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SOME RESEARCH MILESTONES WHERE CHEMISTRY AND NUTRITION ARE INEXTRICABLY INTERTWINED

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Abstract

History, as always, helps us reflect on our humble beginnings or maybe our golden era. It is an invaluable learning curve for those who learned anything through reflection before doing anything else. This review is an effort to raeveal briefly some of the research milestones that lead to the progressive development of the science of nutrition with the support of chemistry. The experiment of Lavoisier on carbon dioxide production in the late eighteen century has set the scene. Chemistry and nutrition, together, have accomplished so much and contributed to human lives. Our improved health and the provision of healthy animal products for human consumption are some examples. Chemistry has assisted nutritionists in better comprehending the mechanisms of actions of nutrients in the prevention and therapy of some diseases besides their metabolic roles and maintenance of body functions in animals and humans. The most recent findings demand a better understanding of cascades of structural changes of nutrients during digestion and assimilation. Personalised nutrient recommendations and precision nutrition will be the future of nutrition science, where chemistry remains its backbone.

Keywords: *chemistry; nutrition; research milestones; challenges*

INTRODUCTION

History is very important in indeed. It is a record of past achievements, great or small and even records of significant failures. By reading history, we remember the past and appreciate it and respect those who made history about something. Martin Luther King Jr once famously stated that "We are not makers of history, we are made by history". It is true in every case for chemistry and nutrition. A very long history of chemistry and nutrition has not been written as a history book but rather, pieces of relevant articles that are available to us were compiled here and organised as such that it forms this article. This is a review of the historical accounts of the most important research milestones in chemistry relevant to animal and human nutrition, food chemistry and nutritional biochemistry. It is an effort to show how chemistry has all along accompanied nutrition in its development to a better understanding of the chemistry of food, digestion and metabolism of nutrients both in animals and humans. In the following, it exposed several research reports in order for us to appreciate the pioneers as well as their pioneering works from over two centuries ago until the last two decades of the twenty-first century. The whole objective of this review is to appreciate chemistry as the central science.

Lavoisier, Margendi And Boussingault Experiments: The First Milestone

Until the late 18th century, there were still opposing ideas between scholars on how the food eaten by animals or humans is processed in their bodies. For example, it was previously thought that the production of carbon dioxide when breathing was understood as a process to cool down the lung. It was not until the experiment of Antoine Lavoisier who measured the respiratory output of carbon dioxide from his coworker Armand Seguin, both during rest and exercise (weight lifting), that shed light on this misconception. This research showed that energy was used up by the body and that carbon dioxide production increased when the intensity of exercise increased [1]. This experiment formed the beginning of interest in nutrient metabolism.

Lavoisier's collaboration with Pierre Simon Laplace enable the first use of ice calorimetry, although not as precise as the bomb calorimetry of today; it was already a breakthrough in those days. It was then that quantitative chemistry was initiated in terms of the first understanding of nutrient metabolism, particularly for the combustion of nutrients to produce energy that the body requires. In a later calorimetry study, instead of using his assistant, Lavoisier used a guinea pig, and this was the first use of an animal model in a nutrition study. They found that most of the animal's body heat as a result of the slow combustion of organic compounds within the body of the animal. The control treatments in this experiment were measuring the heat produced by a lit candle and heat produced by burned charcoal. Thus, a metabolism study both in animals and humans were started. The monumental works of Lavoisier were later appreciated as great achievements in chemistry [2].

The use of animal models in the experiment by Lavoisier was later appreciated by numerous scholars in the area of chemistry and nutrition of animals and humans. It is an ethical consideration that research using human subjects is almost totally prohibited or at least in some cases very limited in nutrition studies especially when some animal species can be used as alternatives [3]. Animals such as rats and mice are now very commonly used in experimental studies in human nutrition although some caution needs to be taken due to some physiological differences to humans [4,5]while studies on the nutrition of companion animals can use dogs and cats [6]. Nutritional studies for farm animals directly use farm animals such as cattle, sheep, pigs and poultry [7]. These studies demonstrate the continuous use of animals to study human nutrition as well as animal nutrition for farm and companion animals.

Francois Margendie was another outstanding figure in the early establishment of understanding nutrition for both animals and humans. His series of very simple yet famous experiments were conducted in the late eighteenth century to challenge the previous belief that "a dog can live only by eating bread"; which we can assume to mean that one type of food is sufficient to supply all the nutritional needs of the animal. Margendie's first experiment was to feed sugar to a dog; the animal remained healthy for the first two weeks but approximately a week later it lost weight significantly and developed a corneal ulcer and after a month, it died. He did another experiment with three treatments namely dogs that were fed olive oil only, dogs that were fed gums only and dogs that were fed butter only. In all cases, all dogs died after a month of feeding them a single feed ingredient. Interestingly, dogs fed olive oil died but did not develop a corneal ulcer. Margendie established the statistically acceptable experiment and later produced a recommendation that applies even until today that "variation and multiplication of feeds are essential to maintain a healthy animal and human [1,8].

Another pioneering work specifically in animal nutrition was that of Jean Baptiste Boussingault of France. He learned chemistry from his geology class and later used it in practice in the area of agriculture in general and animal husbandry in particular. He worked with a famous French chemist, J.B. Dumas, and divided his time between farming and doing research. He was the first to recognise that only leguminous plants were able to use atmospheric nitrogen and these plants made it available in the soil for other plants to absorb. This is a very important discovery and his finding was in opposition to the previous belief that even animals can use atmospheric nitrogen. His other monumental work with cows was the first balanced feeding trial. He compared the daily nitrogen intake of a dairy cow from its feed with that of its output in milk and excreta. This model of a balanced trial is still being used today by animal nutritionists [1,9]. This was truly a breakthrough experiment in animal nutrition, although simple but remains applicable until today.

Invention Of Precision Equipment, Analytical Tools And Methods, The Role Of Analytical And Organic Chemistry: The Second Milestone

There is no doubt that the invention of precision equipment or apparatus for laboratories in animal and human nutrition enable the analyses of nutrient contents of feed and determination of dietary components to be analysed accurately. One of those was the

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calorimeter invented by Lavoisier and La Place.The invention of calorimetry remains attributed to them. This apparatus was developed into a bomb calorimeter by Paul Vieille of France in 1878.This static type Bom Calorimeter was suited only for the analysis of organic elements such as C, H and compounds containing, C, H, O and N but not for compounds containing sulfur and halogens. The bomb calorimeter was later developed to include the latter compounds both in Lund (Sweden) and in Bartlesville (US).This apparatus remains in extensive use today not only in nutrition and chemistry sciences but in broader fields such as environmental engineering and forestry (forest fire fighting) and of course, the food industry. The role of analytical chemistry in the development of various other apparatus that assist the development of nutrition science is enormous. Johan Gustav Christoffer Thorsager Kjeldahl of Denmark was the inventor of the Kjeldahl apparatus in 1883 to analyse nitrogen content of the various plant, animal and other materials still in use until today with only slight modifications [10].

Another very important analytical method was the fat extractor called the Soxhlet apparatus invented in 1879 by Franz von Soxhlet, a German agricultural chemist. His invention enabled us to extract compounds from solid materials by repeated percolation with an organic solvent under reflux. This apparatus is still being used today with very little modification. Another very important invention was the hot oven drier. Loius Pasteur, a French chemist and microbiologist, one of the great scientists of all time; undoubtedly is one of the household names. He was the inventor of the pasteurisation of food and beverages such as beer, canned food, dairy products, eggs, milk, juices and low alcoholic beverages and syrups. He developed not only vaccines against rabies, chicken cholera, anthrax, swine erysipelas and silkworm diseases but he also famously introduced the methods of sterilization, namely the steam sterilizer, autoclave and the hot air oven. All these are in use until today with various slight modifications and adjustments. Another technology that is very important in keeping organic samples fresh regardless of time-lapse was the invention of freeze-drying. Jacques-Arsene d'Arsonval at the College de France in Paris in 1906 invented freeze-drying, which was very widely used in World War II for the preservation of blood samples, and today for the preservation of all other heat-sensitive biological materials [1]. In addition to chemistry, medicine and nutrition, today; the food industry is the biggest user of this technology.

The next outstanding chemist we are going to mention is Izaak Maurits Kolthoff (1894–1993), a Dutch analytical chemist who perfected the concept of pH and many other analytical chemistry concepts, who later worked at the University of Minnesota, US until he passed away at the age of 99. He lived a great legacy and still is widely regarded as the father of modern analytical chemistry. He brought about a transformation in the field of analytical chemistry. He has a great reputation as one of the most well-known teachers, authors and researchers in the area of analytical chemistry. He founded most of the analytical methods in the area and are still being used today. We should not forget, however, when he was in the Netherlands, he had a great teacher, Professor Nicholas Schoorl, who has a well-known motto:' "*theory guides, experiment decides*"; maybe this is also a meaningful motto for us, chemists and nutritionists of today [11,12]. Another outstanding chemist was Herman Francis Mark, an Austrian, who later resided in the US until he died at the age of 95; a founding father of polymer science—who made pioneering contributions both to fundamental studies and to commercial production of fibres, plastics, and rubbers. Food polymers are much related to our understanding of nutrients in animal and human nutrition until today; including new applications in tissue engineering [13,14]. Another analytical tool that are used today in advanced sciences such as molecular biology and biotechnology is chromatography, a technique developed the first time by a Russian scientist, Mikhail Tsvet, in 1900. In chemistry and nutrition experiments, quantifying the behaviour of a chemical is necessary. He coined the term chromatography in the early 20th century, the technology is used extensively in many areas of study until today including in nutrition and food science. He was then worked to separate plant pigments such as chlorophyll, carotenes, and xanthophylls. Another very important chemist in history was

Lawrence Joseph Henderson in 1908 who developed an equation that enabled it to be part of biochemistry. Later his work was perfected by Hasselbach to produce what is later called the Henderson-Hasselbach Equation, used until today to measure the pH of any chemical material. Again, all these require an understanding of basic chemistry.

Identification Of New Chemical Elements And Substances; The Third Milestone Of Chemistry And Nutrition Sciences

In the early 19th century, we have at our disposal records of what elements have been recognised as chemical elements while they have been recognised and used for thousands of years. These include sulphur (S), silver (Au), antimony (Sb), mercury (Hg), and lead (Pb); these are already known and used for 6 to 9 thousand years before [15]. A timeline of the invention of new chemical elements and substances relevant to nutrition sciences has been made recently [16]. In terms of substances, it took forty years (1910 to 1950) to discover all the vitamins B, A, D, E, K and C. It took another twenty years (1930 to 1950), allowances for humans and animals were made for protein, all vitamins, phosphorus, calcium and iron. Within the span of 20 years later (1950-1970), several commodity crops were fortified (biofortification) for improved quality (nutrient content). It was during this period that dietary fat won a place in the hearts of many nutritionists and the community at large that it is the culprit of high blood pressure and cardiovascular diseases, although something later proved to be not true. In the 1970s, the concept of calorie: protein ratio was introduced to fight hunger and malnutrition in the world countries then. From 1980 through to 1990, it was time to fight global hunger, the role of chemistry in the making of dietary recommendations were attributed to analytical chemistry. In the year 2000, we saw conflicting understanding of research results in nutrition science; due mostly to variations in the research methodology and that controlled experiments have not been in general use. From 2010 onwards, a rapid rise in non-communicable diseases (related more to nutrition) was better understood. These diseases include obesity, type-2 diabetes, cardiovascular diseases and cancer [17]. All the above recommendations were based on the improved understanding of analytical and organic chemistry. This is where chemistry meets biology, physics and nutrition at the same time.

Invention Of Enzymes, Discovery Of The Role Of Atp, Discovery Of Dna And Rna: The Fourth Milestone

The invention of enzymes is another breakthrough in chemistry in general and related sciences such as nutrition in particular. About early year 7,000 BC; enzymes, we did not know if people in those days have called them enzymes. The fermented sugar to alcohol and this technology has been that long now or over 9,000 years old. For the reader to understand the complete history of enzymes, very recently, an extensive review on enzyme discovery and what the future holds for them, has been published [18]. Enzymes are proteins, they are excellent biocatalysts, so important that metabolism cannot be imagined to be an efficient process in a biosystem without the unpaid contribution of enzymes. They are so highly specific in their work, that there is only one enzyme for every biochemical reaction in living organisms. Fritz Albert Lipman and Herman Kalckar discovered the central role of adenosine triphosphate (ATP) in 1941, a breakthrough for the understanding of nutrient metabolism. Understandably, this was attributed to the advancement in the study of biochemistry [19]. This discovery has enabled a very fast leap forward in the understanding of energy production and utilisation in living cells. Any study about molecules including the molecules of life, namely DNA and RNA, cannot be completely separated from the basic understanding of chemistry; although it is now under a sub-science of biology and biochemistry called molecular biology.

The Grand Research Challenges In Animal Nutrition And Human Nutrition: The Fifth Milestone

In human nutrition, the grand challenges include the following [16]. Based on the research findings in the multifaceted effects of different foods, methods of processing and preparation, and dietary patterns among numerous cultures, some research area needs focusing on. These include how to formulate an optimal dietary composition to meet the specific needs of people that are under certain

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health conditions, for example, diabetic patients, weight loss programs for obese patients, ascertaining the benefits of prebiotics and probiotics in nutrition, the usefulness of fermented foods, better understanding of gut microbiota and their beneficial relevance to human health, improving nutrient absorption by better of the interface between nutrients and gut microbiota. Other areas of interest for better research is the perceived positive nutritional effects of flavonoids and other plant secondary metabolites, improving our understanding of the use of fatty acids both in health and disease, effects of specific fatty acids, flavonoids, and other bioactive; personalised nutrition. Other non-genetic factors such as sociocultural relevance to patterns of food selection and nutrient consumption are only some of the pressing issues for future research. Personalised nutrition and precision nutrition are even greater challenges of the future for the human nutritionist.

In the area of animal nutrition, the challenges are generally very much the same as those for humans. The challenge, overall, however, may be tougher in animal nutrition for reasons such as the following. First, humans would like to eat more eggs low in cholesterol and high in high-density lipoproteins, Humans also demand leaner meat (more protein) with less fat on top of it, but specifically, some people in some countries even demand a very specific type of meat, what we call as meat with high marbling; meat with evenly distributed intramuscular fat (a premium class of meat). On the other hand, many people are shouting that the carbon footprint of beef and milk is very high and costing the environment dearly. Therefore, farm animals should be fed the so-called feed formulated as such that it is precision nutrition. Precision nutrition can be interpreted as a feed that is ideally suited to feed the animal that will produce products that meet the market demand while at the same time limiting the greenhouse gases production, As we know it, the demand for animal products is ever increasing along with increasing human population and improved income despite the mounting pressures from the globalists (environmental lobbyists). Animal nutrition is also driven by cost because animal nutrition relates to the efficiency of animal production on one hand and good quality and healthy animal products, on the other hand. It is indeed an extremely difficult task for animal nutritionists [20]. The second challenge is macromolecular crowding for both human and animal nutrition. This particular area of study in biochemistry is extremely important because in vitro (a fully controlled experimental environment does not fully represent the real in vivo environment where macromolecules interact in certain ways we now understand macromolecular crowding. Macromolecular crowding has found a new called tissue engineering both in vitro and in vivo. This topic is not only a future research challenge but also is material for biochemistry classes in teaching and learning as our learners do very much need to follow the latest findings in chemistry and nutrition [21].

IMPLICATIONS

Based on the above, some important points worth summing up were as follows. Firstly, the studies of Lavoisier, Margendie and Boussingault may be worth considering as some of the first research milestones in chemistry and nutrition studies. It was also during this era that the so-called Chemistry Revolution occurred and the very reason that Antoine Lavoisier was called the father of Chemistry. Although the list of relevant researchers is not exhaustive, it is adequate, however, to demonstrate that their determination and hard work and scientific meticulousness have laid a very important foundation for the science of nutrition for both animals and humans to develop further. Secondly, it is important to emphasise that this article does not presume to purposely exclude any other outstanding figures on the scene that we were not able to identify due to the vast numbers of relevant literature. Thirdly, it is the same for equipment and apparatus, as well as methods of analyses in chemistry and nutrition, it is tedious to find all the equipment and apparatus both documented and undocumented but at least this article has tried to respect those who have dedicated their lives to what they believe as instrumental to the progress of our knowledge and understanding in the areas concerned. As we know it, we are only conveniently using them today without even thinking about who have actually conceived the ideas on how to design and make them, tested them over and over again; and at the same time, develop methods on how to use them effectively according to certain research objectives both in chemistry and nutrition. Fourthly, great achievements have been made in the areas of chemistry along with nutrition over many decades ago, as stated in the milestones above. However, there is still the need to maintain a consistent momentum of research, teaching and learning in chemistry and nutrition to meet the challenges of the future. Several grand challenges have been stated above and they lie exactly in front of the animal and human nutritionists of today. Such challenges can only be met appropriately when we acknowledge the need for greater collaboration with other sciences, more particularly, chemistry and biochemistry. Finally, we would like to emphasise it strongly that when anyone says something about nutrition, unknowingly that person is also stating something about chemistry; the need for collaboration continues for a time unlimited.

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