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Food Chemistry

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Chapter 1: History of Food Chemistry

Food Chemistry is the study of the composition and the specific properties of food when considering the chemical changes that it undergoes during processes such as handling, processing, and storing (Damodaran et al., 2017). Since all types of food undergo these processes, food chemists are imperative to the understanding what is in the substances that produce energy and sustain human life. This branch of chemistry features aspects of microbiology, chemistry, biology, and engineering. Food chemistry is often related to agricultural chemistry because of the numerous overlaps in their subject matter. Food chemistry was not specifically established as an independent system until the twentieth century, but practices of food chemistry date back much earlier to the late 1700s (Damodaran et al., 2017). Since the chemical compositions of food can be very complex, especially when considering ingredients that are added to naturally occurring substances for the benefit of the consumer, this branch of chemistry is imperative.

One of the earlier studies of food chemistry relates to food preservation. In the 19th century, Louis Pasteur a French chemist and Robert Koch a German bacteriologist conducted experiments in which they were able to relate the presence of certain microorganisms to the decay of organic material such as food and the spread of disease (Newton, 2007). The specific temperature and amount of moisture present in an environment directly impacted bacterial growth in that area. Conditions that were hot and moist were found to be more supportive of bacterial growth while cool and dry conditions did not allow bacteria growth to thrive (Newton, 2007). This discovery was incredibly beneficial to the advancement of food chemistry because it helped explain why certain food preservation techniques were successful. Techniques such as drying, freezing can be explained by their research. Without employing the use of preservation through techniques such as these, is it possible that humans would not be here today as these techniques have been used for millennia.

Throughout its history, food chemistry as a whole has evolved immensely. Practices of food chemistry date back to the beginning of human life despite it not being established as an independent system until the twentieth century. This was a major development and since this milestone, food chemistry research has gotten more focused. The publication of the first food chemistry book in 1847 is a noteworthy example of progression in this field. Chinese scholars Yanbin Xia and Ruijin Yang have categorized the development of food chemistry into four stages (Wang et al., 2012). The focus of the first stage was separating and identifying certain natural components from plants and animals (Wang et al., 2012). Examples of this include lactic acid, citric acid, malic acid, and tartaric acid (Wang et al., 2012). In the second stage laboratories that specialized in food chemistry were established (Wang et al., 2012). In the third stage, food chemistry developed into an independent subject (Wang et al., 2012). Finally, in the fourth and current stage of food chemistry access to previously unknown aspects of food chemistry has allowed for the development of scaled, standardized, and modernized processing of food (Wang et al., 2012). This subject is regarded as the most important discipline for a food scientist. Beginning in 1906, discoveries in this field began to impact legislation which is proof of just how influential this field has become.

Techniques of food chemistry have also evolved immensely. Techniques such as preservation and spicing are some of the earliest food modification techniques, but food chemistry has progressed significantly to be what it is in the present day. This advancement originally came with an increase of industrialization, trade, and food needing to be transported into cities. As food processing and distribution became more centralized, intrapersonal accountability from farmers and those who processed food decreased. This eventually led to discoveries of food adulteration or the modification of food by adding substances. This technique was primarily used to increase economic gain for producers. It was common that one or multiple ingredients in a product would be replaced with a more inexpensive ingredient in order to increase profit (Newton, 2007). Adding substances to foods can make food more desirable by enhancing the natural flavor or color, but food adulteration can be very dangerous especially when ingredients are replaced with those which are not intended for human consumption such as chalk, cattle fodder, sand, and sawdust (Newton, 2007). This practice dates back to ancient Egypt and is primarily used to cut production costs and increase overall profit (Newton, 2007).

Certain ingredients may be added to food for a multitude of reasons. Some examples include preservation, flavor improvement, color enhancement, and increased nutritional value. Over time, the additives of food have evolved. The main area of evolvement regarding food additives is the use of ingredients which were not intended for human consumption. Legislation has been established which has limited what substances can be added to foods. The use of additives that can be harmful to human health have now been barred for the best interest of the consumer but as previously mentioned this was not always the case. As a result of such legislation, additives such as calf's brain can no longer be added to cream as a thickening agent (Newton, 2007). This is a major success for the field of food chemistry and would not have been possible if further exploration of this field did not occur.

One scientist who had a notable role in furthering the exploration of this field was Dr. Harvery Washington Wiley. Dr. Wiley was the Chief Chemist of the United States Department of Agriculture from 1882 to 1907 as well as the first Chief Administrator of the Food and Drug Association from 1907 to 1912 (Newton, 2007). One of Dr. Wiley's main contributions to the progression of making food additives safer for consumers was deciding that the United States needed set laws to prevent adulterating food with chemicals that had the potential to cause illness and death upon consumption (Newton, 2007). His research methods were slightly extreme. He experimented on human volunteers and had some ingest poisonous food additives to measure how it would impact their health (Newton, 2007). Although his methods were unconventional and unethical, his research exposed the leniency of laws regarding food adulteration.

Another scientist who had a notable role in furthering the exploration of this field was Dr. Paul Karrer. Dr. Karrer, a Swiss chemist, made major advancements in vitamin research (Newton, 2007). He was able to produce a vitamin artificially. This discovery opened up many opportunities in regard to adding artificially produced vitamins to foods in order to mitigate vitamin deficiencies among certain populations. In many areas of the world, it can be difficult to attain an adequate intake of certain vitamins and minerals due to a lack of access to the foods that contain them (Newton, 2007). Dr. Karrer noted that diseases caused by vitamin deficiencies such as rickets, beri-beri, and pellagra could be avoided by adding artificially produced vitamins to foods that these populations do have access to (Newton, 2007). This logic was able to be successfully applied in the United States to combat goiter also known as iodine deficiency disorder (Newton, 2007). By adding small amounts of iodine to table salt, a product that many Americans used daily, this disease caused a mineral deficiency was able to be eradicated (Newton, 2007). Without Dr. Karrer's research, treating diseases caused vitamin and mineral deficiencies may have been more of a challenge.

Public concern grew as more and more instances of food adulteration came to light. As a result of the public discovering they often ingested substances such as opium, morphine, heroin, cocaine, and/or alcohol in their medicine, it was evident that the consumer needed legislation to protect them and monitor the food and drug producing system and force accountability (Newton, 2007). The demand for accountability in the food-processing system could no longer be ignored. This resulted in the creation of the United States Food and Drug Administration abbreviated as FDA. The original role of the FDA was to evaluate all of the food and drugs that were intended for human use and consumption in the United States (Newton, 2007). Over the years, the role of the FDA has expanded and now includes regulation of medical devices, radiation-emitting products, cosmetics, tobacco products, animal and veterinary, and vaccines, blood, and biologics in addition to food and drugs (U.S. Food & Drug Administration, 2021). The increased role of the FDA directly reflects the increase in the branches of food chemistry throughout the years since it was acknowledged as an independent system.

One noteworthy branch of food chemistry is preservation. As previously mentioned, the technique of preservation has been utilized since the beginning of human life in order to increase the shelf life of food. Preservation techniques include cooking, smoking, freezing, drying, and salting food. These techniques all modify the environment of the food or add something to it which allows it to last longer by discouraging the growth of bacteria (Newton, 2007). The focus of this branch focuses on the composition and the properties of foods as well as the chemical changes that it will undergo during phases such as handling, processing, and storing (Damodaran et al., 2017). This branch relates to food chemistry because food chemists have been able to study and identify these conditions and how to recreate them in order to make food last longer. When considering fresh produce, meat, and even processed foods, it is the role of food chemists to create conditions for transportation and storage that are suitable to sustain residual life processes (Damodaran et al., 2017). This often requires the manipulation or modification of the environment or chemical makeup of a product. Without an understanding of this branch of food chemistry, food may spoil in transport causing them to be unsellable upon arriving at a place where consumers may purchase them such as a grocery store or a restaurant.

Another noteworthy branch of food chemistry is physical food chemistry. This branch focus on predicting and understanding the properties of food at every stage (Walstra, 2003). It considers qualitative relations based on measurable properties (Walstra, 2003). Changes that may occur include those in texture, flavor, color, nutritional value, and safety for consumption (Damodaran et al., 2017). Any one change may cause a series of other changes to follow. It is important to understand which changes cause which reactions and why so that food remains safe for human consumption. The chemical compositions of food can be very complex and having an understanding of physical chemistry is necessary for improving food quality, developing new food resources, evolving food processing and storing techniques, and for increasing food safety (Wang et al., 2012). This branch relates to food chemistry because food chemists have been able to assess and categorize these chemical reactions that occur. Some may be impacted by the presence of certain enzymes. Some might occur because of the presence of liquid. This branch has been able to qualitatively measure such properties and decipher how they will impact a food system as a whole.

An additional noteworthy branch of food chemistry is synthetic food chemistry. The focus of this branch is chemically created additives. Chemical additives may be added to food to enhance the color, flavor, nutritional value, shelf life, and texture (Newton, 2007). The more similar that foods are in composition, the easier the task of predicting food's properties at every stage becomes.This branch relates to food chemistry because by creating these additives themselves, food chemists are able to achieve their desired results in an attempt to make food products more appealing to consumers. This branch helps to remove the guesswork from other stages because the use of chemicals allows for more focused research.

Chapter 2: Food Preservation

Food preservation is a technique that has been used since the beginning of human life. Food can be preserved through a variety of methods such as drying, refrigeration, fermentation, canning, pasteurization, freezing, smoking, irradiation, vacuum packing, salting, and adding chemicals (Desrosie et al., 2018). Chemicals such as synthetic antioxidants, benzoates, nitrites and nitrates are common chemical additives used with the purpose of preserving food. The purpose of utilizing these processes is to prevent perishable food from spoiling which allows food to last longer.

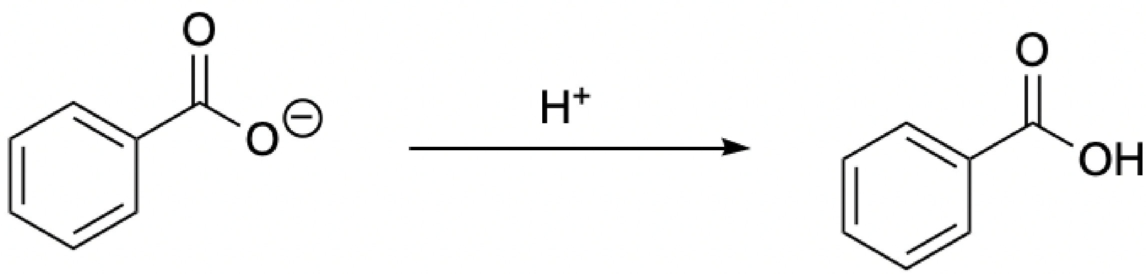
Many factors contribute to food spoilage. Growth of bacteria and other microorganisms as well as physical and chemical changes that occur can make food undesirable or unfit for human consumption (Desrosie et al., 2018). Enzymes that are naturally occurring in food may catalyze reactions which can encourage food to spoil at a more rapid rate (Desrosie et al., 2018). Spoiled food encompases food that has degraded in quality, flavor, nutrition, or texture (Desrosie et al., 2018). Ingestion of such food could cause food borne illness which can be very harmful to a consumer. Foods that offer the conditions desirable for the growth of fungi such as mold and yeast can be very dangerous because these organisms have the ability to form spores which makes them more virulent than other organisms (Desrosie et al., 2018). Halting the growth of these organisms is possible through food preservation techniques. Many food preservation techniques modify bacterial growth environments such as food so that the conditions are not desirable for bacteria to grow or sustain life in.

A common food preservation technique is salting which consists of adding salt or brine to certain foods to prevent them from spoiling as quickly. The main role of salt in preserving food is to dehydrate the food through osmosis. In this process, the salt enters the tissue and the sodium chloride binds to the water present in the tissue which inhibits bacterial growth (Food Processing and Preservation, 2018). This reduces the amount of unbound water available for microbial growth and chemical reactions which increases the shelf life of the food (Boon et al., 2010). Moisture is one of the conditions that bacteria needs to grow and thrive which is why dehydrating food through salting is so effective. Foods that are able to be preserved by adding salt are primarily meat, and fish as well as some vegetables such as cucumbers, runner beans, and cabbage (Food Processing and Preservation, 2018). Aside from preservation when used in moderation salting can also be desirable because it will enhance the natural flavor of the food. Conversely, excessive use of salt may produce an undesirable flavor, color or appearance of food. Many consumers' diets already feature a large amount of salt which can be related to undesirable cardiovascular issues such hypertension and even heart disease (Boon et al., 2010). For this reason, consumers should be aware of the recommended dietary allowance of sodium for their age and gender and consider this when deciding whether to consume foods preserved with salt.

Another common food preservation technique is adding chemicals such as benzoates. Sodium benzoate, a salt of benzoic acid, in particular is a synthetic additive that is commonly used to inhibit the activity of microorganisms and enzymatic reactions that lead to food spoilage (Shahmohammadi et al., 2016). Since it is water soluble, this additive is typically used to preserve liquids as well as margarine, salad dressings, marinades, cider, soft drinks, pickles, fruit salad, wafers, bakery products, jams, jellies, juices, biscuits, cakes, muffins, tomato paste, soy sauce, cheese, some caviar, wine, beer, and olives (Shahmohammadi et al., 2016). The main role of benzoates in food preservation is to add acid. Benzoate is most effective in preserving acidic foods because as a salt it is basic. As seen in figure 1, when benzoic acid is reacted with sodium hydroxide, the product is sodium benzoate.

Figure 1

Acid Base Reaction



Note. Reaction of benzoate (base) with an acid converted to an acid

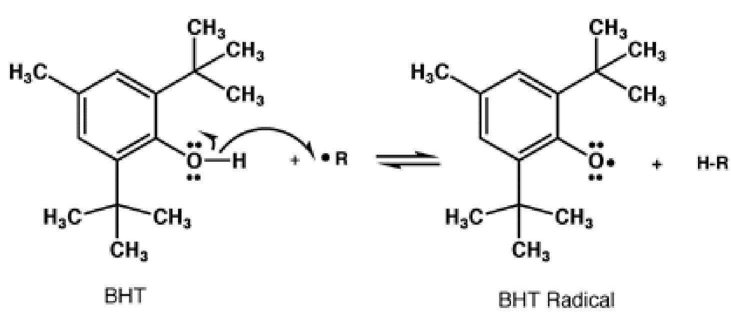
Benzoates manipulate the environment so that it is not inhabitable to bacteria and other microorganisms by altering the pH of the environment. This disrupts the growth of bacteria and enzymes that would allow the food to spoil quicker. When used in a moderate amount, this additive not only increases the shelf life of food but also enhances its flavor. If used at a concentration up to 1%, sodium benzoate will lower the pH of the product too much which will cause an undesirable sour flavor. Some of the negative effects of sodium benzoate when used in excess is that it is linked to attention deficit‑hyperactivity disorder in children as well as impaired memory and motor coordination in mice (Khoshnoud et al., 2018). Despite these links, this chemical is still being added to food because it is generally recognized as safe in the food industry.

Other chemicals that are commonly added to food with the intention of preserving it are nitrates ($NO2$) and nitrites ($NO3$). Nitrites are used more often than nitrates because nitrite is considered the active preservative, but nitrate is known to decompose into nitrite over time. These chemicals are added to food because they are able to protect it from toxin-forming bacteria such as Clostridium botulinum, a spore forming bacteria (Cammack et. al., 1999). They are used in curing and preserving meat and fish as well as the manufacturing of some cheeses (Cammack et. al., 1999). The mechanism of action by which these additives inhibit bacterial growth has been studied for more than 50 years, but despite this, the relationship is still not understood at a molecular level (Cammack et. al., 1999). The decomposition of a nitrite can result in the formation of a nitrosamine which is toxic and can lead to cancer and other illnesses.
Nitrite has three beneficial functions when added to foods such as cured meats: flavor enhancement, color enhancement, and inhibiting the growth of bacteria that would cause the food to spoil (Cammack et. al., 1999). These additives give meat its reddish pink color but grey overtime as nitrite decomposes. Use of synthetically added nitrites have raised safety concerns because when used in high concentrations they are toxic to humans (Cammack et. al., 1999). This is generally concerning, but especially in younger populations such as infants who can experience fatal effects from consuming nitrites in high concentrations (Cammack et. al., 1999). There are also possible links between consumption of nitrates and cancer although it is difficult to establish a clear level of risk associated (Cammack et. al., 1999). As a result of the unclear relationship between nitrite's toxicity to humans and potential of being a carcinogen, the amount of nitrite that is able to be added to food is getting more and more restricted (Cammack et. al., 1999).

Synthetic antioxidants such as benzoates in the forms of Butylated Hydroxyanisole (BHA) and Butylated Hydroxytoluene (BHT) are also commonly added to foods in order to preserve them. These synthetic antioxidants are used to delay or prevent the oxidation of a food, preserve its quality, and maintain its nutritional value which allows it to last longer (Shahidi, 2000). Antioxidants do occur in some foods naturally, but not in large enough quantities to have the same effects of additives in the form of synthetic antioxidants. These additives are found in packaging materials as well as a variant of processed foods such as cereals, sausage, hot dogs, meat patties, chewing gum, potato chips, beer, butter, and vegetable oils (Purdy, 2013). The main role of these additives in food preservation is to stabilize the radical to slow down or control oxidation (Shahidi, 2000). Antioxidants control free radicals by locating them and quenching them so that they can not be oxidized anymore. They produce a new radical which will have four resonance structures meaning they become more stable and less likely to give up a radical.

Figure 2

MOTD BHT



Note. Resonance structure of butylated hydroxytoluene (BHT) antioxidant (*Molecule of the Day: BHT (a Preservative)*, n.d.).

The benefits of preserving food through this technique is that it helps it maintain its color. Produce such as apples will not brown as quickly when treated with antioxidants such as BHA and BHT (Shahidi, 2000). Consumption of naturally occurring antioxidants can be very beneficial because they are perceived to have many health benefits such as preventing heart disease, cancer, cataracts, memory loss, and other conditions (Antioxidants, 2021). There has been growing concern over the synthetic antioxidants such as BHA and BHT being possible carcinogens. As a result of this unknown relationship, the use of BHA as a synthetic additive for food preservation is no longer allowed in Japan (Shahidi, 2000).

Clearly, preserving food through the techniques mentioned above can be very beneficial for both sellers and consumers because it allows the food to last longer. These techniques help maintain a food's quality, flavor, nutrition, and texture overtime so that it remains desirable for consumption. The use of these techniques can help combat premature food spoilage and food borne illness which can be a result of eating spoiled food. However, as mentioned many of these are considered to be controversial because of their links to undesirable health outcomes such as hypertension and cancer. For this reason, many individuals are wary of consuming foods that contain excessive amounts of these preservatives. Processed foods such as those containing benzoates, nitrites, and antioxidants and make up 75 percent of the diet of western societies and each individual is estimated to consume about 8-10 pounds of food additives each year (Shahmohammadi et al., 2016). Clearly, more research needs to be done regarding the safety of consumption of chemical additives considering how commonly they are used and consumed.

Chapter 3: Metabolism of Sugar

Sugar plays a vital role in a human's ability to synthesize adenosine triphosphate (ATP). Through the process of metabolizing or breaking down sugar in various forms, human bodies are able to generate energy which is required in order to perform biological work such as moving, thinking, digesting food, and repairing damaged tissue (Biological Energy Use, Ecosystem Functioning of). This can occur through consuming sugar itself, or through consuming foods that can be broken down to sugar such as carbohydrates.

Carbohydrates are classified as simple sugars or monosaccharides which have the chemical formula of $C_n(H_2O)_n$ and can not be split into smaller carbohydrates (Timberlake, 2015). Carbohydrates are the preferred source of energy for humans because they are easily converted into glucose (Timberlake, 2015). Digestion of carbohydrates begins in the mouth which is the earliest stage digestion can occur. Glucose, $C_6H_{12}O_6$, is one of the most common monosaccharides (Timberlake, 2015). Sugar, specifically glucose, is the body's preferred form because it is the only fuel used by the brain under non starvation conditions as well as the only fuel used by red blood cells (Berg et al., 2002). Glucose is the form of sugar most preferred by the human body because all of the alcohols that are a part of the sugar are in the equatorial position. This means that it is least likely to react with anything; it does not have to break down into simpler sugar molecules when exposed to digestive acids like other sugars have to.

Disaccharides contain two monosaccharides joined together which can be split into two separate monosaccharides (Timberlake, 2015). An example of a common disaccharide is table sugar, $C_{12}H_{22}O_{11}$, which is also known as sucrose (Timberlake, 2015). Disaccharides can be separated in the presence of water or the enzyme disaccharidase.

Polysaccharides contain many monosaccharides which link to form long chain polymers of starch that can split into many separate monosaccharides in the presence of acid or a catalyzing enzyme (Timberlake, 2015). The chemical formula of a polysaccharide is $(C_6H_{10}O_5)_n$ (Polysaccharide, n.d.). Examples of common polysaccharides include glycogen and cellulose (Timberlake, 2015).

The pathway by which glucose is metabolized into adenosine triphosphate (ATP) is known as glycolysis. Specifically, glycolysis is defined as "the sequence of reactions that metabolizes one molecule of glucose to two molecuses of pyruvate with the concomitant net production of two molecuse of ATP" (Berg et al., 2002). Glycolysis occurs in the cytoplasm of the cell. This process can best be explained by focusing on the three stages of glycolysis.

In the first stage of glycolysis, a six-carbon glucose molecule is trapped and destabilized and this stage costs 2 ATP to occur (Berg et al., 2002). In the second stage, the product of stage 1, fructose-1,6-bisphosphate is broken up into two different carbonyl compounds, dihydroxyacetone phosphate and glyceraldehyde 3-phosphate (Berg et al., 2002). The final stage of glycolysis happens twice and in this stage, a total of four ATP are generated (Berg et al., 2002). Since the first step of glycolysis cost two ATP and the final step yielded four ATP, glycolysis has a net gain of two ATP. The key enzymes that catalyze reactions in glycolysis are hexokinase, phosphofructokinase-1, and pyruvate kinase. This is the preferred energy pathway of the human body because it is quicker and simpler than metabolizing other fuel sources such as fats and protein. Consuming carbohydrates or glucose itself will affect blood sugar levels within one to two hours of consumption (Cotton, 2019). All carbohydrates such as bread, rice, pasta, potatoes, vegetables, fruit, sugar, yogurt, and milk can participate in glycolysis because the human body can convert them into glucose (Cotton, 2019). Since the human body converts 100 percent of the carbohydrates consumed into glucose this pathway is very efficient and effective (Cotton, 2019).

Other monosaccharides such as fructose which is naturally found in fruit and galactose can also participate in glycolysis. These sugars must first be converted into glucose-6 phosphate and fructose-6 phosphate respectively which can both be funneled into glycolysis (Berg et al., 2002). Fructose can also be shuttled to the liver where it can also be converted into a substance that the body can actually utilize. For this reason, a diet that features high consumption of the artificial sweetener high fructose corn syrup can be damaging to the liver because it forces it to become overworked and may increase the risk of developing non-alcoholic fatty liver disease (Bryant, 2020). Intake of fructose, especially through artificial sweeteners should be monitored.

Glucose can also be synthesized in the body through gluconeogenesis. Specifically, gluconeogenesis is defined as the synthesization of glucose "from noncarbohydrate precursors such as pyruvate and lactic acid" (Berg et al., 2002). Gluconeogenesis occurs in the liver and in the kidney and helps to maintain sufficient blood glucose levels to meet metabolic demands (Berg et al., 2002). If glucose intake is not adequate enough to meet metabolic demands, the body is able to ensure that ATP can still be synthesized by utilizing stores of glycogen and fat. It is important to note that glycolysis and gluconeogenesis are not simply a reversal of each other (Berg et al., 2002). Glycolysis focuses on glucose while gluconeogenesis focuses on fructose but the two processes are related.

Consuming fuel such as carbohydrates is necessary for humans. The Dietary Guidelines for Americans recommend that carbohydrates should make up 45 to 65 percent of total daily caloric intake (Carbohydrates: How carbs fit into a healthy diet, 2020). Metabolizing sugar such as glucose is required in order to be able to synthesize adenosine triphosphate which is required in order to perform biological work. Consuming an inadequate amount of glucose can impair memory and ability to focus. Since glucose is the body's preferred form of fuel because it can be easily metabolized, consumption of glucose itself or in another form such as carbohydrates is almost necessary for human life. For this reason, glucose is incredibly important in maintaining human life. It should also be noted that sugar should be consumed in moderation and that some foods that are broken down to glucose have more nutritional value than others. Eating a vegetable such as a red pepper that can be converted into glucose is more beneficial than consuming pure glucose itself. A red pepper contains many additional vitamins and minerals that help support proper organ function and other body functions such as vision, the immune system, and reproduction (Office of Dietary Supplements - Vitamin A, 2021). Considering the type of fuel one provides their body with can be beneficial and lead to better health outcomes overall.

Eating too much glucose can negatively impact the human body and cause undesirable health outcomes. Excessive consumption of glucose can lead to high amounts of glucose in the blood also known as hyperglycemia (Hyperglycemia - High Blood Glucose, 2018). This is undesirable especially for those who are diebetic. If too much glucose has been consumed and the body is not able to produce enough insulin or use it properly, this can be very dangerous and could lead to a diebetic coma also known as ketoacidosis (Hyperglycemia - High Blood Glucose, 2018). By being mindful of glucose intake and regularly monitoring blood glucose levels, hyperglycemia can be avoided.

Consuming excessive amounts of glucose can also be very dangerous to cancer patients. This can have a negative impact because glucose is also the preferred fuel source of tumors (Berg et al., 2002). Cancer cells display enhanced rates of glucose uptake because they require much more energy than normal cells and glucose can be easily and quickly synthesized into ATP

(Berg et al., 2002). These abnormal, diseased cells may starve the healthy cells around them in order to invade tissue and metastasize (Berg et al., 2002). By consuming excessive glucose someone with cancer may be inadvertently encouraging their diseased cells to thrive.

Sucrose is another form of sugar that the body can use to synthesize ATP. Sucrose is a disaccharide and a common example of sucrose is table sugar which has the chemical formula $C_{12}H_{22}O_{11}$. Sucrose naturally occurs in sugarcane, sugar beets, sugar maple sap, dates, honey and some fruits and vegetables (Sucrose, 2019). In the presence of water and an acid or an enzyme, sucrose can be split into one molecule of glucose and one molecule of fructose (Timberlake, 2015). Like carbohydrates, enzymes in the mouth begin the process of digesting sucrose however, the majority of metabolization occurs in the small intestine. In digestion, enzymes in the small intestine are responsible for splitting the sucrose molecule into glucose and fructose. As previously mentioned, glucose can participate in glycolysis directly but fructose must be converted into fructose-6 phosphate which is funneled into glycolysis or shuttled to the liver where it can also be converted into a substance that the body can actually utilize (Berg et al., 2002). After participating in glycolysis, the human body will have synthesized ATP that can be used for biological work.

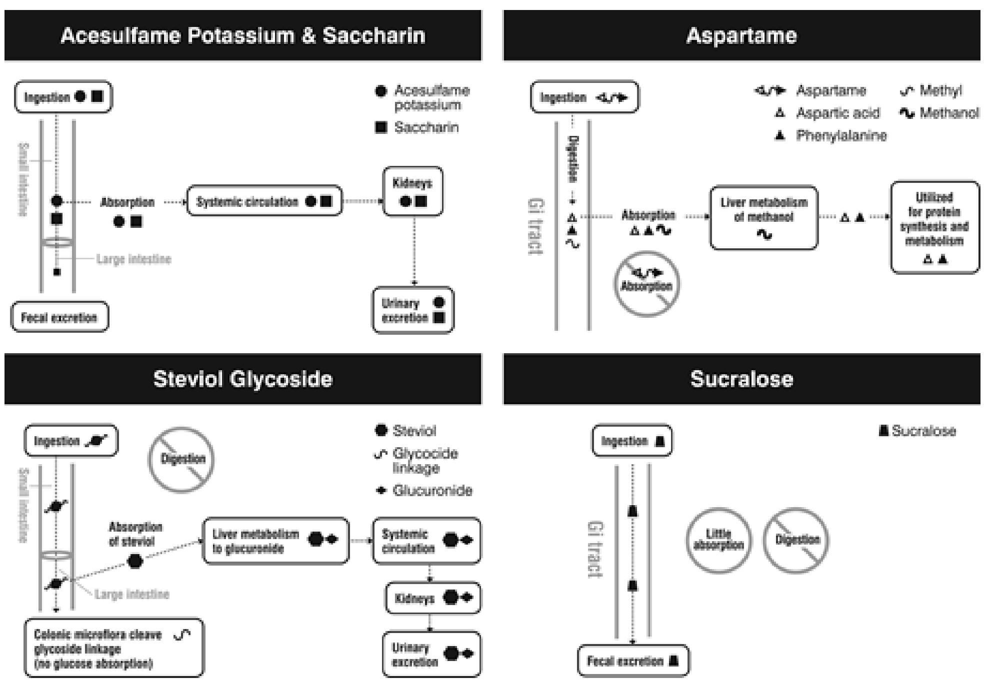
Consuming sucrose helps the body meet metabolic demands by synthesizing ATP and thus plays a necessary role in maintaining human life. Consuming sucrose directly in the form of table sugar can offer the body a quick boost of energy. This can be especially helpful for someone suffering from low blood sugar also known as hypoglycemia (Hypoglycemia (Low Blood Glucose), n.d.). This may occur if caloric intake is not adequate or if the body releases too much insulin after a meal (Hypoglycemia (Low Blood Glucose), n.d.). Since sucrose digestion begins in the mouth and it can be easily converted into glucose which can directly participate in glycolysis, sucrose can have a positive impact on humans. This being said, sugar intake in general should be monitored because of the negative impacts that it can have on the human body when consumed in excess.

Consuming sucrose does offer the body a desirable outcome, synthesising ATP, but excessive sucrose intake is not necessary or recommended. Over consumption of sucrose has been linked to undesirable health outcomes such as diabetes, coronary heart disease, obesity, cavities and hyperactivity in children (Mardis, n.d.). Consuming a sugar such as sucrose in the form of table sugar is not as desirable for the body than another form such as a fruit or vegetable. Consuming sugar is often referred to as consuming empty calories because aside from synthesizing ATP, sugar such as sucrose does not offer additional health benefits that a fruit or vegetable that contains many vitamins and minerals would. For this reason, one should be mindful of the form of sucrose that they consume.

Other forms of sugar such as artificial sweeteners can also be added to foods with the intention of making food more appealing and sweet. These compounds contain little to no calories, are not able to participate in glycolysis, and offer no additional health benefits but are many times sweeter than natural sugar (Pepino, 2015). For this reason, artificial sweeteners can also be referred to as non-nutritive sweeteners (NNSs). Examples of common NNSs include sucralose, aspartame, and saccharin. These sweeteners can be found in candy, baked goods, diet soda, other soft drinks and more (Artificial sweeteners and other sugar substitutes, 2020). NNSs are manufactured specifically so that their structures resemble sugar and taste like sugar. This makes them able to trick the body into thinking that they are sugar, but their structural differences stop them from entering the glycolytic pathway meaning they will not synthesize ATP. The compound sucralose is classified as a chlorinated disaccharide, aspartame is classified as a methylated dipeptide, and saccharin is classified as a benzoic acid sulfimide (Magnuson et al., 2016). Sucralose resembles the structure of natural sugar, but features chlorine which differentiates it from sugar and prevents it from entering the glycolytic pathway (Timberlake, 2015). Aspartame is in the form of a peptide or amino acid but it is capped with a methyl ester so it will not go through glycolysis because of its amino acid sequence (Timberlake, 2015). These structural differences mean that artificial sweeteners are also metabolized by the body differently than normal sugar.

Figure 3

Absorption, Distribution, Metabolism, and Excretion of LNCSs



Note. Major pathways of absorption, digestion, metabolism, and excretion of acesulfame potassium, saccharin, aspartame, steviol glycosides, and sucralose (Magnuson et al., 2016).

Figure three depicts the metabolism of the previously mentioned NNSs sucralose, aspartame, and saccharin. Sucralose goes straight through the human body because the body is not able to recognize that compound. Aspartame is metabolized in the liver and is used for protein synthesis by helping produce amino acid sequences. Saccharin gets absorbed and is processed in the kidneys where glycolysis does not occur then gets excreted.

Non-nutritive sweeteners are generally believed to be healthy sugar substitutes and some are even recognized as safe and use is permitted by the United States Food and Drug Administration (FDA) (Pepino, 2015). Despite the baking of the FDA, negative health impacts have been linked to these sugar substitutes. Excessive consumption of added sugar, especially manufactured artificial sugar, can lead to high blood pressure, inflammation, weight gain, obesity, diabetes, and fatty liver disease (Harvard Health Publishing, 2019). These conditions increase risk of heart attack and stroke. (Harvard Health Publishing, 2019). It has also been hypothesized “that the use of NNSs eakens the ability of sweet taste to predict energy and evoke autonomic and endocrine learned responses that prepare the digestive tract for the optimal process of ingested food, such as the cephalic response” which prepare the gastrointestinal tract for the optimal digestion of ingested foods (Pepino, 2015) For these reasons, sugar consumption, especially added artificial sugar consumption, should be monitored.

Clearly, consumption of sugar in some form is very important to maintain human life. Glucose is one of the most important sugars because of its ability to participate in glycolysis and synthesize adenosine triphosphate. Once being converted to glucose-6 phosphate and fructose-6 phosphate, fructose and galactose can also participate in glycolysis and synthesize ATP. Gluconeogenesis uses stores of glycogen and fat to synthesize glucose which insure that sufficient blood glucose levels are maintained so that metabolic demands can be met. Sugar intake should be monitored and should not exceed necessary amounts as excessive intake can have undesirable health outcomes. Added sugar especially should be monitored because despite many being recognized as safe by the FDA, excessive consumption can have a negative impact on health.

Chapter 4: Genetics and Diet

Nutrigenomics (or nutritional genomics) is the evolving study of the effects of nutrients on the gene expression of an individual's genetic makeup (Nathaniel Mead, 2007). It focuses on how nutrients affect gene expression and how genetic variation affects nutrient response (Nielsen & El-Sohemy, 2012). The study of nutrigenomics has brought awareness to the dietary approach of an individual eating for their specific genome. With the increase in availability of direct-to-consumer genetic tests ranging from $99 to over $2000, following a diet that considers one's DNA is more accessible than ever (Nielsen & El-Sohemy, 2012). Different people respond to various diets in different ways; it has been hypothesized that this is a result of genetic differences among individuals. It is also believed that gene expression as a response to the metabolic process could influence an individual's health (Pavlidis, et al., 2015). Since it is widely understood that everyone does not respond similarly to the same dietary interventions, demand for personalized nutrition that is designed and prescribed to an individual based on their genome and their genetic makeup has increased (Pavlidis, et al., 2015).

Nutrients are able to impact gene expression because they are like signaling molecules that transmit and translate dietary signals into gene, protein, and metabolite expression through the appropriate cellular sensing mechanisms (Pavlidis, et al., 2015). This means that not eating enough of certain foods and nutrients, or eating too much of certain foods and nutrients, can greatly impact the gene expression of an individual. For further clarification, provided below is an example that considers impact on gene nutrient association. The rd5128 genotype has shown significant interaction with intake of fast food, salty snacks, and soft drinks and is related to metabolic syndrome risk (Pavlidis, et al., 2015). This association suggests that individuals who have the rd5128 genotype should moderate their intake of those foods to decrease their risk of developing heart disease, stroke, type 2 diabetes, increased blood pressure, high blood sugar, excess body fat around the waist, and abnormal cholesterol or triglyceride levels (Pavlidis, et al., 2015). In this example, DNA testing would be able to identify whether someone has this genotype or not and would direct them to a certain diet with this information in mind which could lead them to a more desirable health outcome.

The relationship between diet and health is one that has been studied for many years since the two are undeniably related. Since this realization, the relationship between diet and health has continued to gain attention. Commercialized nutrigenomics dates back to the 1980s (Neeha & Kinth, 2012). Nutrigenomics became more established in the 1990s through The Human Genome Project which sequenced the entire DNA in the human genome (Neeha & Kinth, 2012). The Human Genome Project uncovered the need for more personalized nutrition (Pavlidis, et al., 2015). More recently, in 2007, scientists discovered numerous correlations between genes, nutrition, and disease which is formally referred to as nutrigenomics (Neeha & Kinth, 2012).

Many of the early findings surrounding nutrigenomics focused on single-nucleotide polymorphisms (SNPs). SNPs are DNA sequence variations which are the most common type of genetic variation because they account for 90% of all human genetic variation (Nathaniel Mead, 2007). These variations occur when a single nucleotide, adenine (A), cytosine (C), guanine (G), or thymine (T), replaces another (SNPs: VARIATIONS ON A THEME, n.d.). SNPs can serve as biological markers for identifying disease within the human genome because they are typically located near genes associated with certain diseases (SNPs: VARIATIONS ON A THEME, n.d.). As a result, these genes are assumed to have the ability to alter the risk of developing a disease (Nathaniel Mead, 2007). Certain factors such as diet may also alter the effects of SNPs to increase or decrease disease risk supporting the suggestion that diet and health are truly directly related and may impact each other more than consumers think.

A leading force in the field of nutrigenomics is Dr. Michael Fenech, a research scientist at the CSIRO Genome Health and Nutrigenomics Laboratory in Adelaide, Australia (Nathaniel Mead, 2007). Dr. Fenech has been recognized internationally for his research in nutritional genomics and genetic toxicology (Michael Fenech, PhD., n.d.). Dr. Fenech agrees evidence exists supporting the idea ""that genome instability, in the absence of overt exposure to genotoxicants, is itself a sensitive marker of nutritional deficiency"" (Nathaniel Mead, 2007). Throughout their research, Dr. Fenech's team works toward their goal of being able to diagnose and naturally prevent DNA damage through nutrigenomics (Nathaniel Mead, 2007).

Throughout time, the field of nutrigenomics has progressed and advanced however research is still ongoing. Skepticism of many of the findings in this field has exemplified that further research is necessary in order to back many of the claims of nutrigenomics. The possibility of being recommended a diet through nutrigenomics has become more available to consumers than ever because of at home DNA tests. With the use of emerging sequence technology, individuals can become aware of their full-genome sequencing at a reduced cost in a shorter period of time. This has made nutrigenomics more accessible for all consumers. This testing has even become more specific in the past years. The field has expanded past focusing on SNPs. Now, even more variations in DNA can be measured and tens of thousands of SNPs, copy number variants, and many RNA molecules are able to be considered in nutrigenomics (Nathaniel Mead, 2007). Technology now exists that can provide detailed reports into the molecular makeup of an individual (Nathaniel Mead, 2007).

Future findings in this field will continue to evolve as research progresses and becomes more specialized. With access to more advanced technology and more thorough research, Dr. Michael Fenech and his team will be more successful in achieving their goal of being able to diagnose and naturally prevent DNA damage through the use of nutrigenomics (Nathaniel Mead, 2007). He and many other health professionals will be able to use nutrigenomics to prevent or even reverse genomic damage and abnormal gene expression (Nathaniel Mead, 2007). Overall, the future application of nutrigenomics is very promising.

The field of nutrigenomics has the potential to be a great tool for health care professionals such as nutritionists, registered dietitians, and doctors as nutrition therapy to treat certain diseases, especially those that are diet related (Pavlidis, et al., 2015). This field could also help prevent certain diet related diseases from even occurring in the first place (Pavlidis, et al., 2015). This could be very beneficial in addressing diseases such as obesity, diabetes, high triglycerides, and high cholesterol levels which are widely believed to be associated with an individual's genetic profile (Pavlidis, et al., 2015). There is undoubtedly public interest in information regarding gene-diet-disease interaction. Many consumers are very open to trying nutrigenomics and believe that they will see positive health outcomes as a result of following a diet that is tailored to their specific genome. One study cited that of individuals surveyed, 90% of participants selected either "strongly agree" or "somewhat agree" to the statement "interest in the relationship between diet and genetics is high" (Nielsen & El-Sohemy, 2012). In the same study, 87% of participants agreed that they would benefit from learning about how their genetic makeup would affect their diet and 75% agreed that learning about their genetic makeup would affect what they ate (Nielsen & El-Sohemy, 2012). Participants reported that they were motivated to partake in genetic testing to learn more about themselves and encourage them to adopt healthier lifestyles and that understanding their genome would make this a more feasible option for them (Nielsen & El-Sohemy, 2012).

Following a genetic based diet curated from the results of genetic testing might be beneficial for those afflicted with certain chronic diseases. For example, someone with inflammatory bowel disease (IBS) will most likely also experience low zinc levels since that is a characteristic of IBS (Pavlidis, et al., 2015). An individual in this situation might be able to benefit from taking a DNA test and following a diet that considers nutrigenomics based on the results of their genetic makeup. This diet could be tailored to their dietary needs and may help them control certain symptoms of their disease. For those with IBS, increasing zinc intake through diet or supplementation has been shown to significantly improve intestinal barrier function and prevent relapse in those who showed an intestinal response to deficiency (Pavlidis, et al., 2015). Addressing this deficiency could help those affiliated with IBS have more control over helping themselves and controlling their own symptoms.

Individuals who are lactose intolerant could also benefit from following a diet that considers nutrigenomics based on the results of their genetic makeup. Lactose intolerance is an example of a nutrient gene interaction. Individuals with lactose intolerance experience a genetic variation in the lactase glands which prevents an adequate amount of the enzyme lactase from being produced (Pavlidis, et al., 2015). This prevents lactose, the sugar in dairy products, from being efficiently digested and broken down (Pavlidis, et al., 2015). An individual in this situation might be able to benefit from taking a DNA test and following a diet that considers nutrigenomics based on the results of their genetic makeup. If they are not already aware of this genetic variation, this knowledge could be very beneficial and would allow them to alter their diet to accommodate for this (Pavlidis, et al., 2015).

On the other hand, some argue that there is a lack of scientific evidence supporting nutrigenomics. This field is seen as controversial by some and has been criticized due to a lack of research supporting many aspects of the field. Current nutrigenomics is still seen as "too green" by some. They might argue that it simply brushes the surface and offers a glimpse into a larger realm and may not seem specific or regulated enough for proper application. These naysayers recognize the complexity of nutrigenomics and criticize it for not considering environmental factors that could impact gene nutrient association (Pavlidis, et al., 2015) They might argue that other factors such as emotional, economic, metabolic, social, and more may affect someone's chance of losing weight more than their genes would. Links that associate the genes usually examined in nutrigenomics testing and various diet-related diseases are weak (Pavlidis, et al., 2015). This has also been noted by some health care professionals who remark that many other factors such as the genes, the gene protein/ protein network, and determining universal guidelines of certain nutrients' influence on gene and protein expression should be considered (Pavlidis, et al., 2015).

Some may argue that an increase in the availability of direct-to-consumer genetic tests makes nutrigenomics too accessible which makes it lose its personalized touch. An individual can become aware of their exact biological makeup by simply ordering a DNA test online without the direct participation or consultation of a healthcare professional. DTC genetic testing can occur without in person contact, which seems dangerous to some. Being mailed or emailed a report with certain dietary suggestions as a result of one's genotype without the opportunity to discuss these suggestions and results with a medical professional could be confusing. If results offer vague nutrition advice, it may be difficult for a consumer to interpret what the results mean and how they might be able to change their lifestyle to accordance with these recommendations.

As a result, individuals may misinterpret their results and participate in health interventions that are not even necessary. However, one study noted that this was not the case and suggested that dietary recommendations based on genetics can be more understandable than general dietary recommendations because these guidelines are more clear and personalized.

Many studies have been conducted that do not support certain claims of nutrigenomics such as eating for your genome. One study that evaluated food response hypothesized that if genetics plays such a large role in food response then identical twins should have a similar response, but this was not the case (Reinagel, 2019). They were able to conclude that genetics appeared to account for less than a third of the subjects' insulin and triglyceride responses which does not support nutrigenomics (Reinagel, 2019). They found that factors such as sleep habits, exercise, stress, and gut microbes played a larger role than genetics on individual diet response (Reinagel, 2019). This finding is reassuring for consumers because factors such as sleep habits, exercise, and stress can all be controlled by consumers themselves. This suggests that considering a diet and habits that fit individual needs, preferences, and lifestyle may be more beneficial than one that considers an individual's genetic makeup.

Another example of a study that does not support certain claims of nutrigenomics consisted of 424 overweight adults who were randomly assigned either a healthy low-fat or healthy low-carb diet (Begley, 2018). After following the diet for a full 12 months, researchers looked into participants' individual genome to see how many had been randomly matched to the right diet for their DNA and who had been matched to the wrong diet. Their outcomes were compared to see if those who had been matched to the correct diet had more success with weight loss than those who had been matched to the wrong diet (Begley, 2018). A total of 227 participants had been matched to the correct diet for their DNA (Begley, 2018). They found that

There was no significant difference in weight change among participants matched vs mismatched to their diet assignment which again does not support nutrigenomics (Begley, 2018).

Nutrigenomics, the evolving study of the effects of nutrients on the gene expression of an individual's genetic makeup, has provided an opportunity for the exploration of the relationship between diet and health (Nathaniel Mead, 2007). As this field continues to progress, so does the appeal of personalized nutrition since it is becoming more readily available. Links between diet and health are undeniable and the future findings of this field could play a large role in preventing and treating certain diseases, especially those that are diet related. This field will remain controversial until further research can be conducted. It is evident that more research is needed to support many of the claims of this field and to provide more regulation.

Chapter 5: Conclusions

Before beginning this directed study, my knowledge regarding the field of food chemistry was very limited. Writing the first chapter broadened my knowledge by defining food chemistry, recounting the history and evolution of food chemistry, discussing food adulteration, and identifying some of the notable branches related to food chemistry. I now understand that food chemistry is the study of the composition and the specific properties of food when considering the chemical changes that it undergoes during processes such as handling, processing, and storing. It is necessary for food producers and sellers to consider food chemistry in order to ensure freshness for consumers. The conditions that food is exposed to are also important to take into consideration as to guarantee food remains safe and desirable for human consumption. A subject area in this chapter that I found interesting was food adulteration, the modification of food by adding substances. Although adding substances to food can be beneficial for preservation, flavor improvement, color enhancement, and increased nutritional value, it can also be harmful to consumers. Some food producers use this technique as a means to cut costs. They may replace one or multiple ingredients in a product with a more inexpensive ingredient in order to increase profit. This can be especially dangerous when ingredients are replaced with those which are not intended for human consumption such as chalk, cattle fodder, sand, and sawdust. Throughout the evolution of food chemistry, this area has become more heavily regulated to protect consumers which is reassuring to know.

The second chapter focused on different mechanisms of food preservation. Many of the techniques discussed have been used since the beginning of human life. The utilization of these techniques is helpful in preventing perishable food from spoiling which allows them to last longer. Many of these mechanisms alter environmental factors in order to make the environment less supportive of bacterial growth. One specific technique I found interesting was salting. In this technique, salt or brine is added to a food to prevent it from spoiling as quickly. This works because the salt is able to dehydrate the food through osmosis; the salt enters the tissue and the sodium chloride binds to the water present in the tissue which inhibits bacterial growth. This reduces the amount of moisture available which reduces microbial growth. This technique has been used for centuries because salt is so accessible. Salt is not a synthetically produced food additive and can be used by anyone wary of consuming chemical additives. Salting not only acts as a preservation mechanism, but it also enhances the natural flavor of food. This is an added benefit of using this technique which makes it very desirable to food producers.

The third chapter focused on the metabolism of sugar. Sugar plays a pivotal role in a human's ability to synthesize adenosine triphosphate (ATP). ATP is required for performing biological work such as moving, thinking, digesting food, and repairing damaged tissue. The body is able to synthesize ATP through the process of breaking down food. One topic that interested me in this chapter was gluconeogenesis. Although I had a basic understanding about what gluconeogenesis was, I now understand the mechanism behind why and how it occurs. Gluconeogenesis is the process by which the body synthesizes glucose. It occurs in the liver and the kidney. It occurs if glucose intake is not adequate enough to meet metabolic demands. This mechanism ensures that metabolic demands can be met even if glucose intake is not adequate by synthesizing glucose from stores of glycogen and fat which ultimately synthesizes ATP. Artificial sweeteners such as sucralose, aspartame, and saccharin were also discussed in this chapter. Artificial sweeteners contain little to no calories, are often many times sweeter than natural sweeteners, and are not able to participate in glycolysis. As a result, they all have different mechanisms by which they are metabolized in the body. Learning about their structures and how certain aspects of their structure differentiated them from natural sugar and stopped them from participating in glycolysis was very interesting. This was something that I had no understanding of before.

The fourth chapter discussed nutrigenomics, the evolving study of the effects of nutrients on the gene expression of an individual's genetic makeup. Nutrigenomics focuses on how nutrients affect gene expression and how genetic variation affects nutrient response. Nutrigenomics is so desirable to many individuals because it offers the opportunity for personalized nutrition. I had never heard of nutrigenomics or eating for your specific genome before and was very interested in better understanding this field of study. Something that I found over and over while researching this field was the general consensus that since the field is still so new, more research is needed regarding the ability of certain nutrients to impact gene expression. While the relationship between diet and health is undeniable, more research is needed to support many of the claims of this field and to provide more regulation. As someone who is lactose intolerant, having tools available to identify such nutrient gene interactions intrigues me. Had I known that I was lactose intolerant earlier in my life, I could have made dietary changes much earlier and avoided years of gastrointestinal issues.

Understanding what food chemistry is and how it can be applied will benefit me greatly as a hopeful future registered dietitian. Chemistry and nutrition are very strongly related so having even minimal exposure to the field of food chemistry will help me be a learned registered dietitian. This exposure is not only applicable to my personal interest but also the interest of future patients. Having an understanding of many of the topics that were discussed such as food adulteration, metabolism of sugar, and nutrigenomics could help me when providing the proper nutrition care to future patients.

Understanding food adulteration has allowed me to add another reason to my list of why you should be able to read and understand nutrition facts labels on food. Learning about food adulteration has shown me that food companies do not always have your best interest in mind especially when it comes to saving money. Being able to read and understand a nutrition facts label will empower a consumer to take responsibility for what they put into their body and not to leave it up to a food company. If a consumer does not want to eat chemically engineered food additives, being able to recognize them in a list of ingredients allows the consumer to be in control of this aspect of their life.

Having an understanding of the metabolism of sugar may be the most notable in terms of application for future patients. Glycolysis, the pathway by which glucose is metabolized into adenosine triphosphate (ATP) is the quickest and simplest way for the body to synthesize ATP. Knowing that sugar, specifically glucose, is the body's preferred form because it is the only fuel used by the brain under non starvation conditions as well as the only fuel used by red blood cells is very important. Many individuals believe that carbohydrates offer no nutritional benefits and simply turn into fat when they are consumed but this is not the case. When consumed in moderation, carbohydrates are metabolized to glucose which synthesizes ATP to fuel the body. Starving the body of carbohydrates can cause brain fog which is not ideal. Knowing this could help me explain to patients why adequate carbohydrate and sugar intake can be essential to adequate energy production.

Understanding nutrigenomics could also help me as a future registered dietitian as personalized nutrition grows in popularity and accessibility. I can work one on one with patients and offer them the personalized nutrition that they are seeking in a more safe setting. The results of a DNA test that someone could purchase on the internet that offers nutritional advice could be misinterpreted and result in participation in unnecessary health interventions. Where the dietary recommendations of a genetic test may be generalized and vague, I could offer more specific personalized recommendations that could be modified at any time. A patient would actually be able to have a conversation with me regarding my recommendations and have the opportunity to ask any questions which would not be possible a direct to consumer gene test. Actually understanding why they should participate in a health intervention may be more motivational for a patient and having someone to check in with is added accountability that is not an opportunity that a direct to consumer gene test offers.

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