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Escherichia coli Revisited: A Comprehensive Review of Its Dual Role in Global Pathogenicity and Biotechnological Innovation

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Abstract

The study of microbiology relies on E. coli impact, whether it is causing harm or keeping us healthy. Information from recent studies is used in the review to talk about E. coli changes, what it does, its genes and possible causes and outcomes of diseases. Special focus is placed on the harmful increase of microbes that become resistant to several types of antibiotics, with explanations about how this happens and its problems for public health. At the same time, the review looks at the role of E. coli in biotechnology when making recombinant proteins, biosensors, biofuels and in synthetic biology. Referring to clinical microbiology, molecular genetics and environmental studies, the paper points out that E. coli spreads infections and plays a key role in science. In the end, the review points out the main subjects that require additional exploration and gives suggestions for future research, with a focus on overcoming opposition, creating fresh vaccines and making use of biotechnology.

Keywords: Escherichia coli, Global Pathogenicity, Biotechnological Innovation, Review

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Introduction

Escherichia coli (E. coli) is widespread in nature and usually found living in humans and animals' digestive tracts as a Gram-negative, facultative anaerobe. The majority of bacteria live in our digestive systems and are safe, but some called pathogenic bacteria can trigger diseases, like diarrhea or HUS (1). The changes, fast multiplication and recognizable genome of E. coli suggest it is one of the main organisms used in these areas (2). Even now, E. coli strains that are resistant to multiple drugs are bringing major health concerns around the globe and adding to treatment costs (3). The study investigates current research on the biology of the bacterium, how it causes diseases, how to fight it with drugs and the difficulties involved in making the correct diagnosis. Then, it outlines ongoing challenges and advises ways that more research could be done. It studies the environments where E. coli usually grows and their significance for food safety and public health threats. Addressing the concerns relating to E. coli will have to be done, new studies show. Every year in the US, around 265,000 people become sick from food poisoning because of E. coli O157:H7 and similar STEC strains (4). Another problem is that MDR strains are multiplying faster because of horizontal gene transfer and MGEs decrease the effectiveness of older antibiotics. E. coli is important in biotechnology because it helps create insulin and biofuels with the help of synthetic biology (6). By considering these aspects, this analysis gives a clear description of how E. coli can endanger both human health and scientific work.

1. Definition and Historical Background

1.1. Definition of Escherichia coli

In 1885, Theodor Escherich discovered Escherichia coli and saw it was a Gram-negative rod in the Enterobacteriaceae family (7). The usual size of E. coli is 2.0 μm in length and 0.25-1.0 μm in width and it can be found in the digestive systems of mammals as well as in soil or water (8). The bacteria prefer to live in oxygen, however, they can survive and use other carbon sources as well (9). Most E. coli are not harmful and they assist the gut microbes by making vitamin K2 and controlling the spread of bad bacteria (10). Nevertheless, dangerous E. coli, labeled as pathotypes, are STEC, ETEC and EPEC and they greatly increase the chances of serious disease and death in many people (11).

1.2. Historical Significance

Scientific findings in genetics and biotechnology since the 1940s have frequently depended on E. coli in molecular biology. Genetic scientists were able to study the genetic code and processes more easily because M. tuberculosis has only one ring-shaped chromosome (4.6 Mbp) and they could understand its genetics easily (12). Insulin proteins were created with recombinant DNA technology and this was supported in part by using the laboratory E. coli strain K-12 (13). Also, seeing mutations and the sharing of genes in E. coli helps us understand better how bacteria adapt and become diverse (14). After sequencing the E. coli MG1655 genome in 1997, it was clear that roughly a fifth of its genes had come from other bacteria through horizontal transfer after the Salmonella split (15). Because of these discoveries, E. coli is often used in a variety of scientific research.

Table 1: Key Milestones in E. coli Research

Impact	Milestone	Year
Established *E. coli* as a distinct species	Isolation by Theodor Escherich	1885
Advanced understanding of genetics	Adoption as a model organism	1940s
Enabled production of therapeutic proteins	Recombinant DNA technology	1977
Provided insights into bacterial evolution	Genome sequencing of MG1655	1997

2. Structure and Characteristics

Because of its sophisticated organization, Escherichia coli (E. coli) is able to cope and thrive in different conditions. Because of how E. coli is built and functions, it can be found in everything from the intestines of mammals to environmental sites and it is widely used as a laboratory and biotechnology model (16).

2.1. Morphology and Cellular Components

E. coli bacteria are usually 2.0 microns in length and 0.25 to 1.0 microns wide, making them appear as rods (17). One outer membrane and its LPS (lipopolysaccharide) broker the periplasmic space, where a peptidoglycan layer sits next to the inner, cytoplasmic membrane (18). The outer membrane's strength comes from the Omps and EPS present within which also help it interact with objects in the environment (19). A few strains are equipped with flagella and type I fimbriae which help them move and stick to hosts to increase their ability to reproduce (20). The process of biofilm formation that enables E. coli to persist in several habitats is affected by capsular antigens (CA) (21). The surface and shape of colonies vary among strains, where smooth ones form in circles and stick up, while rough ones are flat and not in a circle (22). These two virulence factors (antigen 43 and type I fimbriae) illustrate the genetic characteristics and abilities of E. coli (23). Because K-12 E. coli laboratory strains lack O-antigens, their colonies are "rough" and are easily distinguished from other strains in experiments (24).

2.2. Metabolic Capabilities

It is able to use different carbohydrates and sugars for food, whether there is oxygen or not (25). There has been examination of the metabolic part that drives growth in various supply scenarios by means of both computer simulations and laboratory experiments (26). In response to having lots of carbon and nitrogen, E. coli relies on glycolysis, the tricarboxylic acid (TCA) cycle and the pentose phosphate pathway (27). Being pathogenic, UPEC E. coli has a different ability to produce energy which demonstrates that metabolism plays a key role in causing disease .(28)

Using the adaptable metabolism of E. coli, biologists have created strains suited for producing biofuels and medicines (29). Even so, when bacteria develop disease and build resistance to drugs, their ability to survive and reproduce drops which science does not fully explain (30). Continuing to discover the cost of producing MDR strains can help find weaknesses that can drive the development of new medicines.

2.3. Critical Analysis

Even though E. coli's structure and metabolism are understood well, how environmental factors can affect these is not yet clear. It seems that environmental E. coli protect themselves by building biofilms which can reduce the effectiveness of antibiotics, but exactly how it works is not fully known (31). Also, depending on only K-12 and MG1655 in experiments may lower the value of the results for wild bacteria (32). The studies of E. coli using transcriptomics and metabolomics open doors to understanding its shifts in many living conditions.

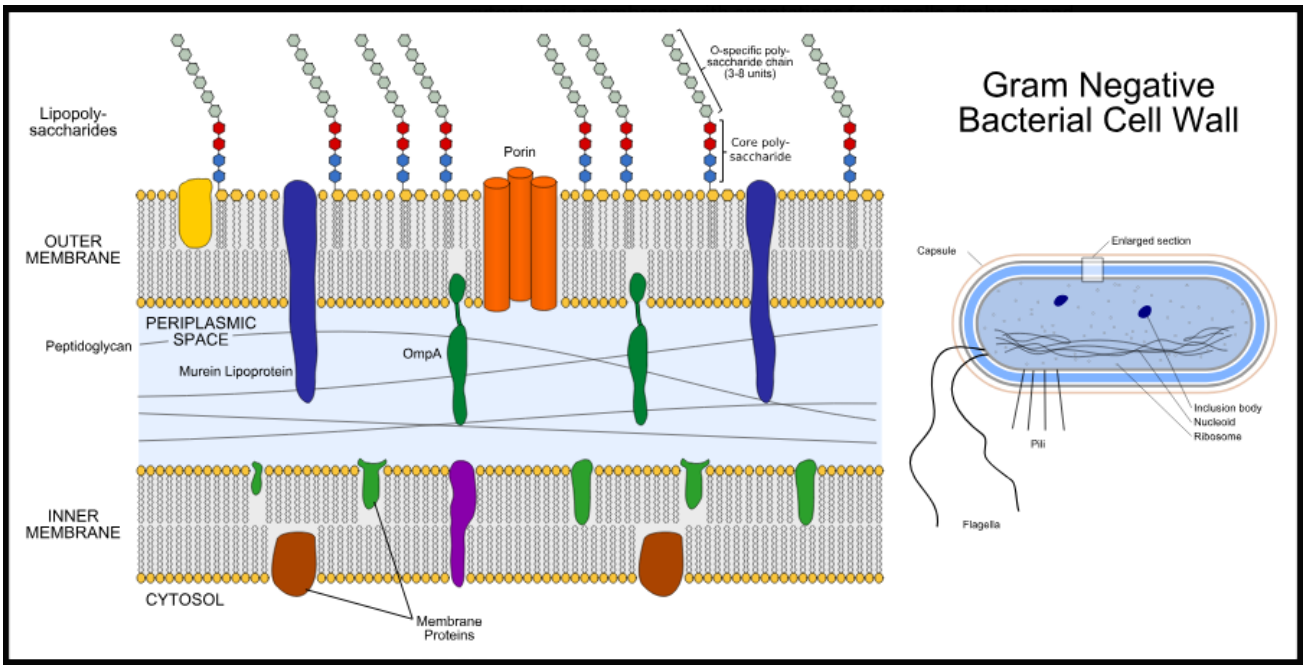

Figure 1. A drawing of the cell envelope of E. coli is presented, showing the three layers (outer membrane, periplasm and cytoplasmic membrane) and including information about flagella, fimbriae and capsular antigens (33).

3. Classification and Genetic Diversity

E. coli gets to adapt and do well wherever it is because of both its taxonomy and the ways its genes vary. It matters a lot to understand these things to follow positive and negative types of E. coli, anticipate their drug-resistance and apply them in biotechnology.

3.1. Taxonomic Hierarchy

E. coli belongs to the following taxonomic hierarchy:

- Domain :Bacteria
- Kingdom :Bacteria
- Phylum :Proteobacteria
- Class :Gammaproteobacteria
- Order :Enterobacterales
- Family :Enterobacteriaceae

- Genus :Escherichia
- Species :*Escherichia coli* (34)

Hence, E. coli is placed with Salmonella and Shigella in the group of enteric bacteria. Since it belongs to the Enterobacteriaceae family, it is used as a sign of sewage pollution in the environment (36).

3.2. Strains and Serotypes

Among E. coli serotypes, the different ones are determined by the presence of the O (LPS) or H (flagellar) antigens (37). Most serotypes are harmless and live safely inside being safe, but only the ones that can harm the body are called pathotypes. The main existing pathotypes in mold medical mycology are as follows:

STEC in particular, usually with the strain O157:H7, is responsible for most cases of HUS (38).

Enterotoxigenic Escherichia coli (ETEC) causes the most cases of traveler's diarrhea around the world, especially in developing countries (39).

Diarrhea in young children, mostly in low-income regions, is commonly caused by EPEC or E. coli of the entero pathogenic type (40).

EIEC bacterium causes symptoms similar to dysentery, whereas diarrhea from EAEC tends to last for a longer period and can be more serious (41).

The methods that pathotypes use to infect and harm are unique which requires different ways to diagnose and treat them (42). The startling resemblance of clinical symptoms leaves researchers perplexed and so it is important to use advanced molecule identification (43).

3.3. Genetic Diversity

The genes of any E. coli strain are arranged so that around 50% are shared by every strain and the rest are special to that subtype (44). When there is horizontal gene transfer, duplication of genes or a change through mutation, new genes are acquired, allowing organisms to survive in several environments (45). One example is MG1655 which was taken from lab strains and has about 4,300 coding genes. About 18% of these genes came from horizontal acquisition after it split from Salmonella.(46)

Researchers using CRISPR techniques have found that the function of genes in E. coli changes a lot depending on the bacterial strain and how they are cultured (47). Since MDR strains contain many genes, their ability to become common is linked to the spread of MGEs sharing genes such as MCR-1 which makes bacteria unresponsive to colistin (48). It is not clear yet how ecology and evolution affect the E. coli pan-genome lived in various environments (49).

3.4. Critical Analysis

Both advantages and disadvantages arise from the genetic characteristics of E. coli. While this feature allows synthetic biology to use the bacterium, it makes it more difficult to deal with harmful forms of the bacteria. The old techniques of serotyping and pathotyping have been supported by whole-genome sequencing (WGS) which makes it much clearer to tell apart different Virus strains (50). As WGS is more costly in much of the world, it is not yet widely

available (51). More could be done to develop straightforward genotyping methods and to link global tracking systems with data on environmental E. coli to keep an eye on changes in the resistance and virulence of these strains.

Table 2: Comparison of *E. coli* Pathotypes

Pathotype	Key Virulence Factors	Clinical Manifestations	Primary Affected Populations
STEC	Shiga toxins	Bloody diarrhea, HUS	Children, elderly
ETEC	Heat-labile/stable toxins	Traveler's diarrhea	Travelers, infants
EPEC	Adherence factors	Persistent diarrhea	Infants in developing countries
EAEC	Aggregative fimbriae	Watery diarrhea	Children, immunocompromised
EIEC	Invasion proteins	Dysentery-like illness	General population

4. Habitat and Distribution

The bacterium E. coli adjusts well whether it lives in living creatures or in various places outside. Since ticks can live almost anywhere and might change habitats, it is hard for those in public health and the environment to keep tabs on them which is why they need to be aware of their habitats and effects..

4.1. Natural Habitats

Most often, E. coli is found inside the intestines of warm-blooded animals, where it produces vitamin K2 and helps stop infections from other dangerous microbes (52). Even if the numbers go down, E. coli usually lives in freshwater, soil and sediments on plants, usually not coming into contact with newer feces (53). There is a difference in the genetic makeup of environmental E. coli versus commensal strains which may suggest they developed to endure in new surroundings (54). Science uncovered that E. coli living in clean water has the ability to multiply with very little food (55). The polysaccharide biofilm around E. coli cells helps the bacteria live longer in environmental sources, by blocking exposure to UV radiation and preventing loss of water through drying (56). Even so, we are not fully aware of which molecular mechanisms keep bacteria resistant, mainly with the spread of antibiotic resistance between bacteria (57). Experts can use metagenomics and learn about E. coli's adaptation in a new environment which could help them design better prevention methods.

4.2. The Presence in Humans and Animals

The vast majority of E. coli found in people and animals lives peacefully, as commensals in the gut (58). There have been many cases of food poisoning and waterborne disease because of STEC, a type of unpleasant E. coli (59). STEC known as E. coli O157:H7 is associated with beef, dairy and leafy greens and it is believed to affect 265,000 (60) Americans each year. Without showing any symptom, E. coli O157 can be found in animals like cattle, sheep and goats and this causes their fecal matter to spread the bacterium in the environment (61).

Experts in epidemiology have found that eating rotten food, being in contact with sick animals or spending time in unhygienic places can allow people to get it (62). Young children and seniors may experience serious side effects such as HUS infection when they use NSAIDs (63). It is clear from the relationship among host conditions, pathogen virulence and environmental sites that integrated study at the boundary of humans, animals and nature is very important.

4.3. Factors From the Outside Affecting Growth

The environment can play a big role in determining how E. coli thrives and survives.

The bacteria is unable to survive in acidic conditions found in the stomach or fermented food, but it thrives when pH is neutral.(64)

E. coli grows well at a temperature of 37°C, but can also live down to 5°C and may be more durable when it is colder.

E. coli needs nutrients found in the water or soil and stress is activated when these are unavailable.(66)

In places like soil or rumen fluid, normal microbiota can stop E. coli growth.(67)

E coli is able to thrive in low and high oxygen levels and it grows a little faster in the presence of oxygen. These effects mixed together can help E. coli in its environment, but all of them have never been studied in a natural setting. Linking data on temperature and rainfall to predictive models may help forecast the presence of E. coli in various areas as the climate changes, assisting in choosing what measures to take (69).

4.4. Critical Analysis

While scientists know where E. coli usually lives in nature, much less is known about its survival for longer periods in other places. The spread of antibiotic resistance occurs by biofilms in water which deserves further investigation (70). In addition, most of the current study of these diseases looks at ways humans and animals transmit diseases, leaving out environmental sources which could also act as hidden reservoirs for pathogens (71). In the future, blending genomics, proteomics and other techniques with machine learning could help show E. coli's behavior and allow us to bring down the chance of contamination.

Table 5: Factors in the Surroundings That Affect E. coli.

Factor	**Effect on *E. coli***	**Public Health Implication**
pH	Acidic pH inhibits growth	Acid-based sanitizers for food safety
Temperature	Survives at low	Refrigeration to control

	temperatures	growth
Nutrient Availability	Fuels growth in rich media	Nutrient management in water treatment
Microbial Interactions	Suppresses growth	Probiotics to limit colonization
Oxygen Levels	Enhances aerobic growth	Aeration control in wastewater

5. Pathogenicity

E. coli is considered highly pathogenic due to many virulence factors, allowing several strains to lead to simple diarrhea or more dangerous full-body infections. Learning about these processes is important for creating effective ways to diagnose and treat diseases.

5.1. Different kinds of Pathogenic E. coli

There are six important forms of pathogenic E. coli called pathotypes and each one causes particular symptoms.(72)

Bloody diarrhea and HUS are related to the presence of Shiga toxin-producing E. coli (STEC). E. coli O157:H7 (73) often causes a high level of alarm.(73)

Among this type of E. coli (ETEC), the watery kind of diarrhea is mostly caused by its enterotoxins and usually found in developing areas.

EPEC (enteropathogenic E. coli) clings to the inside of the intestine and results in infants repeatedly falling ill with diarrhea.(75)

Enteroaggregative E. coli (EAEC): Builds biofilms in the intestine that result in longer periods of diarrhea in those at risk.(76)

This bacterium is known as Enteroinvasive E. coli (EIEC): It settles on the surface of the bowel and may cause a disease such as dysentery.(77)

We know that Diffusely Adherent E. coli (DAEC) is linked to child diarrhea because it can stick to different parts of the intestinal cells.(78)

Another ExPEC strain, Uropathogenic E. coli (UPEC), causes urinary tract infections, sepsis and on some occasions, meningitis, widening the effects of E. coli (79).

5.2. How Infection Happens

While most A. coli species use fimbriae and adhesins to stick to host cells, EIEC has its own method (80). Type III Secretion Systems (T3SS) are used by EPEC and STEC to transfer proteins into host cells, after which the bacteria are able to influence cell activity and remain in or invade the host's body (81). Toxins present in salmonella such as Shiga toxins or enterotoxins, harm cells and can result in both inflammation and death of the cells (82). Although we can control these mechanisms well, we do not yet know what signals from the environment such as nutrients or the immune system, start them (83). Assessing these systems may help scientists find other places to treat diseases with medicines.

5.3. Critical Analysis

Since there are so many types of E. coli, it is not always easy to prevent and handle these infections (84). Blocking T3SS functions is attracting research, though these approaches aren't helpful against MDR infections (85). Because E. coli infections affect many people in lower-income countries, there is a strong need for cheaper methods to diagnose and control the disease (86). By studying E. coli with both genomic and proteomic research, we could come up with anti-virulence plans faster for all the problems it can cause.

6. Antibiotic Resistance

Because there are numerous strains of Escherichia coli now resistant to antibiotics and drugs are given to animals and people often, this makes solving the problem harder. Patients with MDR E. coli are treated more aggressively, the death rate rises and it costs more money. Both sides therefore should swiftly take actions to stop them from spreading (87).

6.1. Evolution and Obtaining of Resistance Gene

A resistance to antibiotics is gained by E. coli over the years as a result of both mutations and the movement of genes by plasmids, transposons and integrons (88). Because resistant genes are found in many bacterial populations, the gut microbiota shares them by transferring them with the help of MGEs (89). All three groups: human, animal and environmental, have seen cases of colistin-resistant E. coli with the MCR-1 gene.(90)

A number of studies have used genetic data to understand how E. coli gains resistance to antibiotics by making varying changes (91). The disadvantage of resistance is that it can limit the rate that medicine can treat infections, causing new solutions to be made (92). There is not much known about the reasons behind wastewater and environmental resistance which underlines the necessity of unified actions (93).

6.2. How Antibiotic Resistance Works

There are different ways E. coli breaks free from the effects of antibiotics.

•Inactivation Through Enzymes: ESBLs and AmpC beta-lactamases are enzymes that hydrolyze cephalosporins and penicillins which inactivates them.(94)

•Overproduction of efflux systems, for example AcrAB-TolC, facilitates the elimination of tetracyclines and quinolones, one of the reasons for MDR development.

•Target Transformation: When PBPs change, they often reduce how well antibiotics can interact with them.(96)

Plasmids with CTX-M, CMY-2 and MCR-1 usually make bacteria resistant to beta-lactams, quinolones and colistin and also promote resistance to other numerous drugs (97). Because of HGT, bacteria are quickly building up resistance, creating new "superbugs" like carbapenem-resistant E. coli which cause significant problems for doctors (98). Resistance genes being present in sewage due to the plants causes them to be distributed further, so new and stronger wastewater treatment technologies are needed (99).

6.3. Roles for Public Health

Those who consume E. coli from MDR strains can end up in the hospital more often, may die more frequently and place an additional stress on the EU economy and American economy by €1.5 billion and $2.8 billion each year. An increase in antibiotic resistance is affecting many countries and often happens when people travel, share goods or use antibiotics wrongly (101). Because there are not enough devices for infection detection, patients in low- and middle-income countries may have to wait for care (102). Though the results are promising for CRISPR and phage therapy, more research is required to define how they should be used and regulated (103).

6.4. Critical Analysis

What makes E. coli resistant to antibiotics is clearly understood, yet it is tough to address properly. If you use broad-spectrum antibiotics, it becomes difficult to stop drug resistance, so drugs that act on only one type of resistant gene are needed (104). Many studies have focused on other sources such as runoff from farms and wasted water, to understand how resistant bacteria develop (105).

Table 6: Ways in which E. coli become resistant to antibiotics.

Mechanism	Example	Antibiotics Affected	Potential Countermeasures
Enzyme Inactivation	ESBLs, AmpC	Cephalosporins, penicillins	Beta-lactamase inhibitors
Efflux Pumps	AcrAB-TolC	Tetracyclines, quinolones	Efflux pump inhibitors
Target Modification	Altered PBPs	Penicillins	Novel antibiotics
Plasmid-Mediated	CTX-M, MCR-1	Quinolones, colistin	Plasmid-curing agents

7 .Understanding When, How and How Long to Avoid

Timely identification of E. coli, accurate diagnostic methods and preventing it are all important parts of preventing serious health problems. Testing methods have improved and so has public health support, but a lot of the globe still does not have easy access.

.7.1 .The process that Labs use to ID an Organism

Bacteriologists use MacConkey or Sorbitol-MacConkey medium to support the culturing of STEC and other E. coli pathotypes which produces red colonies (106). Sometimes, these methods can take a long time and the results are often ready after at least one day (107). Specific PCR tests looking for stx1 and stx2 can find STEC within a short time and with a close to 98% accuracy (108). Thanks to WGS, we can tell apart different strains and know about their resistance which aids in the proper monitoring of outbreaks and epidemics (109). Using these new methods, it is likely that tests will be done more affordably and promptly (110). However, before neuromodulation is adopted in many clinics, guidelines have to be set and its use has to be checked at various centers.(111)

7.2 .Issues during Detection and Surveillance

E. coli is less likely to be found in water and food because these samples usually contain background organisms and only a few microorganisms (112). When bacteria are picked out for growth, the group as a whole can be biased and flow cytometry cannot tell which strains are most important (113). Even though E. coli disease occurs often in weakly equipped areas, it is hard to monitor the transmission because of inconsistent results and poor reporting platforms. In order for WGS to help global monitoring, it should be expanded and linked to existing online data services, but its high costs and lack of available training must be addressed (115).

7.3 .Prevention Strategies

Different methods are needed to reduce infections from E. coli.

•Cleaning your hands, looking after wounds and following proper breathing methods stop the virus from spreading in hospitals and communities.(116)

A steak or hamburger at a core temperature of 160°F (71°C) or stored under 40°F (4°C) won't allow E. coli to grow in your meals (117). Having distinct cutting boards for raw and cooked foods helps to stop possible contamination.(118)

•No human vaccine for E. coli has been developed yet, but new vaccines against STEC and ETEC are now being tested and seem promising. As an example, when mucus membranes are exposed to vaccines containing fimbriae, animals develop defenses against bacteria (119). Reverse vaccinology makes use of genetic material to develop vaccines that protect against several similar diseases.(120)

UV light or certain chemical reactions are used on wastewater to help reduce the amount of E. coli and its resistant genes in the environment.(121)

8 .Biotechnological Applications

The use of Escherichia coli (E. coli) in biotechnology is common because its genes are convenient to work with, it grows very quickly and its metabolism is easy to study. Drosophila is simple to work with which has allowed it to influence many areas of industry, medicine and the environment.(125)

8.1 .Making and producing biopharmaceuticals

Many recombinant proteins, for example, insulin and growth hormones, use E. coli for their production (126). Together, using heterologous genes and T7 promoters, bacteria can make many types of proteins in large quantities (127). For instance, almost a third of biopharmaceuticals on the market are developed using special strains of E. coli called K-12 and a common biopharmaceutical made from these strains is insulin used in diabetes treatment (128). The fact that some proteins are hard to modify by glycosylation in E. coli has prevented its use for complex proteins, so scientists are currently working on how to modify E. coli to improve its usefulness (129).

8.2 .Applications of Synthetic Biology and Metabolic Engineering are used by researchers.

Since E. coli can utilize many nutrients, it allows scientists to make biofuels, biomaterials and industrial compounds (130). Some kinds of modified E. coli are able to create bioethanol, butanol and polylactic acid which can help supply sustainable products that rely on fossil fuel (131). Using heat shock promoters and RNA thermosensors to make use of HSR, a new type of biosensitive device was built. A good example is that biosensors based on E. coli are used to examine water for any heavy metals which also keeps pollution monitoring more affordable (133).

Table 7: Biotechnological Applications of *E. coli*

Application	Example Product	Advantage	Challenge
Biopharmaceuticals	Insulin, antibodies	High yield, scalable	Limited glycosylation
Biofuels	Bioethanol, butanol	Sustainable alternative	Metabolic burden
Biosensors	Heavy metal detection	Rapid, cost-effective	Sensitivity optimization
Biomaterials	Polylactic acid	Biodegradable	Low yield for complex molecules

9 .Important Ideas from Other Similar Organisms

Even though E. coli is a prime organism for prokaryotic biology, additional model organisms study eukaryotes and multicellular life which in turn helps us understand more about biological functions.(137)

9.1 .Saccharomyces cerevisiae (Baker's Yeast)

S. cerevisiae, belonging to the eukaryote group and found as a single cell, is used to investigate aging, the process of protein folding and how drugs act (138). Thanks to its ability to do post-translational modifications, it is preferred for producing complex biopharmaceuticals, since E. coli is limited in this regard (139). For example, scientists use S. cerevisiae to help generate artemisinin, an important antimalarial medication, using modified metabolic pathways.(140)

9.2 .Elegans Caenorhabditis and Drosophila melanogaster

Thanks to nematode C. elegans and fruit fly D. melanogaster, it is easier to study multicellular topics like development, the nervous system and disease processes (141). C. elegans is favored for studying aging and neurodegenerative conditions, but D. melanogaster is useful in finding out about cancer and the immune system (142). They use E. coli to represent various human diseases, allowing researchers to easily test new treatments (143).

9.3. Critical Analysis

The integration of E. coli and other organisms in research helps us learn biology as a whole, focusing on molecules and what organisms can do. Still, connecting the data from these models is difficult because the genetics and physiology are not the same (144). More work should be done on cross-species computational models to lessen the difference between research done in animals and its human application (145).

10. Possible Further Research

Having multipurpose utility as a commensal, pathogen and tool in biotechnology can create opportunities as well as difficulties for further studies. Important areas of priority involve:

Researchers are creating new treatments such as phage therapy and anti-virulence drugs, to tackle antibiotic-resistant E. coli strains (146).

• Environmental Surveillance: Engineers are now using metagenomics and machine learning to detect E. coli and its resistance genes in environmental samples which can guide rules for safer water and foods (147).

• Using synthetic biology tools, scientists hope to improve how E. coli produces complex molecules, aiming to solve ongoing problems with output and efficiency (148).

• Making Vaccines: Working to produce multi-use vaccines that fight many types of E. coli, keeping costs low for places with few resources (149).

For these guidelines to effect a global solution, Microbiology, Genomics and Public Health should come together and join their efforts. Research must be supported by adequate financing and improved infrastructure to become useful (150).

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