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An Interdisciplinary Approach in Integrated Science Studies: Using Webbed Models to Understand Biotechnology Content

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Abstract:

This article discusses the application of an interdisciplinary approach in the study of biotechnology through webbed models. By integrating concepts from different disciplines such as biology, chemistry, and physics, this model allows for a more holistic understanding of complex interactions in biotechnology processes. This research highlights the content of biotechnology that can be discussed integratively, including aspects of metabolism and microorganisms in fermentation processes from a biological perspective, Maillard reactions and acid-base salts from a chemical perspective, and heat transfer and diffusion from a physics perspective. In addition to the challenges of interdisciplinary communication, this article also identifies opportunities that can be leveraged through information and communication technology to support collaboration. It is hoped that this approach can improve students' skills and prepare them to face the complexities of the ever-evolving world of biotechnology.

Keywords: Interdisciplinary Approach, Webbed Model, Biotechnology

Introduction:

In the era of globalization and rapid technological development, science education faces increasingly complex challenges. Science and technology are constantly evolving, and students need to be prepared to face these changes with a deep understanding and relevant skills (Susianita & Riani, 2024). Therefore, an interdisciplinary approach in the learning of Natural Sciences (IPA) is becoming increasingly important. This approach ot only teaches students about scientific concepts separately, but also integrates various disciplines to provide a more holistic understanding (Zakarina & Ramadya, 2024). One way to achieve this integration is through integrated science learning, which combines elements from chemistry, physics, and biology in relevant contexts (Irda Sukmawati Dewi, 2021). Integrated science learning allows students to see the relationships between different disciplines and how they interact with each other in everyday life (Risdalina & Yusnaidar, 2019). With this approach, students not only learn theory, but also understand the practical applications of scientific concepts.

The webbed model, introduced by Fogarty (1991), is one of the effective methods in integrated science learning. This model integrates a wide range of disciplines through central themes that are relevant to the student's environment and culture (Damayanti et al., 2023). Using the webbed model, students can explore the relationships between chemical, physical, and biological concepts in real-world contexts, thereby improving their understanding of the material being studied (Widharnati et al., 2022). In the context of biotechnology, webbed models can be used to introduce basic concepts of biotechnology in an interesting and relevant way (Sasmita et al., 2023). Biotechnology is a field that combines the principles of biology, chemistry, and physics to study biological processes and their applications in everyday life. By associating biotechnology with traditional foods, such as seblak, students can see the relevance of scientific concepts in their lives. Seblak, as a traditional Indonesian dish, is a good example to illustrate the application of biotechnology. The process of making seblak involves fermentation, which is a clear example of the interaction between microorganisms and foodstuffs. In this context, students can learn the role of microorganisms in fermentation, as well as the chemical changes that occur during the process. Through learning that connects chemistry, physics, and biology with traditional food themes such as seblak, students can gain a deeper understanding of scientific concepts (Juriyah, 2021). For example, they can study the chemical reactions that occur during fermentation (chemistry), the influence of temperature on the activity of microorganisms (physics), and the role of microorganisms in the fermentation process (biology) (Sinaga & Anas, 2022). This approach not only provides conceptual understanding, but also encourages students to think critically and analytically. The importance of an interdisciplinary approach in science education cannot be ignored. By integrating various disciplines, students can develop critical thinking, problem-solving, and decision-making skills (Virlya Citra Dewi et al., 2021). Juriyah (2021) emphasizing that relevant and contextual education can increase students' motivation to learn, as they feel that what they learn is directly related to their daily experiences.

Webbed models in biotechnology studies based on local cultures, such as seblak making, provide students with the opportunity to develop the skills necessary to face real-world challenges (Nurjanah & Mukarromah, 2021). By understanding how scientific concepts are applied in their cultural contexts, students can more easily relate learning to everyday life (Fauzi, 2022). In addition, this approach can also increase student involvement in the learning process. When students feel that the material they are learning is relevant to their lives, they tend to be more motivated to learn and actively participate in learning activities (Purnamasari, 2020). This can create a more dynamic and interactive learning environment. However, the application of an interdisciplinary approach in science education requires adequate support from various parties (Priscylio & Anwar, 2019). Teachers need to be equipped with the necessary training and resources to effectively implement the webbed model. In addition, the curriculum also needs to be adjusted to support the integration of various disciplines in learning.

Overall, the interdisciplinary approach in science learning through the webbed model offers great potential in improving the quality of education (Aulia et al., 2023). By integrating chemistry, biology, and physics in a cultural context such as making seblak, students can understand scientific concepts in an applicative, relevant, and meaningful way (Prayuda & Ratnawulan, 2019). The application of this approach not only enriches the learning experience of students, but also prepares them to face future challenges (Damayanti et al., 2023). In the context of education in Indonesia, it is important to develop a curriculum that supports this interdisciplinary approach. A curriculum that is flexible and responsive to students' needs will allow teachers to integrate various disciplines more effectively. Thus, students will have a richer and more rewarding learning experience (Nugraha, 2022).

In this study, the authors will explore the application of the webbed model in the context of biotechnology by analyzing the various components involved and the interactions between them. This article will also present concrete examples of biotechnology applications that use an interdisciplinary approach, as well as discuss the challenges and opportunities faced in interdisciplinary collaboration. The main objective of this article is to provide insight into the importance of an interdisciplinary approach in the study of biotechnology, as well as to highlight the role of education in preparing the next generation of scientists who are capable of facing the complexities of this field. It is hoped that this article can be a reference for researchers, educators, and practitioners to encourage more significant advances in biotechnology and provide greater benefits to society.

Method:

The research method used in this study is a literature review. Literature review is an approach that aims to collect, analyze, and synthesize information from various secondary sources relevant to the research topic. In this context, the main focus is on interdisciplinary learning in the Natural Sciences (IPA), webbed learning models, and biotechnology concepts. By using this method, researchers can gain a deeper understanding of the integration of various disciplines in education. The flowchart of this research is as follows.

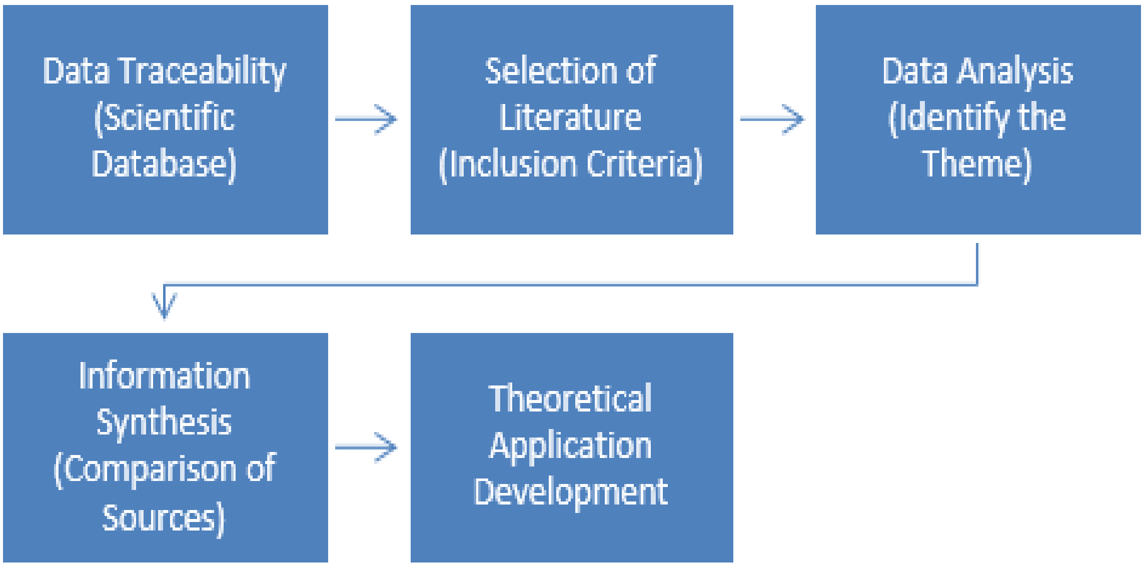

Figure 1. Research Flowchart

Data for this study were collected from scientific journal articles related to the topic being studied. Literature searches were conducted through leading scientific databases, such as https://link.springer.com, using specific keywords such as "interdisciplinary science education," "webbed model," "biotechnology in food education," and "local culture in education." The selection of literature is based on strict inclusion criteria, including relevance to the research topic, availability of empirical data, and reliability of sources. Priority is given to publications published in the last five years to ensure that the information obtained is current and relevant.

Data analysis is carried out by reading and critically evaluating the content of the literature. This process aims to identify key themes that support the research objectives. Data from various relevant literature are then categorized into several themes, such as the integration of chemistry, physics, and biology in science learning, the implementation of webbed models, and the use of biotechnology in the context of local culture, such as the creation of seblak. In this way, researchers can organize the information obtained to facilitate further understanding and analysis. The synthesis process is carried out by comparing and connecting information from various sources to get a holistic and in-depth picture. The validity of the data is maintained by ensuring that the literature sources used have gone through a peer review process or been published by a credible academic institution. It is important to ensure that the information presented in this study is accountable and has a solid basis. By using this literature review method, the research aims to compile an applicable theoretical guide regarding the integration of interdisciplinary approaches in science learning, especially in the context of biotechnology based on local culture. The results of this study are expected to make a significant contribution to the development of a more relevant and contextual educational curriculum, as well as improve students' understanding of scientific concepts through a more integrated approach.

Findings and Discussion:

This study aims to explore the integration of the concept of biotechnology in integrated science education using a webbed model. The results show that this approach has succeeded in improving students' understanding of complex scientific concepts. Biotechnology content can be discussed integratively based on the integration of Biology, Chemistry, and Physics. Physics is applied in the concepts of heat transfer and diffusion (osmotic pressure), Chemistry is applied in the concepts of Maillard reactions and acid-base salts, whereas Biology is applied in the concepts of metabolism and microorganisms in fermentation processes. The Webbed model in Biotechnology Content is described in Figure 2.

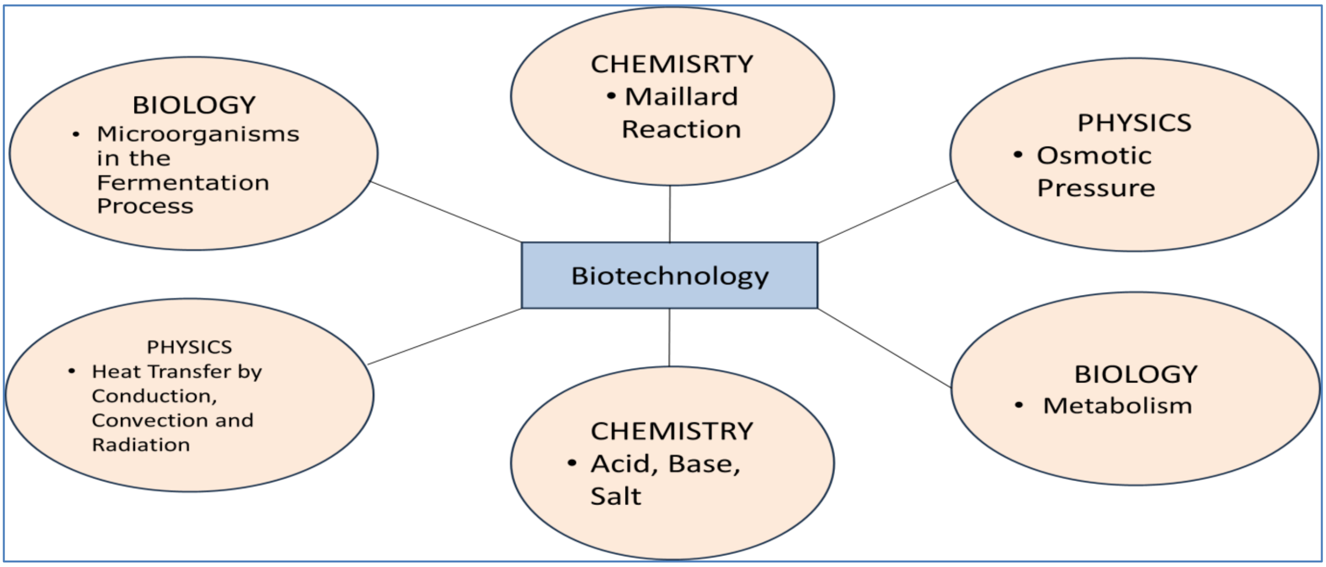

Figure 2. Biotechnology Content Webbed Model

Heat Transfer

Heat transfer is a property of all matter composed of atoms and molecules. Atoms are constantly moving in various ways. Heat or heat energy is produced by the motion of atoms and molecules, and it exists in all matter. Heat energy increases with the amount of molecular mobility. On the other hand, heat transfer is the process by which heat energy moves from an object with a high temperature to one with a low temperature. The definition of heat transfer in thermodynamic systems is "the movement of heat across the boundaries of a system due to the temperature difference between the system and its surroundings." The 'potential' that drives heat transmission from one location to another is this temperature differential. There are various ways that heat can travel from one location to another. Conduction, convection, and radiation are some of the different ways that heat is transferred. Heat will transfer from the hotter system to the colder system if the two systems have different temperatures (Budiyanto et al., 2019). The heat transfer process is described in Figure 3.

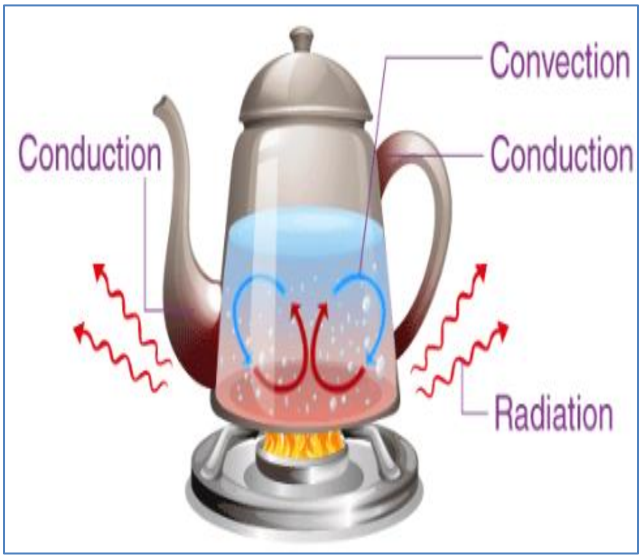

Figure 3. Heat Transfer - Radiation, Convection, and Conduction

Conduction It is described as the process of moving energy between particles in a medium when they are in close proximity to one another. Heat energy is transferred from regions with higher kinetic energy to regions with lower kinetic energy. Slower-moving particles gain kinetic energy when they collide with high-velocity particles. It is a common way that heat is transferred through physical touch. Conduction is sometimes referred to as heat conduction or thermal conduction (Eswanto et al., 2022). The conduction rate can be calculated by the following equation:

$$Q = \frac{[K.A.(T_{hot} - T_{cold})]}{d}$$

Where:

(Q) is the heat transfer per unit time

(K) is the thermal conductivity of the material

(A) is the heat transfer area

(Thot) is the temperature of the hot region

(Tcold) is the temperature of cold areas

(d) is the thickness of the material

According to the coefficient of thermal conductivity, metallic materials are better at conducting heat than non-metallic ones. An illustration of conduction Heat is transferred from the iron to the clothing when it is ironed. When ice cubes are held in the hand, heat is transferred from the hands to the cubes, causing them to melt. It is possible to feel the heat moving through the beach's sand in the summer. Sand is an excellent heat conductor (Saputra & Aziz, 2019).

Convection is the transfer of fluid molecules from an area of greater temperature to one of lower temperature. Thermal expansion is the phenomenon wherein a liquid's volume grows in tandem with its temperature. The equation for calculating the convection rate is as follows:

$$Q = h_c.A.(T_s - T_f)$$

Where:

(Q) is the heat transferred per unit of time

(hc) is the convective heat transfer coefficient

(A) is the heat transfer area

(Ts) is the surface temperature

(Tf) is the temperature of the fluid

Boiling water is an example of convection, where denser molecules travel downward and less dense ones move above, creating a circular motion. Cooler water at the poles moves toward the equator, while warmer water near the equator moves toward the poles. Convection helps warm-blooded animals circulate their blood, which in turn helps control body temperature (Gani & Taufiqurrahman, 2021).

Radiation is the process of heat transfer that takes place when electromagnetic waves are released. The haphazard motion of molecules in matter generates thermal radiation. These waves can pass through transparent materials, such as liquid or solid, or through a vacuum. A thermocouple, a device used to monitor temperature, is used to measure thermal radiation. However, using radiant heat transfer to measure temperature might lead to mistakes. The wavelength in the radiation spectrum that is released decreases with increasing temperature, and shorter wavelengths of radiation are released. Thermal radiation can be calculated by Stefan-Boltzmann's law:

$$P = e . \sigma . A . (T_r - T_c)^4$$

Where:

(P) is the net strength of the radiation

(A) is the radiation area

(Tr) is the temperature of the radiator

(Tc) is the ambient temperature

(e) is emissivity

(σ) is Stefan's constant ($\sigma = 5.67 \times ^{10\text{-}8Wm\text{-}2K\text{-}4}$)

Examples of radiation: Microwave radiation emitted in an oven, UV light coming from the sun, Release of alpha particles during the decay of Uranium-238 to Thorium-234 (Eswanto et al., 2022).

Osmotic Pressure

Osmotic pressure is the lowest pressure necessary to stop pure solvent solution from passing through the semipermeable membrane and entering the membrane. The osmosis index, which gauges a solution's propensity to absorb pure solvents, is another name for this. Potential osmotic pressure is the maximum osmotic pressure that a solution can produce if it is isolated from its pure solvent by a semipermeable membrane (Ramli & Wahab, 2020). Osmosis happens when two solutions with different solute concentrations are separated by a selectively permeable membrane. The solvent molecules pass through the membrane selectively from a solution with a low concentration of solute to one with a larger concentration. Until equilibrium is achieved, the solvent molecules will keep moving. The lowest pressure required to stop solvent molecules from passing through a semipermeable membrane (osmosis) is known as osmotic pressure. The concentration of solute particles in the solution determines this colligative behavior. Osmotic pressure can be calculated with the help of the following formula:

$$\pi = iCRT$$

Where

(π) is osmotic pressure
(i) is the Van't Hoff factor
(C) is the molar concentration of solute in solution
(R) is a universal gas constant
(T) is the temperature

Dutch chemist Jacobus van't Hoff proposed a connection between a solution's osmotic pressure and the molar concentration of its solute. It is crucial to remember that this equation only holds true for solutions that exhibit optimal behavior. 'Osmosis' is the process by which solvent molecules flow from a region with a low solute concentration to one with a high solute concentration across a semipermeable membrane. Ultimately, a balance is achieved between the semipermeable membrane's two sides (the solute concentration is the same on both sides). Only solvent molecules can flow through semipermeable membranes; solute particles are unable to do so. The osmosis process is halted if enough pressure is applied on the side of the semipermeable membrane solution. Osmotic pressure is the lowest pressure necessary to stop the osmosis process (Musliman & Damayanti, 2023).

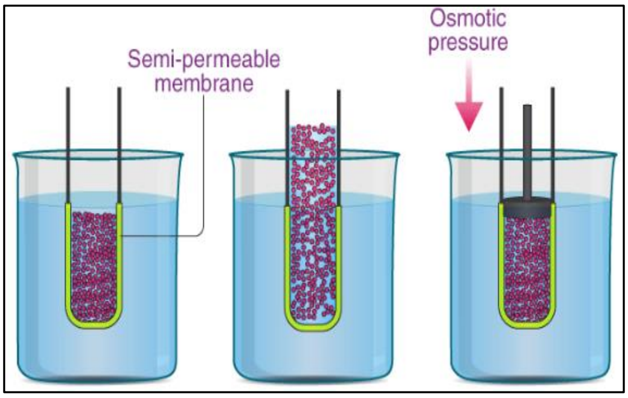

Figure 4. Osmosis Process

It is evident from the preceding picture of Figure 4 that unless osmotic pressure (solution) is applied to the solution side, the solvent molecules have a tendency to flow across the semipermeable barrier to the solution side. What occurs if the side of the solution is subjected to a pressure greater than the osmotic pressure? In this case, the solvent molecules will start to flow from the solution side, where the solute concentration is high, to the solvent side, where the solute concentration is low, via the semipermeable membrane. We refer to this technique as reverse osmosis. Examples and Applications: Osmotic pressure helps plants keep their erect posture. The plant's cells, which contain some salts, absorb water and swell when it receives enough of it. Plants stand erect as a result of the increased pressure on their cell walls brought on by their expansion. The plant's cells become hypertonic (shrink as a result of water loss) when it receives insufficient water. They wilt as a result, losing their strong, erect posture (Rusdiana et al., 2023). The molecular weight of a molecule can also be ascertained by measuring its osmotic pressure. The desalination and purification of saltwater, which uses the reverse osmosis technique, is another significant use of osmotic pressure.

1. Metabolism

All of the chemical processes that the body uses to create energy are collectively referred to as metabolism. It entails a number of intricate procedures that convert fuel into energy-dense, specific molecules. Adenosine triphosphate (ATP) is the primary final agent used by the body to produce energy. A significant amount of energy is released when cells consume or break down ATP. The growth and division of cells, the synthesis of vital substances, the contraction of muscles, and numerous other critical processes all depend on this energy. As a result, metabolism generates energy for all of the body's tissue processes. Food or chemicals in the body are broken down into smaller parts by metabolism. After that, it can undergo a unique process to create ATP. The body recycles the residual elements and uses them to create new compounds. Three primary kinds of molecules are utilized by the body to produce energy:

a. Carbohydrates: These are substances found in the body that resemble sugar. Bread, cereals, potatoes, fruits, and foods with added sugar or beverages are among the foods that include carbohydrates. Carbohydrates are broken down into smaller molecules, such glucose (simple sugar), in the digestive tract. The liver and muscles are the body's primary reservoirs of carbs.
b. Lipids: These are essentially fats from diet or stored in adipose tissue, or body fat, like cholesterol. For energy, lipids are broken down into smaller parts known as fatty acids. As a result, lipids are essentially just fatty acid chains that combine.
c. Protein: It comprises over three-quarters of the body's solid materials. Thus, protein is a fundamental structural element of the organism. They are composed of smaller substances known as amino acids, which are believed to constitute the building blocks of proteins. Foods including meat, eggs, nuts, and dairy products include protein.

Carbohydrates are often the body's primary energy source. They are the most effective in generating energy or ATP, which means that they generate more ATP for every unit of fuel that is broken down. Carbohydrates are specifically broken down by the body first, followed by fat and proteins, only if the other two fuels are exhausted. Since proteins are typically less effective in generating energy, this is significant. Furthermore, proteins carry out a number of crucial tasks, thus certain systems may malfunction if they are disrupted.

For instance, the body will begin to break down body fat stores when famine occurs since there are fewer carbohydrates available. After the body has used up all of its stores of fat and carbohydrates, it will start breaking down protein to provide energy. The primary energy sources for the body are summarized in the diagram below. Enzymes break it down into smaller pieces. After then, these little carbon chains can follow a unique route to generate energy (Seruni et al., 2019).

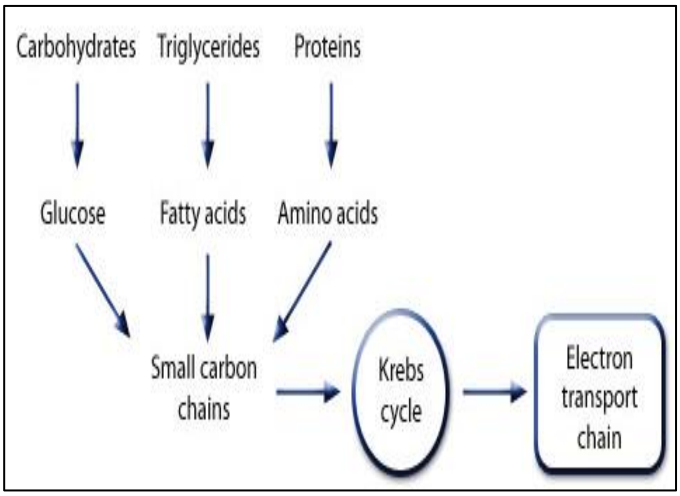

Figure 5. Metabolism Overview

Aerobic Metabolism

The metabolic activity that takes place while oxygen is present is referred to as aerobic metabolism. When different fuels burn, oxygen serves as an oxidizing agent. The electrons eventually receive oxygen (small negatively charged particles) as a result of a unique process. As a result, ATP is created and energy is released. Water and carbon dioxide, which are readily eliminated from the body, are its waste products. The primary fuel for aerobic metabolism is carbohydrate. Some reactions cannot occur when oxygen is not present. Pyruvic acid is involved in a variety of actions that also result in the synthesis of ATP. Cells can withstand oxygen deprivation for a few more minutes because to this process. Lactic acid accumulates as a result of anaerobic metabolism. It is also a less effective method of energy production. Each original fuel molecule produces less ATP.

Carbohydrate Metabolism

Smaller, more absorbable simple sugars are produced when carbs are broken down in the intestines. The primary substance generated is glucose. As soon as glucose enters the cell, it is either broken down to create energy or transformed into glycogen, which stores glucose. The liver and muscles are the body's primary reservoirs of glycogen. If energy is required, these sources can be utilized. Glucose is produced by breaking down glycogen. ATP is ultimately produced by a sequence of processes involving glucose. An appropriate quantity of glucose and oxygen is necessary for this reaction to occur. As previously mentioned, glucose can still be broken down by a number of distinct processes even in the absence of oxygen. However, if glucose is deficient, the body will switch to other sources of fuel for energy.

Glucose metabolism involves the following steps:

a. **Glycolysis**: In essence, this describes how glucose is broken down into pyruvic acid. This process results in the production of several ATP molecules.
b. **Krebs cycle**: Acetyl-CoA is produced when pyrrhic acid enters the Kreb cycle. Once more, a sequence of events results in the fuel breaking down into carbon dioxide and water. More useful energy is produced as a result. For the cycle to continue, the initial compound is renewed. The cell's mitochondria are where the Krebs cycle takes place. It is a tiny, oval-shaped, double-membraned organ that serves as the cell's power source.
c. **Oxidative phosphorylation**: A significant amount of potential energy is transferred as electrons to another molecule known as NAD during the Krebs cycle. The electron transport chain breaks these down. Electrons are transferred in parallel to the following chemical in a chain reaction. Oxygen is the final agent to receive electrons. A significant amount of energy is produced by this process and transformed into ATP.

Lipid Metabolism

Lipids are basically fats in the body that include cholesterol, triglycerides and phospholipids. Its main component is fatty acids that are released when lipids are broken down. Fatty acids are absorbed through the intestines and absorbed through the lymphatic system. Fats can be used for energy or can be stored as adipose tissue. Lipid metabolism involves the following processes:

a. Lipolysis: This refers to the breakdown of fats into fatty acids and other components. Some of these agents can go directly into the Krebs cycle for oxidation. Triglycerides are broken down into fatty acids and glycerol. The latter is converted into pyruvic acid which can enter the Krebs cycle.
b. Beta-oxidation: This refers to the breakdown of fatty acids within the mitochondria. ATP is produced from this process as well as acetyl-CoA which can enter the Krebs cycle and produce more energy.

Lipid metabolism is efficient in terms of ATP production. However, lipids are insoluble in the blood so their storage is difficult to access. Therefore, they are not relied upon for the production of large amounts of ATP in a short period of time but rather are used when the supply of carbohydrates is limited.

Ketosis

Ketosis refers to an increase in the concentration of ketone bodies in the blood. The most commonly produced ketone is acetic acid. This is caused by a fat-dominated metabolism without sufficient carbohydrate metabolism. Thus it is characteristic of starvation, diabetes mellitus (because insulin is not available to transport glucose to cells) and sometimes occurs when the diet consists almost entirely of fat.

When carbohydrates are not available for energy, the body switches to fatty acid metabolism. The body takes it from adipose tissue (the body's fat stores). The resulting fatty acids can be broken down for energy or can be converted into ketone bodies in the liver. Some ketones can be excreted in the breath and give off a sweet odor (acetone breath).

Protein metabolism

The body is made up of a wide variety of proteins with various structures and functions. The main component of protein is amino acids. About 20 different amino acids make up the building blocks of all proteins. Amino acids are classified as essential (meaning they are necessary in food because the body cannot synthesize them) and non-essential (meaning the body can produce them if needed).

The correct balance of amino acids is necessary for all essential proteins to be synthesized. When proteins are digested, the bonds between amino acids are broken and released. Usually amino acids will be recycled and used to produce new proteins. But if energy sources are limited, amino acids can be used to produce energy. This will only happen when energy stores of carbohydrates and fats are depleted because proteins make up some important structures in the body. If they are metabolized extensively, it can interfere with tissue function.

The following processes occur in protein metabolism:

a. Deamination: The first step in breaking down amino acids is the removal of amino groups (the part of the structure of amino acids that contain nitrogen and hydrogen). Ammonia is produced by this process which is converted into urea by the liver. Urea can then be excreted through the urine. The amino acids are converted into compounds called keto acids, which can enter the Krebs cycle.
b. Oxidation of amino acids: This refers to the breakdown of ketoic acid and the formation of ATP, similar to acetyl-CoA in the metabolism of carbohydrates and lipids. The amount of ATP produced from protein metabolism is slightly less than glucose metabolism for equivalent weight (Siregar & Makmur, 2020).

Microorganisms in the Fermentation Process

Microbial fermentation is the breakdown of nutrients, mostly sugars and carbohydrates, by metabolic enzymes from microbes in the absence of oxygen. Generally, many types of microorganisms are present during the fermentation process and each has a different set of enzymes, leading to the formation of complex mixed byproducts that characterize the smell and taste of fermented foods. The fermentation process has traditionally been used by the human population to increase the shelf life of perishable agricultural products such as milk, vegetables, and meat. This has resulted in a wide variety of fermented foods and beverages that are still a major part of the human diet in many underdeveloped countries and in most countries in Southeast Asia. In North America and Europe which have highly efficient and fast distribution systems and the availability of overall cooling and freezing systems, most traditional fermented products, with the exception of fermented milk (yogurt and cheese) and meat (sausages) have been replaced by fresh agricultural produce, making the fermentation process obsolete. This trend away from fermentation seems to have stopped recently and is now gradually reversing. More and more people (and food companies) are regaining interest in traditional and more natural foods and there is a growing dislike towards the processing and energy inputs required to maintain the freshness of agricultural crops. In addition, the food and beverage industry is constantly striving to innovate within the boundaries of sustainability and naturalness. All these recent developments have led to an increase in interest and activity in fermentation technology by all consumer goods industries, large and small (Wasilah et al., 2019).

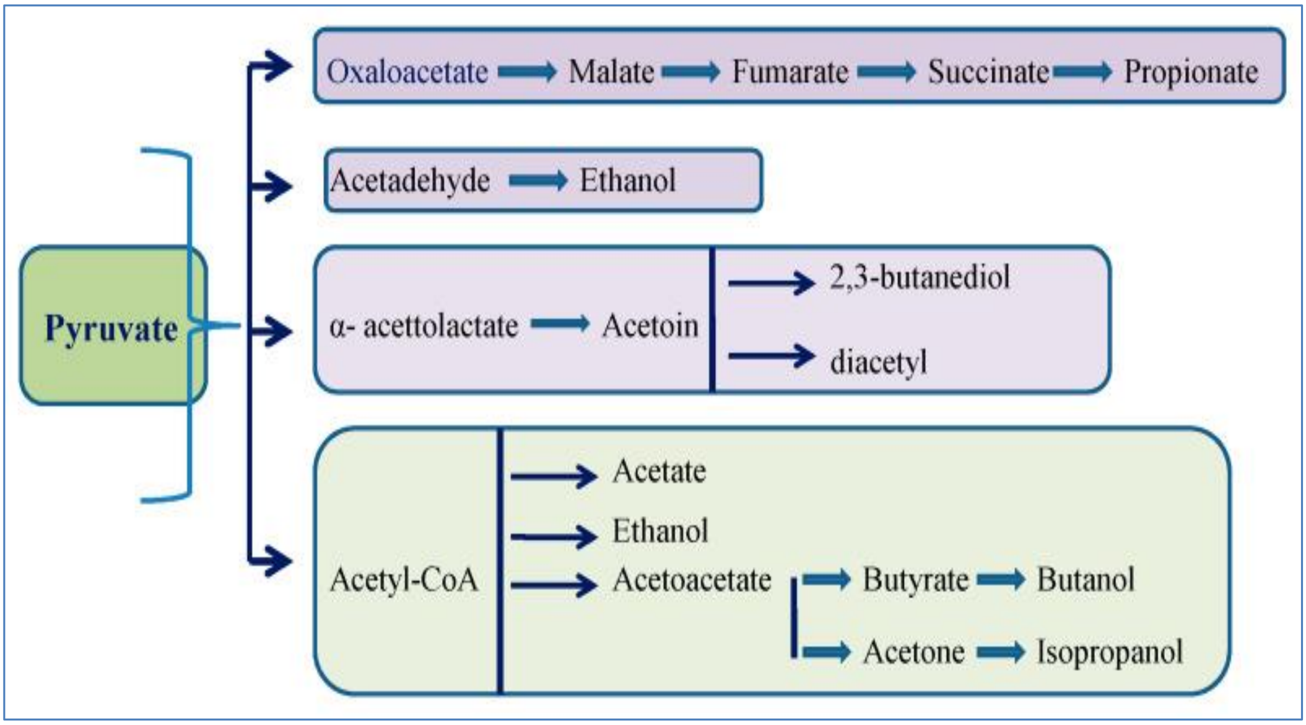

Figure 6. Metabolic Pathway of Pyruvate Conversion to Various End Products

Pyruvate, a central intermediate in cellular metabolism, can be metabolized through a variety of pathways depending on the organism, environmental conditions, and enzymatic capabilities. Here's a detailed explanation of the process shown:

a. Oxaloacetate Pathway:

Pyruvate can be converted to oxaloacetate, an intermediate of the citric acid cycle. From there, it undergoes a series of enzymatic reactions to form malate, fumarate, succinate, and finally propionate. This pathway is typical in anaerobic and facultative organisms involved in fermentative metabolism, especially in propionate-producing bacteria.

b. Acetaldehyde to ethanol pathway:

Pyruvate is decarboxylated to form acetaldehyde, which is then reduced to ethanol through alcohol dehydrogenase. This pathway is common in yeast and some bacteria during the fermentation of alcohol under anaerobic conditions.

c. Acetolactate Pathway:

Pyruvate can be converted to α-acetylalactate, which is then metabolized to form acetoine. Acetin can be further processed into 2,3-butanediol or diacetyl. The production of these compounds is prevalent in the fermentation process of certain bacteria, such as those found in milk fermentation.

d. Acetyl-CoA Pathway:

Pyruvate is converted to acetyl-CoA through decarboxylation, which serves as a central precursor for various metabolic routes:

1) Acetyl-CoA can be converted into acetate and ethanol, a common pathway in mixed acid fermentation.
2) Acetyl-CoA can also be converted to acetoacetate, leading to the production of butyrate and butanol, usually in Clostridia species.
3) Alternatively, acetoacetate can form acetone, which can then be reduced to isopropanol.

Each of these pathways reflects the versatility of pyruvate metabolism in producing a diverse range of end products, which serve a variety of biological functions, including energy generation, redox equilibrium, and biosynthesis of complex molecules. This metabolic route is critical in industrial applications, such as biofuel production, food fermentation, and the synthesis of organic acids and solvents (Sriwahyuni & Parmila, 2019).

There are two types of fermentation (regarding the way fermentation microorganisms are used):

a. Natural fermentation: Fermentation in which fermentation microorganisms are already part of the natural microflora present in the foodstuff, so there is no need to add them. The only thing that is necessary is to create the necessary conditions for its development (for example, the creation of anaerobic conditions, as in the production of pickles or olives), or the suppression of competing microflora (for example, by the addition of salt or vinegar to the product) (Robert W. Hutkins, 2006; Tamang, 2015; Tamang & Kailasapathy, 2010).

b. Controlled fermentation with starter cultures: Fermentation that begins with the addition of inoculation corresponding to a large population of desired fermentation microorganisms, is required when the raw material is pasteurized (e.g., pasteurized milk) or when it is difficult for the desired fermentation microorganism to prevail over competing microorganisms (e.g., in brewing, where wild yeast can prevent alcohol fermentation by strains of Saccharomyces). Starter cultures contain natural fermenting agents that are already present in the food microflora, but in much higher concentrations than usual, to ensure that they easily triumph over damaging microorganisms. Therefore, with the addition of starter cultures, we better ensure a smooth fermentation process, spoilage prevention and product standardization (stable qualitative and organoleptic characteristics).

Table 1. Fermented Food Biotechnology Products

No.	Microorganism	Material	Producing
1.	a. Rhizopus oligosporus b. Rhizopus stolonifer c. Rhizopus oryzae	Soybean	Tempeh
2.	Aspergillus oryzae	Soybean	Tauco
3.	a. Aspergillus soyae b. Aspergillus wentii	Soybean Soybean Meal	Soy sauce On Screen
4.	Neurospora crassa	Milk	Yogurt
5.	a. Streptococcus thermophillus b. Lactobacillus bulgaricus	Milk	Cheese
6.	Streptococcus lactis	Milk	Butter
7.	a. Lactobacillus plantarum b. Streptococcus c. Pediococcus	Vegetable	Pickle
8.	Sakaromises cerevisiae	Cassava Flour	Tape Bread
9.	Acetobacter xylinum	Coconut water	Nata de coco
10.	Pediococcus cerevisiae	Beef/chicken	Sausage

The safety factor in food products is the main aspect that needs to be considered because it concerns consumer health. The fermentation process can improve and improve the safety of food products. Fermented products containing high levels of organic acids (>100mM), low water activity, salts, nitrites, and other antimicrobial components tend to have a long shelf life. In addition, alcoholic beverage products containing 4% or more with a pH of less than 4.5 are microbiologically safe. Fermented products have a relatively high level of safety because some BALs (both original and added as starters) are capable of producing antimicrobial components such as bacteriocins that can inhibit unwanted bacteria such as Listeria, Clostridium, and Staphylococcus (Sumarmono & Setyawardani, 2020). These unwanted bacteria can cause contamination of the product, thus damaging its quality. In addition, BAL is able to produce antimicrobial components, including:

a. Organic acids, acetaldehyde, and ethanol

   Acetic acid has a higher ability to inhibit yeast, fungi, and bacteria as compared to lactic acid.

b. Hydrogen peroxide

   Hydrogen peroxide formed during the lactic acid fermentation process can inhibit the growth of some microorganisms.

c. Carbon dioxide

   The formation of carbon dioxide through the fermentation process creates anaerobic conditions that are toxic to some aerobic microorganisms.

d. Diacetyl

   Diacetyl plays a role in giving butter and some fermented dairy products an aroma and taste.

e. Reuterina

   Reuterin has antimicrobial properties that can combat viruses, fungi, and protozoa.

f. Bacteriocins

   Bacteriocins play a role in the depolarization of the target cell membrane.

Fermented food products can also improve food safety and nutritional value by removing toxins or anti-nutrient substances in ingredients. Some foodstuffs contain toxic components and must be removed. In bitter raw cassava, there are cyanogenic glycoside toxins that must be removed through fermentation, soaking in water (to dissolve the poison), or other methods to prevent the consumption of the poison. Sourdough made from wheat contains phytic acid, which is an anti-nutrient that can interfere with reabsorption. With fermentation, phytic acid decreases, thereby increasing calcium, magnesium, iron, and zinc in bread. Sourdough fermented products are suitable for individuals who are intolerant to gluten and those suffering from irritable bowel syndrome because sourdough fermentation can reduce the concentration of immune proteins, including the amylase-trypsin inhibitor (Vishnu, 2020).

Pathogenic contamination poses a threat to food products because it affects the safety of food products. Pathogenic microorganisms are capable of producing toxins and metabolites that are harmful if consumed. However, food products fermented by BAL, yeast, and fungi do not produce toxins or metabolites that are harmful and non-pathogenic. The thing to remember when making fermented food is that the ingredients used must be safe. However, some low-acid cheeses and fermented foods are at risk of contamination by Listeria monocytogenes, Salmonella, Clostridium botulinum, or other foodborne pathogens. Although it has no direct effect on the body, some microorganisms (including Lactobacillaceae such as Enterococcus and Staphylococcus) associated with long-aged cheeses, sausages, and other fermented foods are capable of carrying antibiotic resistance genes.

Microbial metabolites (under certain conditions) can indicate food safety risks, so they should not be consumed in excess. Some BALs are capable of producing histamine, tyramine, and other biogenic amines through the decarboxylation of amino acids during fermentation in cheeses, meats, vegetables, soybeans, and wines. To reduce these contaminants, it can be done by applying hygiene and using decarboxylase negative starter cultures.

The fermentation process occurs due to the role of microorganisms such as bacteria, yeast, or fungi. The microorganisms that play a role in fermenting each food ingredient are different. For example, the lactic acid bacteria Streptococcus thermophilus plays a role in fermenting milk into yogurt, the yeast Saccharomyces in bread fermentation, and the Rhizopus oligosporus fungus in the production of tempeh. During the fermentation process, components that can combat pathogens are produced as well as compounds that can eliminate unwanted substances. Fermented foods have many health benefits, especially in increasing the diversity of the gut microbiota. In addition, fermentation can increase nutritional value and serves as an easy method of food preservation because it occurs spontaneously (Novia et al., 2021).

Maillard's reaction

The Maillard reaction is an organic chemical reaction in which reducing sugars react with amino acids to form a complex mixture of compounds. This reaction is responsible for the distinctive taste and aroma of browned foods. The Maillard reaction is named after the French chemist Louis Camille Maillard. One of the first scientists to give a more general picture of the reactions that produce the aroma of this type of food was Louis Camille Maillard. This reaction can be classified as a non-enzymatic browning reaction. The optimum temperature for this reaction ranges from 140°C to 165°C. It is important to note that caramelization is not a Maillard reaction (it takes place at higher temperatures and involves the pyrolysis of sugars). Several flavor compounds are formed during the Maillard reaction. These compounds can decompose to produce other flavor compounds. Therefore, different types of food produce different flavor compounds when undergoing the Maillard reaction (Tampa'i, 2019). The Maillard reaction has been named after the French physicist and chemist Louis Camille Maillard (1878–1936) who originally described it. It is often defined as a nonenzymatic browning reaction. While food is processed or cooked at high temperatures, a chemical reaction occurs between amino acids and reducing sugars that produce different brown flavors and colors (Figure 5). So it is often used in the food industry to give different flavors, colors, and aromas of food.

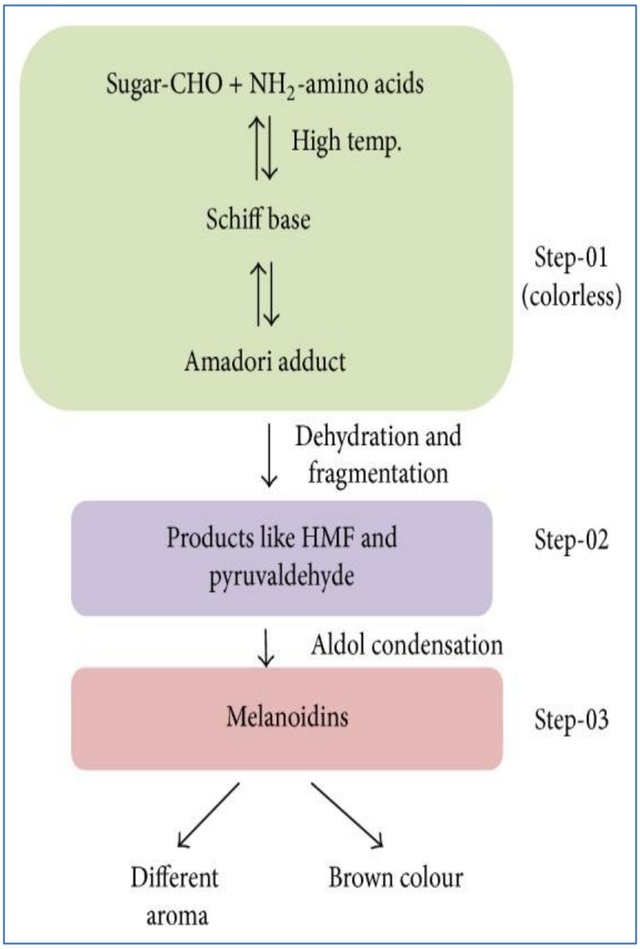

Figure 5. Maillard Reaction Mechanism

Based on the literature, Hodge (1953) first described the steps involved in the Maillard reaction product (MRP), also known as the advanced glycation end product (AGE), formation. The whole MRP forming process can be divided into three main stages depending on the color formation. In the first stage, sugars and amino acids condense, and after condensation, the rearrangement of Amadori and 1-amino-1deoxy-2 ketosis is formed. In the second stage, dehydration and fragmentation occur in sugar molecules. Amino acids are also degraded at this stage. Hydroxymethylfurfural (HMF) fission products such as piruvaldehide and diacetyl are formed at this intermediate stage. This stage can be slightly yellow or colorless. In the final stage, aldol condensation occurs and finally a heterocyclic nitrogen compound is formed, melanoidin, which is very colored. Maillard reactions can also occur in living organisms. It has been reported that some MRPs, especially melanoidin, have beneficial effects on health, such as antioxidant and antibiotic effects. However, some reports also suggest that

MRPs, such as high carboxymethyl lysine (CML) increase diabetes and cardiovascular disease, while acrylamide acts as a carcinogen (Fahmiati et al., 2019).

There is an ever-increasing preference for instant food over traditional cooking, especially among the new generation. It has been reported that people who consume high amounts of processed meat, pizza, or snacks experience insulin resistance and metabolic syndrome compared to people who have a high intake of vegetables and low processed foods. MRP changes during food processing may be one of the important factors for disease progression or disease fighting (Kanya et al., 2023).

Acid, Base, and Salt

The term "acid" is very familiar in everyday life. For example, you are certainly familiar with vinegar which is often used in daily life to add a sour taste to food. Or you are certainly familiar with the name citric acid, which is commonly found in various fruits that taste sour like oranges and lemons. Likewise, the base solution and salt. In our body, there is a balance system that is strictly regulated by the acidity of the blood and the saline solution. Thus, the concepts of acid, base, and salt are important to learn considering their many applications in daily life.

a. Sour

Acids are substances that, when dissolved in water, can release H+ ions. H+ ions do not exist as free protons, but are chemically bound to water molecules in the form of hynium ions, H3O+. Acids in their pure state (do not contain water) are made up of covalently bound molecules. When water is added to an acid, the molecules will react with the water to form ions, a process known as ionization. Acids are said to be strong if they are fully ionized in water. Hydrochloric acid is an example of a strong acid produced by the stomach to aid the digestive process in the body and kill microbes that are not beneficial to the body. In water, the hydrochloric acid (HCl) solution contains only H+ ions (aq) and Cl^- ions (aq), and no HCl molecules.

HCl (aq) + H2O (l) → H3O+ (aq) + Cl^- (aq)

Weak acids are a type of acid that is partially ionized when dissolved in water. Unlike strong acids, weak acids in water still leave weak acid molecules behind. Only a small amount of acid produces H+ ions (aq) when dissolved in water. For example, a vinegar or acetic acid solution, CH3COOH, is an acid that is partially ionized in water into H+ ions (aq) and CH3COO- ions (aq), with the remainder present as CH3COOH molecules. Here is the difference between strong acid ionization and weak acid in water.

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

Citric acid, carbonic acid, and acetic acid are examples of acids found in foods. In fact, acetic acid is also commonly used to preserve food.

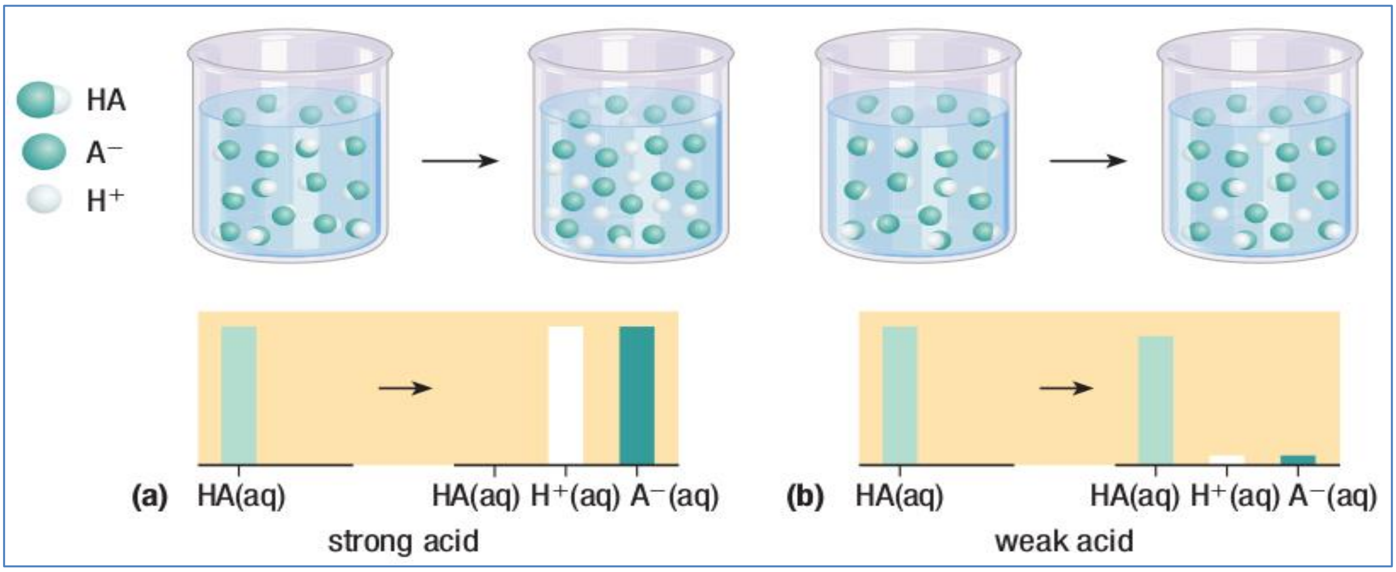

Figure 6. Difference between ionization of strong acids and weak acids in water

b. Base

Bases are substances that, when dissolved in water, can release OH- ions or substances that can accept H+ ions present in solution. Just like acids, a substance is classified as a strong base if it is completely ionized in water, producing OH ions and corresponding cations, whereas a weak base is a substance that is only partially ionized when dissolved in water. Some examples of basic ingredients that you can find in everyday life are the basic substances found in toothpaste, detergents, and cleaning liquids. The acid-base balance in the human body is maintained, among other things, by neutralizing excess H+ ions with OH- ions to produce water, thereby reducing the number of H+ ions and the acidity level of body fluids. In Figure 7, the pH of some of the compounds found in everyday life is shown.

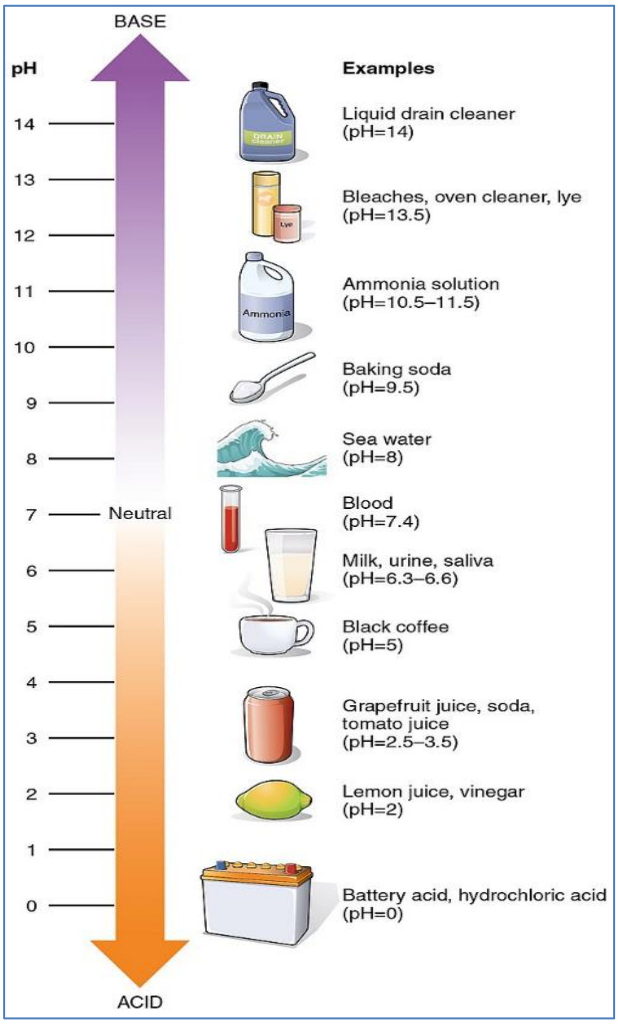

Figure 7. pH scale and pH of some compounds commonly found in everyday life

Acidosis is a condition in which there is an excess of acid in the blood or other parts of the body. Acidosis is caused by inefficiencies in a person's respiratory function, which leads to the accumulation of CO2 and H+ in the blood. Metabolic disorders can also lead to the production of acids that cannot be neutralized by available bases. The opposite of acidosis is alkalosis, which is caused by an excess of alkalinity in the body or other tissues.

c. Salt

In addition to sodium chloride, other common salts are sodium nitrate, barium sulfate etc. Sodium chloride or regular salt is a product of the reaction between hydrochloric acid (acid) and sodium hydroxide (base). Solid sodium chloride is made of a group of positively charged sodium ions and negatively charged chloride ions held together by electrostatic forces. The electrostatic force between opposite charges is inversely proportional to the dielectric constant of the medium. In other words, we can say that compounds that have acidity in their properties and compounds that have alkaline properties, can produce salts when combined together. The universal solvent, water, has a dielectric constant of 80. Therefore, when sodium chloride is dissolved in water, the dielectric constant of water reduces the electrostatic force, allowing ions to move freely in solution (Cita Indira, 2015). They are also well separated due to hydration with water molecules.

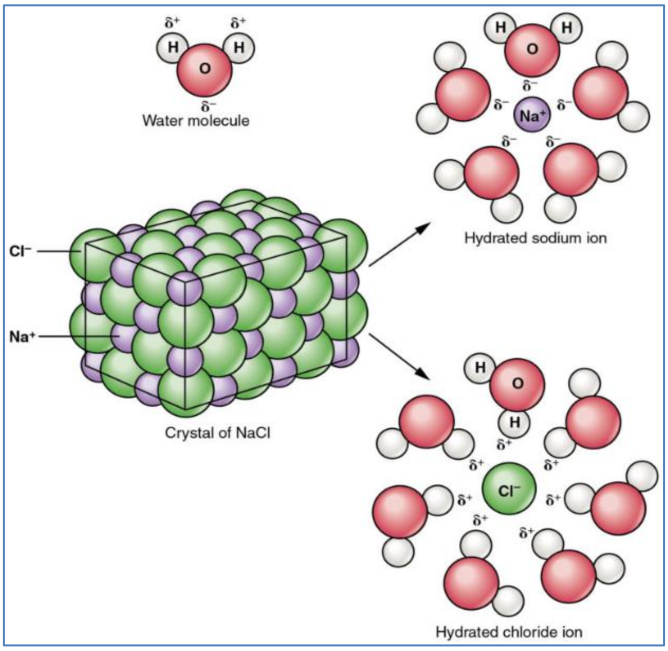

Figure 8. Dissolution of sodium chloride in water

Ionization and dissociation

Dissociation is the separation of ions from ionic crystals when solid ionic compounds are dissolved in water. On the other hand, ionization is a process in which neutral molecules break down into charged ions when dissolved in solution. The ionization rate depends on the bond strength between the ions and the rate of dissolution of the ions. The three most important modern concepts of acids and bases are:

a. Arrhenius Concept

According to Arrhenius' concept, Substances that produce H+ ions when dissolved in water are called acids while substances that are ionized in water to produce OH– ions are called bases.

$HA \rightarrow H+ + A^-$ (Acidic)

$BOH \rightarrow B+ + OH-$ (Basic)

Arrhenius proposed that acid-base reactions are characterized by acids if they dissociate in an aqueous solution to form hydrogen ions (H+) and bases if they form hydroxide ions (OH^-) in an aqueous solution.

Limitations of Arrhenius' Concept

1) The presence of water is absolutely necessary for acids and bases. Dry HCl cannot act as an acid. HCl acts as an acid in water only and not as another solvent.
2) This concept does not explain the acidic and alkaline character of substances in non-aqueous solvents.
3) The neutralization process is only possible for reactions that can occur in aqueous solutions, although reactions involving the formation of salts can occur in the absence of solvents.
4) The acidic nature of some salts such as AlCl3 in aqueous solutions cannot be explained.
5) An extended and artificial explanation is needed to define the basic properties of NH3.

b. Bronsted-Lowry Concept

Bronsted and Lowry in 1923 independently proposed a more general definition of acids and bases. According to them, acid is defined as a material containing hydrogen (molecules, anions or cations) that can donate protons to other substances and Bases are any substance (molecules, cations or anions) that can accept protons from other substances. Therefore, acids are proton donors while bases are proton acceptors.

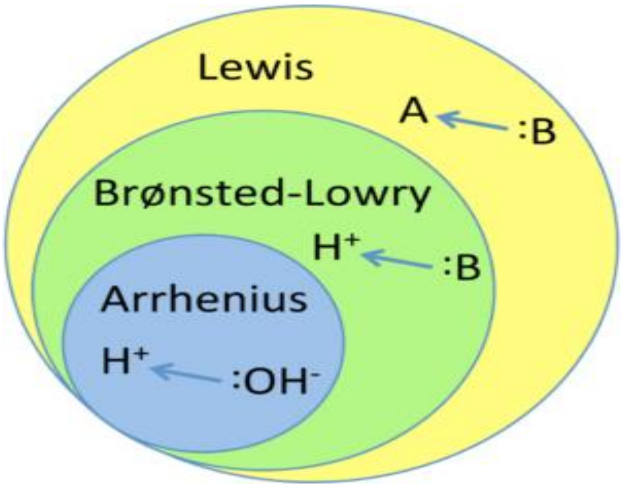

Figure 9. Acid-Base Theory Comparison: Arrhenius, Brønsted-Lowry, and Lewis

Conjugated Acid-Base Pairs

Consider the reaction

Acid1 + Base2 → Acid2 + Base1

$\mathbf{H_2O + HCl \Leftrightarrow H_3O^+ + Cl^-}$

In this reaction, HCl donates protons to H_2O and is therefore an acid. Water, on the other hand, receives protons from HCl, and, therefore, is a base. In a reverse reaction that at equilibrium takes place at the same rate as the forward reaction, the H_3O^+ ion contributes a proton to the Cl^- ion, therefore H_3O^+, the ion is an acid. Cl^- ions, because they receive protons from H_3O^+ ions, are basic. Acid-base pairs in which reaction members can be formed with each other by the gain or loss of protons are called conjugate acid-base pairs.

Limitations of the Bronsted Lowry Concept

1) Bronsted Lowry could not explain the reactions that occur in non-protonic solvents such as $COCl_3$, SO_2, N_2O_4, etc.
2) It cannot explain the reaction between acidic oxides such as etc and alkaline oxides such as etc that can easily occur in the absence of solvents as well, e.g. (No proton transfer)
3) Substances such as BF_3, $AlCl_3$ etc., do not contain hydrogen which means they cannot donate protons, still they behave as acids.

Lewis Concept

According to Lewis's acid-base reaction theory, bases donate electron pairs and acids receive electron pairs. Thus, it can be said that Lewis acid is an electron pair acceptor. The advantage of Lewis' theory is that it complements the oxidation-reduction reaction model. The oxidation-reduction reaction occurs in the transfer of electrons from one atom to another, with a net change in the amount of oxidation of one or more atoms. Lewis' theory further suggests that acids react with bases and share a pair of electrons but there is no change in the number of oxidation of any atoms. Either electrons are transferred from one atom to another, or atoms come together to share a pair of electrons.

$Al(OH)_3 + 3H^+ \rightarrow Al^{3+} + 3H_2O$ (Aluminum hydroxide acts as an alkaline)

$Al(OH)_3 + OH– \rightarrow Al(OH)^{4-}$ (Aluminum hydroxide acts as an acid)

This reaction shows clearly: When Aluminum hydroxide receives a proton, it acts as a base. When it receives electrons, it acts as an acid. Lewis's acid-base theory also explains why non-metallic oxides such as carbon dioxide dissolve in H_2O to form acids, such as carbonic acid H_2CO_3.

CO_2 (g) + H_2O (l) → H_2CO_3 (aq)

Limitations of Lewis' Concept

1) Lewis's concept provides a general idea including all coordination and compound reactions. This is not always true.
2) The idea of the relative strength of acids and bases is not provided by Lewis' concept.
3) Lewis's concept is not in line with the concept of acid-base reaction.
4) Lewis's concept has not addressed the behavior of protonic acid like HCl (Irsalina & Dwiningsih, 2018).

Discussion:

In the context of biotechnology, the interdisciplinary approach proposed in this article is particularly relevant for understanding the complexity of the biological systems involved. The webbed model, which integrates a variety of disciplines, allows students and researchers to see the relationship between chemical, biological and physical concepts that interact with each other in biotechnology processes (Damayanti et al., 2023). Using this model, it is possible to describe how various components, such as microorganisms, enzymes, and substrates, collaborate in biochemical reactions that produce biotechnology products. This is in line with the background that emphasizes the importance of a holistic understanding in the study of biotechnology, where each discipline makes a significant contribution to the final outcome (Wasilah et al., 2019). One of the important concepts that emerged in this discussion is the role of microorganisms in fermentation, which is one of the main applications of biotechnology. In webbed models, microorganisms can be viewed as central components that interact with other factors, such as temperature, pH, and substrate concentration. By understanding how microorganisms function in different environmental contexts, we can optimize the fermentation process to produce more efficient and high-quality products (Vishnu, 2020). This discussion underscores the importance of an interdisciplinary approach in understanding the complex interactions that occur in biotechnology systems, which cannot be explained by just one discipline.

In addition, the concept of Maillard reactions that often occur in food processing can also be analyzed through the lens of a webbed model. This reaction involves the interaction between sugars and amino acids, which produce new compounds that give food its distinctive taste and aroma (Kanya et al., 2023). By integrating knowledge from chemistry and biology, students can understand how these reactions contribute to the quality of the final product. This interdisciplinary approach not only enriches students' understanding of biotechnology, but also provides practical insights that can be applied in the food industry. This shows that webbed models can be used to bridge theory and practice in the context of biotechnology (Irda Sukmawati Dewi, 2021). In this discussion, it is also important to highlight the challenges faced in the implementation of an interdisciplinary approach. One of the main challenges is the language and paradigm differences between different disciplines, which can hinder communication and collaboration. To overcome this, efforts are needed to create a learning environment that supports interaction between students from different disciplines (Priscylio & Anwar, 2019). By facilitating dialogue and collaboration, it can reduce the gap between disciplines and encourage a better understanding of complex biotechnology concepts.

In addition to challenges, there are also opportunities that can be taken advantage of in the application of an interdisciplinary approach. One of them is the use of information and communication technology (ICT) to support interdisciplinary collaboration. ICTs can provide a platform for sharing information and resources, as well as facilitate distance learning that allows students from different backgrounds to collaborate on biotechnology projects. By utilizing ICT, we can create a more dynamic and interactive learning experience, which is in line with the goals of interdisciplinary education (Widharnati et al., 2022). In the context of education, this article emphasizes the importance of equipping students with the skills and knowledge necessary to work interdisciplinarily. By integrating various disciplines in the curriculum, students will be better prepared to face the complexities of the ever-evolving world of biotechnology. Relevant and contextual education can increase students' motivation to learn, as they feel that what they learn is directly related to their daily experiences (Juriyah, 2021). Therefore, it is important to develop a curriculum that supports this interdisciplinary approach, so that students can gain a deeper understanding of biotechnology.

Finally, by applying webbed models in biotechnology studies, we can drive more significant advances in this field. Through a better understanding of the interactions between different disciplines, it is hoped that more innovative and effective solutions to the challenges faced in biotechnology can be found. This article aims to be a reference for researchers, educators, and practitioners in the field of biotechnology to better understand and apply an interdisciplinary approach in their research and teaching. Thus, we can provide greater benefits to society and prepare for

Conclusion:

The application of an interdisciplinary approach through a webbed model in the study of biotechnology provides deep insights into the interactions between different disciplines. By understanding the role of microorganisms and other important concepts, students can develop the skills necessary to face challenges in the field of biotechnology. Despite the challenges of interdisciplinary communication, the opportunities that exist, especially through the use of ICT, can increase collaboration and innovation. Therefore, it is important to integrate this approach in the educational curriculum to prepare the next generation of scientists who are able to adapt to the complexities of the biotechnology world

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