INTERDISCIPLINARY APPROACHES IN CHEMISTRY AND APPLIED SCIENCES

Edited by
Dr. Nazangül ÜNAL

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Preface

The advancement of science throughout human history is a result of our efforts to understand and transform nature. In this period, chemistry has served as a bridge touching every aspect of life by examining the structure, transformation, and interactions of matter. Today, this is not just theoretical knowledge; it is also intertwined with technology, with practical applications.

This work, titled *"Interdisciplinary Approaches in Chemistry and Applied Sciences",* aims to reveal the interaction of chemistry with current technologies and to understand the potential arising from this interaction. Within the book, you will see how classical chemical principles are interpreted and applied across a wide spectrum, from nanotechnology and energy conversion systems to environmental chemistry and materials science.

This book has been prepared as a resource for both the academic community and professionals working in the sector, as well as students and researchers. Our aim is to demonstrate that chemistry is not confined to the laboratory, but rather a powerful tool capable of providing solutions to real-world problems.

In an age where accessing knowledge is becoming easier but delving deeper is becoming more difficult, I hope that this work, prepared with an interdisciplinary approach, will open new horizons and inspire readers.

I would like to express my sincere gratitude to my esteemed teacher, Prof. Dr. Cezmi TEZCAN, who encouraged me and always believed in me in the creation of this book, and to all my teachers, colleagues, and family who have contributed to this day.

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CHAPTER 1

SOLAR ENERGY IN TÜRKİYE FUNDAMENTALS, TECHNOLOGIES AND APPLICATIONS

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1. INTRODUCTION:

In the 21st century, energy has become one of the main determinants of economic development, technological progress and social welfare. Since the industrial revolution, global energy demand has been constantly increasing, and this need has been largely met by fossil fuels (coal, oil and natural gas). However, the limited reserves of fossil fuels, their high environmental impacts and their largely import-based structure are among the important factors threatening energy supply security and sustainable development.

Global climate change, increasing greenhouse gas emissions and environmental degradation have forced the international community to turn to renewable and environmentally friendly energy sources. International initiatives such as the Paris Agreement, the European Green Dealand the United Nations Sustainable Development Goals have prioritized the use of renewable energy sources to achieve carbon neutral targets. In this context, interest in solar energy, as a sustainable, environmentally friendly and long-term economic solution, is increasing day by day due to its inexhaustibility and easy availability. Solar energy (including concentrated solar power (CSP) and solar photovoltaic (PV) power) is increasingly contributing to global electricity production as a form of renewable energy sources. Technological development to utilize solar energy and achieve sustainable development has progressed considerably in recent years. In recent years, the cost of energy production (power, heating and cooling) from solar sources has decreased significantly. Many studies on resource exploration and new conversion technology development have provided progress in this regard (Østergaard, P. A., et.al., 2022). It has proven itself firmly among other renewable energy technologies by accounting for approximately 31% of the total installed renewable energy capacity in 2022 and has become the second renewable energy source after hydroelectric energy. Although solar energy is the largest and continuous energy source reaching the Earth, the effective utilization rate of this potential has not yet reached the desired level in many countries (Renewable Energy Agency (Irena), 2023). However, solar radiation enables energy production both directly (direct) and indirectly (diffuse). This energy can be converted into electrical energy through photovoltaic systems or into thermal energy through thermal collectors. In addition, although there has been a significant increase of approximately 22% in global solar installed capacity between 2021 and 2022, literature research reveals that there are still many shortcomings in the field of solar energy. In the next three decades, solar PV field can become the second important production source by building more solar farms, allowing it to produce approximately 25% of the world's total electricity needs by 2050 (Pourasl, H. H. et al, 2023). Turkiye is one of the countries with high solar energy potential due to its geographical location. The annual average sunshine duration is around 2,700-2,800 hours, which is above the European average. Despite this, the development of solar energy investments has been limited for many years due to various legislative deficiencies, financial restrictions and access to technology problems. In recent years, significant developments have been made in this field with the increasing interest of both public policies and the private sector (Irena 2023).

Table 1. Top fourteen solar installers in 2022 (Irena 2023)

No	Country	Installed Capacity (GW)
1	China	393.0
2	USA	113.1
3	Japan	78.8
4	Germany	66.5
5	India	63.1
6	Australia	26.8
7	Italy	25.1
8	Brazil	24.1
9	Netherlands	22.6
10	Korea Republic	20.9
11	Spain	20.5
12	Vietnam	18.5
13	France	17.4
14	UK	14.4

GW: Gigiwatt, a gigawatt is one billion times a watt.

Table 1 shows the top 14 countries with highest installed capacity and the data for these countries. In this section, the basic physical principles of solar energy, its technological applications, the current situation and potential in Türkiye, advantages and disadvantages and the legislative structure will be discussed in detail. The aim is to analyze Turkiye's position in the field of solar energy within a scientific and technical framework, to evaluate what needs to be done in this field and to present policy recommendations.

2. SOURCES OF SOLAR ENERGY

Solar energy is the portion of the electromagnetic radiation released as a result of nuclear fusion reactions in the Sun that reaches the Earth's surface. The large amount of energy produced by the conversion of hydrogen atoms into helium in the center of the Sun is radiated into space. This energy reaches the Earth in approximately 8 minutes and 20 seconds and carries a power of approximately 1.74×10^{17} watts per year. This energy, which reaches the upper limit of the Earth's atmosphere, is called the "solar constant" and its average value is approximately 1361 W/m^2 (Duffie and Beckman, 2013).

The amount of solar energy reaching the Earth depends on many factors such as atmospheric conditions, geographical location, time of day, time of year and inclination/angle. Solar energy is a continuous and inexhaustible energy source with extremely low environmental impacts.

2.1. Types of Solar Radiation

Solar energy reaching the Earth is generally examined in three main components:

- Direct radiation: The component of the light coming from the Sun that reaches the surface directly without any scattering or reflection in cloudless weather conditions. Solar tracking systems make the best use of direct radiation.
- Diffuse radiation: Sunlight scattered by clouds, gases and particles in the atmosphere. This radiation can also reach shaded areas and is important for fixed PV panels.
- Global radiation: The sum of direct and diffuse radiation. The total energy received by solar panels is evaluated with this component

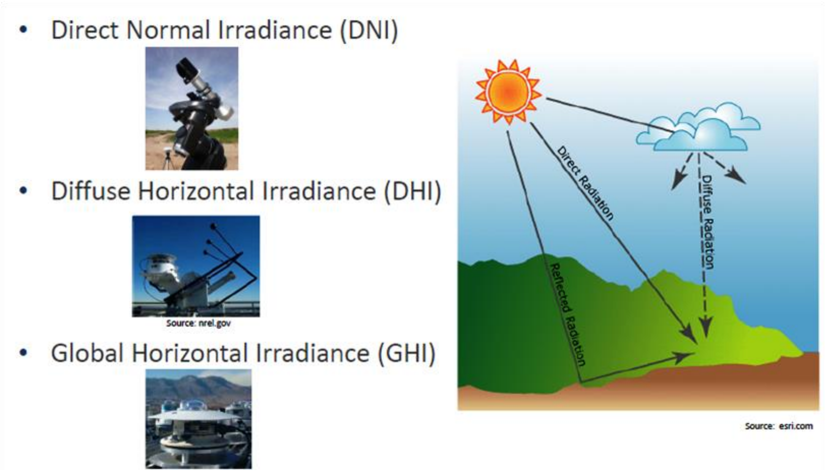


Figure 1. Types of radiation (https://firstgreenconsulting.wordpress.com/2012/04/26/differentiate-between-the-dni-dhi-and-ghi/; access date: 29.09.2025)

These radiation components directly affect the efficiency of solar energy systems and should be taken into account in the design process.

2.2. Measurement of Solar Energy and Parameters

Radiance measurements are critical for the design and performance analysis of solar energy systems. The basic parameters used for this purpose are as follows:

- Irradiance (W/m^2): It expresses the instantaneous amount of solar energy falling on a unit area. It evaluates the efficiency of solar energy systems instantly.

Insolation (kWh/m^2-day): The total amount of energy per unit area on a daily, monthly or annual basis. This value is the basic indicator for system design and economic analysis.

- Angle and direction: The tilt angle and orientation (azimuth angle) of the solar panel directly affect the annual total efficiency. The optimum tilt in Türkiye generally varies between 25°–40° depending on latitude.
- Sunshine duration: It refers to the period when solar radiation is above a certain threshold value. The average annual sunshine duration in Türkiye varies between 2600–2800 hours.

2.3. Solar Spectrum and Atmospheric Effects

Electromagnetic waves coming from the Sun consist of three basic components: ultraviolet (UV), visible light and infrared (IR). Photovoltaic cells operate at maximum efficiency, especially in the visible and infrared spectrum range. The structure and composition of the atmosphere can affect the reach of this radiation to the Earth's surface, causing fluctuations in efficiency. For example; humidity, cloudiness and air pollution can reduce direct radiation by increasing the diffuse radiation rate. This section provides the scientific background necessary to understand the physical basis of solar energy and the parameters to be considered in system design.

3. SOLAR ENERGY TECHNOLOGIES

Solar energy can be converted into electrical and thermal energy through different technologies. This conversion is basically examined in two main categories: photovoltaic (PV) systems and solar thermal systems. In addition, hybrid solutions combining these systems have become increasingly widespread in recent years.

3.1 Photovoltaic (PV) Systems

Photovoltaic systems are technologies that directly convert sunlight into electrical energy. The basic building block of these systems is PV cells with semiconductor properties. When sunlight falls on the PV cell surface, electrons excited by photons change their energy levels and create an electric current. This process is called the "*photoelectric effect*". PV cells are usually connected in series and parallel to form modules; modules are then combined into panels. The direct current (DC) obtained from the panels is converted into alternating current (AC) through inverters and transferred to the grid or used directly for local consumption.

The International Energy Agency's (IEA) Sustainable Development Scenario envisages the commissioning of 4,240 GW of PV solar power generation capacity by 2040, a 10,000-fold increase from 385 MW in 2000. (Kruitwagen, L., et.al., (2021).

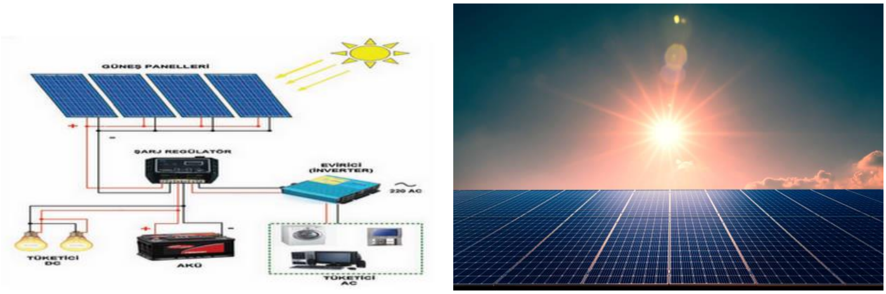


Figure 2. (a) Working principle of solar panels (https://noyabilgisayar.net/gunes-enerji-sistemi-kursu.html; access date: 29.09.2025; **(b)** Cell system of solar panels (https://www.businessgreen.com/news/4344832/solar-breakthrough-oxford-university-researchers-hail-flexible-solar-cells-applied-surface; access date: 29.09.2025)

3.1.2. PV Cell Types

Photovoltaic cells are classified according to different semiconductor materials:

- Monocrystalline Silicon Cells: High efficiency (>20%), long life and compact structures are prominent. More costly to produce.
- Polycrystalline Silicon Cells: Low cost but their efficiency (15–18%) is lower than monocrystals.
- Thin Film Cells (CdTe, CIGS, a-Si): They can be integrated into different surfaces thanks to their flexible and lightweight structure. Their efficiency is low, but they offer a cost advantage.
- New Generation Cells (Perovskite, Organic PV): These cells, which are in the research phase, can potentially offer low-cost and high-efficiency solutions.

3.1.3. PV System Components

- Inverters
- Mounting systems
- Monitoring and control systems
- Battery (optional)
- Grid connection equipment

3.2 Solar Thermal Systems

1. Flat Plate Collectors: Flat plate collectors are used for low-temperature applications (e.g. hot water production). The black-surfaced absorbent plate absorbs incoming sunlight and converts it into heat. This heat is transferred to the liquid in the copper pipes and then transported to the area of use. Heat losses are minimized thanks to isolation.

2. Vacuum Tube Collectors: Vacuum tube collectors greatly reduce heat losses by creating a vacuum between the external environment and the collector surface. They are suitable for higher temperature applications and offer high performance even in winter conditions.

3. Concentrating Solar Systems (CSP): CSP systems produce heat at high temperatures by concentrating sunlight to a single point (focal point) with the help of mirrors or lenses. This heat can then be used as steam to drive a turbine for electricity generation or as thermal for industrial processing. Concentrated solar power plants built since 2018 integrate thermal energy storage systems to generate electricity during cloudy periods or after sunset or before sunrise, CSP systems can also be hybridized with combined cycle plants, resulting in hybrid plants that provide high-value, dispatchable power. CSP systems are generally used in large-scale power plants. Although sample applications are limited in Turkey, R&D studies are ongoing.

Figure 3. Concentrated solar energy systems (solarspaces)
(https://salesask.click/product_tag/52269029_.html; access date: 29.09.2025)

3.3 Hybrid Solar Energy Systems

- PV/T Systems: Integrated systems that produce both electricity and heat on the same surface. Thanks to the heat exchangers placed under the PV panels, the temperature of the panel is reduced, thus increasing the electrical efficiency and heat energy is obtained.
- PV-Diesel Hybrid Systems: Structures where PV and generator systems work together, especially in areas independent of the grid. When solar energy is insufficient, the diesel generator is activated and provides uninterrupted energy.
- PV-Storage Systems: PV systems integrated with battery systems make the energy supply more stable. Excess energy produced during the day can be stored in batteries and consumed at night.

In this section, solar energy conversion technologies are explained in general terms, and in the next section, Turkiye's application level and potential of these technologies will be discussed in detail.

4. SOLAR ENERGY POTENTIAL IN TÜRKİYE

Turkiye is among the countries with high solar energy potential due to its geographical location. Located between 36° and 42° north latitude and 26° and 45° east longitude, Turkiye receives significant amounts of solar radiation throughout the year. This advantage offers a great opportunity for the country's energy supply security, reduction of carbon emissions and reduction of external dependency on energy.

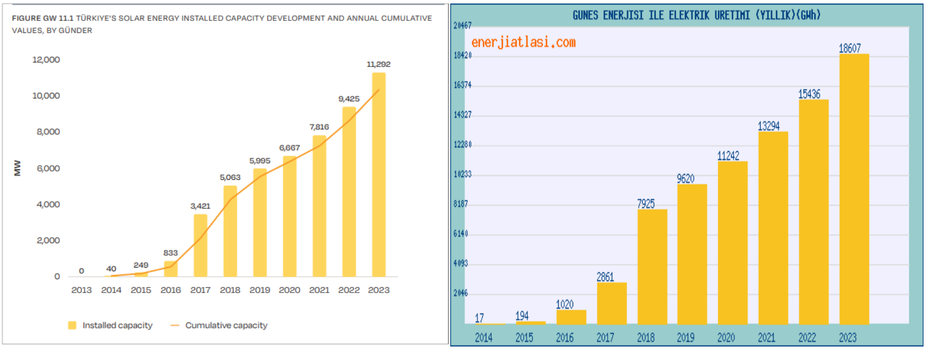
4.1 Sunshine Duration and Radiation Values

The average annual sunshine duration in Turkiye is approximately 2,737 hours, and the daily average is around 7.5 hours. The annual average total solar radiation amount is determined as 1,527 kWh/m^2-year. This value is higher than most European countries.

Table 2. Sunshine durations by regions in Turkiye

Region	Solar Radiation (kWh/m²-year)
Southeast Anatolia	~3,000 ~1,800
Mediterranean Region	~2,900 ~1,700
Central Anatolia	~2,800 ~1,600
Marmara	~2,400 ~1,400
Black Sea	~1,800 ~1,200

As can be seen from the Table 2, especially the southern and inner parts of Turkiye are quite suitable for solar energy investments. These data are provided by institutions such as the General Directorate of Meteorology (Meteoroloji Genel Müdürlüğü → MGM), the Ministry of Energy and Natural Resources (Enerji ve Tabii Kaynaklar Bakanlığı → ETKB) and solar energy industrialists and industry association (Güneş Enerjisi Sanayicileri ve Endüstrisi Derneği → GENSED).



(a) **(b)**

Figure 4. a) Increase in solar energy production in Türkiye between 2013 and 2023, (https://reglobal.org/solar-power-outlook-for-eu-and-turkiye/, access date: 29.09.2025), **b)** Annual electricity production with solar energy in Turkiye between 2014-2023 (Gwh) (https://www.enerjiatlasi.com/elektrik-uretimi/gunes; access date: 29.09.2025)

The above graph shows the increase in solar energy installed capacity in Türkiye between 2013 and 2023. The rapid growth that started in 2014 gained momentum especially after 2016. This situation reveals that Turkiye's investments in solar energy and the energy policies it implements yield effective results.

The Solar Energy Potential Atlas (GEPA), supported by the Ministry of Energy and Natural Resources, is an important resource that maps the solar energy potential in different regions of Turkiye. According to GEPA; Provinces with the highest solar potential: Şanlıurfa, Mersin, Antalya, Konya, Gaziantep, Van. Regions with the lowest potential: Eastern Black Sea coastline and Northern Marmara region. GEPA data are used as a reference in the planning of both licensed and unlicensed solar power plant projects. Solar Energy Potential Atlas (GEPA)

4.2. Solar energy production potential by region

Turkey has a technical potential of approximately 380 billion kWh/year of solar energy production capacity. However, only a small part of this potential is being used. As of 2024, the installed solar energy capacity has exceeded 12,000 MW (12 GW). This corresponds to approximately 10% of Turkey's total electricity generation capacity. The distribution of installed solar energy capacity by region is presented in Table 3. It is clearly seen from this table that the highest capacity is in the Central Anatolia region.

Table. 3. The distribution of installed solar energy capacity by region is as follows:

• Central Anatolia	28%
• Mediterranean	24%
• Southeastern Anatolia	18%
• Aegean	12%
• Other regions	18%

Considering the estimated costs for an unlicensed megawatt solar power plant project, a detailed plan is required for the necessary materials and the area where it will be installed. For example, for a 1MW plant, approximately 4000 260/265 watt solar panels, aluminum construction mounting systems, inverters, and equipment such as remote monitoring systems are required. Additionally, factors such as land preparation, environmental planning and security systems need to be taken into consideration.

4.3. Karapınar Solar Power Plant (SPP) and Other Example Projects

Karapınar SPP (Konya): It is one of the largest solar power plants in Europe and one of the few in the world. Its total installed capacity is **1,350 MWp** and its annual production is at the level of 2.6 billion kWh. This facility contributes to the prevention of approximately **1.5 million tons of CO_2** emissions annually.

Other noteworthy projects include:

- Niğde-Bor SPP
- Gaziantep SPP projects
- Rooftop PV systems installed in Organized Industrial Zones (OSB)

4.4. Suitability for Solar Energy Investments

The suitability assessment for solar energy investments is made according to criteria such as the amount of radiation, land slope, direction, access roads, and grid connection point. Many regions of Turkey have advantages in terms of these criteria. In addition, **rooftop SPP systems**, energy cooperatives, and controlled SPP applications in agricultural lands have also become widespread in recent years. In light of this data, Turkey's solar energy potential is quite strong in terms of both centralized and distributed energy production. However, in order to fully utilize the potential, further progress needs to be made in the areas of legislation, financing, domestic technology production and education.

5. SOLAR ENERGY APPLICATIONS IN TURKİYE

The areas of use of solar energy in Türkiye are increasingly diversifying with technological developments and legal regulations. In addition to electricity generation, solar energy applications are also becoming widespread in heating-cooling, agriculture, transportation and industry. In this section, applications are examined according to scale, purpose of use and sectoral distribution.

5.1. Solar Energy Systems for Electricity Generation

5.1.1. Licensed Solar Energy Plants (SPP)

Licensed plants are large-scale facilities with a capacity of over 1 MW and operating with production licenses issued by the Energy Market Regulatory

Authority (EPDK). As in the example of Karapınar SPP, these facilities both increase domestic energy production and reduce external dependency.

5.1.2 Unlicensed Solar Energy Systems

With the Electricity Market Law No. 6446, which entered into force in 2013, production facilities with an installed capacity of up to 1 MW were granted the right to unlicensed production. These systems are especially preferred in industrial establishments, municipalities and agricultural irrigation areas. With the regulation made in 2022, the upper limit of unlicensed installation was increased to 5 MW.

5.2 Roof and Facade Applications

Integrating solar panels into roofs and building facades has become attractive for individual and institutional consumers, especially during periods when energy costs are high.

- Residential rooftop solar power plants: These are installed by homeowners and can be sold to companies that generate more incoming electricity.
- Industrial roofs: Systems installed in Organized Industrial Zones (OSB) significantly reduce companies' electricity costs.
- BIPV (Building Integrated PV Systems): Systems integrated into architectural structures combine aesthetics and functionality.

5.3 Agricultural Applications

The use of solar energy in the agricultural sector provides both energy independence and contributes to sustainable agricultural practices:

- Irrigation systems: Pumps operating with photovoltaic panels eliminate diesel and grid dependency in rural areas.
- Greenhouse farming: Greenhouse heating systems with solar collectors increase energy efficiency.
- Solar power plant installation in agricultural lands: Solar power plant installation is encouraged in non-agricultural areas or low-yield lands.
- Agrovoltaic systems: Allows for both agriculture and solar energy production in the same area.
- Photovoltaics (PVs) have become the cheapest technology for generating electricity in many regions, while ground-based PV

requires large areas for installation and can therefore reduce agricultural land use. In regions with scarce land resources, agriculture and PV can lead to competition between land use, threatening both food and energy security. However, agrivoltaic systems allow for dual use of land for both agriculture and PV power generation, allowing PV capacity to be expanded on agricultural land without interfering with agricultural activities, while enabling farming activities to continue. In recent years, agrivoltaics have been dynamically adopted, driven by Japan, China, France and Germany. (Trommsdorff, M., et.al., 2022).

a) **b)**

(Trommsdorff, M. et.al. 2022).

Figure 5. a) Fraunhofer ISE pilot plant, Heggelbach, Southern Germany, **b)** Ha vineyard built by Sun'Agri in France

5.4 Heating and Hot Water Applications

Solar collectors used for hot water production are widespread, especially in the Mediterranean and Aegean regions. These systems:

- Providing hot water in individual residences
- Supplying hot water needs in public areas such as hotels and dormitories
- Pool heating and industrial heat applications

It offers economical and environmentally friendly solutions. Turkey is among the top five countries in the world in flat plate collector production.

5.5 Transportation and Mobile Systems

- Solar street lamps, park-garden lighting
- Mobile charging stations and solar-powered bus stops
- PV system integration for electric vehicle charging stations
- Use of solar panels in satellites and space technologies

applications such as these, demonstrate the potential of solar energy in portable and distributed systems.

5.6 Industry and Industrial Use

The use of solar energy in energy-intensive sectors is increasing. In the industry;

- Solar thermal systems for process heat requirements,
- Roof-type PV systems for electricity consumption,
- Green energy certified production processes aimed at reducing carbon footprint

are prominent. Many factories produce their own energy within the scope of “Green OSB” projects supported by the Ministry of Industry and Technology. In this section, solar energy applications in Turkey are examined on a sectoral basis. The diversity of application areas makes the economic, environmental and social effects of solar energy even more visible.

6. ADVANTAGES AND DISADVANTAGES OF SOLAR ENERGY

In this section, the environmental, economic and technical aspects of solar energy systems and their strengths and weaknesses will be evaluated on a scientific basis.

Solar energy stands out as one of the most important renewable energy sources in line with sustainable development goals. However, as with every type of energy, solar energy has various advantages and some limitations.

6.1 Advantages

a) Renewable and Sustainable Resource: Solar energy is an inexhaustible and constantly renewed source. Unlike fossil fuels, solar energy does not decrease as it is used and is constantly re-supplied within natural cycles.

b) Environmentally Friendly and Emission-Free Energy Production: Solar energy systems do not emit greenhouse gases during electricity production. Therefore, it is an effective tool in the fight against climate change. Carbon-free energy production is of strategic importance in terms of national and international environmental policies.

c) Energy Independence and Security: Solar energy can be used to generate energy domestically, reducing dependence on foreign sources. In countries with high energy imports, such as Türkiye, solar energy plays a crucial role in energy supply security.

d) Modularity and Flexibility: Solar energy systems can be installed in different sizes, from small-scale individual applications to large-scale power plants. This flexibility allows use in both rural and urban areas.

e) Low Operation and Maintenance Cost: Solar energy systems have a long lifespan after installation and, because they contain no moving parts, low maintenance costs. In the average region, this can be achieved with a few panel cleanings and system checks. Therefore, it is necessary to have it cleaned a few times a year. You can always have this done by professional cleaning companies for a fee. The most reliable solar panel manufacturers give a 20-25 year warranty for their products. In addition, since there are no moving parts, wear and tear is low. The Inverter used in Solar Energy Projects is almost the only part that needs to be replaced after 5-10 years, because it works continuously to convert solar energy into electricity and heat. Apart from the inverter, the cables also need maintenance to ensure that your solar system operates at maximum efficiency, so you won’t have to spend much on maintenance and repairs after you cover the initial cost of the solar system.

The initial investment cost of purchasing a solar system can be high. This includes expenses for solar panels, inverter, batteries, cables and installation. Also, solar energy technologies are constantly evolving. Therefore, prices may decrease shortly after you make the investment. However, this possibility will always exist with developing technologies.

6.2. Dısadvantages

a) Land Use and Shading Problems: Large-scale solar power plant projects require large areas of land and can compete with agricultural areas. In addition, in rooftop applications, surrounding trees, buildings or chimneys can create shading and reduce efficiency.

b) Recycling and Waste Management: PV panels require recycling processes at the end of their lifespan (approximately 25–30 years). Globally standardized systems for PV panel waste management have not yet been developed sufficiently.

c) Weather Dependent: Although solar energy can still produce on cloudy and rainy days, the efficiency of the solar energy system will decrease. Solar panels need sunlight to effectively collect solar energy. Therefore, a few cloudy and rainy days can have a noticeable negative impact on the energy system. You should also consider that solar energy cannot be collected during the night. On the other hand, if you also want your water heating to work at night or during the winter months, thermodynamic panels are an alternative to consider.

6.3 Comparative Assessment

The growth and increase of solar, fossil and wind energy is presented in Table 4. While solar energy offers significant environmental and strategic advantages, it also has some technical and economic limitations.

Table 4. Environmental and strategic advantages of solar energy

Criteria	Solar Energy	Fossil Fuels	Wind Energy
Resource Sustainability	Very High	Very Low	High
Emission Level	Low	High	Low
Installation Cost	Medium-High	Medium	High
Operation-Maintenance	Low	High	Medium
Energy Storage Need	High	Low	Medium
Continuity (Uninterrupted Production)	Low	High	Medium

7. SOLAR ENERGY POLICIES AND INCENTIVES IN TÜRKİYE

The development of solar energy in Turkiye is directly related to the energy policies, incentive systems and legislative regulations implemented by the state. Legal and administrative studies carried out in this field are aimed at the dissemination of renewable energy sources and the improvement of the investment environment.

7.1.The basic legal regulations regarding solar energy in Turkiye are as follows:

a) Renewable Energy Law No. 5346 (REL): this law, which entered into force in 2005, was prepared to encourage the use of renewable energy resources in Türkiye. It covers resources such as solar, wind, hydroelectric, geothermal and biomass. A purchase guarantee was provided to renewable energy facilities. A basic incentive infrastructure was established for unlicensed production and distribution activities.

b) Electricity Market Law No. 6446: This law, enacted in 2013, paved the way for unlicensed production systems in particular. The spread of small-scale projects based on solar energy accelerated with this regulation.

License exemption for systems up to 1 MW

Right to connect to the distribution grid

Possibilities such as selling excess energy to the grid were granted.

c) Renewable Energy Resource Areas (RERA) Regulation. The RERA model is a competitive bidding system that offers capacity allocation and domestic production incentives to investors in large-scale projects. Giant projects such as Karapınar GES have been implemented with this method.

d) Purchase Guarantee (Feed-in Tariff – FiT): A fixed-price electricity purchase guarantee is offered for licensed projects for a specified period. While dollar-based FiT was applied until 2021, a system based on Turkish Lira and local contribution was put into effect afterwards**.**

e) Value Added Tax' and Customs Duty Exemption: For domestic or imported solar energy system components

Customs duty exemption

Value Added Tax (VAT) exemption

Supports are provided within the scope of the Investment Incentive Certificate.

f) Net Metering (Net Metering System): It is based on the principle of reflecting the invoice to the user according to the difference in energy produced and consumed. This system provides a great advantage for rooftop applications. Excess production can be given to the grid and the electricity bill can be reduced.

g) Agriculture and Rural Development Supports: The Ministry of Agriculture and Forestry provides 50-70% grant support for solar-powered irrigation systems within the scope of IPARD (EU Rural Development Program).

7.2. Strategic Documents and Plans

a) National Energy and Mining Policy (2017): This policy document is based on three main objectives:

- Maximum use of domestic resources
- Energy supply security
- Predictable market structure

Solar energy has been evaluated as the main pillar of domestic and clean energy production.

b) 11th Development Plan (2019–2023): The Development Plan aims to increase renewable energy investments, encourage domestic panel production and develop grid integration. In addition, energy efficiency and R&D studies are emphasized.

c) 2053 Net Zero Emission Target: Turkiye ratified the Paris Climate Agreement in 2021 and announced its net zero carbon target by 2053. In this context, solar energy investments will play a critical role in reducing greenhouse gas emissions.

d) Domestic Production and Industrial Policies: It is aimed to reduce external dependency in panels, cells, inverters and assembly equipment by supporting domestic production. Domestic production is mandatory especially in RERA projects.

- Integrated domestic production from cell to panel is carried out thanks to production facilities such as Kalyon PV.

- Solar technology clusters are supported in organized industrial zones by the Ministry of Industry and Technology.

e) The Role of Municipalities and Local Governments: Local governments play an active role in issues such as rooftop solar power plant installation, solar lighting systems, public transportation applications and public awareness. Many municipalities such as Istanbul, Izmir, Eskisehir and Konya Municipalities have developed exemplary projects in this field.

This section details the current legal infrastructure, incentive mechanisms and strategic goals related to solar energy in Turkiye. Sustainability and effective implementation of policies are of great importance in terms of fully evaluating the solar energy potential.

8. FUTURE PERSPECTIVE AND RECOMMENDATIONS FOR TÜRKİYE

Turkiye has a great potential in solar energy thanks to its geographical advantage, young energy market and high sunshine duration. However, the full utilization of this potential depends on strategic steps to be taken in technological, economic and administrative areas.

8.1 Future Perspective

8.1.1. Increase in Installed Capacity: Turkiye's installed solar energy-based capacity is around 12 GW as of 2024. It is aimed to increase this capacity to 52 GW by 2035 (Ministry of Energy and Natural Resources 2023). This growth will be achieved through RERA tenders, unlicensed projects and roof applications.

8.1.2. New Generation Solar Technologies.

- **Perovskite and tandem cells** promise more efficient and flexible use compared to traditional silicon technology.
- **BIPV (Building Integrated PV**) applications will enable roof and facade systems to directly turn into energy-producing elements.
- Floating solar power plants projects are installed on water surfaces, both reducing evaporation and protecting agricultural lands.

8.1.3. Digitalization and Smart Grids: Applications such as artificial intelligence-supported forecasting systems, IoT devices, and blockchain-based energy trading will make energy production and consumption more efficient. R&D investments in these technologies should be supported in Turkiye

8.2. Updating the Legislation

- The unlicensed production limit should be increased (for example, it can be increased to 5 MW and above).
- Bureaucratic processes should be simplified, permit processes should be digitalized.
- Incentives and regulations for energy storage systems should be accelerated.

8.2.1. Localization and Technology Transfer

- Local production should be supported for high-tech products such as PV cells and inverters.
- Joint R&D centers should be established with international companies.
- University-industry collaboration should be increased, and a qualified workforce should be trained.

8.2.2. Dissemination of Rural and Agricultural Applications

- Solar energy solutions for agricultural irrigation should be disseminated.
- Agrovoltaic systems on agricultural lands should be supported.
- Energy access should be increased with micro-SPP projects in rural areas.

8.2.3 Education and Awareness Studies

- Renewable energy topics should be taught as a compulsory course in schools and universities
.• Public education should be organized through municipalities.
- Accurate and encouraging content about solar energy should be increased in the media.

8.2.4 International Collaborations

- Turkiye should be integrated into the European Green Deal process.
- International financing institutions and carbon credit mechanisms should be used effectively.
- More grants and loans should be provided for solar energy investments within the scope of climate finance.

Conclusion

Turkiye, thanks to its high sunshine duration and extensive surface area, has significant potential for solar energy production. The nationwide average annual sunshine duration is approximately 2,700 hours, making Turkey among the best-performing countries in Europe in this area. This natural advantage presents an opportunity to develop perspectives on energy supply security, carbon emission reduction, and energy import reduction.

Turkiye has experienced remarkable growth in the solar energy sector in recent years. Solar power installed capacity, which stood at only 40 MW in 2014, reached 14,000 MW by 2024, representing a nearly 350-fold increase. This growth has been made possible by both the sustained impact of public policies (EMRA RERA, etc.) and the acceleration of private sector investments.

Solar energy-based electricity production has similarly increased. Production, which was only around 17 GWh in 2014, has risen to approximately 18,000 GWh (18 TWh) by 2023, representing a 5.7% share of total electricity production. Despite this payment increase, it appears that Türkiye's theoretical solar energy production potential is estimated at 380–500 TWh annually, and that this resource is not yet being utilized effectively.

In the future, the contribution of solar energy to total energy supply will increase, not only reducing the magnitude of the energy increase but also ensuring sustainability and securing significant contributions. Achieving this goal requires aligning the group with alternative sources, expanding energy storage capacity, and increasing domestic technology development capacity.

In conclusion, while Turkiye has made significant progress in solar energy, its natural potential needs to be revitalized and integrated energy policies are needed to utilize it more effectively and sustainably. This economical solar energy is prioritized as a resource poised to play a central role in Türkiye's future in terms of energy.

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CHAPTER 2

TANNIC ACID

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Introduction

Microorganisms, which play a fundamental role in the lives of creatures, have profound effects not only on the functioning of nature but also on human health. Therefore, understanding the effects of microorganisms on health is crucial for both disease prevention and the development of modern treatment methods.

Drugs used to treat infectious diseases caused by microorganisms are called "*antimicrobials*". These substances are natural substances produced by certain bacteria and fungi that inhibit the growth of or destroy other bacteria (Saran and Karahan, 2010). The belief in the potential of these substances to heal disease has persisted since the dawn of humanity. Throughout human history, people have consumed these natural substances either by making a poultice and applying it to open wounds, by boiling them and drinking their water, or directly as food (Erdoğan and Everest, 2013). The interest in these compounds with antimicrobial properties obtained from natural sources is increasing day by day (Kaczmarek, 2020).

Polyphenols have also received significant attention in recent years due to their antimicrobial properties. These substances are also being evaluated for their antibacterial and antiviral properties. Polyphenols are large organic compounds with a complex structural diversity. They contain numerous phenolic rings with common carboxylic acid and hydroxyl groups in their structures. Because of these functional groups, polyphenols can cross-link proteins and other macromolecules (Kaczmark, 2020; Xia et al., 2015). Polyphenol compounds include flavonoids, stilbenes, and lignans. Tannins are a group of polyphenols widely found in nature (Kaczmarek, 2020).

The modern era of tannins started in the 17th century with the Italian chemist Giovannetti's exploration of the interactions between solutions of iron and substances named "astringents". By 1772, the majority of researchers had discovered the presence of an acid in the compounds. Scheele isolated this acid and named it "gallic acid". Considering the experiments of Deyeux and Bartholdi, studies on tannins continued by Proust at the end of the 18th and the beginning of the 19th century, and they were officially defined as a separate group of molecules based on the presence of gallic acid (Pizzi 2019).

Tannins are a complex group of water-soluble polyphenolic compounds synthesized by plants as secondary metabolites (Prigione et al., 2018; Jing et al., 2022; Pizzi 2019; Orlowski et al., 2016). For thousands of years, various Asian countries, particularly China, have used tannin-containing plant species to prevent diarrhea, stop bleeding, and protect against cancer and various microorganisms (Jing et al., 2022; Saltan 2019). These compounds have also been used as antidotes against certain insects.

Tannins are a group of substances that are soluble in polar solutions and differ from polyphenols in their ability to dissolve in polarized solutions (Besharati 2022). Tannins generally appear as white amorphous powders to off-white amorphous powders, shiny, pasty substances and nearly colorless, amorphous substances in the form of flakes or spongy masses (Pizzi 2019; Kolaç et al., 2017). From a chemical perspective, it is very difficult to handle tannins in a single way because their chemical structures and molecular weights are different from each other (Jing et al., 2022).

There are two main sources of tannins in nature: natural and synthetic. Natural sources include various fruits, vegetables, grains, herbs, forage crops, legumes, seasonings, and spices. Tannins can be synthesized synthetically using cresols, naphthalenes, and other higher hydrocarbons as primary components (Sharma et al., 2021). Tannins can also form naturally in nature through the decomposition of natural organic matter found in the soil. Because of their essential functions in plant defense against insects, foodborne fungi, infections, and bacteria, they are found in almost every part of the plant, including roots, bark, wood, seeds, and leaves (Prigione et al., 2018; Jing et al., 2022; Pizzi 2019). Those found in bud tissues protect plants from freezing, those found in leaf tissues protect leaves from herbivores by reducing their palatability, and those found in root tissues protect roots from plant pathogens. The most important source of TA is quercus infectoria (Kolaç et al, 2017).

Tannins have a wide range of applications due to their protein-binding ability, their complexation capacity with metals, and the antioxidant capacity of the polyphenolic rings in their molecules (Prigione et al., 2018). Tannins have found applications in a wide variety of industries, including food, pharmaceuticals, leather, furniture, and mining (Jing et al., 2022; Saltan, 2019; Dinç, 2020).

There are two classes of tannins: hydrolyzable tannins, such as and ellagi-tannins and gallo-tannins and condensed polyflavonoid tannins, the latter of which are stable and rarely hydrolyzable (Pizzi 2019). Tannic acid is one of the most significant substances related to hydrolysable tannins.

Tannic acid (TA) is a polyphenol substance belonging to the tannin group and exhibits anticarcinogenic, antioxidant, antimutagenic, and antimicrobial properties (Soyocak 2011). Although the TA molecule lacks a carboxylic acid group, it is called "*acid*" because it contains numerous phenol groups, which are responsible for its acidic character. TA's phenolic hydroxyl groups can readily interact with tyrosine, cysteine and lysine, As a result, TA has been widely used as a natural protein crosslinker, particularly for gelatin and collagen (Alavarse vd., 2022). TA is a weak acid that is water-soluble because of its phenolic groups (Fael and Demirel, 2020). TA is also soluble in acetone and ethanol but insoluble in chloroform (Zang et al., 2023). TA consists of five galloyl esters and one glucose (Figure 1) (Hu et al., 2015). The pKa value of TA is a very important tool for predicting its structural properties. The pKa values reported in the literature are 2.2 and 8.5 (Certiat et al., 2024). TA found in foods at levels between 10 and 1300 ppm is considered safe (Tokaç et al., 2014). The daily intake for TA was found to be 13.6 g/60 kg (Fael and Demirel, 2020).

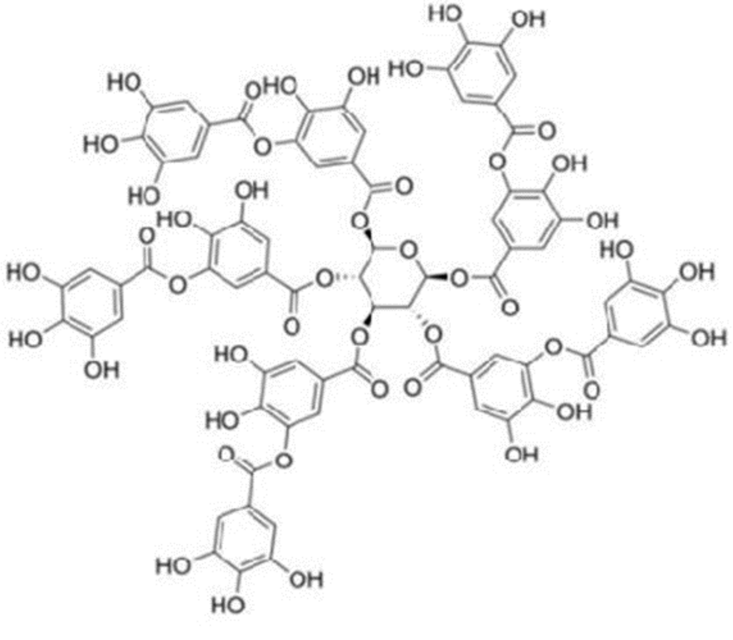

Figure 1. Chemical Structure of Tannic Acid

TA is approved for use in pharmaceuticals by the US Food and Drug Administration (FAD) and is considered safe to use (Sahiner et al., 2016). Excessive amounts of TA in water lowers the pH of the environment, causing it to have a toxic effect (Dinc 2020). Due to this feature (ecotoxic and phytotoxic), TA is included in the class of pollutants (Certiat et al., 2024).

The most widely known feature of tannic acid is its strong adhesion to the surfaces of various materials, including inorganic, hydrophilic, organic, and hydrophobic materials. The phenyl and polyphenol hydroxyl structures in tannic acid allow them to cross-link with most polymer molecules containing hydroxyl, ether bonds, carboxyl, sulfonates, amino, and phosphates through hydrogen bonding. Therefore, cross-linking TA with polymer molecules increases the cohesion of the polymer network. Crosslinking between TA and polymers occurs primarily through physical crosslinking, including hydrophobic interaction forces, hydrogen bonding, electrostatic interaction forces, and Van der Waals forces. Ambient temperature and pH are known to affect the crosslinking process between TA and polymers (Zang et al., 2023).

Effects Of Tannins On Human Health

Antioxidants affect all cells in the body, reducing the harmful effects of free radicals, which are known to be linked to cardiovascular and pulmonary diseases, cancer, cataracts, the aging process, and other diseases. It is known that tannins have antioxidant properties (Kolaç et al., 2017).

Historically, tannin-containing plants have been used as traditional medicine for a variety of diseases by both Western and Eastern cultures (Jing vd., 2022). Due to their high molecular weight, tannins exhibit a high degree of hydroxylation of aromatic rings, which is the reason for their antioxidant activity. Epidemiological data show that tannins are also useful in treating injuries and skin inflammations, and that tannin intake may prevent the onset of chronic diseases. TA exhibits a neuroprotective effect due to its potent anti-inflammatory and antioxidant effects (Jing et al., 2022). Among the health effects of tannins are their ability to increase glucose absorption, lowering blood sugar and reducing the risk of diabetes. Tannins, due to their different sources and chemical structures, have different antiviral properties. Extracts from dates exhibit potent antiviral effects against various viruses (Tong et al., 2022). Tannins also inhibit P24 HIV-1 replication and are beneficial in the inactivation of viruses such as enteric viruses, herpes simplex viruses, and polioviruses (Sharma et al., 2021).

In addition to the positive effects mentioned above, tannins also have negative effects. Some of these effects include: tannins form complexes with minerals such as phosphorus, calcium, and magnesium, preventing their absorption by monogastric animals. Additionally, tannins bind to dietary proteins and interfere with food digestion. As a result of enzymatic oxidation of tannins, an increase in toxicity and enzyme inhibition occurs (Sharma et al., 2021).

Discussion

Tannic acid, a prominent member of the naturally occurring tannins, is a highly valuable polyphenol compound with a high level of interaction with biological systems and a highly valuable pharmacological compound. Tannic acid, with its broad spectrum of antimicrobial, antioxidant, antitumor, antimutagenic, and antiviral properties, offers both preventive and therapeutic potential. The use of tannic acid in traditional medicine as a wound healer, astringent, and antidiarrheal is supported by modern scientific data, paving the way for its application in numerous sectors, including pharmaceutical formulations, biopolymer systems, food additives, and surface coating technologies. Furthermore, its FDA-approved safety and water-soluble structure offer advantages in a wide range of applications. However, despite its positive aspects, this valuable compound also has limitations that must be carefully considered. Tannic acid, especially when taken in high doses, can complex with nutrients, reducing vitamin and mineral absorption, inhibiting protein digestion, causing liver toxicity, and potentially causing mutagenic/carcinogenic effects, necessitates its controlled use. In conclusion, tannic acid is a very important natural compound, both for its historical use in traditional medicine and for its therapeutic effects demonstrated by modern scientific studies. Current biomedical and pharmaceutical research is crucial for more efficiently and safely utilizing the potential of tannic acid. Advanced research on this compound will make significant contributions to the development of more effective, natural and sustainable solutions, especially in the prevention and treatment of diseases.

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CHAPTER 3

GREEN CHEMISTRY: A REVIEW

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1. Introduction

Over the last two centuries, the field of chemistry has witnessed an era innovation and discovery. However, because chemists lacked a full understanding of the impact of the procedures and methods they used, they were often unaware of the damage chemicals posed to the environment and human health. Consequently, chemicals released into the environment caused significant harm to the environment and living organisms. However, in recent years, science has significantly expanded our understanding of the harmful effects of chemicals (Perosa and Zecchini, 2007). It has started to provide us a molecular understanding of these effects, which enables us to minimize these negative effects in the design of our chemical products and transformation processes (Ghernaout and Naceur., 2011). In the production and use of chemical products, green chemistry effectively uses raw materials, preferably renewable ones, eliminates waste, and stays away from the use of hazardous and/or poisonous solvents and reagents (Sheldon, 2012).

With significant advancements in aqueous catalysis (biphase) and the application of supercritical fluids in chemical reactions, the ecologically friendly solvents has emerged as one of the primary areas of study in green chemistry. The environmental and health benefits of ionic liquids and fluorinated media will determine how green they are. At the same time, the sustainability value of new biobased solvents needs to be demonstrated. The long-standing goal of organic chemists to develop and effectively implement the most efficient synthesis. To advance the objectives of green chemistry, new catalytic processes are constantly being developed, and in situ spectroscopic approaches, as well as microwave and ultrasonic synthesis, have been widely employed. These fields of study represent just a small portion of the several subjects that are closely related to green chemistry and are being investigated by scholars worldwide (Horvath and Anastas, 2007).

There will probably be a significant change in the feedstock portfolio that currently forms the foundation of the chemical industry due to factors like availability, efficiency, economy, public pressure, and governmental regulations. Future research in Green Chemistry is directed towards increasing raw material diversity. Significant progress has been made in the use of biobased materials such as sugar and starch as basic chemical building blocks. However, for scientific innovations to translate into economic sustainability and social benefit, these raw materials must be accessible. This suggests that one major area of research for Green Chemistry will probably be how to use agricultural waste products to obtain biobased building blocks. The only way to solve this problem is to convert biomass products such as carbohydrates, proteins, lipids and terpenoids into drugs and polymeric materials by using them on a large scale in industry. For this purpose, cost-effective, environmentally friendly and efficient process methodologies need to be researched and developed. Furthermore, products with similar industrial application processes should be developed, while also ensuring the production of the same basic chemicals with as little modification as possible to the composition of products derived from petrochemical sources and biomass components (Horvath and Anastas, 2007).

Ligno-cellulose, which gives plants and trees strength, is the greatest material generated annually by volume in the world. It usually contains 40–50 weight percent cellulose, 25 weight percent hemi-cellulose, and 25 weight percent lignin. It is clear that future studies on the use of biobased building blocks will focus on developing new catalysts, new enzymes, new processing systems, and new plant hybrids.

Since the currently popular methods are not only inefficient in terms of energy and materials, but also have negative effects on human health and the environment due to the reagents they use, basic research in Green Chemistry will have to concentrate on the synthetic methods we use to transform our starting materials. While the chemical community has worked to increase the reactivity of our reagents and substrates to reduce reaction times and energy requirements, the relationship between reactivity and toxicity has been overlooked in the design of our synthetic techniques (Patnaik, 2007).

To achieve the required selectivity, low energy, and fast reaction times without using materials harmful to humans or the environment, catalysts that can carry out transformations will need to be made from relatively less reactive substrates. Currently, insufficient knowledge is available to design these systems from scratch. While catalysts have been quite successful in the chemical industry over the last 50 years, we have still not mastered the design of multifunctional catalysts that can selectively perform transformations at multiple points. Green catalysis, in particular, can play a significant role in optimizing atomic efficiency and simplifying the process when producing fine, specialty, and medicinal chemicals and materials. Future research in homogeneous catalysis should primarily focus on combining single-point catalysis with simple catalyst separation and recycling. Another key goal of developing green catalysts should be the efficient use of enzymes in new chemical reactions. By applying a fundamental understanding of enzyme reaction mechanisms, the production of biomimetic analogs can lead to the development of new and efficient catalytic systems. Sustainable/green industrial catalysts can also be achieved by producing single-sided heterogeneous catalysts. Since many chemicals containing chiral centers may interact with our environment, the application and/or design and synthesis of chiral catalysts should also be included (Thomas and Raja, 2006).

Chemists have made tremendous progress in the field of covalent bonding over the past two centuries, achieving the greatest success in human history, enabling them to produce virtually any small molecule. The same cannot be said for weak bonds. Significant advances have been made in understanding weak bond interactions and how they affect the properties of specific molecules and materials. Furthermore, remarkable research has been conducted to elucidate specific synthetic interactions by understanding weak bond interactions in the reactant-solvent system and during the transition stages of certain processes. A crucial component of developing an environmentally friendly process is the tuning of the interactions between the aromatic rings in the substrate(s) and the chiral catalyst(s) or reactant(s). However, the strong interactions between them are difficult to manipulate easily. One of these challenges is the ability to directly generate carbon-fluorine bonds (Horvath and Anastas, 2007).

It's important to note the fundamental distinctions between "sustainable chemistry" and "green chemistry." Green chemistry deals with the design, production, and use of chemicals in ways that reduce their pollution potential. It provides a fundamental framework for modifying the natural properties of a chemical product or process to make it less hazardous to humans and the environment. This prevents pollution, which in turn solves environmental problems and contributes to industrial ecology and pollution prevention. Sustainable chemistry, in addition to green chemistry, also considers the impacts of materials, energy, processing, and economics. Life cycle assessment of a process, product or activity covering its entire life is the focus of sustainable chemistry. Green chemistry is a very effective strategy for advancing sustainability (Martínez et al., 2022).

2. The "E factor"

The 1990s saw initiatives aimed at producing chemicals using the least hazardous reagents and solvents possible. These initiatives also highlighted a factor that determines the environmental friendliness of an industrial process. This factor, called the "*efficiency factor*" or "*E-factor*," was introduced by Roger Sheldon. It is calculated by dividing the mass of the final product (kg) by the volume of waste generated (kg). In this context, everything produced during the process-excluding the final product-is considered "*waste*." Therefore, the goal for every process should be the lowest possible E-factor. When calculating this component, truly green processes should yield zero (Sheldon, 1997). It can be observed that the E-factor decreases with increasing segment production. For example, an oil refinery with an annual production of 1 to 100,000,000 tons has an E-factor of 0.1, while the pharmaceutical industry, with an annual production of 10 to 1,000 tons, has an E-factor of 25-100. Therefore, from the E-factor calculation, it can be seen that, contrary to popular belief, large-scale production processes have less environmental impact than small-scale operations (Poliakoff and Licence, 2007). Industrial facilities in the pharmaceutical and fine chemical industries are constructed using traditional stoichiometric processes, which produce a lot of waste in the form of inorganic salts, and therefore perform poorly in this area (de Marco et al., 2019).

Due to their high volatility, most solvents can quickly pollute the air. Many are also toxic and flammable. Therefore, water should be used instead of organic solvents whenever possible. This is often not possible because most organic molecules are insoluble in this solvent. Supercritical CO_2, a byproduct of other processes and non-toxic, is an alternative to organic solvents. It also does not contribute to climate change. Ionic liquids are also an excellent option because they evaporate very little and do not escape into the atmosphere (Poliakoff and Licence, 2007).

3. The twelve principles of green chemistry

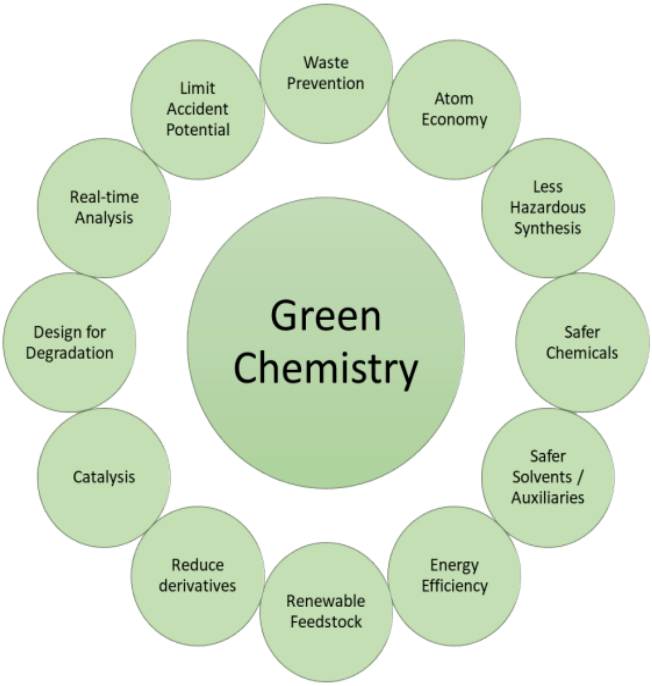

Fig. 1. The 12 principles of green chemistry (Istasse, 2021).

The elimination or reduction of hazardous solvent use in chemical analyses and processes, along with the prevention of residues as byproducts of these procedures, form the basis of the 12 principles of green chemistry. Therefore, the use of renewable and safe raw materials, as well as atomic and energy savings, play important roles. Catalysis accelerates chemical reactions and can also contribute to other issues such as waste reduction and energy conservation. One guiding principle addresses the purposeful production of chemicals, ensuring that they are degraded at the end of their useful life and converted into environmentally safe degradation products while preventing bioaccumulation. As can be seen, these principles address the planning of the product from synthesis, processing, analysis, and final destination. The primary goal is to reduce the environmental and workplace risks associated with industrial activity (de Marco et al., 2019).

3.1. Prevent waste

It's better to prevent waste rather than treat it after it's generated. Stoichiometric reagents (acids and bases; oxidants and reductants); solvent losses (air emissions and aqueous waste); and multi-step syntheses are major sources of waste (Sheldon, 2012). The use of valuable rare metals and their contamination of products should be prevented. The principle of waste prevention encompasses nearly all of the other eleven principles. In particular, it ensures complete consumption of the starting components (Principles 2 and 9), preventing the formation of waste or unusable residues. Because a disturbing waste is also a solvent that must be removed from the polymer solution following the synthesis reaction, it's better to use a solvent-free approach (Principle 5). Processes that require excessive amounts of energy can also indirectly generate waste (Principle 6). Therefore, processes that produce products at room temperature without requiring energy are more beneficial. The increased susceptibility of natural materials to environmental degradation is often a consequence of their incorporation into the structure or network (Principles 7 and 10).

Partially blocking the functional groups of substrates significantly increases the product's usability. For example, blocking isocyanate groups significantly increases the durability of powders used to produce polyurethane coatings. Unfortunately, these blocking groups are often waste products of synthesis that evaporate into the atmosphere (Principle 8). Intramolecular blocking can be a solution. Catalytic reactions have long been used in polyurethane production. It has long been known that the reaction between isocyanate groups and hydroxyl, amino, or carboxyl groups must be accelerated. Furthermore, the selectivity of catalysts directs specific reactions. Therefore, catalytic processes, rather than stoichiometric processes, are often used to produce polyurethanes, avoiding the use of excess reagents that could cause post-reaction waste (Principle 9) (Brzeska and Piotrowska-Kirschling, 2021).

3.2. Maximize atom economy (synthetic efficiency)

When planning synthetic procedures, it's important to consider the use of as many reagents as possible in the finished product. This will reduce waste production (de Marco et al., 2019). Developing ideal reaction conditions and selecting the appropriate reactants and their interactions are crucial elements in designing the synthesis process. This ensures the best possible performance of the product in question. Utilizing every atom of the substrate in the production of the finished product is highly advantageous. Numerous factors influence the efficiency of polymerization. The correct selection of substrates leads to a successful reaction (Brzeska and Piotrowska-Kirschling, 2021).

3.3. Design less hazardous chemical syntheses (benign syntheses, safer chemical synthesis)

Materials used in synthetic processes should have minimal or no toxicity to humans and the environment. Therefore, replacing solvents with hazardous ones with low or no toxicity is highly recommended (de Marco et al., 2019). Several new reactions developed in the last decade have been added to the green reaction literature. For example, one class of efficient reactions consists of previously described processes based on multicomponent coupling or rearrangement cycloaddition. Enzymatic reactions, C-H activation, and cascade or tandem reactions are relatively new techniques that represent cleaner and more efficient synthetic tools available to organic chemists (Anastas and Eghbali, 2010). When biological enzymes are used instead of hazardous chemicals in many industrial processes, the results are cleaner and more cost-effective. For example, the fundamental premise of a new polycarbamate production method is simple: it involves replacing the harmful carbonyl dichloride ($COCl_2$) with CO_2. This process also results in the removal of the solvent dichloromethane (CH_2Cl_2). Polycarbamate and ethylene glycol, CO_2, bisphenol-A ($C_{15}H_{16}O_2$) and ethylene oxide $(CH_2)_2O$ are the end products of the entire reaction (Abdussalam-Mohammed et al., 2020).

3.4. Design safer chemicals and products (benign products)

When designing chemical products, minimizing toxicity without diminishing essential function is crucial. One of the most challenging aspects of producing safer products and processes is minimizing toxicity while maintaining function and efficiency. This requires an understanding not only of chemistry but also of the fundamentals of toxicology and environmental science. Furthermore, striking a balance between optimal performance and chemical product function is the goal of developing safe chemicals (non-carcinogenic, non-mutagenic, non-neurotoxic) while minimizing toxicity and hazard. However, whenever possible, harmful compounds should be replaced with favorable and hazardous ones should be avoided, while also considering their effectiveness (Li and Chan, 2007).

This approach has facilitated the development of new herbicides and pesticides that target organisms and break down into ecologically safe compounds. Another example is the application of highly toxic organic tin-based organic compounds (Sn), which were once coated to prevent plankton and seaweed from adhering to them. These organic compounds have been replaced with a non-toxic alternative, Sea-Nine. The development of an oxidant activator for hydrogen peroxide is another example. This enables the replacement of ozone-depleting chlorine bleaches with hydrogen peroxide in paper production (Abdussalam-Mohammed et al., 2020).

3.5. Use safer solvents and reaction conditions (avoid auxiliaries)

Solvents and separation agents are compounds that should be avoided whenever possible and used sparingly. Most conventional organic solvents are corrosive, toxic, and flammable. Their recycling results in significant losses in energy-efficient distillation (Abdussalam-Mohammed et al., 2020). It is best to avoid the use of solvents and other reagents. The best way to avoid solvent evaporation, condensation, and purification problems is to use solvent-free techniques. Because of improved substrate mixing and addition kinetics, it is sometimes more advantageous to perform the reaction in a solvent (Sirrine et al., 2016).

3.6. Increase energy efficiency

The energy required for synthesis is quite harmful to the environment. Therefore, using atmospheric pressure and performing the reaction at room temperature is the ideal method. To overcome the energy barrier, the kinetics of many reactions require the provision of an appropriate amount of activation energy. Consequently, strategies are pursued to perform a specific task that reduce energy use (Brzeska and Piotrowska-Kirschling, 2021). The reaction to produce oligoetherols, required for the synthesis of polyurethane foams with improved thermal resistance, is an example of a procedure that simplifies the reaction, reduces the number of intermediate steps, and saves energy use (Lubczak, 2015).

3.7.-Use renewable feedstocks (raw materials)

Renewable raw materials should be used to replace non-renewable ones wherever technically and economically feasible (de Marco et al., 2019). In research, substances derived from renewable resources are frequently used instead of crude oil-based substrates. This pattern can also be seen in the production of polyurethanes. Natural chemicals are used instead of synthetic isocyanates, low-molecular-weight diols, and most importantly polyols. Polyols are the most commonly used naturally occurring substrates in polyurethane production. Typically, lignocellulose, proteins, carbohydrates, and vegetable oils are used to produce bio-based polyols. These have been used for many years, primarily to create coatings and foams (Noreen et al., 2016).

Sustainable materials (polylactic acid, chitosan, lignin, tannins, etc.) are becoming increasingly important in efforts to reduce the impact of human activities on the environment and crude oil consumption. Plant extracts containing tannins are a useful alternative for green chemistry. These are naturally occurring phenolic compounds found in large quantities in wood and bark, and in smaller amounts in the leaves and fruits of many different plant species. Plants use tannins to defend against many harmful organisms (bacteria, fungi, mammals, and insects), free radicals, and to protect against light (UV rays). They are also known to protect some plants against desiccation through molecular mechanisms, such as in resurrection plants. They can be extracted using simple techniques. Weak acids and bases can hydrolyze tannins to produce phenolic acids and carbohydrates.

The main characteristic and benefit of tannins is their phenolic structure. Their antioxidant properties are another important feature. Furthermore, they are actively used today in leather tanning, adhesive production (especially wood adhesives), fishing, beverage production, animal feed production, and numerous other industries. Hydrolyzable tannins have antiviral and antibacterial properties.

3.8. Avoid chemical derivatives (avoid protecting groups, reduction of derivatives

It is recommended to avoid or minimize unnecessary derivatization procedures because they generate waste and require the use of additional reagents (de Marco et al., 2019). This includes steps such as adding blocking groups, temporarily altering physical or chemical processes, and protecting or deprotecting, as these require additional reagents and generate waste. Whenever possible, biological synthesis should be used (Abdussalam-Mohammed et al., 2020).

3.9. Use catalysts, not stoichiometric reagents (catalysis)

Stoichiometric reagents are of lower quality than catalytic reagents. Using stoichiometric amounts of chemicals often results in chemical waste. The principle of catalysis, however, encourages the use of degradable catalysts to protect the environment, prevent the use of organochlorine chemicals, and reduce energy consumption for wastewater disposal (Anastas and Eghbali, 2010). Stoichiometric reagents are not as effective as catalytic reagents when used selectively (de Marco et al., 2019). Using the right catalyst can control some reactions and produce a very high-quality product (Kiss et al., 2021).

Biocatalysis is also an example of green chemistry because it is a biomimetic strategy based on naturally occurring or artificially modified enzymes. It typically refers to the direct application of purified enzymes and modifications performed by genetically modified organisms. Meanwhile, the reaction conditions are quite mild, as the transition can be carried out in water at room temperature and atmospheric pressure. Furthermore, enzymes exhibit higher stereochemistry and chemical selectivity. Moreover, biocatalysts offer several advantages over non-biological catalysts in terms of reaction speed, cost, and catalytic specificity. However, they are less sensitive to heat and have lower stability (Anastas and Eghbali, 2010).

3.10. Design chemicals and products to degrade after use (degradation or recovery)

According to De Marco et al. (2019), chemicals must break down into harmless degradation products at the end of their useful life and not persist in the environment for extended periods. Persistence is a long-standing issue that first emerged in the early stages of industrial development (Boethling et al., 2007).

Ongoing problems with environmental pollution demonstrate the difficulty of designing biodegradable materials and chemicals. After decades of data collection, trends have been identified. Certain chemical structures, such as branched chains, halogenated moieties, quaternary carbons, tertiary amines, and specific heterocycles, should be avoided because they may have greater persistence. On the other hand, integrating functional groups such as esters or amides recognized by ubiquitous enzymes can aid in the design of environmentally degradable products (Nendza, 2012).

3.11. Analyze in real time to prevent pollution (real-time analysis)

The application of analytical techniques that generate less waste and are safer for the environment and public health is known as "green analytical chemistry." This concept covers both the environmental drawbacks associated with classical analysis and real-time monitoring of a chemical process. Waste-free chemical measurement is the aim of green analytical chemistry. The analytical procedure itself is usually connected to the environmental problems associated with analytical chemistry. Goods utilised in the production of analytical instruments ought to be taken into account. When developing new sensors, green chemists and engineers should be cognizant of the toxicity and possible environmental risks related to the materials they work with. For example, electrochemistry frequently uses mercury electrodes. The effective solution has proven by replacing them with carbon-based electrodes such as nanotubes or nanofibers (Anastas and Eghbali, 2010).

3.12. Minimize the potential for accidents (prevent accidents)

To maximize occupational and environmental safety, the materials and methods used in a chemical process should be selected to minimize hazards such as leaks, explosions, and fires (de Marco et al., 2019). In the past, designers paid little attention to how new chemicals and materials would affect human health during the design phase. However, subsequent research has shown that by considering worker hazards and risks when designing or redesigning manufacturing processes in accordance with green principles, health benefits, environmental advantages, and cost savings can be maximized. Similarly, government policies aimed at developing green chemical technologies, while embracing occupational health and safety, have been shown to improve worker health. Implementing these principles can reduce energy use and the amount of waste released into the environment, while also helping to protect and improve worker health and safety (Hughes et al., 2009). Even processes and products that promote energy conservation, sustainability, and the use of renewable resources can pose serious physical and toxicological risks.

There are many situations where workers in "green" or “renewable energy jobs” face the risk of exposure to harmful substances. For example, exposure to silane during thin-film photovoltaic production is extremely dangerous due to its pyrophoric properties and potential to irritate the skin and respiratory system. Workers can be exposed to lead, mercury, rare earths, and other heavy metals during the recycling of electronic components (Wath et al., 2011). Workers are most exposed to these risks when handling raw materials during production, packaging, and transportation processes; when using a product; or when recycling or disposing of a product at the end of its life. Conversely, when considering occupational health and safety, the results and products of processes that utilize green chemistry principles can be advantageous for workers. For example, by reducing the amount of harmful intermediates used in the production of chemicals, worker exposure to hazards can be reduced (Schulte et al., 2013).

4. Green catalysis

4.1. Catalytic C-H bond activation reactions

These include homogeneous C-H activation via metal complex catalysis; Pd-catalyzed carbon-heteroatom bond formation; Pd-catalyzed carbon-carbon bond formation; heterogeneous catalytic methods for C-H activation; enzymatic C-H activations; and C-H activation with organocatalysts (Zhang and Cue, 2018). In the fields of organosilicon chemistry and green chemistry, the formation of carbon-silicon bonds is considered an exciting achievement. Recent advances in this field will enable the sustainable chemical conversion of silicon resources into synthetically valuable molecules. One of the most challenging problems in organic chemistry and green chemistry is catalytic silylation via C-H bond activation without directing groups or hydrogen acceptors. In the past few years, successful new catalytic approaches have been developed for the silylation of aromatic molecules via C-X bond cleavage or C-H bond activation. Potassium tert-butoxide-catalyzed, environmentally friendly heterocyclic silylations are considered a significant advance in synthetic chemistry (Xu and Xu, 2015).

4.2. Polymer supported asymmetric organocatalysis

These include polymer-supported chiral amines for enamine and iminium catalysis; polymer-supported organocatalysts; polymer-supported phase transfer catalysts; solid acid-supported organocatalysis; polymer-supported phosphoric acid catalyst; polyoxometalate-supported chiral amine catalysts; ionic liquid-supported organocatalysts; solid sulfonic acid-supported chiral amine catalysts; magnetic nanoparticle-supported organocatalysts; silica-supported proline and its derivatives; silica-supported asymmetric organocatalysts; silica-supported MacMillan catalysts and clay-imprisoned organocatalysts (Zhang and Cue, 2018).

Asymmetric organocatalysis is one of the most important methods for synthesizing chiral compounds required for bioactive chemicals, agricultural pesticides, and pharmaceuticals. This method is compatible with many green chemistry techniques. Intensification techniques such as flow, high pressure, ball milling, or light provide high yields, faster reactions, and simpler product isolation, as well as new reactivities. The sustainability profile of many organocatalytic processes is significantly improved by using more environmentally friendly reaction media such as water, ionic liquids, deep eutectic solvents, and green solvent substitutes. Numerous green chemistry techniques can be effectively combined with asymmetric organocatalysis. Flow, high pressure, light, ball milling, and other acceleration methods provide increased yields, faster reactions, simpler product isolation, and new reactivities (Kristofíkova et al., 2020).

4.3. Fluorous catalysis

These include fluorinated organocatalysis, synthetic fluorinated catalysis, hydroformylation, hydrosilylation, hydrogenation; cross-coupling reactions, oxidation, hydroboration, esterification, acetylation, and transesterification (Zhang and Cue, 2018).

Fluorinated synthesis, along with solution-phase and solid-phase synthesis, has emerged as a new field of chemical synthesis. It combines the advantages of both solution-phase and solid-phase synthesis through homogeneous reaction and heterogeneous separation/purification. Fluorinated catalysis offers catalysts with similar catalytic activity and techniques such as liquid-phase extraction, solid-phase extraction, and simple phase separation. This has become a popular green chemistry approach in catalysis due to its ability to recover costly catalysts and eliminate catalyst pollution in the environment and products (Jiang et al., 2014).

4.4. Catalysts for solid-supported synthesis

These include immobilized rhodium catalysts; immobilized palladium catalysts, immobilized ruthenium catalysts, immobilized copper catalysts, immobilized cobalt catalysts, immobilized iridium catalysts; Heck-Mizoroki reactions in water, Suzuki reactions, Sonogashira reactions in water: Rhodium (II) carbenoid chemistry, Tsuji-Trost reactions in water; Rhodium(I)-catalyzed conjugate addition reactions, Rhodium-catalyzed carbonylation reactions, Rhodium-catalyzed hydrogenation reactions, Ruthenium-catalyzed metathesis reactions, Ruthenium-catalyzed opening of epoxides, Ruthenium-catalyzed transfer hydrogenation, Ruthenium-catalyzed cyclopropanation reactions, Ruthenium-catalyzed halogenation reactions (Zhang and Cue, 2018).

Solid-phase synthesis was first developed to produce peptides and nucleotides efficiently. The idea was later transferred to organic synthesis to produce tiny organic compounds. The biological assessment and synthesis of diverse heterocyclic compounds in a library style are crucial from the perspective of medicinal chemists. Synthetic chemists focus on generating libraries of chemicals through the use of solid-phase method, which offers advantages in terms of economy, efficiency, and speed. Synthetic chemistry has relied heavily on a metal-catalyzed C-C bond formation process, which is also highly influential in natural product synthesis and medicinal chemistry (Barve and Sun, 2018).

4.5. Biocatalysis

Biocatalysis has been a fundamental technique used since the mid-1990s to address the growing need for environmentally friendly and sustainable chemical production, particularly in the pharmaceutical industry (Hoyos et al., 2014). Within the framework of sustainable development and green chemistry, biocatalysis offers a number of attractive features. The catalyst, an enzyme, is produced from renewable resources, is biocompatible (and sometimes even edible), and is biodegradable. Using biocatalysis, products can be free of rare precious metals such as rhodium, palladium, and platinum. Some elements considered endangered, including some noble metals, may not be economically viable in the long term. Furthermore, removing traces of noble metals from final products can be expensive. Reactions are carried out in an environmentally acceptable solvent (water) under appropriate conditions (physiological pH, ambient temperature, and pressure). High activities, chemo-, regio-, and stereoselectivities are observed in reactions of multifunctional compounds, unlike traditional organic syntheses, steps for functional group activation, protection, and deprotection are generally not required. This allows for the development of procedures that are more cost-effective, energy- and raw material-efficient, less wasteful, and therefore more environmentally and financially attractive than traditional methods. Compared to traditional chemical or chemocatalytic procedures, biocatalytic techniques generally yield products of superior purity due to their higher selectivity and milder reaction conditions. Unlike fermentations, enzymatic processes can be carried out in traditional multifunctional batch reactors, eliminating the need for additional investments in high-pressure equipment, for example. Because biocatalytic reactions occur in environments with similar temperatures and pressures, integrating various reactions into environmentally friendly catalytic cascade systems is not very difficult (Sheldon, 2016).

The stability of the enzyme is one of the most important factors to determine the value of the reaction in biocatalysis (Matsuda, 2013). Limitations of enzymes are: 1) Low operational stability and shelf-life, 2) Cumbersome recovery & re-use, 3) Product contamination, 4) Allergic reactions of proteins (Sheldon, 2012).

5. Green synthetic techniques

5.1. Green Solvents

These include ionic liquids, supercritical carbon dioxide, water, perfluorinated solvents, biosolvents, petroleum solvents.

5.1.1. Ionic liquids: Ionic liquids (ILs) are a family of nonmolecular substances composed entirely of ions. Their melting points are below 100 degrees Celsius. Compared to traditional organic solvents, inert solvents (ILs) offer numerous advantages, including low vapor pressure at room temperature and superior thermal stability. This makes them nearly perfect for use in extraction procedures. It is possible to manipulate physical and chemical properties, such as viscosity, thermal stability, and solubility in water and other organic solvents, simply by creating combinations of cations and anions.

Furthermore, by adding desired functional groups to cations and/or anions, process-specific ILs (TSILs) can be created that can interact with solutes in specific ways (Zhao and Anderson, 2012). Ionic liquids are a type of organic salt that generally melts at temperatures below 100 °C. Over the last few years, scientists have become increasingly interested in ionic liquids due to their amazing capabilities and surprising tunability in terms of their chemical structure (Chakraborty, 2021).

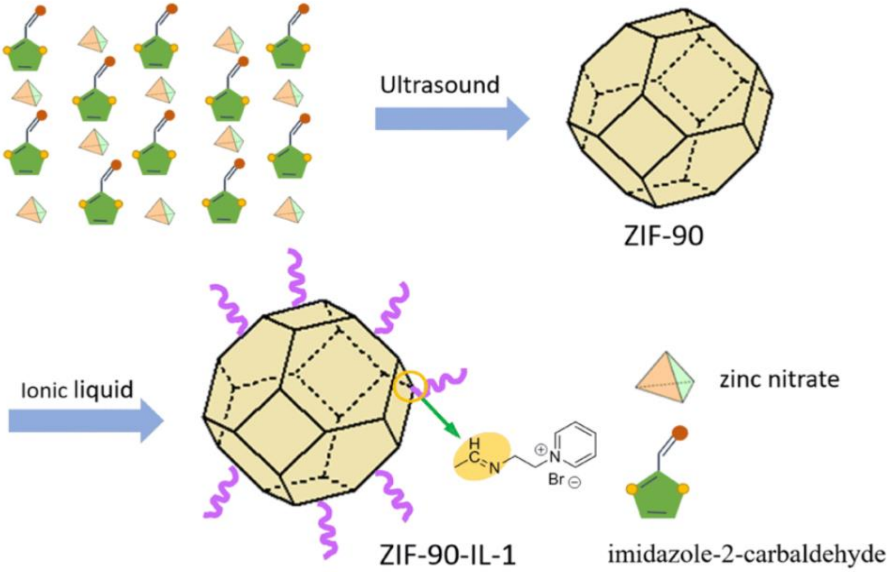

Fig. 2. Synthesis of ionic liquid functionalized ZIF-90 (Yuan et al., 2020).

5.1.2. Supercritical carbon dioxide: Carbon dioxide (CO_2) is said to be in a supercritical state ($scCO_2$) when it is maintained at or above its critical temperature and critical pressure. Because of its density close to a liquid and viscosity close to a gas, $scCO_2$ is an environmentally safe mass and heat transfer fluid. In addition to being non-toxic and non-flammable, $scCO_2$ is reasonably priced, especially compared to other solvents, and is readily available in highly pure form on an industrial scale. A key advantage of $scCO_2$ is that it can be used to separate and dry products through direct expansion, and the gas can be recovered, recycled, and reused without further purification. Furthermore, these properties make $scCO_2$ a preferred medium for chemical processes. Small pressure changes can alter reaction rates by up to two-fold, and unique product distributions offer the opportunity to create innovative products. Many industrial processes, particularly in the food, pharmaceutical, and textile industries, have already been developed on a commercial scale. These processes utilize $scCO_2$ to replace traditional organic solvents, which are significantly more harmful to the environment (Liu et al., 2016).

5.1.3. Water: Volatile organic compounds (VOCs), solvents widely used in the past and present, are harmful to the environment. Their vapors have the potential to exacerbate the greenhouse effect and contribute to global warming. Furthermore, in certain circumstances, vapors from solvents can act as catalysts that destroy the ozone layer, which protects the planet and living things from short-wavelength ultraviolet light. Vapors can also cause diseases and be harmful to humans, plants, and animals. The liquids themselves can also pose a problem. They can directly harm the environment and gradually release their vapors when released into the soil, rivers, or ocean. While it is technically possible to completely capture and purify solvents for further use in production, some environmental loss is inevitable. Therefore, there is growing interest in the use of solvents in environmentally friendly chemical reactions. Supercritical carbon dioxide, a pressurized liquid with attractive solvent properties, is one such candidate. However, unless fully contained and reused, it will leak gaseous carbon dioxide, a greenhouse gas. The potential use of water as a solvent in chemical reactions is attracting increasing interest. Nature uses water, an environmentally neutral solvent, to perform biological activities. However, only organic compounds with polar groups, such as alcohols and carboxylic acids, work well as solvents. The water is an affordable and environmentally friendly solvent.

Even insoluble substances can perform better in water, as various effects observed in aqueous solutions can also be observed in water suspensions.

5.1.4. Perfluorinated solvents: Fluorinated biphasic systems (FBSs) are a result of research aimed at improving process efficiency in organic synthetic protocols. FBSs have been shown to provide a way to recycle a catalyst-containing reaction medium from which products can be readily recovered. Alkane-based perfluoroheptane, perfluoro methylcyclohexane, and perfluoropolyethers are examples of perfluorinated solvents. Perfluorinated alkanes are generally immiscible with organic solvents at room temperature. Their inflexible conformation and lack of polarizability are the primary reasons for this. Therefore, perfluorinated alkanes are considered even less polar than hydrocarbons because they can only participate in weak intermolecular interactions (Nostro et al., 2005).

Although a perfluorinated solvent can be used in a reaction without a corresponding second liquid phase (organic or aqueous), the reaction is usually planned so that the product does not bind to the fluorinated phase in this nonpolar environment. Consequently this method works best in reactions that make the substrate more polar to remove the products. Examples of transformations that can benefit from the use of a perfluorinated solvent include oxidations and hydroformylations (Breeden et al., 2012).

5.1.5. Biosolvents: Another method for replacing solvents is to produce solvents from biomass. This not only reduces the need for limited resources but also allows for rapid replenishment of the resource with minimal pollution, depending on the biomass used (Clark and Deswarte, 2014). However, this solution is insufficient because bioderived volatile solvents carry the risk of volatile organic compounds (VOCs), including many petroleum compounds. Due to the wide variety of potential feedstocks available, a traditional organic solvent may not be completely replaceable by a bioderived version. The most well-known application of a biosolvent is the use of 2-methyltetrahydrofuran (2-MeTHF) as the reaction solvent, replacing both DCM and tetrahydrofuran (THF) (Ripin and Vetelino, 2003). Ring-closing metathesis, Diels-Alder cycloaddition, and cross-coupling are examples of processes that use green solvents.

5.1.6. Petroleum derived solvents: Switching from traditional petroleum-based solvents to bioderived or non-traditional solvents is often done without considering their environmental friendliness. However, this is not the case in industry; organic and medicinal chemists are already familiar with most of the classical solvent classes for more environmentally friendly synthetic applications (Alfonsi et al., 2008). The key to selecting the most appropriate solvent is using a solvent selection guide. Everything resulting from chemical synthesis has an environmental impact; not only the solvent's life cycle, but its impact must also be minimized. The solvent used can influence catalyst selection. Once a clear hierarchy distinguishing solvent performance for a particular reaction has been established, a solvent selection guide can be used as an additional tool for selecting the best solvent. The development of solvent selection guides has shown that not all solvents derived from petroleum are equally environmentally friendly, and this should be seriously considered before switching to new, more complex solvents (Breeden et al., 2012).

5.2. Organic synthesis in water

These include pericyclic reactions, nucleophilic ring-opening reactions, Passerini and Ugi reactions, transition-metal-catalyzed reactions, addition reactions, pericyclic reactions, coupling reactions, oxidations and reductions, transition-metal-catalyzed reactions of carbenes, organocatalytic reactions, Aldol reactions, Mannich reactions, Michael additions and cycloaddition reactions (Zhang and Cue, 2018).

Using water as a solvent is not only harmless but also offers several advantages, such as increasing reactivities and selectivities, accelerating processing, enabling catalyst recycling, facilitating mild reaction conditions, and enabling group-free syntheses. Furthermore, exploring organic chemistry in water can yield unique selectivities and reactivities that enhance organic chemists' synthetic toolkit in organic solvents. Understanding the chemistry of water also helps us understand how nature carries out chemical synthesis. However, using water as a solvent is not always environmentally friendly (Simon and Li, 2012).

5.3. Solvent-free synthesis

These include mortar and pestle; ball milling; microwave assisted solvent-free synthesis (Zhang and Cue, 2018).

5.3.1. Mortar and pestle: For thousands of years, humans have been able to perform chemical reactions using mortars and pestles. Oxidation, reduction, and condensation processes using mortars and pestles have been investigated in solvent-free environments. Many of these processes have been found to work better in solvent-free environments than in solutions. As a general rule, liquids or low-melting-point solids that can only dissolve when stirred can be used in solvent-free reactions with a mortar and pestle. High-melting-point solids can be used in mortar and pestle processes, but this is a general rule. Solvent-free organic syntheses were typically performed using a mortar and pestle, but reliable, consistent, and newer, more modern techniques are now used to perform solvent-free reactions. Additionally, compared to hand mortars and pestles, more powerful automatic mortars and pestles provide more consistent response conditions and adaptability (Mack and Muthukrishnan, 2012).

5.3.2. Ball milling: During ball milling, solid reactants are placed in a container with one or more ball bearings, eliminating the need for solvents. The two most popular mills for conducting chemical reactions without the need for solvents are planetary mills and vibrating mills. During a chemical process in a vibrating ball mill, the solid reactants and a ball bearing are placed in a container. After being sealed, the container is placed inside the milling machine and mixed. The ball possesses sufficient kinetic energy to initiate a chemical reaction by striking the reactants through high-speed agitation. In contrast, vibrating mills and planetary mills operate quite differently mechanically. In a planetary mill, several balls are used to frictionally grind the components during a chemical process. Therefore, the chemical reaction in planetary mills is initiated by a high-impact friction source, rather than by throwing the ball through the container as in a vibrating mill (Mack and Muthukrishnan, 2012). The efficiency of organic reactions carried out by ball milling is increasing. Over the last decade, numerous articles have been published in organic chemistry using ball milling for synthesis. However, the chemistry of ball milling remains relatively unknown to organic chemists, especially compared to other techniques that have paved the way for sustainable synthesis (such as microwaves, ultrasound, and ionic liquids). In recent years, interest in this method has steadily increased, leading to the development of numerous sophisticated synthetic processes spanning the entire spectrum of organic synthesis (Stolle et al., 2011).

In ball milling, reactions are thought to occur in two stages. The first stage is the activation stage, which involves sizing the particles so they can react. The second stage is the ignition stage, when ball collisions trigger a chemical reaction (Kaupp, 2009). The speed of these two steps is determined by a number of factors. These procedures depend on the mechanical performance of the mill, the mechanics of the specific collisions, the chemical reaction, structural changes, and the formation of defects. This innovative method depends on a number of variables, including milling time, speed, ball-to-powder ratio (i.e., mass of solids/mass of balls), ambient and mill temperature (Stolle et al., 2011).

5.3.3. Microwave assisted solvent-free synthesis: Over the past 20 years, microwave-assisted organic synthesis (MAOS) has gained popularity as a rapid and efficient method for synthesizing various classes of compounds, from pure chemicals to agricultural chemicals. Despite the critical role of the solvent in reactions, most reactions can occur without it (Mack and Muthukrishnan, 2012). Environmentally friendly solvents, energy savings, and improved reaction results requiring less purification are some of the environmentally friendly aspects of microwave heating. In microwave chemistry, glycerol, ionic liquids, water, and solvent-free processes are examples of environmentally friendly solvents. Microwave-assisted carbonylation reactions and C-H bond activation are examples of catalysis (Zhang and Cue, 2018).

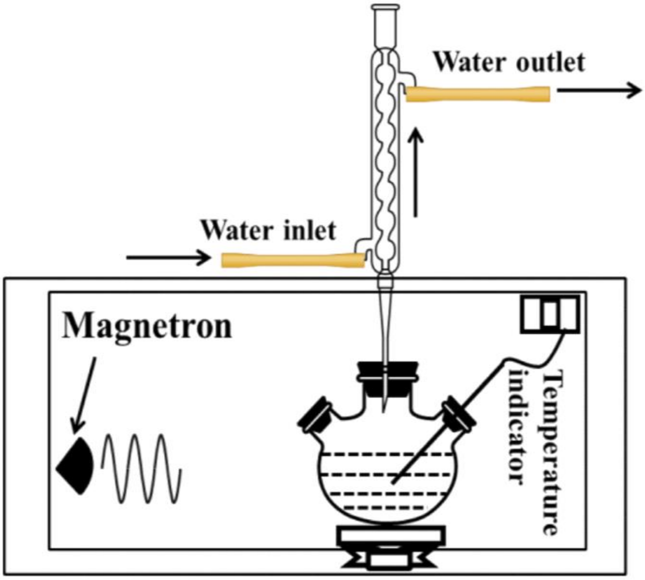

Fig. 3. Apparatus used for the microwave-assisted synthesis of $Cu_{2-x}Se$ nanostructures (Zhao et al., 2019)

5.4. Ultrasonic reactions (Sonochemistry)

The exceptional qualities of sonochemistry and ultrasonography are vital in meeting the "*green chemistry*" or "*sustainable chemistry*" concept among existing activation techniques. Sonochemistry is easy to use (Draye et al., 2019). According to Zhang and Cue (2018), ultrasonic reactions include coupling reactions, condensation reactions, Michael additions, Mannich reactions, and heterocyclic synthesis. The transducers used in most contemporary ultrasonic devices are made of piezoelectric materials. Cavitation causes extremely high local pressures and temperatures within bubbles, which enhances mass transfer and induces turbulence in the liquid flow. Aldol/condensation reactions are an important category of organic reactions because they play a key role in the synthesis of C-C bonds. Cella and Stefani (2018) used a one-pot technique and a phosphine-free system to synthesize 133 units of 4-styryl biphenyl via a step reaction involving Wittig-Suzuki. Diels-Alder reactions are an important synthetic technique for the synthesis of heterocyclic and cyclic compounds in organic chemistry. Heterocyclic compounds are of great importance in many scientific fields. Furthermore, the Sonogashira cross-coupling reaction is the most effective reaction for alkynylation of aryl or vinyl halides.

5.5. Photochemical synthesis

Photochemical syntheses are inexpensive and leave no residue in the reaction mixture; Solar photons are excellent green reagents. It has been shown that solar radiation can be used as an alternative to hazardous or expensive chemical reagents to overcome the activation energy in organic reactions (Protti and Fagnoni, 2009). According to Zhang and Cue (2018), photochemical syntheses include the synthesis and rearrangement of open-chain compounds, the synthesis of larger rings, the synthesis of three-, four-, five-, and six-membered compounds, as well as oxygenation and oxidation. For nearly a century, the synthetic community has aimed to achieve organic photochemical synthesis by mimicking plant photosynthesis seen in nature. In the last decade, there has been a noticeable resurgence in organic photochemical synthesis, particularly when it comes to visible-light-driven synthesis. More importantly, direct photoexcitation of substrates, reactants, or their complexes has given rise to various photoactivation modes, such as photo-SET (single electron transfer), ET (energy transfer), PCET (proton-coupled electron transfer), etc., which have ushered in a series of new or previously unheard-of chemical transformations for organic synthesis under mild, accessible conditions (Chen et al., 2019).

5.6. Solid-supported synthesis

These include solid-supported heterocyclic chemistry; combinatorial library synthesis; multicomponent reaction; diversity-oriented synthesis; solid-supported natural products synthesis; multistep parallel synthesis; solid-supported synthesis of peptides; soluble-supported synthesis; solid-supported synthesis of carbohydrates (Zhang and Cue, 2018).

5.7. Fluorous synthesis

Fluorinated techniques offer a wide range of powerful solutions spanning the field of organic synthesis, from large-scale chemical processes to traditional fine syntheses and modern chemical breakthroughs using combinatorial methods. These techniques directly address the separation problems inherent in the synthesis of small organic molecules. Because practicing organic chemists are familiar with the experimental techniques used in fluorinated methods (liquid-liquid extractions, solid-phase extractions, and solution-phase reactions), these approaches are attractive and easy to use. The use of fluorinated materials distinguishes these methods from traditional organic methods. Due to the scarcity of fluorinated reagents, reactants, labels, solvents, silica, and other necessary materials, the use of fluorinated techniques has been limited to a limited number of specialized facilities (Curran and Lee, 2001).

6. Conclusions

Green Chemistry has offered chemists and chemical engineers a framework to contribute to the vast field of global sustainability for over thirty years. From a theoretical concept, the clean and efficient conversion of renewable raw materials into functional chemicals and fuels has emerged as an interdisciplinary area driven by fundamental advancements in synthetic chemistry and directed by real-world applications of biorefineries. The need for biorefineries to have flexible feedstocks, somewhat mild operating conditions, and minimal environmental effect has led to the development of extremely creative techniques for defunctionalizing and refunctionalizing biomass feedstocks into materials and chemicals with added value. The secret to sustainable development is green chemistry, which will provide fresh approaches to old issues. In addition, it will offer chances for novel procedures and goods, with scientific and technological innovation at its core. The potential harm that our chemical goods and processes provide to the biosphere's inhabitants and systems ought to be considered a serious defect in design, with main functioning and sustainability being the defining criteria.

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CHAPTER 4

USE OF RAMAN AND FTIR SPECTROSCOPY COMBINED WITH CHEMOMETRICS IN HUMAN SERUM SAMPLES

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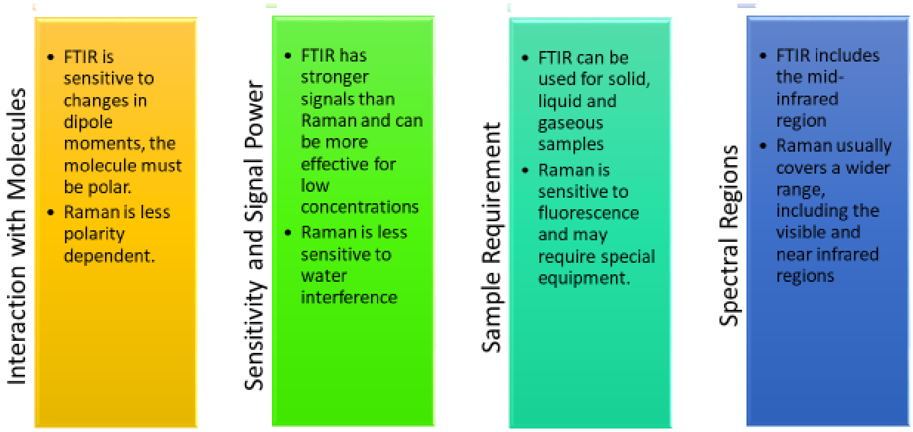
1- Introduction

FTIR and Raman Spectroscopy are used to identify specific compounds and explain their chemical structure, providing detailed information on chemical functional groups. It is often used for chemical analysis, material characterization and quality control. Today, FTIR and Raman spectroscopy are important and environmentally friendly analytical techniques that provide information on molecular vibrations. Raman and Infrared (IR) spectroscopies are vibrational spectroscopy (VS) commonly used for the analysis of solid, liquid, gas or semi-solid samples. In vibrational spectroscopy, electromagnetic radiation in the infrared regions interacts with samples and fingerprint spectra are produced due to the appearance of molecular vibrations.

Raman spectroscopy and IR spectroscopy are similar in that they are generally concerned with vibrational energy level transitions. For a molecule to perform infrared absorption, there must be a change in the dipole moment (μ) of the molecule or an associated charge distribution. This allows the molecule to absorb the infrared photon and be excited to a vibrational level. In Raman spectroscopy, on the other hand, there must be an instantaneous disturbance in the distribution of electrons around the bond in the molecule, and the bond must return to its normal state, producing beam emissionAs a result, for a molecule to be Raman active, it must be polarized with a frequency equal to the frequency of the photon with which the molecule interacts during vibration, and a periodic and transient dipole moment must be formed. For this reason, the intensity of the peaks in the Raman and IR spectra of the same substance are often different and some peaks are even absent in the other spectrum. Diatomic molecules such as hydrogen have no dipole moment, so they do not absorb light at vibrational frequency and are IR inactive. However, in these molecules the bond between two atoms can be polarized and Raman scattering is observed.

Raman spectroscopy is a complementary method to IR. Weak peaks that cannot be observed in IR can be observed here. However, the Raman effect is very weak. Therefore, it has low sensitivity, which makes it difficult to acquire spectra of low concentration samples. For this, the Resonance Raman technique is more suitable. The fluorescence of some substances can interfere with spectrum acquisition. Some of the differences between Raman and FTIR spectroscopy are shown in Figure 1.



Interaction with Molecules
- FTIR is sensitive to changes in dipole moments, the molecule must be polar.
- Raman is less polarity dependent.

Sensitivity and Signal Power
- FTIR has stronger signals than Raman and can be more effective for low concentrations
- Raman is less sensitive to water interference

Sample Requirement
- FTIR can be used for solid, liquid and gaseous samples
- Raman is sensitive to fluorescence and may require special equipment.

Spectral Regions
- FTIR includes the mid-infrared region
- Raman usually covers a wider range, including the visible and near infrared regions

Figure 1. Differences between FTIR and Raman spectroscopy.

The use of Raman and FTIR spectroscopy in biological samples is increasing with the continuous development of the technology. Both methods provide a real-time analytical tool for analyzing molecules in various states and are easy to use, quick, non-destructive, specific, and provide fingerprint. Additionally, because these techniques are straightforward and don't require a lot of sample pre-treatment, they are occasionally referred to as "green analytical methods." Biofluids contain a variety of biomolecules, including carbohydrates, proteins, lipids, and nucleic acids. Due to their direct contact with human organs, these biomolecules can be utilized as biomarkers to identify certain disorders (Rohman et al., 2016). For example, it is widely used to diagnose diseases such as lung cancer, glioma and breast cancer (Song et al., 2024; Wang et al., 2022).

1. Use of FTIR and Raman Spectroscopy in Human Biological Samples

FTIR is a sensitive analytical technique that can effectively study biochemical changes occurring in cells, body fluids or tissues at the molecular level with very small amounts of samples (K et al., 2021) . In the literature, it has been used to analyze tumor tissues (Kaznowska et al., 2018), cells (Tabtimmai et al., 2020), saliva (Rodrigues et al., 2017), urine (Paraskevaidi et al., 2018), etc. Serum, which contains many biomolecular information such as lipids, proteins and nucleic acids, is frequently used in clinical practice (Sala et al., 2020). For example, a study was performed to differentiate liver cirrhosis and liver cancer by FTIR and serum was used in the study. The study reported significant differences in protein secondary structure and blood lipid levels in FTIR spectra of serum samples from healthy people and patients affected by liver cirrhosis (Figure 2) (Thumanu et al., 2014).

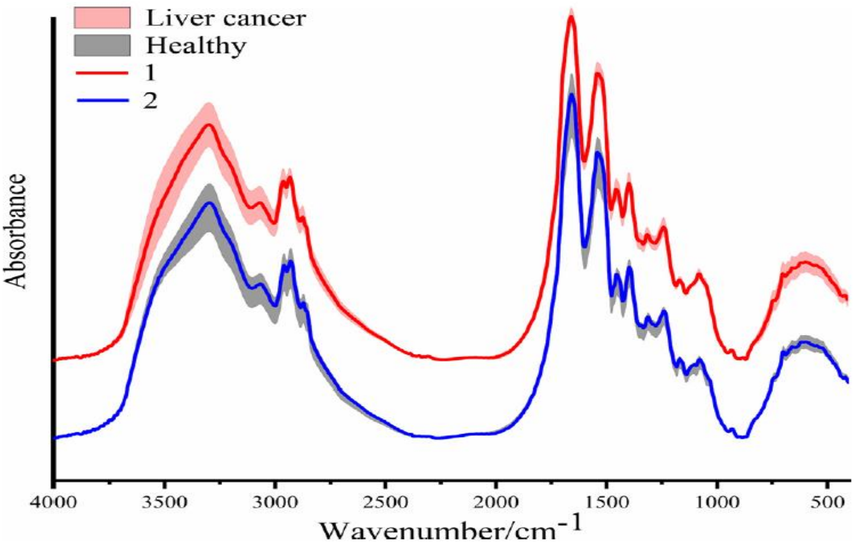


Figure 2. FTIR spectra of serum samples of healthy and liver cancer patients (Yang et al., 2021).

Similar to FTIR, Raman spectroscopy does not require any reagents and can detect different molecules in very small amounts of sample. This makes Raman spectroscopy a powerful tool for the analysis of biological samples (Zhang et al., 2018). In the literature, it has been reported that Raman can measure different amounts of glucose and various dissolved blood components in blood samples using the excitation wavelength in the near infrared region (Berger et al., 1997). Hemoglobin and hematocrit concentrations have also been measured (Hunter et al., 2002). Different types of cancer have been studied in Raman spectroscopy using blood samples For example, oral (Sahu et al., 2015), prostate (Medipally et al., 2017), breast cancers (Bhattacharjee et al., 2015), etc. have been studied using Raman spectroscopy. Figure 3 shows the Raman spectrum of a serum sample from healthy and gastric cancer patients.

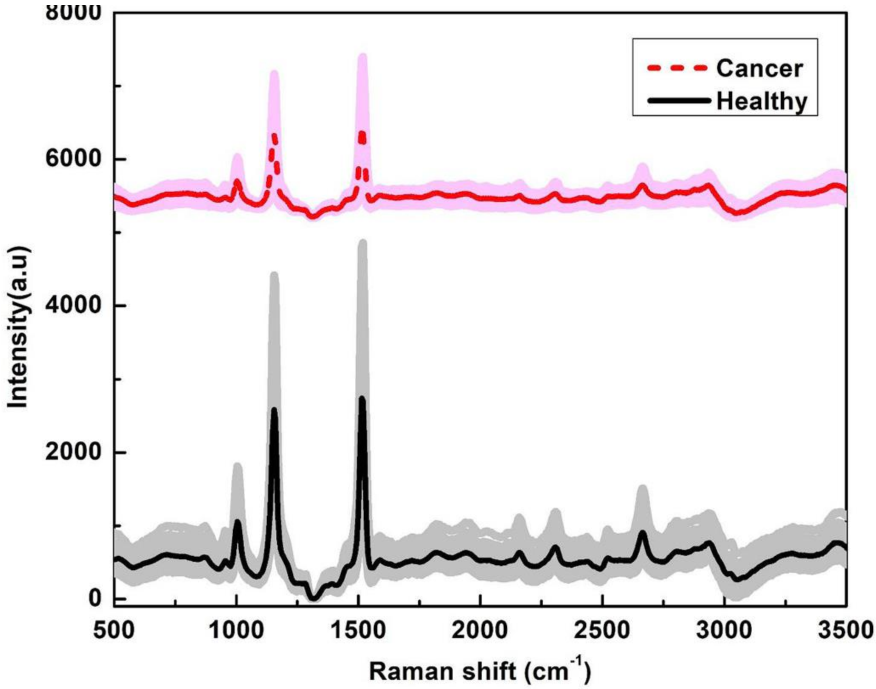


Figure 3. The Raman spectrum of a serum sample from healthy and gastric cancer patients (Bahreini et al., 2019).

Raman and infrared spectroscopy have different and complementary properties in the qualitative and quantitative study of molecules. By combining these two spectroscopic methods for sample detection and analysis, clearer and more comprehensive information about samples can be provided. For example, Raman spectroscopy and infrared spectroscopy have been combined to diagnose thyroid diseases (Chen et al., 2020). In the literature, Raman and FTIR Raman spectroscopy were combined to develop a rapid diagnostic method for renal cell carcinoma (RCC) using serum samples. Figure 4 shows the average Raman spectra and IR spectra of renal cell carcinoma and healthy serum samples (Chen et al., 2022).

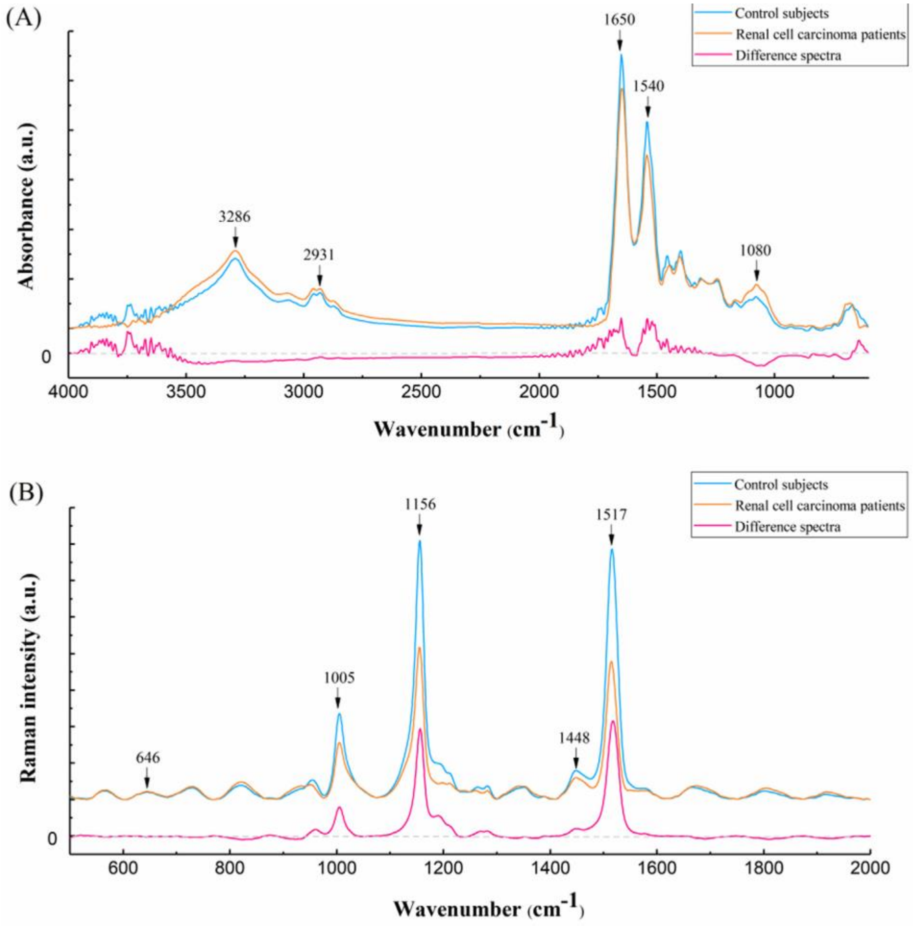


Figure 4. The average Raman spectra and IR spectra of renal cell carcinoma and healthy serum samples (Chen et al., 2022).

2. Spectral Investigation

The functional groups in the spectrum of IR absorption for the particular biomolecules in biomedical fluids, particularly lipids, proteins, carbohydrates, and nucleic acids were shown in Figure 5.

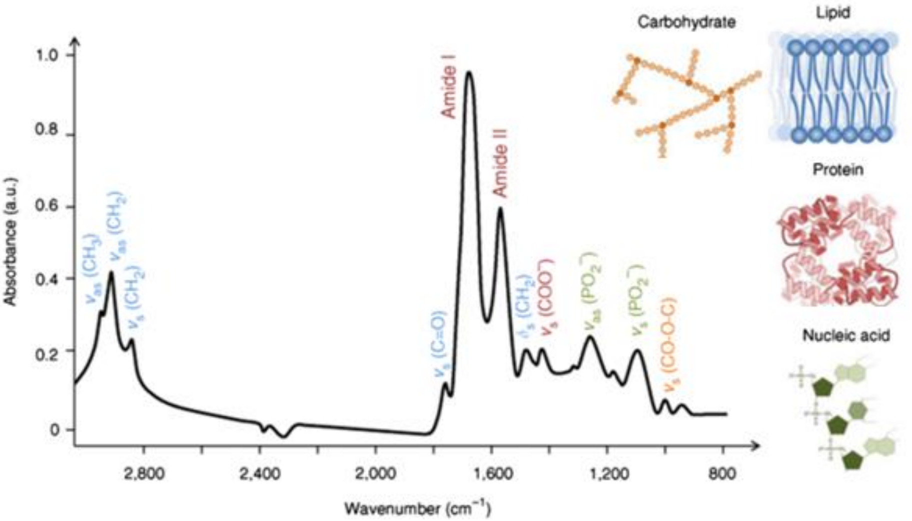


Figure 5. FTIR spectra of biomolecules in biofluids (Baker et al., 2014; Rohman et al., 2019).

Lung cancer is a deadly tumor that has been threatening human health for many years. For its detection, the discovery of a highly sensitive diagnostic method is of great importance. In the literature, serum samples of lung cancer patients and healthy people have been analyzed with both FTIR and Raman and the results have been compared. Table 1 shows the important peaks used. Raman spectra of serum samples were reported to provide more biological information than FTIR spectra of serum samples (Yang et al., 2021).

Table 1. Peak assignments of FTIR and Raman spectra (Yang et al., 2021).

Wavenumber (cm^{-1})	Peak assignments for FTIR
2959	C-H asymmetric stretching vibration of CH_3 in lipid
2930	C-H asymmetric stretching vibration of CH_2 in lipid
1740	C=O stretching vibration from ester carbonyl in triglycerides
1646	α-helix structure in amide I protein
1542	N-H functional group in amide II protein
1243	P=O asymmetric stretching vibration
1079	P=O symmetric stretching vibration
Raman shift (cm^{-1})	**Peak assignments for Raman**
1005	Symmetric ring breathing mode in phenylalanine, CHO, and protein
1129	C-N stretching in protein
1155	C-C stretching in glucose, CHO, and protein
1302	C-H vibration in triglycerides
1448	CH_3-CH_2 bending of phospholipids and the protein side chains
1520	C=C stretching in porphyrin
1656	C=C stretching in lipid and amide I protein

3. The Chemometric Methods Used

Raman and FTIR spectra of biological samples are often complex. Therefore, chemometric methods are often used for quantitative analysis and classification. Chemometrics is the use of mathematics and statistics to process chemical data of biomolecules in biological samples in spectra. Chemometrics allows the simultaneous determination of several independent variables against several dependent variables. The chemomertic methods used for Raman and FTIR are given in Figure 6.

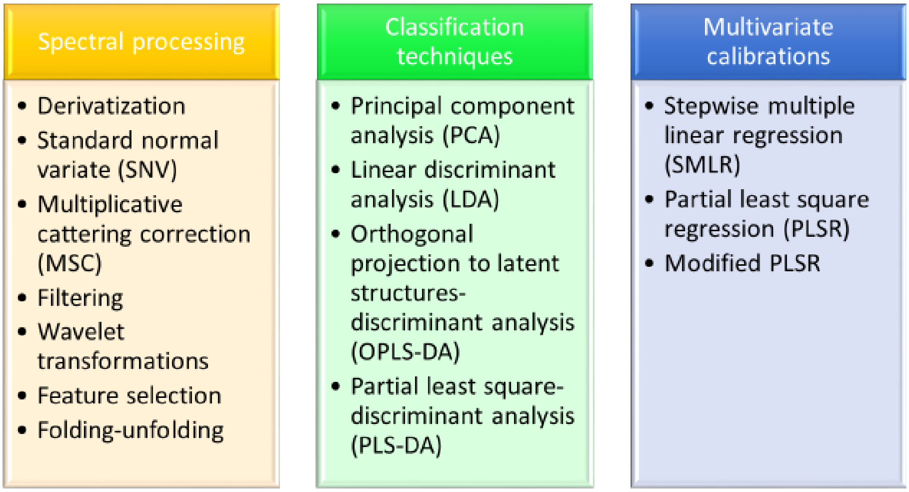


Figure 6. The chemomertic methods used for FTIR and Raman (Rohman et al., 2016, 2019).

4. Conclusion

Raman and FTIR spectroscopy are non-destructive, environmentally friendly, reagent-free and rapid fingerprinting techniques for the analysis of biomolecules such as lipids, glucose, protein, and nucleic acids in serum samples. Raman and FTIR spectroscopies combined with chemometric methods offer powerful and rapid analysis of biomolecules in serum. FTIR and Raman Spectroscopy will continue to develop in the diagnosis of different diseases, tumor monitoring, cancer research, etc. using serum samples, which are very useful.

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CHAPTER 5

QUANTUM DOTS (QD) : BIOCHEMISTRY, SYNTHESIS, INDUSTRIAL AND BIOCHEMICAL APPLICATIONS

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1. Introduction

Advancements in nanotechnology provide the ability to control matter at the atomic or molecular level, offering significance at many scales.[1] Nanotechnology holds a very important position in today's scientific world. When nanotechnology is mentioned, the first thing that comes to mind is size.[2] Humans have been attempting to produce using nanotechnological materials for many years; therefore, materials smaller than 100 nm are associated with nanotechnology.[3] Quantum dots, which play an important role in these developments, have recently attracted great attention in scientific, technological, and medical fields.[4]

Quantum dots are nanometer-scale crystals, semiconductors, and artificial materials containing thousands of atoms within them.[5] Depending on their size, they exhibit variable physical and chemical properties. Quantum dots generally have diameters between 2 and 10 nanometers (nm). However, this range may vary slightly depending on the type of material used, production method, and targeted optical properties.[6]

They were first discovered in 1981 by Russian physicist Alexey I. Ekimov.[7] Quantum dots exhibit unique electronic properties that lie between bulk semiconductors and individual molecules. These properties partly result from their unusually high surface-to-volume ratios. The most notable consequence of this is fluorescence, where nanocrystals produce distinct colors depending on their particle size.[8]

2. General Properties of Quantum Dots

Quantum dots are semiconductor nanocrystals at the nanometer scale and assist significant scientific research due to their unique properties.[9] One of their most important features is their size-dependent optical behavior.[10] As the diameter of quantum dots decreases, their energy band gap increases, resulting in light emission at shorter wavelengths. This phenomenon is explained by the mechanical condition called "*quantum confinement*"[11].

Quantum Dot Type	Size (nm)	Description
CdSe (Cadmium Selenide)	2-8	Emits visible light; shifts toward red as size increases
PbS (Lead Sulfide)	4-10	Operates in the infrared region
InP (Indium Phosphide)	3-9	Cd-free alternative; widely used in biomedicine
Carbon Quantum Dots	2-10	Biocompatible and environmentally friendly

Quantum dots can emit any color of light from the same material by changing the dot size. They have bright and pure colors with high efficiency, longer lifetimes, and high quantum yields. A high quantum yield makes them ideal for optical applications. High-quality quantum dots are ideal for optical encoding and multiplexing due to their narrow emission spectra and broad excitation profiles. Examples of optical applications include light-emitting diodes (LEDs), solid-state lighting, displays, and photovoltaics.[12]

The most commonly produced quantum dots based on their optical and electrical properties are CdSe, InAs, CdS, GaN, InGeAs, CdTe, PbS, PbSe, and ZnS.[13] They are called "*artificial atoms*" because their band gap can be tuned by changing their size. Thus, quantum dots are size-controllable parameters, and combined with quantum confinement effects, they possess extraordinary optical and electrical properties.[14]

Quantum dots typically range between 2 and 10 nanometers in size. This size range causes the electron energy levels to become discrete.[15] Therefore, their energy band gap is size-sensitive, determining their light emission characteristics. For example, smaller quantum dots emit light in the blue region, while larger dots emit in the red region.[16] These quantized energy levels relate quantum dots more closely to atoms than bulk materials, hence their nickname "*artificial atoms*."[17] Generally, as the crystal size decreases, the energy difference between the highest valence band and lowest conduction band increases.[18]

Additionally, quantum dots exhibit high photostability, making them much brighter, more durable, and longer-lived compared to traditional fluorescent dyes.[19]

3. Types of Quantum Dots

Quantum dots vary based on material type, structural form, solubility characteristics, and surface functionalization capacities. These classifications directly affect the fields in which quantum dots are utilized[20].

3.1. Based on Composition

Quantum dots are primarily classified by their composition. The most common are II-VI group semiconductor materials like cadmium selenide (CdSe), cadmium telluride (CdTe), and zinc sulfide (ZnS), which exhibit high fluorescence quantum yields in the visible light region.[21] However, they may pose toxicity concerns due to heavy metal content.[22] As an alternative, III-V group-based quantum dots such as indium phosphide (InP) and gallium arsenide (GaAs) are preferred for their lower toxicity. Carbon quantum dots are favored in biomedical fields for their biocompatibility and environmental friendliness.[23]

3.2. Based on Structural Properties

Quantum dots can be structurally a single crystal core or produced in a core/shell form.[24] Core-shell structures are used to improve optical properties and reduce surface defects. For example, coating a CdSe core with a ZnS shell increases quantum efficiency and photostability, and magnetic and electrical properties can also be enhanced.[25]

3.3. Based on Solubility Characteristics

Quantum dots can be classified based on their solubility environment. Water-soluble quantum dots are modified by adding hydrophilic groups on their surface, preparing them for biomedical applications.[26] Those soluble in organic solvents are typically obtained via colloidal synthesis and used in optoelectronic systems. Such solubility differences play important roles in their application areas.[27]

3.4. Based on Functional Surface Modification

Quantum dot surfaces are functionalized with active molecules to interact effectively with biological systems. Such bio-functionalized quantum dots, developed with biomolecules like antibodies, aptamers, or DNA, are used in targeted diagnosis and therapy applications. Additionally, some quantum dots combined with nanoparticles serve both imaging and magnetic separation purposes.[28]

In conclusion, the diversity of quantum dots makes them versatile materials adaptable to various disciplines. This diversity allows quantum dots to be customized for a wide range of fields from optoelectronics to biomedicine.[29]

4. Synthesis of Quantum Dots

The synthesis of quantum dots controls their sizes, shapes, and surface properties. These variations are crucial for tailoring quantum dots for specific applications.[30]

Quantum dots are synthesized mainly via two fundamental methods: top-down and bottom-up approaches. The top-down approach reduces larger crystals to the nanoscale by physical or chemical means, while the bottom-up method involves controlled assembly of atoms or molecules.[31]

Chemical synthesis methods, especially colloidal synthesis, dominate. Colloidal synthesis is the most widely used laboratory-scale method, where homogeneous-sized quantum dots are obtained through high-temperature reactions in organic solvents. In this method, compounds thermally decompose in a controlled solvent environment, allowing nanocrystals to nucleate and grow. Parameters like temperature, concentration, and reaction time are regulated for size control.[32]

Other widely used methods include microemulsion and hydrothermal synthesis. Additionally, advanced techniques like lithography, electrochemical deposition, ultrasonic methods, and laser ablation offer more precise control.[33]

Another common technique is epitaxial growth, used for producing quantum dots in solid-state systems. Epitaxy is the growth of crystal layers on a substrate. Lattice mismatch between the substrate and deposited material induces strain that leads to quantum dot formation.[34]

Molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) are commonly used epitaxial methods. MBE allows precise control over layer thickness and composition, while MOCVD provides scalability and reproducibility in quantum dot production. Epitaxial methods enable integration of quantum dots into semiconductor devices, promoting optoelectronic and quantum computing applications.[35]

Recently, biologically compatible (green synthesis) methods have gained attention. These aim to synthesize quantum dots at low temperatures without environmental harm using plant extracts, enzymes, or microorganisms.[36]

5. Applications of Quantum Dots

The unique size and observable electronic properties of these tiny semiconductor quantum dots make them highly significant for various applications and new technologies. Quantum dots have begun to be used in many fields. Carbon dots, with abundant functional groups on their surface and tunable carbonization levels, are widely used in bioimaging, chemical sensors, biosensors, nanomedicine, biomolecule/drug delivery, light-emitting diodes, photocatalysis, optoelectronics, photodiodes, analytical chemistry, and electronics due to their optical and chemical properties.[37]

Zero-dimensional quantum dots have a sharper density of states than higher-dimensional structures. Their small size also means electrons do not need to travel as far as in larger particles, allowing electronic devices to operate faster. Applications taking advantage of these unique electronic properties include transistors, solar cells, ultrafast all-optical switches, logic gates, quantum computing, and more.[38]

5.1. Industrial Applications of Quantum Dots

Due to their size tunability, optical, and electronic properties, quantum dots have played an important role in many industrial areas in recent years. Despite their nanometer scale, their advantages such as high photoluminescence efficiency, narrow emission spectra, broad absorption bands, and photostability have allowed wide-ranging industrial applications. Some of these are:[39]

5.1.1. Optoelectronics and Imaging Systems:

Quantum dots play a significant role in display technology. Quantum Dot Light Emitting Diode (QLED) screens provide more vivid and saturated colors than LCDs, offering energy efficiency advantages. Quantum dots are also evaluated as next-generation light-absorbing layers for solar cells (photovoltaics), improving energy conversion efficiency.[40]

5.1.2. Lighting Technologies:

Quantum dots can emit light at desired wavelengths by controlling their size. Their pure color emissions are used as phosphor materials to improve color stability in white LED production. Especially, quantum dots placed on blue LEDs enable more natural white light, offering advantages in both indoor and automotive lighting.[41]

5.1.3. Environmental Analysis and Sensor Technologies:

Quantum dots are effective in chemical sensors used for detecting heavy metals or toxic substances in water, air, and soil samples. Their small size and high selectivity increase the sensitivity of environmental analyses.[42]

5.2. Biochemical Applications of Quantum Dots

Quantum dots are actively used in biochemical research today due to their high sensitivity, stability, and multifunctionality. In biochemistry and biotechnology, quantum dots play important roles in bioimaging and diagnostics. Compared to fluorescent dyes, quantum dots produce longer-lasting and stronger signals, making them useful for intracellular imaging and live cell observation.[43]

Quantum dots functionalized with antibodies can recognize specific biomolecules. Quantum dot markers are used to detect and localize cancer cells for diagnosis .Additionally, they serve as signal enhancers in DNA and RNA sequencing studies.[44]

5.2.1. Biomarker and Imaging Applications:

Quantum dots are used as fluorescent biomarkers for monitoring biological structures at cellular and molecular levels. Because different quantum dots emit light at different wavelengths, simultaneous bioimaging is possible. This feature offers significant advantages in tracking intracellular dynamics and diagnosing cancer cells.[45]

5.2.2. Protein Interactions and Enzyme Analysis:

Quantum dots are used to monitor protein interactions and enzymatic reactions. Substrates bound to quantum dot surfaces change optical properties upon interaction with enzymes, facilitating real-time and precise monitoring of biochemical reactions.[46]

5.2.3. Targeted Diagnostic Systems:

At the interface of biochemistry and medicine, quantum dots are used for targeted diagnostic systems. For example, when cancer cell-specific antibodies are attached to quantum dots' surfaces, they bind only to relevant cells, enabling highly sensitive imaging of tumor tissues. This technology forms the basis of image-guided diagnosis systems.[47]

5.2.4. Drug Delivery and Controlled Release Systems:

Functional quantum dots are also used as drug carriers. These structures, which simultaneously possess diagnostic and therapeutic functions, are called "*theranostic agents*". Thus, disease diagnosis can be observed while drug release is carried out.[48]

6. Conclusion

Quantum dots are used in many areas of modern science due to their tunable optical and electronic properties. Their nanoscale size is also of great importance in scientific research. Typically ranging from 2 to 10 nanometers, these nanocrystals exhibit atom-like energy levels due to the quantum confinement effect. Because of these properties, they are frequently referred to as artificial atoms in the literature. The increased band gap with decreasing size directly affects their emission colors, making quantum dots highly valuable in fluorescent imaging, optoelectronic systems, and sensor technologies. Moreover, core/shell structures, doped systems, and functional surface modifications optimize performance criteria such as photostability, brightness, and specific binding.

Considering industrial applications, quantum dots have broad uses especially in QLED display technologies, white LED lighting systems, quantum dot solar cells, security inks, and environmental sensor systems. These systems aim to utilize high efficiency, pure color emission, and long-lasting performance. In addition, quantum dots are employed in biochemical applications, ranging from fluorescent biomarkers for cell imaging to genetic analyses, biosensors, and drug delivery systems. Their multi-target tracking capability and high signal-to-noise ratio push them beyond traditional fluorochromes.

In all these aspects, quantum dots hold great importance not only in fundamental scientific research but also in biomedical diagnostics, energy technologies, and high-tech products. However, overcoming limiting factors such as toxicity and biocompatibility will enable broader industrial and clinical usage of this technology. In the future, with the development of more environmentally friendly and functional quantum dots, these nanomaterials are expected to make an even greater impact.

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CHAPTER 6

SOME MICROBIAL EVENTS IN THE RUMEN AND SOME CHEMICAL ACTIVITIES REGARDING CARBOHYDRATE DIGESTION

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Introduction

Digestive systems of ruminants differ significantly from those of other animals. The stomach of ruminants consists of four parts; rumen, reticulum, omasum, and abomasum. The feed consumed by animals follows this order and enters the lower digestive system. The digestion of cellulose (found in plant structures) and its derivatives occurs in the first part, the rumen, through fermentation (Aschenbach et al., 2011). Thanks to the parts of their stomachs, ruminants can consume roughage and digest them quite well.

Some Characteristics of the Rumen Internal Medium

Parameters such as temperature, pH, and buffer capacity of the rumen medium should reach optimal values for breeding of microorganisms. There are many studies in the literature that emphasize the temperature parameter. However, while these studies are basically similar, different temperatures related to the breeding temperatures of the rumen were mentioned in these studies. While Wahrmund et al. (2012) found the optimum temperature range to be 39 - 39.5 ºC, García et al. (2018) determined this range as 38.4-39.8 ºC.

Maintaining the ruminal acid-base (pH) balance in bovine is critical for optimal rumen function (Dijkstra et al., 2012). Therefore, pH is also a crucial parameter. The rumen pH range of a healthy ruminant should generally be between 5.5 and 7.0 (Krause and Oetzel, 2006).

To maintain internal rumen balance, the pH range must be kept constant. Saliva plays an important role in balancing rumen pH. The bicarbonate found in saliva behave as a buffer, thus the pH of the medium is constant. Thanks to continuous chewing activities in ruminants, saliva production will continue and thus the stabilization of the rumen pH range is supported (Aschenbach et al., 2011).

Some Components of the Rumen Ecosystem

Carbohydrate digestion in the rumen is carried out by a wide range of microorganisms. These microorganisms are examined into four groups: bacteria, protozoa, anaerobic fungi, and archaea (Belanche et al., 2012). These rumen microorganisms start to work with fermentation, which occurs during the breaking down of cell wall components in feed (Zhang et al., 2007). Bacteria and fungi contribute approximately 70-75% of digestion, while protozoa contribute 25-30% (Zheng et al., 2019).

Rumen microorganisms produce various enzymes. These enzymes are used for digestion and fermentation the feed consumed by ruminants. Therefore, the rumen is considered as a fermentation vessel (Aschenbach et al., 2011).

Cellulolytic bacteria are the main group of microorganisms responsible for cellulose degradation in the rumen (Hua et al., 2022). The number of microorganisms in rumen fluid is quite high; bacteria 10^{10}, protozoa 10^{7} and fungi 10^{6} cells/ml (Chen et al., 2020).

Some Microbial Activities in the Rumen and Some Biochemical Events Regarding the Digestion of Carbohydrates

Microorganisms in the rumen can convert roughage into volatile fatty acids (VFAs) and microbial proteins that ruminants can use (Jami and Mizrahi, 2012). Energy metabolism in ruminants is provided by the digestion of structural carbohydrates of plants, such as cellulose. The breakdown of cell wall elements occurs through the interoperation of bacteria, fungi, and protozoa in the rumen (Schofield, 2000). The speed and extent of fermentation of carbohydrates used as food in the rumen are important criteria in terms of providing nutrients to the animal. (Hall, 2004).

Carbohydrates are important part in the ration of lactating ruminants. Carbohydrates can be divided into two categories: those containing fiber and those not. Fiber-containing carbohydrates (hemicellulose, cellulose, etc.), with the exception of lignin, are digested slowly in the digestive tract. Lignin is resistant to digestion and cannot provide energy for animals (Lanzas et al., 2007). Concentrated feeds are digested quickly, while roughages are digested slowly (Beauchemin et al., 2008). The main reason for this is the structural elements contained in roughage.

Ruminants can digest low-quality, cellulose-containing feeds into meat and milk components thanks to the microorganisms living in their rumen. This can be achieved thanks to the enzymes produced by rumen microorganisms (Burns, 2008).

The enzyme activities confirmed to exist in the rumen are diverse. The microbial diversity found in the rumen also includes a wide variety of fibrolytic enzymes with diverse activities; cellulose, xylanase, β-glucanase and pectinases (Behera et al., 2017). Different enzymes can be used to break down the structural components of roughage. In this way, ruminants can benefit from roughage resources.

Cellulose consists of linear chains of glucose units bonded by β-1,4 linkages. It is the most abundant polysaccharide in the cell wall. It constitutes 20 to 30% of the dry weight of most plant primary cell walls. Hemicellulose, on the other hand, consists primarily of xylans with a skeleton structure composed of xylose residues bonded by β-1,4 linkages, and the addition of various side chains (e.g., acetic acid, arabinose, coumaric acid, ferulic acid, glucuronic acid, 4-O methylglucuronic acid) to the xylose residues (Wang and McAllister, 2002).

Short-particle feeds have a shorter retention time in the rumen. As a result, they reduce rumination time and rumen pH (Maekawa et al., 2002).

Some Fermentation By-Products

Some microorganisms such as protozoa, fungi, and fibrolytic bacteria (Ruminococcus albus and R. flavefaciens, etc.) break down carbohydrates and produce hydrogen (Chaucheyras-Durand et al., 2010).

Roughage sources are important for ruminant animals in terms of both the stability of microorganisms in the rumen medium and the economy of animal nutrition costs. Ruminants can produce various VFAs, microbial proteins, as well as vitamins B and K, through rumen microorganisms that they ingest along with the roughage they consume (Chen et. al., 2022). Rumen microorganisms can also synthesize water-soluble vitamins. Therefore, in most ruminants, there is no need to supplement diets with water-soluble vitamins (Weiss, 2017).

The hydrolysis of carbohydrates (mono-, di-, and oligo-polysaccharide forms) in the rumen is a complex process involving many enzymes (Pereira et al., 2022). After carbohydrates are broken down into monosaccharides, the monosaccharides are first fermented to pyruvate. The pyruvate is then fermented, releasing VFAs (acetate, propionate, and butyrate). Various gases (hydrogen (H_2), methan (CH_4), etc.,) are also released during this process. (Ungerfeld, 2020).

The concentration of dissolved H_2 in the rumen is the main factor determining the VFAs formation pathways and end products (Janssen, 2010). VFAs are absorbed through the rumen wall to provide energy for the body.

Metabolic H_2 formed in the rumen is also used in the production of CH_4 along with CO_2 by methanogenic microorganisms in the rumen (Pereira et al., 2022). Rumen fermentation can produce both beneficial and undesirable components for ruminants. Methane is one of these components (Kingston-Smith et al., 2012).

The resulting methane gas is harmful to both animals and the atmosphere. For this reason, in recent studies, innovative studies have been carried out to reduce the amount of methane gas produced in the rumen medium.

Fermentation end products (VFAs and gases) become toxic to microorganisms when they accumulate in excessive amounts in the rumen medium. This accumulation also inhibits fermentation (Owens and Basalan, 2016).

In ruminants, the energy obtained from carbohydrate digestion in the rumen is used in microbial protein synthesis (Koenig et al., 2003).

Discussions

The rumen, with its microbial diversity and biochemical transformation capacity, forms the basis of ruminant nutrition. Maintaining rumen parameters is essential for the sustainability of microbial balance and fermentative efficiency. Strategies to reduce methane production, in particular, stand out as a critical area of research in terms of both optimizing animal production performance and minimizing environmental impacts.

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CHAPTER 7

COLLOIDS AND ITS APPLICATIONS

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Introduction

Colloids are called solutions formed by the dispersion of a substance in a solvent that does not dissolve it, with dimensions of 10^{-5}-10^{-7} cm. Colloids were first discovered in 1861 by Scottish scientist Thomas Graham. Graham Thomas performed research with a parchment membrane and observed that some substances passed through the membrane rapidly, while others did so very slowly. For example, he observed that molecules like albumin and gelatin move very slowly through the membrane, while molecules like NaCl, KOH, and sugar move very quickly. Using the data he obtained, Graham divided these particles into groups according to their passage through the membrane:

1. Crystalloids
2. Colloids

Crystalloids: These are particles that can pass through plant and animal cells quickly and easily, and that diffuse rapidly. Their solutions may or may not be electrolytes (urea, sugar, salts, and other crystalline substances). These are generally small molecular particles. Serum (Ringer lactate), which is widely used in medicine, is a solution in this group.

Colloids: Colloids are large molecular particles. These pass through plant or animal cell membranes very slowly or not at all (cellulose, protein, starch, etc.). Dextran solutions, silver solutions (used for their antimicrobial properties) and heparin (especially used during cardiac surgeries) are also among the important colloids used in medicine (Çorapçıoğlu, 1197; Petica et al., 2008).

Some molecules exhibit colloidal and crystalloid properties depending on their environment. For example, NaCl is a crystalloid in water, but exhibits colloidal properties in benzene. Similarly, soap exhibits colloidal properties in water, and crystalloidal properties in benzene. A substance exhibits crystalloid properties by dissolving in a chemical structure similar to its own, and colloidal properties in a chemical structure that is not similar (like dissolves like).

Colloids can be classified in different ways: For instance;

a) Colloids can be categorized based on their dispersion medium; sol, emulsion, foam, gel, aerosol, etc.

b) They are categorized into two groups based on their appearance: sols and gels.

Sol: The dispersion of a solid in a liquid or a solid in another solid. Sols are named according to their dispersion environment; e.g. if the dispersion medium is air, they are called aerosols, if it is water, they are called hydrosols, and if it is alcohol, they are called alkosols.

Gel: Gels are semi-solid sols in which the entire dispersion medium acts on the sol particles. The solidity of gels varies from substance to substance (Atkins, 1998; Goel, 2006). Some substances can form both sols and gels (e.g. If the temperature of a gel is increased and its concentration is decreased, this gel can be converted into a sol).

c) Based on the interaction between the dispersed phase and the dispersion medium:

According to Perrio and Freundlich, colloids can be examined in two groups: lyophilic (solvent-attracting) and lyophobic (solvent-repelling).

Lyophilic Colloids: Lyophilic colloids are generally natural colloids (proteins, starch, etc.) and can be easily dispersed in the dispersion medium. In these solutions, the dispersed phase has a very high affinity for dispersion within the dispersion medium. The behavior of these solutions is similar to that of real solutions, and their stability is quite high. The stability of lipophilic colloids varies depending on their charge and solvation. Lyophilic dispersions form spontaneously because the interaction between the dispersed phase and the dispersion medium is high. They are thermodynamically stable and reversible. When the dispersion medium separates from the dispersed phase, it can easily return to its original state. The viscosity of the dispersion medium varies depending on the concentration of the dispersed phase. If our dispersion medium is water, they are called "*hydrophilic*". Inorganic colloids are hydrophilic. If a substance can form lyophilic colloids in organic solvents, they are called lipophilic colloids. Lyophilic colloid solutions are relatively easy to prepare (Çelebi, 2007; Goel, 2006; Verwey and Overbeek, 1999).

Lyophobic Colloids: In these colloids, the dispersed phase has very low or no dispersion affinity within the dispersion medium. These have little or no interaction with the dispersion medium. For this reason, increasing the concentration of the dispersed phase does not affect viscosity. They have very low stability. They are irreversible due to their thermodynamic instability.

Once the dispersed phase is separated from the dispersion medium, it is very difficult or impossible to return to its original state. Unlike lyophilic colloids, they are quite difficult to prepare. These require special preparation techniques. For this purpose, either small particles are brought to colloidal size or the size of larger particles is reduced (Çelebi, 2007; Goel, 2006; Verwey and Overbeek, 1999). Solutions of insoluble substances such as metal solutions (gold, platinum, etc.) and metal sulfides and oxides are examples of lyophobic solutions.

Lyophilic solutions do not precipitate easily, while lyophobic solutions can precipitate with the addition of electrodes or shaking. In lyophilic solutions, the surface tension is generally lower than that of the dispersing medium. In lyophobic solutions, the surface tension is approximately the same as the dispersive medium.

d) They are classified as positive and negative colloids based on their charges within the colloidal phase. If the dispersed phase carries a positive charge in the dispersion medium, it forms a positive colloid ($Fe(OH)_3$ sol carries a positive charge in water, making it a positive colloid). If the dispersed phase carries a negative charge in the dispersion medium, it forms a negative colloid (As_2S_3 (orpiment) sol carries a negative charge in water, it is a negative colloid) (Goel, 2006).

e) Colloids are also classified according to their structure. Molecular colloids and micellar colloids. Molecular colloids are single macromolecules, and their structures are similar to those of small molecules. Micellar colloids are formed by the association of many molecules or groups. These molecules are held together by Van-der Waals forces. Detergents and silicones are examples of this group.

f) Colloids can be classified as spherical or linear based on their particle shapes. Particle size is an important factor in colloidal systems. Because, this it is a significant factor affecting the product's appearance, sedimentation rate, and stability. This also affects the in vitro release and bioavailability of the active ingredient within the pharmaceutical formulation. Colloidal particles can also be found in shapes such as small ellipses and threads (Çelebi, 2007; Goel, 2006).

g) Colloids are divided into two groups based on their chemical composition: inorganic and organic.

Inorganic Colloids: These are also divided into three groups among themselves:

- Oxide sols
- Hydroxide sols
- Salt sols

Organic colloids can be categorized into three groups:

- Homopolar sols (rubber with benzene solution),
- Hydroxy sols (starch)
- Heteropolar sols (aqueous solution of soap) (Goel, 2006).

PROPERTIES OF COLLOIDS

Optical Properties:

Some organic colloids are optically active. These can rotate polarized light (plane polarized light) to the right or left. When a light beam is passed through a colloidal solution, the colloidal particles absorb some of the incident light while scattering the rest. Colloidal sols reflect their color according to the wavelength of light they absorb. In lyophobic colloids, color depends on particle size and the distance between these particles. For example, gold sol with small particles is red, while gold sol with large particles is blue. The phenomenon of light scattering by colloidal systems is known as the ”*Faraday-Tyndall effect*”. The Tyndall effect is not observed in real solutions.

Although colloidal particles are not directly visible, they can be quantitatively analyzed because the luminous dots are associated with the particles. An electron microscope is used for this purpose. Light scattering method is used to determine the molecular weights of colloids (Çelebi, 2007; Ghash, 2009).

Kinetic Properties:

The kinetic properties of colloids are related to the movement of particles in the dispersion medium. These are:

- Thermal behaviour (Brownian movement, diffusion, osmotic pressure)
- Gravitational effect (sedimentation)
- Externally applied effect (viscosity) (Çelebi, 2007).

Thermal Behaviour:

- *Brownian Motion:* It was proposed by the English botanist Robert Brown in 1827. While examining pollen particles floating in water under a microscope, Brown observed tiny particles moving randomly within the pollen cavities. Brownian motion is defined as the random motion of colloidal particles under a microscope. It forms as a result of the bombardment of particles by molecules in the dispersion medium. Decreasing particle size increases their speed of movement. Increasing viscosity slows down the movement of the particles.

When the dispersion medium is water, Brownian movements are very fast, but the addition of glycerin, propylene glycol, etc. to the medium reduces Brownian movements (Çelebi, 2007; Ghash, 2009).

- *Diffusion:* Diffusion is a result of Brownian motion. This is the movement of colloidal particles from a region of high concentration to another region of low concentration. This process continues until the concentration is equal on both sides.

Gravitational effect:

- *Sedimentation (Precipitation):* In disperse systems, when the density of the particles forming the disperse phase is greater than the density of the dispersion medium, the particles show sedimentation under the influence of gravity. Precipitation rate has great importance for assessing the physical stability of suspensions and emulsions. In colloidal dispersions, particles smaller than 0.5 μm are held in suspension by Brownian motion and do not precipitate. For precipitation of this type colloidal solution, centrifugation is necessary.

Properties affected by external influences:

Viscosity: It is the resistance of a solution to flow. If intermolecular interactions increase, viscosity also increases. With increasing temperature, the interaction between molecules decreases due to the increase in kinetic energy.

Electrical Properties:

The electrical properties of colloidal systems depend on their surface charge. Particles dispersed in liquid media can acquire charge in various ways. The first is the ionization of functional groups on the particle surface. For example, the ionization of carboxylic acid or free amine groups in proteins depends on the degree of charge ionization. The pH of the dispersion medium is also crucial. At low pH, proteins become positively charged, while at high pH, they become negatively charged. The pH at which the net charge is zero is known as the isoelectric point of proteins.

Colloidal particles become negatively or positively charged by adsorbing ions in the dispersion medium. These particles are surrounded by other charged ions opposite to their charge, forming a monolayer (monomolecular). A second ion layer (Helmholtz double layer) forms around this layer, which is not bound to the particle. Outside this double layer, there is a neutral area where positive ions are equal to negative ions. The potential difference between the particle's surface and this neutral region is called the Zeta potential. Zeta potential indicates the net effective charge on the surface of a particle and is of great importance in assessing the stability of a colloidal system. As the zeta potential increases, the stability of the colloidal system also increases (Çelebi, 2007). Zeta potential is measured with a Zeta meter and is measured in millivolts. Finally, particles can acquire a charge due to the difference in dielectric constant between the particle and the dispersion medium. The kinetic stability of colloids is due to the electrical charge on the particles' surfaces. Due to this charge, oppositely charged ions accumulate around them, forming an ionic atmosphere.

PREPARATION OF COLLOIDAL SOLUTIONS

Lipophilic sols are easy to prepare, but special processes are required to prepare lyophobic sols. These are summarized as follows:

- Dispersion
- Condensation

Dispersion Method:

It involves the comminution of larger particles into colloidal-sized particles. This method is examined in three groups:

a) *Mechanical Dispersion:* With this method, large particles are placed in the dispersion medium and ground into smaller particles using two discs that touch each other and move in opposite directions at 7000 rpm/min. Paints, inks, varnishes, etc. are prepared using this method (Goel, 2006).

b) *Electrical Dispersion (Bredig's Arc) Method:* This method is used to prepare colloidal solutions of metals. The two electrodes to be used to prepare the colloidal solution are immersed in the dispersion medium, and a potential difference is created between them using an electric arc, allowing current to flow between them. The dispersion medium is then cooled with ice. In this way, the metal vapor generated by the electric arc condenses into colloid-sized particles in the dispersion medium.

c) *Peptization:* We can convert a freshly prepared precipitate into colloidal form by adding suitable electrolytes. These electrolytes are called "peptimizers" or "stabilizers. Sugar, electrolytes, gelatin, etc., are used as peptizing agents. For example, a colloidal solution can be obtained by adding a small amount of $FeCl_3$ to a freshly prepared $Fe(OH)_3$ precipitate. Thus, the resulting sol becomes positively charged.

Condensation Method:

It is the process of bringing small particles to colloidal size. Lyophobic colloids can be prepared through supersaturation and chemical reactions.

Supersaturation: By adding stabilizing agents to a colloidal system, particles aggregate and precipitate. This process is called supersaturation.

Chemical Reactions: Lyophobic colloids can be prepared through chemical reaction processes such as hydrolysis, oxidation, etc. For example, colloidal sulfur can be obtained by the chemical reaction between hydrogen sulfide and sulfur dioxide (Çelebi, 2007).

$$2H_2S + SO_2 \rightarrow 3S + H_2O$$

PURIFICATION OF COLLOIDS

Some methods used to purify colloids are as follows:

1. *Dialysis:* When colloidal solutions are passed through a semipermeable membrane, the solvent and electrolytes pass through the membrane, while the colloidal particles are retained on the membrane surface. This process is called ”*dialysis*”. Dialysis can be accelerated by increasing the surface area of the semipermeable membrane. Explanation of dialysis at the cell level; ions and small molecules pass from the blood into tissue fluids through the natural semipermeable membrane, and the colloidal components of the blood are retained within the capillary system. If the diffusion process is accelerated using hot water, it is called hot dialysis.

2. *Ultrafiltration:* This method is used not only to purify the sol but also to increase its concentration. The pores of the filter paper are large enough to allow colloidal particles to pass through. If these pores are small, colloidal particles are retained by the filter paper. This process is called ”*ultrafiltration*“.

3. *Electrodialysis:* In this method, an electric potential is applied to the semipermeable membrane to increase the dialysis rate.

4. *Electrodecantation:* This method is used not only to purify the sol but also to increase its concentration. If electrodialysis is performed without stirring the sol, the concentration of the upper phase of the colloidal solution decreases while the concentration of the lower phase increases. This process is called ”*electrodecantation*“.

5. *Ultracentrifugation:* It is the rapid sedimentation of colloidal particles in a colloidal solution by rotating them at high speed (Çelebi, 2007; Goel, 2006).

APPLICATION AREAS OF COLLOIDS:

- Paper Production
- In paint and ink production
- In mineral purification
- Detergent production
- In food products
- In medicine
- In the pharmaceutical industry
- In wastewater treatment techniques

Surfactants (e.g., sodium lauryl sulfate, zepiramine, etc.) and thickeners (xanthan gum, sodium alginate, etc.) are also colloids and are frequently used. Surfactants are used in detergent production. Thickeners are used in food (e.g., sodium alginate is frequently used in ice creams, carrageenan in fruit yoghurts, etc.), cosmetics (xanthan is used in shampoos and toothpastes) (Ünal, 2010).

DISCUSSION

This study focuses on colloids, which play a particularly important role in the pharmaceutical industry. However, the importance of colloids is not limited to the pharmaceutical industry; they also have a wide range of applications in food, medicine, paint, cosmetics, and many other fields. These areas of application demonstrate the crucial importance of colloids in terms of product quality, efficacy, and reliability. The study gives a detailed information about colloids' behavior in solution, their classification, preparation and purification methods, optical, electrical, and kinetic properties, and their applications. More effectively demonstrating the potential of colloids is invaluable for creating higher-quality products in both pharmaceutical and other industries. Therefore, this study not only highlights the multifaceted importance of colloids but also serves as a guide for future research.

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