–7]. This cutting-edge bioanalytical technology has brilliant light (a million times brighter than sunlight), nondivergent beam light, and an effective small source size [5,6]. It is capable of revealing the molecular structure of biological tissue at ultra-high spatial resolutions [4,8–12]. Using synchrotron-based bioanalytical technology makes it possible to obtain several types of information simultaneously (Fig. 1): tissue structure, tissue nutrition, tissue chemistry, and tissue environment [2,13,14].

To date, little application has been found in the animal science community for the use of SR-IMS to study the interactive relationship between feed molecular structure and molecular nutrition or conventional animal nutrition. Similarly, little application has been found for the use of advanced synchrotron-based bioanalytical technology to explore the inherent structural makeup of the cellular and

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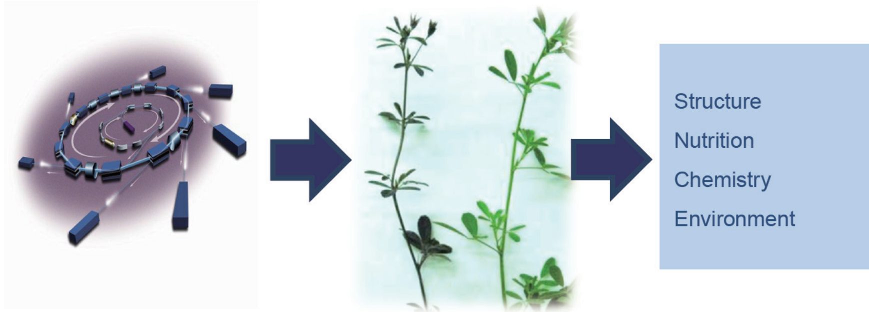

Fig. 1. Advanced synchrotron-based bioanalytical technology can provide four kinds of information simultaneously, including tissue structure, tissue nutrition, tissue chemistry, and tissue environment.

subcellular dimensions in animal feeds, which are associated with nutrient delivery in animals [15,16]. Along with other factors such as the nutrient matrix, the inherent molecular structure and makeup of a feed affects feed quality, nutritive value, biofunction, fermentation behavior, degradation kinetics, and digestion in animals [12,17]. The feed molecular structure conformation or structural makeup strongly impacts the protein that is absorbed in the small intestine, and strongly impacts the protein's accessibility to internal digestive enzymes in the animal gastrointestinal tract [18,19]. Reduced accessibility to internal digestive enzymes causes poor digestion and poor absorption, and thus results in poor protein nutritive value in animals [20–22].

The objective of this article is to introduce our novel research ideas and bioanalytical techniques (i.e., the advanced synchrotron-based bioanalytical technology) as a new approach for the animal science community in quantifying the interactive relationship between feed molecular nutrition and molecular structure.

This review article covers the following material. Section 2 presents the concept of synchrotron-based bioanalytical technology, along with the major components of this technology. It then presents some synchrotron molecular spectroscopy techniques. Section 3 presents applications of this technology in the form of advanced synchrotron-based research programs. Section 4 follows with conclusions.

2. Nutrition and feed research programs based on novel synchrotron-based bioanalytical technology

2.1. The concept of a synchrotron radiation facility

What is a synchrotron? A simple answer is that a synchrotron is a giant particle accelerator that turns electrons into light [4–6]. A synchrotron radiation facility includes various components such as an electron gun, a linear accelerator, a booster ring, a storage ring, many beamlines (e.g., an infrared line, soft X-ray line, and hard X-ray line), and experimental hutches or stations [4–6]. A mid-sized synchrotron radiation facility is roughly the size of a football field; one example of a mid-sized facility is the Canadian National Synchrotron Radiation Facility—Canadian Light Source (CLS), which is located at the University of Saskatchewan in Saskatoon, Saskatchewan, Canada. However, some synchrotron radiation facilities are larger, such as the Advanced Photon Source in Chicago, Illinois, USA; the National Synchrotron Light Source II in Upton, New York, USA; and the SPring-8 in Harima Science Park City, Hyogo Prefecture, Japan. The size of the facility is partially dependent on the synchrotron target energy levels (ranging from 0.8 GeV to 8.0 GeV).

2.2. Using a synchrotron radiation facility for feed molecular structure research

Synchrotron light is extremely brilliant; it is a full-spectrum photon beam and a source of electromagnetic radiation. The accelerator causes electrons to move at rapid speeds with high energy. Bending magnets and device undulators (or "wigglers") in the synchrotron facilities transform the high-energy electron beam into a photon beam. This photon beam is called "synchrotron light." Scientists usually work at experimental stations at the end of each synchrotron beamline to study molecular structure though an analysis of the synchrotron-based spectrum [1,5,6,23,24]. The only disadvantage of using this technology is the necessity of having access to a synchrotron facility, which costs millions of dollars to build.

2.3. Plant-based amides research using cutting-edge synchrotron-based bioanalytical technology

Plant-based feeds, seeds, green forage, and silage protein have unique molecular chemical makeups or molecular conformations; therefore, the molecular spectrum for each plant-based feed protein is unique. The spectrum of a plant-based feed protein in the vibrational middle-infrared region contains two important and significant characteristics: the protein amide I spectrum, with a spectral peak at about 1600–1700 cm^{-1}, and the protein amide II spectrum, with a spectral peak at about 1500–1560 cm^{-1}. These two unique spectral peaks are due to protein backbone vibrations—that is, stretching and bending [25–28]. The plant-based feed protein amide I spectrum, rather than the protein amide II spectrum, is usually used for protein α-helix, protein β-sheet, protein random coil, and protein β-turn analysis [29,30].

2.4. Multivariate molecular spectral analyses using cutting-edge synchrotron-based bioanalytical technology

To detect differences in the molecular structure of plant-based feeds, multivariate techniques or methods can be used to analyze the molecular spectra from feeds. Two of these methods are agglomerative hierarchical molecular spectral cluster analysis and principle component analysis. In these multivariate analyses, it is not required that the spectral assignments be known, because the aim is simply to discriminate between and qualitatively separate treatments that impact molecular structure and induce molecular structure changes that may affect nutrient absorption in animals [30–33].

3. Applications and studies using synchrotron-based bioanalytical technologies for feed and molecular nutrition research

3.1. Application I: Molecular chemistry imaging of animal feeds

The first application involves using synchrotron-based bioanalytical technologies for the molecular chemistry imaging of animal feeds [31]. Examples of this application include imaging the molecular