Microbial Biodiversity

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Edited by

P. Ponmurugan and J. Senthil Kumar

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PREFACE

Biodiversity is one of the richest and hottest treasures on earth. This common fact of life is revealed in expressions such as “There’s plenty of room at the bottom”. Despite its small size, it plays a vital role in the environment in monitoring and makes the earth sustainable. Microorganisms preserve and assist the planet’s plants and animals either directly or indirectly. Microbes are generally preferred in most biological research due to their faster growth, as well as their greater reproductive, metabolic, and genetic diversity. Only about 1 to 5% of species have been discovered out of all the microorganisms on Earth. Due to their omnipresence in nature, they have been able to make their habitats in various conditions, such as in extreme temperatures, as well as in water, soil, salt, medical waste, agro waste, and air.

The incredible, fascinating, and diverse nature of microorganisms makes them fit to live with us, in us, and around us. Microorganisms are also unicellular and extremely diverse. The broad group of microorganisms comprises domains, such as **bacteria (prokaryotes)**, which are both gram positive and gram negative (some live harmlessly in humans and assist in digestion and the absorption of vitamins; **fungi (eukaryotes),** which are visible to the naked eye as well as mold with filamentous growth, yeast with non-filamentous growth, single cells, and mushrooms with fruiting bodies that produce spores (these uncompromised pathogens cause disease in plants and contaminate food); **viruses (DNA/RNA, protein coat)** that enter into the human system in order to hijack the replication machinery and cause disease in other humans; **algae**, either prokaryotes or eukaryotes, due to their photosynthetic nature; and, finally, **archaea** and **protozoa**, which are lesser known microorganisms.

A look at the microbes identified before 2018 proves that approximately 90% of organisms remain undiscovered. There are microbes with an optimal pH (1285), an optimal temperature (2084), susceptible to antimicrobials (1724), spore forming (3204), biofilm forming (1679), gram strains (3450), gram negative (2253), gram positive (1180), gram intermediate (17), human microbiomes (4732), plant pathogens (5024), and animal pathogens (4703); the total microbe count is currently 7667 (Source: Microbe directory).

Microbes are important in human culture and health. They aid food fermentation, sewage treatment, medical waste, agro waste, soil waste, industrial waste decomposition, antibiotics, soil fertility, model organisms, bio warfare agents, human microbiota, gut microbiota, and are also responsible for infectious diseases. Recently, microbes have acted as an ingredient for synthesizing nanoparticles; these are known as green nanoparticles. In conclusion, there is plenty of room for further research with microbes in order to explore the benefits they offer society.

CHAPTER ONE

BIOPROSPECTING OF ECO-FRIENDLY NATURAL DYES USING NOVEL MARINE BACTERIA AS AN EFFICIENT ALTERNATIVE TO TOXIC SYNTHETIC DYES

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Abstract

Synthetic dyes are toxic and they cause severe health disorders and environmental problems. Currently, marketable dyes, cosmetics, food, and pharmacy products are attractive due to the use of synthetic colorants. Some synthetic dyes are carcinogenic and nonbiodegradable. Moreover, the effluent from the industry causes harmful effects. Therefore, there is an increasing demand for the synthesis of eco-friendly and safe natural pigments. Natural pigments are mostly obtained from plants and microbes. Plant pigments are sensitive to heat and light; are low water soluble; and are not always available. However, microbial pigments are highly stable, easily biodegradable, and non-toxic. More shades can also be obtained from microbes. Microbes have a fast multiplication rate within a short period of time. Microbes offer more scope for natural pigments than plants

and are a safe alternative to synthetic pigments. The production technologies of microbial pigments are cost effective due to the utilization of waste as a substrate. Natural pigments have multiple applications, such as dyes for the textile, food, cosmetics, and pharmaceutical industries. Most of the natural pigments have extraordinary medicinal values, which include anti-cancer, anti-diabetic, antioxidant, antibiotic, and anti-inflammatory properties. Microbes can effectively utilize waste for the production of natural dyes in the cheapest way. This is an eco-friendly waste management method that prevents pollution problems. There is a growing need for low-cost production of natural pigments using microbes from waste. Marine bacteria are more efficient than other microbes because of their ability to adapt to extreme climatic conditions. Hence the present study deals with bioprospecting novel marine bacteria for the synthesis of eco-friendly natural dyes.

Keywords: Bacterial pigments, eco-friendly, natural dyes, marine bacteria, alternative, synthetic dyes, agro waste, solid-state fermentation.

Introduction

Most synthetic dyes are banned due to their high toxicity and carcinogenic nature. The World Health Organization (WHO) also recommends using a safe dose of colorants in food, cosmetics, and pharmaceutical products. Moreover, there is an increasing demand for coloring agents in paint, paper, printing, and plastic industries. Therefore, there is a current need to seek out natural pigments that are safe for both human beings and the environment. Microbes are a significant source of natural pigments, due to their availability throughout the period; they are also cost-effective, stabile, and support easy downstream processing (Joshi et al., 2003). Natural pigments are produced either by submerged or solid fermentation using microbes. Most waste materials are utilized for the production of different types of pigments with significant clinical values using microbes. Most microbes, including fungi and algae, are exploited for biopigment production. However, pigment production from bacteria, especially marine bacteria, is in its infancy. This means that there is a need for more research on marine bacteria in order to use waste materials as substrates for natural pigment production, which also reduces costs and increases various applications in different industries.

The role of marine bacteria in bio pigment production

Pigment production from novel marine bacteria is an emerging field. The marine environment is an untapped source of novel microbial diversity and the greatest biodiversity is observed in the oceans (Stach et al., 2003; Donia and Hamann, 2003). Marine microbes gained special importance because of their ability to produce novel secondary metabolites. Unlike terrestrial microbes, marine microbes have an indigenous genetic diversity due to their ability to adapt to specific climatic conditions, such as low to high pressure, salinity, and temperature, in the marine ecosystem. Hence, marine microbes, especially actinomycetes, are an important source for the discovery of novel secondary metabolites (Magarvey et al., 2004; Jensen et al., 2005; Fiedler et al., 2005). It is reported that marine microorganisms have more novel characteristics than terrestrial microbes. Compounds with distinctive biological activities have been isolated from novel marine microbes; this indicates that they are an important source of novel secondary metabolites and various pigments. The distribution of novel bacteria in the sea is largely unexplored. Therefore, there is a need to utilize novel marine bacteria with extraordinary features for the production of natural pigments.

As marine microorganisms, actinomycetes have the greatest genomic and metabolic diversity and so they should be explored as a possible source of novel secondary metabolites. Most of them are very different from their terrestrial counterparts in terms of their 16S rRNA sequences. Novel actinomycetes will provide a new source of secondary metabolites (Maldonado et al., 2005). The Indian coastal area is a major source of actinomycetes and the isolation created in these unique ecosystems is a prolific source of novel secondary metabolites (Gulve and Deshmukh, 2012). Therefore, more efforts are needed to explore novel bacteria, such as marine actinomycetes, from these aquatic ecosystems for biopigment production.

Utilization of agro waste for biopigment production

The accumulation of agro waste and its improper disposal results in harmful effects to human beings and the environment. High levels of nutrients are leached from the damp fills and pollute water bodies; this is also associated with the growth of water weeds. The impact of agricultural waste on the environment depends not only on the amounts generated but also on the disposal methods used. Some of the disposal practices pollute the environment (Tumuhairwe et al., 2009; Sabiiti et al., 2011). For example, agricultural waste burning is a common practice in undeveloped countries, but it is a source of atmospheric pollution. According to Ezcurra et al. (2001), agricultural waste burning releases pollutants, such as carbon monoxide, nitrous oxide, nitrogen dioxide, and particles. These pollutants are accompanied by the formation of ozone and nitric acid and result in acid deposition, thereby increasing the risk to human beings and the environment. Environmental pollution from solid waste is a global concern and is serious. It has an impact on the environment, as well as water quality, soil deterioration, and air pollution. Agricultural waste can be a valuable resource; however, if it is not disposed of properly, it will create environmental pollution and harm to human health. India is an agricultural country with an enormous quantity of different agricultural residues, which could be utilized effectively for biopigment production using microbes.

Production of biopigments using solid state and submerged fermentation

Fermentation is the biological conversion of complex substrates into simple compounds by various microorganisms. Microbes yield effective biopigments during fermentation. Both solid state and submerged fermentation are used for biopigments production. Solid-state fermentation is the growth of microorganisms under controlled conditions using a solid substrate with lower moisture content for the production of certain items. It has advantages over submerged fermentation, such as high volumetric productivity, low cost of the equipment involved, better yields, less waste generation, and less time-consuming processes (Robinson, 2001). When using this technique, the substrates are utilized uniformly and can be used for long fermentation periods and also support the controlled release of nutrients. It is best suited for fermentation techniques involving fungi and other microbes that require low moisture content. The low availability of water reduces the possibilities of contamination by bacteria and yeast. It has a low energy and easy downstream processing; it is also cheaper, less time consuming, and has a high recovery yield (Singh et al, 2010). The product obtained using this fermentation technique has different desired properties. Submerged fermentation has free-flowing liquid substrates and is utilized quite rapidly; therefore, it needs to be constantly supplemented with nutrients. This fermentation technique is best suited for microorganisms that require high moisture content. It is primarily used in the extraction of secondary metabolites that need to be in liquid form.

Higher water activity becomes the major cause of contamination in submerged fermentation and makes the downstream process difficult and very expensive. A high quantity of liquid waste is produced, which causes difficulties in terms of dumping. The cost of products produced by submerged fermentation is higher than in solid-state fermentation (Mienda et al., 2011; Subramaniyam and Vimala, 2012). The utilization of waste for biopigment production by microbes solves its disposal and pollution problems. It is an efficient eco-friendly method of waste management. Different parameters, like the incubation period, pH, temperature, sodium chloride concentrations, inoculum level, carbon source, nitrogen source, metal ions, particle size, substrate concentration, moisture content, and different agro waste are optimized for efficient biopigment production.

Bacterial Pigments

Different bacteria produce varieties of pigments such as red (prodigiosin), yellow (riboflavin), blue (indigoidine), purple (violacein), bluish green (pyocyanin), and so on. Some pigments, like anthocyanins, are soluble in water, and canthaxanthin and carotenes are soluble in fat. The different varieties of pigments from bacterial sources (Kamla et al., 2012; Malik et al., 2012; Chaudhari et al., 2013; Panesar et al., 2015; Bhat and Marar, 2015) are represented in Table 1.

Table 1: Different types of bacterial pigments

Sl. no.	Bacteria	Pigment	Color
1	*Streptoverticillium rubrireticuli*	Prodigiosin	Red
2	*Serratia marcescens*	Prodigiosin	Red
3	*Pseudoalteromonas rubra*	Prodigiosin	Red
4	*Vibrio gaogenes*	Prodigiosin	Red
5	*Rugamonas rubra*	Prodigiosin	Red
6	*Serratia rubidaea*	Prodigiosin	Red
7	*Streptomyces echinoruber*	Rubrolone	Red
8	*Pseudoalteromonas denitrificans*	Cycloprodigiosin	Red
9	*Streptomyces sp.*	Undecyl prodigiosin	Red
10	*Streptococcus agalactiae*	Granadaene	Orange red
11	*Bradyrhizobium sp.*	Canthaxanthin	Orange red
12	*Haloferax alexandrinus*	Canthaxanthin	Dark red

13	*Dietzia maris*	Canthaxanthin	Dark red
14	*Salinicoccus sp.*	Carotenoid	Orange
15	*Planococcus maritimus*	Carotenoid	Orange
16	*Micrococcus luteus*	Carotenoid	Yellow
17	*Agrobacterium aurantiacum*	Astaxanthin	Pink red
18	*Paracoccus carotinifaciens*	Astaxanthin	Pink red
19	*Streptomyces virginiae*	Melanin	Dark brown
20	*Bacillus thuringiensis*	Melanin	Dark brown
21	*Bacillus subtilis*	Riboflavin	Yellow
22	*Flavobacterium sp.*	Zeaxanthin	Yellow
23	*Paracoccus zeaxanthinifaciens*	Zeaxanthin	Yellow
24	*Sphingobacterium multivorum*	Zeaxanthin	Yellow
25	*Brevibacterium sp.*	Zeaxanthin	Orange yellow
26	*Achromobacter*	Zeaxanthin	Creamy
27	*Staphylococcus aureus*	Staphyloxanthin	Golden yellow
28	*Xanthomonas oryzae*	Xanthomonadin	Yellow
29	*Corynebacterium insidiosum*	Indigoidine	Blue
30	*Pseudomonas aeruginosa*	Pyocyanin	Blue green
31	*Rhodococcus maris*	Beta-carotene	Bluish red
32	*Chromobacter violaceum*	Violacein	Purple
33	*Janthinobacterium lividum*	Violacein	Purple
34	*Pseudoalteromonas tunicate*	Violacein	Purple

Applications for bacterial pigments

Bacterial pigments have applications in food, cosmetic, pharmaceutical, dyeing, textile, paper, and printing industries. The advantages of biopigments from microbes increase the exploration of novel microbes from extraordinary habitats. Their production costs are low due to the utilization of waste as substrates by microbes.

Environmental applications for bacterial pigments

Microbial pigments play an important role in the environment as an indicator of pollution. They are very helpful in solving many pollution problems. The environmental applications of bacterial pigments (Pankaj and Kumar, 2016) are shown in Table 2.

Table 2: Environmental applications for bacterial pigments

Sl. no.	Bacteria	Pigment	Indicator
1.	*Chlorobiump haeovibroide*s	Brown	Hypoxic condition
2.	*Vogesella indigofera*	Blue	Chromium contamination
3.	*Flexibacter*	Violet	Polluted drinking water

Food Industry applications

Customers are attracted to colored food products. Synthetic food colorants cause severe health disorders. Therefore, we need natural colors from microbes. Microbe pigments serve as effective food colorants. Their yield is increased due to the improvement of the strain and optimized conditions. Bacterial colorants in food products are eco-friendly, colorful, and have probiotic health benefits (Nagpal et al., 2011). Microbial colorants enhance farmed salmon's pink color. Some natural food colorants are used as antioxidants. They are safe to use and approved by the FDA. Pigments are produced from microbes using fermentation methods. Zeaxanthin from *Flavobacterium* could be used in the poultry industry in order to increase the yolk's yellow color. It is used as a colorant in food industries. Pyocyanin from *Pseudomonas aeruginosa* is used as a colorant in beverages and in the baking industry in cakes, puddings, and confectionary. The application of pigments in the food industry (Panesar et al., 2015; Tuli et al., 2014) is shown in Table 3.

Table 3: Applications of bacterial pigments in the food industry

Sl. no.	Bacteria	Pigment	Significant activities
1.	*Flavobacterium*	Zeaxanthin	Additive in poultry feed, colorant in the food industry
2.	*Pseudomonas aeruginosa*	Pyocyanin	Colorant used in beverages and baking

Pharmaceutical and biomedical applications

There is a current need to create efficient bioactive compounds from microbes. Microbial pigments are used as antibiotics and are antidiabetic, immunosuppressive, and anticancer agents. Prodigiosin has antimalarial, antibiotic (prodigiosin25-C), immunosuppressant, antiproliferative, and antidiabetic activities (Kim et al., 2003). Violacein has antiprotozoan, anticancer, antiviral, antibacterial, and antioxidant activities (Yada et al., 2007; Kodach et al., 2006). Anthocyanin has anticancer and anti-inflammatory properties and also modulates the immune response (Katsube et al., 2003; Lazze et al., 2004). Carotenoids have the capability to modulate immunological reactions. Using astaxanthin could prevent cardiovascular disease. It also boosts the immune system (Venil et al., 2013). Therefore, pigments from bacteria provide novel applications in biomedical research. The biomedical and pharmaceutical activities of bacterial pigments (Tuli et al., 2014) are represented in Table 4.

Table 4: Applications of bacterial pigments in pharmaceutical and biomedical fields

Sl. no.	Bacteria	Pigment	Color	Significant activities
1	*Serratia marcescens*	Prodigiosin	Red	Anticancer, antimalarial, immunosuppressant, antibiotic
2	*Streptomyces sp.*	Prodigiosin	Red	Anticancer, antiproliferative
3	*Pseudoalteromonas rubra*	Prodigiosin	Red	Anticancer, antioxidant, immunosuppressant
4	*Vibrio gaogenes*	Prodigiosin	Red	Anticancer, antioxidant,
5	*Rugamonas rubra*	Prodigiosin	Red	Anticancer
6	*Serratia rubidaea*	Prodigiosin	Red	Anti-cancer, antioxidant
7	*Pseudoalteromonas denitrificans*	Cycloprodigiosin	Red	Antiplasmodial, anticancer
8	*Streptococcus*	Granadaene	Orange,	Antioxidant,

	agalactiae		red	detoxify ROS
9	*Bradyrhizobium sp.*	Canthaxanthin	Orange, red	Antioxidant, anticancer
10	*Agrobacterium aurantiacum*	Astaxanthin	Pink, red	Antioxidant, anticancer, photoprotectant, anti inflammatory
11	*Streptomyces virginiae*	Melanin	Dark brown	Antibiotic, antifungal
,12	*Xanthomonas oryzae*	Xanthomonadin	Yellow	Protects against photodamage
13	*Staphylococcus aureus*	Staphyloxanthin	Golden yellow	Antioxidant
14	*Corynebacterium insidiosum*	Indigoidine	Blue	Antimicrobial
15	*Pseudomonas aeruginosa*	Pyocyanin	Blue, green	Cytotoxicity, proinflammatory, neutrophil apoptosis
16	*Chromobacter violaceum*	Violacein	Purple	Antioxidant, detoxify ROS
17	*Janthinobacterium lividum*	Violacein	Purple	Antioxidant, detoxify ROS
18	*Pseudoalteromonas tunicate*	Violacein	Purple	Antioxidant, detoxify ROS

Textile industry applications

The textile industry uses greater quantities of synthetic pigments, which results in harmful environmental effects. They also create toxicity during synthesis, processing, and effluent disposal. They cause groundwater contamination, as well as having lethal effects on aquatic and terrestrial organisms. This means that there is an increasing demand for natural pigments from microbes because of their multiple advantages. Newer shades can be obtained from novel microbes. Microbial pigments are eco-safe, hypoallergenic, and noncarcinogenic in nature. The multiple uses for bacterial pigments in the textile industry (Alihosseini et al., 2008; Kumar et al., 2015) are represented in Table 5.

Table 5: Applications of bacterial pigments in the textile industry

Sl. no.	Bacteria	Pigment	Activities (for dyeing)
1.	*Chromobacterium violaceum*	Purple	Cotton, silk, rayon, and polyester
2.	*Serratia marcescens*	Red	Cotton, polyester, acrylics, and silk
3.	*Roseomonas fauriae*	Pink	Cotton
4.	*Janthinobacterium lividum*	Bluish purple	Cotton, silk, wool, and nylon
5.	*Vibrio sp.*	Red	Nylon, wool, acrylic fibers, and silk

Future perspectives

Microbial pigments are the best environmently-friendly alternatives for many synthetic agents used in the textile, cosmetics, and food industries. They play a significant role in the pharmaceutical industry and have many clinical applications to help cure certain diseases. Nowadays, there is an increased awareness of natural pigments, which is due to the harmful effects of synthetic pigments. There is an urgent need to explore more efficient pigments that can be created from novel marine bacteria, which has extraordinary features. Novel marine bacteria have the capability to yield different shades of stable pigments. Strain improvement and the use of genetically modified microbes produced by biotechnology enhance the quantity and quality of pigment production. Moreover, the use of agro waste for pigment production by solid-state fermentation is the best practice for eco-friendly waste management and reduces the cost of production.

Conclusion

Biopigments from microbes are the best alternative to synthetic pigments. Microbes are the best source of natural pigments due to their advantages. Currently, the demand for eco-safe and human-safe pigments is rapidly increasing in many fields. Novel marine bacteria are a promising source of efficient production of non-toxic natural pigments, which could be used in different fields, such as the food, textile, and pharmaceutical industries. Biotechnology plays a significant role in enhancing the efficient large-scale production of biopigments from marine bacteria.

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CHAPTER TWO

DO WE LIVE FOR MICROORGANISMS OR DO THEY LIVE FOR US?

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Abstract

> "Microorganisms will give you anything you want, if you know how to ask them."
>
> Kinichiro Sakaguchi

Microorganisms surround us and are also surrounded by all living things. Most single-cell organisms, such as bacteria, some fungi (yeast), microalgae, and viruses are microorganisms. Microbes belong to diverse communities in groups known as microbiomes. Microorganisms can be beneficial and dangerous to other living organisms, such as humans, plants, and animals. We will discuss whether we live for microorganisms or whether they live for us. Of course, many microorganisms are harmful to us as a disease-causing agent; however, many more are harmless and actually help to maintain our health. The normal flora that live on the skin, mouth, and nose fight against pathogenic bacteria, which try to enter the body to cause disease. These good bacteria act like defenders and keep away the harmful bacteria that make us sick. Some microorganisms that colonize humans are commensal and we have a mutual relationship with

others. These interactions are important for humans to grow and stay healthy. Microorganisms need to live with the support of other living things for their nutrition, growth, and reproduction. God created both microorganisms and humans for some reason, although whether this is good or bad is unclear. Still, there is confusion over whether we are live for microorganisms or if they live for us.

Keywords: Microbes, Microbiomes, Human, Harmful, and Harmless.

1. Introduction

Microorganisms are the oldest form of life on earth and have been around for more than 3.5 billion years. Microbes have grown with humans for the past six billion years. Over this period of time, microbes and humans have formed multifaceted relationships with each other. Humans want microbes as they provide health benefits and many microbes require the specific atmosphere provided by the human body to live. Humans and microbes play on these interactions in order to grow and stay healthy. Microbes are more our friends than our enemies. Microbes perform many important jobs in medicine, bioremediation, biodecomposition, biofertilizers, and genetic engineering. We have been using microbes for many years to make the products we need and enjoy. For example, we have used fungi in the food industry to make food products since time began. Fungi and bacteria produce antibiotics, which fight off the harmful bacteria that cause diseases. For example, *Bacillus thuringiensis* is a common soil bacterium and pest-controller; *Arbuscular mycorrhizas* is a fungus that lives in the soil and acts as a biofertilizer; *Saccharomyces cerevisiae* is a baker's yeast that makes bread rise; *Escherichia coli* is a colon bacteria which lives in our digestive system to help digest food; *Streptomyces* is a bacteria in soil that makes an antibiotic to treat infections; *Pseudomonas putida* makes clean waste from sewage water at water treatment plants; and *Lactobacillus acidophilus* turns milk into yogurt. We have discussed one aspect of how microorganisms are useful to us and how they affect our lives in a positive way.

Additionally, humans live for microorganisms, which use us for their own purposes by residing within our body and causing many diseases. According to health care experts, infectious diseases caused by microbes are responsible for many deaths. This includes deaths from viral infections, bacterial infections, fungal infections, and protozoan infections. Among them, a bacterial infection is very pathetic condition, which causes bacterial diseases, such as tuberculosis, typhus, plague, diphtheria, typhoid fever, cholera, dysentery, and pneumonia. In this review article, we will briefly explain whether microbes live for us or if we live for microbes; we will also consider their positive and negative effects.

2. Microorganisms Live for Us: The Benefits of Microorganisms for Humans

As we know, microbes and microorganisms are tiny microscopic entities, which are classified into different groups, such as bacteria, fungi, protozoa, microalgae, and viruses. They can live in soil, water, food, or the intestines of animals. Microorganisms that live for human beings have multiple purposes. Microbes are used in several fields, such as the food industry, agriculture, and the waste disposal industry; they are also used to develop vaccines and within the field of medicine. We should not conclude that all microbes are beneficial to human life because some microbes pass on diseases to animals and plants (Todar, 2008). However, microorganisms are beneficial in various industries and for human life.

2.1 The Food and Fermentation Industries

Tasty food, such as milk and milk products, chocolate, tea, bread, and root beer, is produced with the help of microbes. Microbes can be used to preserve foods using a process called "fermentation". Fermentation is an anaerobic process, which involves the conversion of sugars to simpler compounds. Microbes require energy (Lasztity, 1996). Different microbes, such as bacteria and yeast, help to make the following food: cheese, chocolate, olives, sausages, bread, wine, beer, soy sauce, and yogurt.

2.1.1 Beer and Wine

Barley is converted to beer with the help of yeast (*Saccharomyces cereviceae*). Yeast is a fungus and can be grown without air to produce alcohol (ethanol). Any fruit juice can be converted to wine with the help of yeast using the fermentation process.

2.1.2 Bread

The same yeast that is used to make beer can also be used to make bread. Grains are fermented using yeast in order to make bread. Bread should be soft and it rises by kneading flour with yeast so that it produces carbon dioxide. Yeast secretes zymase enzymes, which make sugar produce carbon dioxide and ethanol. Carbon dioxide gas makes the bread rise. The ethanol evaporates during baking.

2.1.3 Chocolate

Chocolate is one of the most delicious foods in the food industry. Microbes help to prepare the chocolate. Chocolate is taken from the seeds of cacao trees. The seeds are encased in fleshy white pods. Fermentation removes the seeds from the pods. Microbes, which include yeasts and bacteria, produce an acid that helps to destroy the pods.

2.1.4 Natto

Natto, which is served with rice, is one of the Japanese's favorite foods. It is made by the action of microbes on soybeans that are soaked in water. Natto has the appearance of mucus-like mush with an ammonia smell.

2.1.5 Yogurt

Yogurt is a fermented milk product. Milk is rich in all nutrients, particularly a sugar called lactose. Sugar is the main carbon source for microbes because it is easily utilized. Lactobacilli are gram-positive bacteria, which are rod-shaped and convert milk to yogurt through the lactose fermentation process. Lactic acid is the end product, which makes the yogurt have a sour taste. (http://www.edu.pe.ca/southernkings/microcafeteria.htm).

2.2 Medicine and Science

Microbes have significant potential in the field of medical science. They are used in many industries for the production of antibiotics, anti-cancer drugs, vitamins, statins, vaccines, and insulin. They are also used to diagnose disease.

Antibiotic means "against life" and it is a chemical compound that produces microbes. These microbes attack the other pathogenic microbes and unicellular organisms that may be damaging to humans. The first antibiotic was penicillin; this is able to kill several bacteria without having a harmful effect on human cells. Alexander Fleming discovered it in 1929 and he named it *Penicillium notatum*. Bacteria called *Streptomyces* can produce more than 500 different antibiotics. Similarly, there are many fungi responsible for producing thousands of antibiotics.

2.3 Waste management and decomposers

Microbes play a vital role as **decomposers** when living things die. Microorganisms feed on and break down complex plant and animal matter. If there were no decomposers, then all living things would be messy. Dead organisms contain complex organic molecules, which can be broken down by microbes. They also release substances that can be used by other living organisms in the ecosystem.

Microorganisms play an important role in the management and disposal of domestic and industrial waste. Microbes are involved in a biological process called organic decomposition or stabilization; in this process, they clean both domestic and industry waste. The biological decomposition process is called composting and the final product is known as compost. It can be categorized as anaerobic compost when living organic matter is decomposed by microbes. Breaking down living organic matter raises the temperature and creates carbon dioxide. This gives it its soil-like appearance.

We know that large quantities of waste water are generated every day in cities and towns. A major component of this waste water is human excreta. Municipal wastewater is also called sewage. It contains large amounts of organic matter and microbes, which are often pathogenic. Have you ever wondered where this huge quantity of sewage or urban waste water is disposed of daily? It cannot be directly discharged into natural water bodies, like rivers and streams. Therefore, it needs to be treated in sewage treatment plants (STPs) to make it less polluting before disposal.

2.4 Microflora

"But as long as humans can't live without carbon, nitrogen, protection from disease and the ability to fully digest their food; they can't live without bacteria"

Anne Maczulak, famous microbiologist

There are 400 different types of bacterial species present in humans: some are beneficial and others are harmful. Some microorganisms that colonize in humans are commensal because they are able to co-exist with humans without causing harm, whereas other microbes have a mutual relationship with their human host where both receive benefits; this is known as a symbiotic relationship. One kilogram of body mass per person is composed of microbes called microflora. Microflora is responsible for protecting the body from bacteria and fungi that are harmful to human health. It also produces vitamin K, which is necessary to regulate blood-clotting processes. A diverse population of microbes can be found on the human skin; there can be as many as a thousand different microbes present. Most of them are harmless and beneficial to human life.

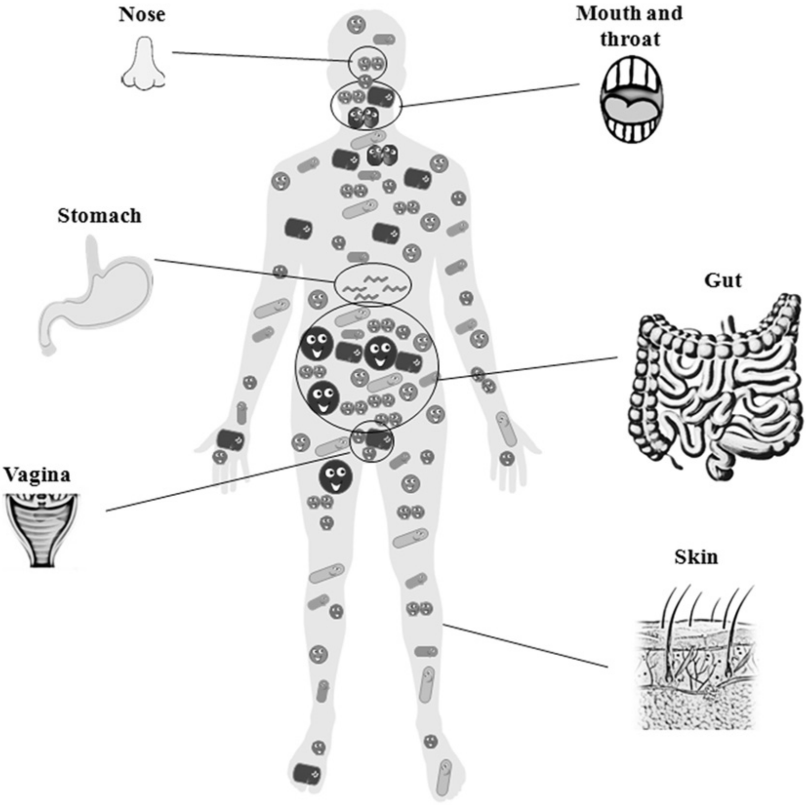

Figure 1: Some parts of the body contain billions of microbes

The healthy human gut has billions of microbes, which are known as microbiota. This normal population is referred to as “indigenous microbiota”. Some microbes are pathogenic and may produce toxins but most can be beneficial, as they can provide essential vitamins or are able to help prevent allergies. Normal gut flora supports the body's immune system. Colon bacteria are able to break down food that has not been previously processed and digested. The balance between the two types of microorganisms can ensure the sustainability of life. Probiotics are beneficial bacteria that live in our gut and they can also be purchased commercially. They are commonly found in a variety of milk products. Non-digestible food components are called prebiotic and they support useful gut bacteria. An example of this is cellulose. Prebiotics may be considered "food for good bacteria".

2.5 Air

Air is composed of gases, dust particles, and water vapor and also includes microbes in the form of algae, fungi, spores, vegetative cells, viruses, and protozoan cysts. Aerobic microbes are accountable for the degradation of dead cells, which are released from human skin. The world would contain mountains of dead skin if aerobes did not exist.

2.6 Biotechnology

The branch of science that deals with the manipulation of living organisms through genetic engineering is called biotechnology. It has many applications in the biological sciences and depends directly on microorganisms. Microbial biotechnology makes a major contribution to biotechnology, which is an area of science that applies microbial genetics to produce various microbial products. Microbes play a key role in recombinant DNA technology and genetic engineering. Microbial cells, genes, and enzymes are important tools in biotechnology. The main advantage of microbial biotechnology is producing pest or insect resistant varieties of animals and plants. In general, a combination of microorganisms with biotechnology could be used to develop substitute energy sources, biofuels, bioalcohol, and advancements in agriculture.

2.7 Agriculture

Microorganisms play a vital role in agriculture because the soil is the main source that gives support to plants; it also provides the supplements needed for their growth. Soil microbes are natural fertilizers and are referred to as biofertilizers and pest controllers. The agricultural industry uses this type of microorganism for the production of biofertilizers and biopesticides. This means that crops can be grown in a controlled and safe