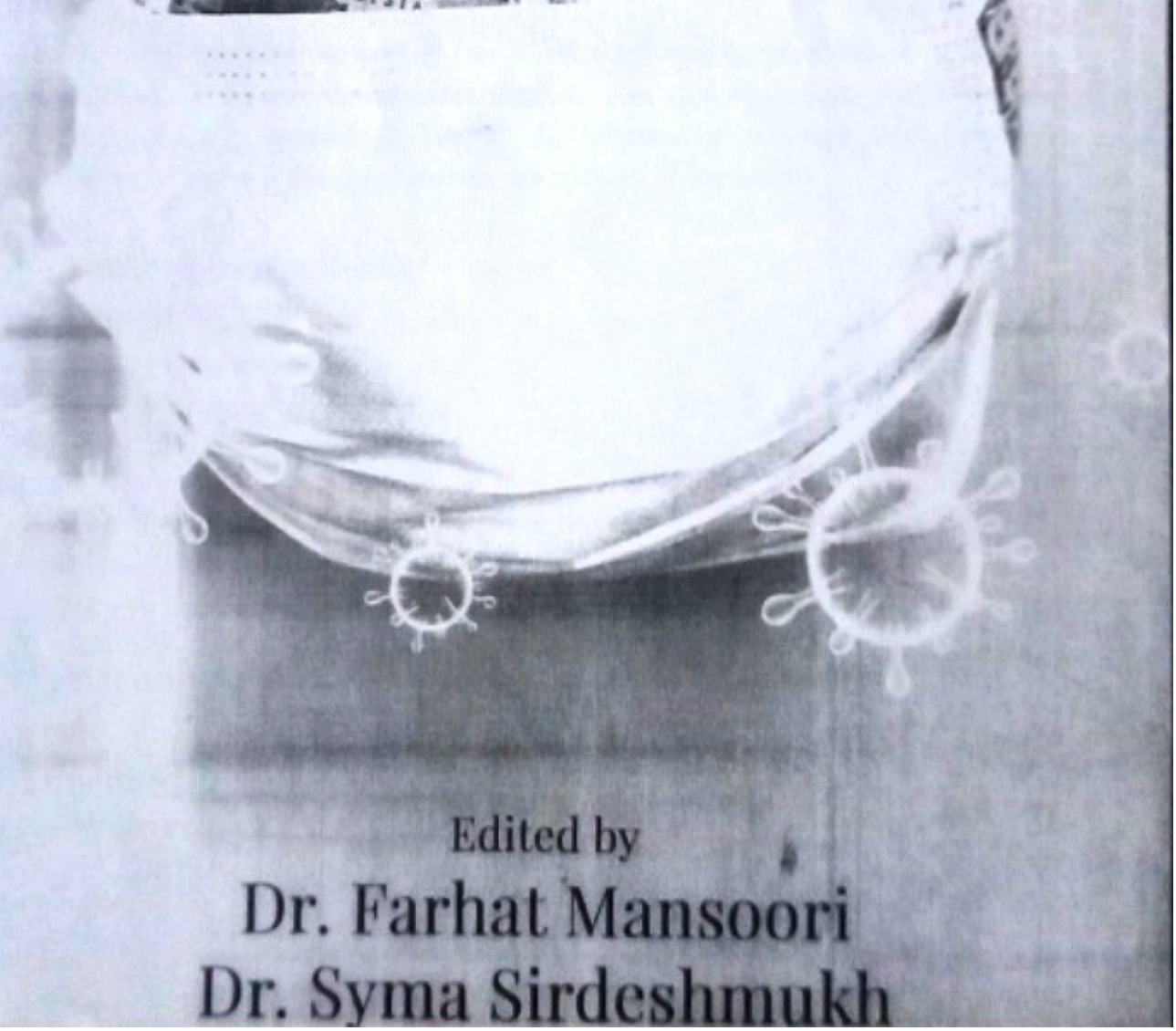
PANDEMIC EFFECTS ON

HEALTH, SOCIETY, ENVIRONMENT & ECONOMY



Edited by

Dr. Farhat Mansoori

Dr. Syma Sirdeshmukh

PANDEMIC EFFECTS ON HEALTH, SOCIETY, ENVIRONMENT & ECONOMY

by: Dr. Farhat Mansoori, Dr. Syma Sirdeshmukh

■

RED'SHINE PUBLICATION PVT. LTD.
Headquarters (India): 88-90 REDMAC, Navamuvada,
Lunawada, India-389 230
Contact: +91 76988 26988
Registration no. GJ31D0000034

In Association with,
RED'MAC INTERNATIONAL PRESS & MEDIA. INC
India | Sweden | UK

■

■

ISBN: 978-93-95456-46-3
ISBN-10: 93-95456-46-9
DIP: 18.10.9395456469
DOI: 10.25215/9395456469
Price: ₹ 400
October, 2022 (First Edition)

■

■

www.redshine.co.in | info@redshine.in
Printed in India | Title ID: 9395456469

CHAPTER 22

CORONA PANDEMIC AND ONLINE BUSINESS (E-COMMERCE) IN INDIA

Dr. Neelam Gandhi
Assistant Professor (Commerce),
St. Thomas College, Bhilai, Chhattisgarh

ABSTRACT

The retail industry is one of the pillars of the Indian economy, contributing around 10% of its GDP. However, it has become more challenging for customers to visit stores and shop in this era of epidemics; as a result, they are more likely to turn to internet shopping. Consumers choose to purchase while staying at home to avoid the outbreak. Consumers acknowledged in a survey that even while overall spending fell over the final three months of 2020, they did more online shopping. Customers prefer shopping online purely for convenience. 90% of people still shop online, according to a Business Today poll conducted on June 24, 2020. Statista . com – According to a survey on Indian online shopping behavior conducted in May 2020, about 29% of respondents said that they purchased online several times due to Pendemic. Cnbctv18.com/India- In view of the corona virus pandemic and persistent concerns 85% of Indian consumers prefer online shopping over physical shopping, (SAYS PIPL SAY CONSUMER CONFIDENCE TRACER).

KEY WORDS *Online Shopping, Offline Shopping, Consumer Preferences, Medium of Shopping, Internet, Consumer Satisfaction, e-commerce, Covid-19, Pandemic.*

INTRODUCTION

The global economy has been significantly impacted by the Covid-19 outbreak. A fragile global economy was initially hit by the epidemic in the first few weeks of 2020. The majority of countries had to impose stringent lockdowns, and some of them did so again in reaction to the second wave that arrived over the winter.

The economy stopped working. Due to the temporary shutdown of businesses and industries, the output of goods and services reduced. There were substantial disruptions to supply lines. In parallel with the supply shock, there was a contraction on the demand side. Business closures resulted in job and income losses for many people. Additionally, the overall effective demand fell.

In other words, the supply and demand fell independently, synchronously, and globally during the economic crisis brought on by the epidemic. The shocks to the real economy have an impact on the financial and external sectors. Finally, the pandemic has transformed from a health catastrophe into a major economic issue.

The epidemic brought about significant issues for the Indian economy, much like it did for the world economy.

ONLINE BUSINESS (e-commerce)-

E-business, often known as online business, refers to commercial activities conducted over the internet. In 1996, the word "e-business" was first used. Electronic business is referred to as e-business. As a result, the buyer and vendor are not meet personally. We can shop from home and find excellent offers without having to leave our actual location. . We now find it simple to shop thanks to e-commerce.

Social media, product content, return and exchange policies, product descriptions, vendor information, delivery dates, shipping costs, web series or movies, product price, and traditional advertising are just a few of the variables that have an impact on the adoption and usage of e-commerce.

ADVANTAGES OF ONLINE SHOPPING

Business companies have shifted from the conventional method of selling items to the electronic method due to the quick development of technology. The internet is the primary means of conducting business for organisations.

1. Online shopping saves time
2. Online shopping saves money
3. Online tracking
4. Convenience of Shopping at home.
5. Wide variety / range of products are available.
6. Good discounts / lower prices.

EFFECT OF CORONA PANDEMIC ON ONLINE BUSINESS (e-commerce) IN INDIA

"The Indian eCommerce industry (sic) has witnessed a huge upsurge due to COVID-19 and there is substantial room for future growth." said Phil Pomford, managing director of Asia Pacific, Worldpay from FIS.

The COVID pandemic problem has forced a lot of small businesses to revaluate their decades-old conventional business structures or face going out of business forever. New and established technologies are now a part of every firm toolkit, and forward-thinking businesses are addressing the talent concerns brought on by these developing digital business skill sets.

In order to avoid having to interact directly with people, there has been a surge in online purchasing and the use of the internet for e-commerce. The shift from traditional currency to digital services has resulted in increased consumer use and transaction patterns.

In particular, the second wave of the virus in the spring of 2021 had a significant impact on India. the largest GDP fall in the country's history, however this may still underestimate the damage done to the finances of the poorest households.

India was badly impacted by the outbreak, particularly during the second wave of the virus in the spring of 2021. the largest GDP decrease in the country's history; however, this may still be an underestimate of the financial harm done to the poorest households.

India has quickly embraced online shopping and electronic payment systems, leading to the creation of new programmes, websites, and other services. It is essential for all stakeholders to comprehend the elements that affect customers' decision to keep using e-commerce platforms after the COVID-19 pandemics.

DESCRIPTION OF ONLINE BUSINESS FEATURES DURING PANDEMICS

According to many reports released between 2020 and 2022, the following are the key characteristics of online business in India during a pandemic: -

Only China and the US have a larger online consumer base than India, which will have 140 million e-retailers by 2020.

The coronavirus epidemic's effect on consumer demand will cause India's e-commerce business to grow by 84 percent to $111 billion by 2024,

According to the poll, mobile shopping would drive a 21% annual growth in India's e-commerce industry over the next four years. The majority of online payments in 2020 were made with credit cards (15%), debit cards (15%), and digital wallets (40%) respectively.

India's retail market contrasted in the fiscal year ending in March 2021: the whole retail market shrank by 5%, while the GDP shrank by 7.3% as a result of widespread lockdowns. Despite a multitooth shutdown, the e-retail market increased by 5% to reach $38 billion. This was a result of Covid-19, which led to a rise in the usage of internet channels.

India's e-retail penetration received a significant boost through Covid-19, which caused it to grow by 12 months to reach roughly 4.6% in FY21. This surge was much more pronounced in metro areas, where one in three people conducted at least one online purchase in the previous year. With one in two residents purchasing online at least once last year, Bengaluru set the pace. According to international e-retail marketplaces, growth should continue, sustaining at levels higher than those before the Covid-19 pandemic, though lower than peak levels.

"The India e-retail market is expected to grow at 25%–30% annually over the next five years to reach $120–140 billion by FY26, which is higher than Modern Trade. Small-town India will fuel this growth, accounting for four of every five new shoppers. During the pandemic, reverse migration from metro cities further accelerated growth in smaller towns. In addition to small towns, women and older shoppers continue to increase the e-retail base."

DISADVANTAGES OF ONLINE SHOPPING

The main factor behind e-success commerce's is its usability. Although purchasing a goods online is quick and simple, some people prefer to utilise this technology sparingly. Before purchasing a product in a store, they view the internet as a way to learn more about it. Others worry about developing an addiction to online buying.
The following are the main drawbacks of online shopping:-

1. Frauds in online shopping
2. Delay in delivery
3. Lack of product touch and feel while shopping online

SUGGESTION TO IMPROVE THE DRAWBACK OF ONLINE SHOPPING

1. Online shopping is easy but it can be made more secure.
2. More privacy should be implemented.
3. Product displayed sometimes differs with the product supplied. It should be improved.

CONCLUSION

Now a day people in India, like Western Countries are showing greater interest towards online shopping. Online shopping becoming more popular day by day with increase in the usage of World Wide Web known as www. Having access to online shopping has truly revolutionized and influenced our society as a whole. This use of technology has opened new doors and opportunities that enable for a more convenient lifestyle today.

Due to the coronavirus outbreak, which has afflicted the entire world, people have been forced to stay at home. Consumer perceptions of online shopping have shifted as a result of the numerous lockdowns that were put in place during the early stages of the pandemic. The e-commerce market in India saw a seismic upheaval as a result of the epidemic, which raised the sector's potential for 2021.

Consumers are increasingly choosing online marketplaces over traditional brick-and-mortar businesses, supermarkets, and shopping centres for the purchase of goods ranging from basic necessities to branded goods.

Social isolation has been used for a very long time to inhibit the spread of a highly contagious disease, despite the fact that it may seem novel. Customers are consequently less inclined to venture outside to acquire needs, which fuels a continual flow of online sales.

This prompted a number of businesses and small shops to move online, which aided in the industry's further expansion. It has also been reported that on various e-commerce platforms, the number of first-time buyers who had previously been put off from shopping online has dramatically increased

As is correctly noted, some people may find optimism even in the most dire situations. The virus outbreak caused the Indian e-commerce industry to undergo a sea change. According to a study, Indian e-commerce would increase from $30 billion in 2017 to $200 billion in 2026.

Continuing its upward growth trend, India is anticipated to surpass the US in 2034 to become the second-largest E-commerce market worldwide.

References

1. Agarwal G.K., Research Statistics, SahityaBhavan Publication, 2004
2. Rao K. B., Research methodology in Commerce and Management, 2004
3. Dr. Lalvaniya M.M., Social Research, First Edit Ramaswari V.S., Marketing Management (Global perspective Indian consent), Third Edition, Macmillan ,2006
4. Arun Kumar, Marketing Management, First Edition, vilas publication house,2006
5. Ramaswari V.S., Marketing Management (Global perspective Indian consent), Third Edition, Macmillan ,2006
6. Kiotier Philip, Marketing Management (A South Asian Perspective), Twelth Edition, 2007
7. Chunavalla S.A., Foundations of Advertising (Theory and practice) Seventh Edition, Himalaya publishing house,2008
8. Goyal S.N., Principles of Management, First Edition, Sahitya Bhawan Publication, 2009
9. SS Kothari C.R., Research Methodology, Second Edition, New Age International Publishers, 2009.
10. Statista . com
11. Business Today survey (24/06/2020)
12. www.mospi.nic.in
13. https://www.businesstoday.in
14. https://blogs.worldbank.org
15. https://www.indianretailer.com
16. Home / Article / Technology / Innovation / Effect of the pandemic on the indian e-commerce industry,Effect of the Pandemic on the Indian E-Commerce Industry,Technology & e-commerce, March 22, 2021
17. Online Shopping Behavior during COVID-19 Pandemic: An Indian Perspective June 2021SSRN Electronic Journal,DOI:10.2139/ssrn.3874348

18. Authors: Amit Ranjan, Indian Institute of Information Technology Allahabad Madhvendra Misra, Indian Institute of Information Technology Allahabad
19. Jitendra Yadav, K L University
20. https://www.business-standard.com
21. Indian e-commerce to grow 84% in 4 years, helped by Covid-19 impact: Study
22. Authors
23. Arpan Sheth, Global Capability Leader, Vector Solutions Group, Mumbai
24. Shyam Unnikrishnan, Partner, Bengaluru
25. Manan Bhasin, Partner, Mumbai
26. Abhishek Raj, Associate Partner, Mumbai
27. https://accountlearning.com , Advantages and Disadvantages of Online Shopping

The material of Modern Programming in "C" is largely derived from the lectures. The modern Programming in "C" is a highly structured and middle level programming language. I delivered to the participants of the MCA, M. Sc., B. Engg., B. Tech., Polytechnic, PGDCA, BCA, B. Sc. and DCA. This book includes introduction, Character sets and Data types, Operators and Expressions, Branching, Looping, Arrays, Strings, Functions, Pointers, Structures and Unions, DMA, File Handling, Data Structures in C and Statistics chapters. Compiled C Program's with flowchart & Algorithms are given in this book. Advanced syllabus of programming in C is covered. This is useful for Learner, Tutors, Programmers, Developers and Software Engineers.

Dr. Santosh Kumar Miri is presently working as Assistant Professor in Computer Science, St. Thomas College, Bhilai, Chhattisgarh, India since 2000. In the past, he has also held the positions of Vice-chancellor nominee and member of Board of Studies, Hemchand Yadav University, Durg (C.G.), member of board of studies of Kalyan P.G. College, Bhilai and Govt. P.G. Digvijay College, Rajnandgaon (C.G.). He is also a Ph. D. Guide, software developer, data mining and data science expert. He holds Ph. D. in Computer Science. He is teaching UG and PG classes since 2000. His areas of interest comprising Database Management System, Image Processing, Machine Learning, AI, Cyber Security & Crimes and Software Engineering.

Dr. Miri published more than 15 research papers in the National and International Journals. He presented 40 research papers in the State, National and International Conferences, symposium, workshop and seminars. He developed video lectures during the COVID-19 pandemic which are uploaded in the CG School Portal. He delivered lectures in the Webinars. He is working as trainer in the Faculty Development Programme. He has good command in the Oracle, C++, Java, MYSQL, R Programming, XML and Python language.

BlueRose ONE
ACADEMIC

MODERN PROGRAMMING IN C

The High Level Structured Programming C Language

DR. SANTOSH KUMAR MIRI

MODERN PROGRAMMING IN C

FIRST EDITION

(Based on Latest Syllabus for DCA, PGDCA, B.Sc., B.E., B. Tech., M. Sc. & MCA)

By

Dr. Santosh Kumar Miri

(Ph. D., M. Phil., M. Sc.)

Assistant Professor in Computer Science

P. G. Department of Computer Science & IT

St. Thomas College, Bhilai

(Affiliated to Hemchand Yadav University, Durg)

Chhattisgarh, India

2023

BlueRose Publishers

Blue Rose Publishers – Best Book Self Publishing House in India

Published by Blue Rose Publishers - Best Book Self Publishing House in India, 4233/1, First Floor, Main, Ansari Road, near Allahabad Bank, Daryaganj, Delhi, 110002

MODERN PROGRAMMING IN C

First Print 2023

Blue Rose Publishers - Best Book Self Publishing House in India

First Edition

ISBN (13 digits): 978-93-5704-403-5

Syed Asad Hassan - Managing Director
Pranavi Jha - Publication Manager
Cover and Book Designer: Dr. Santosh Kumar Miri

GRATITUDE

(आभार)

यह पुस्तक मेरे दादा स्वर्गीय श्री खूनर-कुबरा-साधु नकुल मिरी जी तथा मेरे पिता स्वर्गीय श्री श्याम लाल मिरी जी के स्मृति में समर्पित है।

Dr. Santosh Kumar Miri

email: stc.santosh.miri@gmail.com

Village : Birgahani, Post: Budgahan

Tahsil & Block : Baloda

District : Janjgir Champa (C. G.)

Pin Code: 495559

ABOUT THE AUTHOR

Contents

ISBN : 978-93-92568-44-2

LEARNER AND LEARNING PROCESS

Veetraga Research Foundation

www.vrf.org.in

DR. DIVYA SHARMA
DR. ROLI TIWARI

DR. DIVYA SHARMA
DR. ROLI TIWARI

Creativity

Dr. Jyotsna Gadpayle
Assistant Professor
Department of Education
St. Thomas College, Bhilai, Durg, Chhattisgarh

Introduction

Creativity includes the ability to come up with new ideas and use information and goals in novel ways. It can involve big ideas that change the world, such as inventing tools that affect people's lives, or small creative acts, such as finding new ways to perform tasks in everyday life.

Creativity is the phenomenon of creating something new and valuable. The objects created can be intangible (ideas, scientific theories, musical works, jokes, etc.) or physical objects (inventions, printed works of literature, paintings, etc.).

Creativity is defined as the tendency to develop or perceive ideas, alternatives, or possibilities that may help solve problems, communicate with others, and entertain oneself and others.

Three reasons to be creative:

1. Need for novel, varied, and complex stimulation.
2. Need to communicate ideas and values.
3. Need to solve problems.

The English word *creativity* comes from the Latin term*care*, "to create, make".

Definitions of Creativity

The dictionary definition usually refers to creating something ... whereas creativity usually involves recombining and modifying

existing ideas. Definitions in education range from brand-new ideas to new ways of looking at things and solving problems, from artistic creativity to scientific breakthrough ideas. According to Csikszentmihalyi (1996), most commercial programs aimed at increasing individual creativity focus on divergent thinking which is seen as important to create fluency and originality (relative rarity of an idea).

That "creativity" is commonly used:

1. Persons who express unusual thoughts, who are interesting and stimulating - in short, people who appear to be unusually bright.
2. People who experience the world in novel and original ways. These are personally creative individuals whose perceptions are fresh, whose judgments are insightful, and who may make important discoveries that only they know about.
3. Individuals who have changed our culture in some important way. Because their achievement is by definition human, it is easier to write about them. (e.g., Leonardo, Edison, Picasso, Einstein, etc.)

Creativity is any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one...What counts is whether the novelty he or she produces is accepted for inclusion in the domain."

Characteristics of the creative personality:

1. Creative individuals have a great deal of energy, but they are also often quiet and at rest.
2. Creative individuals tend to be smart, yet also naive at the same time.
3. Creative individuals have a combination of playfulness and discipline, or responsibility and irresponsibility.
4. Creative individuals alternate between imagination and fantasy at one end, and a rooted sense of reality at the other.

5. Creative people seem to harbor opposite tendencies on the continuum between extroversion and introversion.
6. Creative individuals are also remarkably humble and proud at the same time.
7. Creative individuals to a certain extent escape rigid gender role stereotyping and tend to androgyny.
8. Generally, creative people are thought to be rebellious and independent.
9. Most creative persons are very passionate about their work, yet they can also be extremely objective about it.
10. The openness and sensitivity of creative individuals often expose them to suffering pain yet also a great deal of enjoyment.

Two primary components of creativity include:

1. **Originality:** The idea should be something new that is not simply an extension of something else that already exists.
2. **Functionality:** The idea needs to work or possess some degree of usefulness.

Some of these key traits include:

- **Energy:** Creative people possess a great deal of physical and mental energy. However, they also spend a great deal of time quietly thinking and reflecting.
- **Intelligence:** Psychologists have long believed that intelligence plays a critical role in creativity. In Terman's famous longitudinal study of gifted children, researchers found that while a high IQ was necessary for great creativity, not all people with high IQs are creative. Csikszentmihalyi believes that creative people must be smart, but they must be capable of looking at things in fresh, even naïve, ways.
- **Discipline:** Creative people do not just sit around waiting for inspiration to strike. They are playful, yet they are also disciplined in the pursuit of their work and passions.

Types of Creativity

Experts also distinguish between different types of creativity. The " four- C" model of creativity suggests that there are four different types:

1. **Mini-C Creativity:** ideas and insights that are personally meaningful and are only known to the self.
2. **Little-C Creativity:** everyday problem-solving and critical thinking, and the ability to adapt to changing environments.
3. **Pro-C Creativity:** creative within the context of their field, though do not gain eminence for their work.
4. **Big-C Creativity:** creating works or ideas within a particular field that are largely recognized and considered great.

Creative thinking involves four stages:

1. **Preparation:** At this stage, the thinker formulates the problem and gathers the facts and materials that are deemed necessary to find new solutions. Even after days, weeks, or months of focused effort, we often cannot solve the problem. If the problem is not resolved, the thinker then turns away and proceeds to the next stage.
2. **Incubation:** During this time, some of the ideas that were blocking the solution tended to fade away. At this stage, there is no obvious activity and sometimes even thoughts about the problem. However, the unconscious thought processes associated with creative thinking are at work during this time.

The thinker will be busy with other activities like reading literature or playing games, etc. Despite these activities, the contemplation about finding a solution to the problem will be going on in the mind.

3. **Illumination:** Following the period of incubation creative ideas occur suddenly. Consequently, the obscure thing becomes clear. This sudden flash of the solution is known as illumination and is

similar to an 'aha (eureka)' experience. For example, Archimedes found the solution to the crown problem.

4. **Verification:** A solution is obtained in the lighting stage, but we need to verify whether this solution is correct. So in this last step, the solution is evaluated. If the solution is not satisfactory, the thinker goes back to the creative process from the beginning.

If it is satisfactory, the same will be accepted and if necessary, minor modifications may also be made to the solution.

Creativity Test

Creativity tests are usually divided into four main components:

Divergent thinking, convergent thinking, artistic evaluation, and self-evaluation.

Divergent thinking is the ability to consciously generate new ideas that lead to many possible solutions to a particular problem. These solutions or responses are scored against four components:

1. **Originality:** statistical infrequency of response.
2. **Fluency:** number of responses.
3. **Flexibility:** the degree of difference of the responses, in other words, do they come from a single domain or multiple domains.
4. **Elaboration:** the amount of detail in the response.

Convergent thinking is the ability to correctly hone in on the single correct solution to a problem. In creativity convergent thinking often requires taking a novel approach to the problem, seeing the problem from a different perspective, or making a unique association between parts of the problem. These solutions are evaluated as right or wrong.

Artistic reviews are reviews of works of art (paintings, stories, poems, compositions, collages, drawings, etc.). Judging is usually done by two or more of her judges who must closely agree on the creativity of the product.

Self-assessment is a person's response to the level of creativity they perceive to be exerting. People's reaction to the amount of creativity they think a person is exhibiting.

Assessment of Creativity

Creative behaviour and expression, like other behaviour patterns, possess their basic components in the form of cognitive, conative, and affective behaviour. Consequently, we can label a child creative to the extent to which he can demonstrate creative aspects in his thinking, feeling, and behaviour. For this, we may employ two different approaches.

1. Making use of tests of creativity.
2. Making use of non-testing devices observation, interviews, rating scales, personality inventory, checklists, etc.

Creativity Tests

We have used creativity tests for labeling a child as creative. There are so many tests available in India and abroad for this purpose. We are mentioning a few tests are as below:

➢ **Tests Standardized Abroad**

1. Minnesota tests of creative thinking.
2. Guilford's Divergent Thinking Instrument.
3. Remote Associate Test.
4. Wallach and Kogan Creativity Instrument.
5. A.C. Tests of creative Ability.
6. Torrance Tests of Creative Thinking.

➢ **Tests Standardized in India**

1. Baquer Mehdi's Tests of Creative Thinking-Hindi and English.
2. Passi's Tests of Creativity.
3. Sharma's Divergent Production Abilities Test.
4. Saxena's Tests of Creativity.

As mentioned earlier, creativity is a complex combination of multiple skills and traits. Therefore, all creative tests always attempt to capture these abilities and traits with the help of verbal and nonverbal test items. The factors or dimensions involved are fluency, flexibility, originality, divergent thinking, and sophistication.

Let us now illustrate the measurement of the creativity component using two of his creativity tests, the standardized test abroad and the standardized test in India.

Torrance Test of Creative Thinking: It consists of two tests, a verbal test, and a non-verbal test. Developed by the famous American psychologist E. Paul Torrance, this test can be used to test the creativity of children from kindergarten through high school.

For testing creativity through non-verbal and verbal performance. Torrance has thus developed figural forms A and B and verbal forms A and B (Forms B are the equivalent alternatives of the forms A).

The Figural Form (nonverbal testing device). The activities required in this test are non-verbal. Subjects are required to perform a specific non-verbal activity. H. Draw a picture or do something according to the test item. This test has three sub-tests as described below:

1. **Figure or picture completion test:** In this sub-test, there are some incomplete figures. The subject is asked to complete these figures in whatever way he desires.
2. **Picture or figural construction test:** In this sub-test, the subject is provided with a piece of colored paper cut in a curved shape and asked to think of a figure or picture of which this piece of paper may be a part.
3. **Parallel lines test:** In this sub-test, there are several pairs of straight lines. The subject is required to draw as many objects or pictures by using such a pair.

The verbal forms (used as a verbal testing device) The subtest items of this form require respondents to provide written responses. Six subtests are containing the following types of activities:

1. **Asking type**: Here the subject is encouraged to reveal his ability to perceive all things that are not normally perceived by others.
2. **Guess cause and guess consequences types:** Here the subject is encouraged to reveal his ability to formulate hypotheses concerning cause and effect, i.e. what is behind the situation in the picture, and what its consequence may be.
3. **Product Improvement Type:** The subjects are asked to suggest ways and means to improve a toy, a machine, or other products.
4. **Unusual Uses Type:** These are meant to test the divergence about the ways of using a product. Here the subjects have to tell about as many unusual uses as they can point out to use a product.
5. **Unusual Questions Type:** Here for a particular object or verbal description, the subjects are required to ask as many unusual questions as they can.
6. **Just Suppose Type:** The subjects are required to predict outcomes of unusual situations. The responses of the subject are scored in all the sub-test items of both the forms (figural and verbal) and then his total score is computed for providing an estimate of his overall creative potential.

Baquer Mehdi's Tests of Creativity: This test has been developed by Dr. Baquer Mehdi. It is published by the National Psychological Association, Agra. There are four verbal subtests and three nonverbal subtests. This oral form has four subtests:

Consequence Test (duration 12 minutes). In this test, the subject is asked to think of as many consequences as soon as possible for situations like:

I. What would happen if we could fly like a bird?

II. What would have happened if your school had wheels?

III. What would happen if you do not have any need for food?

1. **Unusual uses test** (duration 15 minutes). It includes test items like-Write as many novels as, interesting and usual uses for objects like a piece of stone, a wooden stick, or water.

2. **New relationship test** (duration 15 minutes). It has the test items below.

   Think of as many relationships between the following pairs of words, as possible. (i) Tree, house (ii) Air, Water (iii) Chair, ladder.

3. **Product improvement test** (duration 6 minutes). It consists of test items like as below:

   You have a toy horse. Now think of many new things or features that can make it more interesting and useful.

Non-verbal Sub-tests: The three sub-tests of this category are of the following types:

(a) **Picture construction test:** (duration 20 minutes). It contains test items like below:

There are two geometrical figures a semi-circle and a rhombus. Construct and elaborate pictures using each figure as an integral part. For each picture assign a separate title.

(b) **Line figure completion test:** (duration 15 minutes). Below the figure, there are 10 incomplete line drawings. You have to draw interesting and meaningful pictures using each of them. Also, give a suitable title for each of your creations.

(c) **Picture construction test:** (duration 10 minutes). There are seven triangles and seven ellipses here. Use these diagrams in multiple associations to create interesting images with different meanings.

All these creativity tests assess verbal and non-verbal activities in terms of relevant creative skills such as fluency, originality, flexibility, and sophistication, as outlined above. A high score on this creative test increases the likelihood that a subject will be declared creative. However, such explanations may require further support from the results of evaluations performed on other test devices.

Use of Non-Testing Devices

The creative aspect of a child can also be assessed through some non-testing devices like the Natural observation method, Situational techniques, Rating scale, Checklist Interview, Personality inventories, Interest inventories, and Attitude scales. Aptitude tests, Value schedules, Projective techniques, and so on. These devices help in the revelation of those personality traits and behavioral characteristics that are supposed to be present in a creative child. Some of these traits are identified by the research workers in the field of creativity, which are mentioned below:

Personality and Behavioural Characteristics of a Creative Child

1. Demonstrates originality in ideas and actions.
2. Is more adaptable as well as adventurous.
3. Possesses good memory and broad knowledge background.
4. Possesses a high degree of keenness, attentiveness, alertness, and power of concentration.
5. Is very curious about nature.
6. Possesses little tolerance for boredom but greater for ambiguity and discomfort.
7. Possesses foresightedness in abundance.
8. Has the capacity to take independent decisions.
9. Shows interest in vague and ambiguous ideas.
10. Enjoy a reputation for having strange and silly ideas.

11. Shows preferences for complexity, incompleteness, asymmetry, and open-mindedness.
12. Possesses a high degree of sensitivity towards problems.
13. Can express his ideas as fluently as possible.
14. Shows flexibility in his thinking, feeling, and behaviour.
15. Demonstrates the ability to transfer learning or training from or situation to another.
16. Demonstrates very rich imagination characterized as 'creative imagination'.
17. Is divergent and diversified in his thinking that is convergent and stereotyped.
18. Possesses the ability to elaborate, i.e. to work out the details of an idea, plan, or outline.
19. Is not frightened by the unknown, the mysterious, and the puzzling and on the contrary is often attracted towards it.
20. Welcomes novelty of designs or new solutions to a problem gets enthused and suggests other ideas.

Methods of Developing Creativity among children

Creativity, as a natural endowment, needs stimulation and nourishment. Most of the creative talent, if not given proper training, education, and opportunities for creative expression, results in wastage. Moreover, creativity, as we have emphasized earlier, is universal. It's not the monopoly of a few geniuses. Each of us has a certain amount of creative power. In a democratic system like ours, genius isn't the only thing needed to create, manifest, and produce. Some people, whether mediocre or below average, need to think constructively and creatively.

Therefore, it becomes essential for the teachers as well as parents to realize the need of providing a proper environment and creating conditions for complete growth and development of the creative abilities

of children. The basic problem is vital, but there is a solution. It lies in the proper stimulation and nurturing of the abilities that seem related to developing creativity. Originality, flexibility, ideational fluency, divergent thinking, self-confidence, persistence, sensitiveness, ability to see the relationship and make associations, etc. some abilities are attached to creative output. The following few suggestions can work satisfactorily in the stimulation and nourishment of these abilities:

Freedom to Respond

Most often we, teachers and parents, expect a routine type of fixed response from our children and thus kill the very creative spark by breeding conformity and passivity. Therefore, we should allow adequate freedom to our children in responding to a situation. They should be encouraged to think about as many ideas as they may for the solution to a problem. Also, we must let them have their way when they strongly need a particular sort of novel expression.

Opportunity for Ego Involvement

The feelings like "It is my creation", I have solved it", give much satisfaction to children. They can only be expected to put their determined efforts into creative activities when their ego is involved. i.e., When I feel that a particular creative work is due to my efforts. Therefore, we need to provide opportunities for children to experience the satisfaction of being objects.

Encouraging Originality and Flexibility

Originality on the part of children in any form should be encouraged. Constant submission to the facts, unadulterated copying, passive reception, and rote memorization discourage creative expression and therefore, it should be checked as far as possible. In solving a problem or learning a task if they need to change their methods of learning or solving the problem, they essentially are encouraged to do it. Adequate training can also be given by making them answer the problems like: How would you dig the earth if you don't have a spa

Or how would you draw an angle if you do not have the proper instrument for drawing it? Or how would you cross a river if there is no bridge over it?

Removal of Hesitation and Fear

Most of the time (especially in a country like ours where the inferiority complex is too strong) there is a great deal of hesitation mixed with an inferiority complex and fear of taking the initiative of creative expression. We, generally, listen to comments like "I know what I mean, but cannot write or speak before others." The causes of such hesitation and fear should be discovered and removed as far as possible. The teachers and parents should persuade such children to say or write something, anything, no matter how crude it may be.

Developing Healthy Habits Among Children

Diligence, perseverance, reliability, and self-confidence are some of the traits that lend themselves to creative achievement. Therefore, it is necessary to help children absorb these qualities. Additionally, they need to confront criticism of their creative expression. You should feel that everything you make is unique and expresses what you want to express.

Using the Creative Resources of the Community

Children should be made to visit the centers of creativity for scientific and industrial creative works. It can stimulate and inspire them for doing some creative work. Occasionally, creative artists, creative scientists, and creative persons from other fields may also be invited to schools. It can help enhance the span of the knowledge of our children and kindle the spark of creativity among them.

Avoidance of Blocks to Creative Thinking

Conservatism, teaching methods of faculty and staff, inconsiderate treatment, rigid and rigid work habits, fear and frustration, high-performance standards for low-level tasks, over-emphasis on

school performance, and authoritarianism of teachers and parents factors such as positive attitudes are known. Harmful to fostering children's creativity. Therefore, parents and teachers should try to avoid such factors as much as possible in the upbringing of children.

Reform in the Evaluation System

Our education system is full of exams. Therefore, the grading system needs to be properly reformed to encourage creativity. Abandoning the emphasis on memorization, rigid single-answers, convergent thinking, etc. that destroy children's creativity, and introducing appropriate assessment systems to achieve a complete and balanced approach in the development of children's creative behaviors. Experience should be encouraged.

References

- Dorfman, L., Locher, P., & Martindale, C. (Eds.). (2006). New directions in aesthetics, creativity, and the arts (Foundations and Frontiers in Aes- thetics). Amityville, NY: Baywood Press.
- Kaufman, J. C. (2009). *Creativity 101*. New York: Springer.
- Kaufman, J. C., & Sternberg, R. J. (2007). *Resource review: Creativity*. Change, 39, 55- 58.
- Piirto, J. A. (2004). *Understanding creativity*. Scottsdale, AZ: Great Potential Press.
- Puccio, G. J., Murdock, M. C., & Mance, M. (2006). *Creative leadership: Skills that drive change*. Thousand Oaks, CA: Sage.
- Runco, M. A. (2007). *Creativity: Theories and themes: Research, development, and practice*. San Diego, CA: Elsevier Academic Press.
- Sawyer, R. K. (2006). *Explaining creativity: The science of human innovation*. Oxford: Oxford University Press.

- Simonton, D. K. (2004). *Creativity in science: Chance, logic, genius, and zeitgeist.* New York: Cambridge University Press.
- Weisberg, R. (2006). *Creativity: Understanding innovation in problem-solving, science, invention, and the arts.* Hoboken, NJ: John Wiley.

===00000===

VEETRAGA RESEARCH FOUNDATION

Academic + Research = Excellence Registration Number- 5152

Certificate of Publication

This is to certify that Dr. Sumita Singh has written a chapter entitled Measuring Intelligence- Verbal, Non- Verbal and Performance Tests (One, representative of group test and individual test each) in the Edited Book entitled *Leaner & Learning Process* Published by VEETRAGA RESEARCH Foundation with the ISBN 978-93-92568-44-2 in

Smt. Manisha Sharma
Veetraga Research Foundation

Dr. Suchitra Sharma
Vice President
Veetraga Research Foundation

Dr. Divya Sharma
Chairperson
Veetraga Research Foundation

Dr. Ruli Tiwari
Co- Editor
Member of Advisory board
Veetraga Research Foundation

The Science of Psychology

by

Dr. Sumita Singh

Dr. Gurpreet Kour Chhabra

Swapnil Rumita Jana

&

Dr. Shalini Verma

AG PH Books

2022

The Science of Psychology

Dr. Sumita Singh, Dr. Gurpreet Kour Chhabra, Swapnil Rumita Jana and Dr. Shalini Verma

ISBN – 978-93-95936-43-9

Published by:

AGPH Books (Academic Guru Publishing House)

Bhopal, M.P. India

Contact: +91-7089366889

Preface

The scope of modern psychology stretches from the borders of medicine and the biological sciences to those of the social sciences. Given that humans are biological beings embedded in a dynamic social environment, psychologists investigate a wide range of variables in their quest to comprehend the mental workings that underpin our unique patterns of thought and action. This variety of issues may at times seem daunting; nevertheless, we want to present a framework that will substantially simplify problems.

While psychology is a dynamic and expansive field, the wide range of subjects often taught in an introductory course might give the impression that the subject is irrelevant and disjointed to students. While we have updated each chapter extensively, we have also made some significant structural adjustments to better communicate psychological research.

The book presents an in-depth analysis of fundamental ideas, drawing on both established and cutting-edge sources. Discourses in psychology represent the variety of the field itself, as well as the wide range of cultures and groups that exist across the world.

About Book

The science of psychology was prepared for the purpose of educating and informing readers about the present state of psychological knowledge and about anticipated advances in behavioural science research and practice. This book is the most recent contribution in a long tradition of the presentation of an account of the important historical developments and landmarks in the field of psychology.

One of the book's main aims is to help students better understand themselves so that they may better react to the requirements and problems of the modern world. Its goal is to help students acquire the knowledge and abilities they'll need to successfully navigate the demands of the working world. With that in mind, this curriculum is designed to provide students with the knowledge and abilities they'll need to adapt to a dynamic world, both in and out of the classroom and the workplace.

By providing research and examples from a wide range of sociocultural contexts, this book aims to make psychology a more engaging and approachable subject for the wide range of students that enrol in this course. This has led to a comprehensive book that provides students with a wide range of engaging psychological themes.

Table of Content

Chapter 20

Current applications of biomolecules in biotechnology

Garima Madhariya[a], Shubha Diwan[b], Ravishankar Chauhan[c,d], Nagendra Kumar Chandrawanshi[e], and Pramod Kumar Mahish[a]

[a]*Govt. Digvijay Autonomous PG College, Rajnandgaon, Chhattisgarh, India,* [b]*St. Thomas College, Bhilai, Chhattisgarh, India,* [c]*National Center for Natural Resources, Pt. Ravishankar Shukla University, Raipur, Chhattisgarh, India,* [d]*Pandit Ravishankar Tripathi Govt. College Bhaiyathan, Surajpur, Chhattisgarh, India,* [e]*School of Studies in Biotechnology, Pt. Ravishankar Shukla University, Raipur, Chhattisgarh, India*

Abbreviation

ATP	adenosine triphosphate
BAP	benzylaminopurine
CT	computerized tomography
CTL	cytotoxic T lymphocytes
DHA	docosahexaenoic acid
DNA	deoxyribose nucleic acid
DOPA	dihydroxyphenylalanine
ds	double-stranded
EC	enzyme commission
FDA	Food and Drug Administration
FRET	fluorescence resonance energy transfer
GA3	gibberellic acid
HIV	human immunodeficiency virus
Lgc	low glutelin content
LGC	low-glutelin cultivar
LNA	locked nucleic acid
miRNA	microRNA
MRI	magnetic resonance imaging
MS	Murashige and Skoog
MSG	monosodium glutamate
NAA	naphthalene acetic acid
PCR	polymerase chain reaction
PTGS	posttranscriptional gene silencing
RNA	ribose nucleic acid
RNAi	RNA interference
SELEX	systemic evolution of ligands by exponential enrichment
siRNA	small interfering ribose nucleic acid

20.1 Introduction

Where nature finishes producing its species, man begins, using natural things and with the help of this nature, to create an infinity of species.

Leonardo da Vinci

In connection to the above-mentioned statement of Leonardo da Vinci, human civilization has witnessed the utilization of products derived from plants-/microorganism-based biomolecules for medical applications and in other industries since

Handbook of Biomolecules. https://doi.org/10.1016/B978-0-323-91684-4.00027-X

ancient times [1,2]. From a microorganism to a huge tree each living being possesses biological molecules. They are composed of nucleic acids (DNA/RNA), amino acids, proteins, carbohydrates, lipids, and plant secondary metabolites, and are the chief building blocks of life and its defense system [3,4]. The unique structure and function of those biomolecules are responsible for various physiological functions including reproducibility, sustainability, and mortality in various life forms [5,6]. The most interesting characteristic feature of biomolecules is their hierarchical organization through which they can produce rigid and flexible biological systems and biomaterials [7,8]. Natural evolution has led to extremely functional assemblies of biomolecules that perform intricate tasks that are still unknown in many ways. For instance, the protein synthesis machinery, in which the nanometer-sized ribosome self assembles itself to produce messenger RNA led to the production of various peptides that performs numerous tasks in the living system [9].

Historically, biotechnology arose more than a 1000 years ago utilizing biological components. In the early period, humans by his consciousness used several biological processes for the production of alcoholic beverages, dairy products, vinegar, etc., which are currently known as fermentation products of microbes or microorganism-derived biomolecules [2]. The 20th century has a remarkable improvement in the field as various lives saving biomolecules have been introduced to the world such as penicillin, as the first antibiotic in 1928 and interferons in 1950. Further, science has grown toward biotechnological advancements after the discovery of the double-helical structure of DNA and restriction enzymes; the biomolecules which driven the production of biological molecules [10]. And thereafter, the recombinant DNA technology which is also known as genetic engineering brought insights into the fundamentals of many biochemical processes and the progression of biotechnology in the health, pharma, agriculture, and food industries [10,11]. For instance, an enzyme known as Dicer or endoribonuclease Dicer that cleaves double-stranded RNA into small dsRNA fragments named small interfering RNAs has immense potential to make a revolution in the agricultural sector to fight against pests that are aggravating in agriculture [12]. With the biotechnological development in the 1980s, new approaches were targeted for vaccine productions which consist of proteins derived from pathogens such as viruses and bacteria [13]. In this case, usually, a surrogate organism produced the proteins by expressing the gene encoding for the targeted protein [14]. Amylase and β-glucosidase have been introduced to the bioprocessing industries, enzymes that driven the decomposition of cellulose-based polysaccharides into monomeric sugars, and have large-scale applications in the food, textiles, detergent, and biofuel industry [15,16].

Recently, from the tree of biotechnology, another twig has been emerged as nanotechnology including medicine, engineering, and life science. In these interdisciplinary sciences, nanoscale materials such as nanoparticles, nanofibers, and nanotubes were combined with various biomolecules [17]. Various types of antibodies, biological cell receptor-ligands, enzymes, pro-teins, and several drugs have been immobilized on/within the biomaterial's surface for extensive diagnostic, therapeutic, cell or tissue regeneration, and bioprocess applications [18]. Heparin immobilization on colloidal graphite polymer surface is the very first example of biologically functional biomaterial [19]. Inline, different oxidase enzyme-based electrodes, the basic components of biosensing devices, and electrochemical biosensors that are further used for disease diagnosis were invented for biomedical applications [20]. Moreover, for tumor diagnosis, different biological molecules such as arginine-glycine-aspartate peptides, folate, transferrin, or minute antibody fragments were surface-modified over nanoparticles which facilitates specific cell targeting. Folate is an eminent biological molecule often used as a tumor cell-targeting ligand and the chemical conjugation of this molecule onto the nanoparticle surface can extensively promote its targeted delivery into tumor cells that finally triggers the overexpression of folate receptors [21]. Thus, the current chapter provides insight into such ground-breaking developments in biological science merged with interdisciplinary science to take benefit of the superior evolutionary biological components to engender new products for the welfare of the society which has opened the gateway toward modern biotechnology.

20.2 Applications of amino acid and peptides

Amino acids form the basic unit of the most abundant biomolecule of the living system called proteins. Chemically composed of amino and carboxyl groups, amino acids have a plethora of applications and thus have considerable industrial importance (Table 20.1) [22–31,33–42]. The most abundant use of amino acids is found in food industries. For centuries, different amino acids have been used as food additives and flavor enhancers. The most prominent example is the sodium salt of L-glutamic acid (MSG) which is used as an additive to enhance the flavor of spices, sauces, meat, and fish. The aromatic amino acid L-phenylalanine is majorly used for the synthesis of aspartame, a low-calorie sweetener used in diet drinks and food. Being a natural compound, and thus being safe, amino acids are also getting used as an active ingredient in pharmaceutical and nutraceuticals. Among the major applications of amino acids, animal feeds also form a large share and contribute to its rising industrial demand. The amino acids L-lysine, L-methionine, L-threonine, and L-tryptophan are important amino acids for addition in animal feed. Moreover, the sodium salts of the reaction products of fatty acids with

TABLE 20.1 Major applications of amino acids.

Amino acid	Major applications	References
Glutamic acid	Flavor enhancer as MSG	[22]
Lysine	Food supplement to assist calcium absorption and formation of collagen, pharmaceutical, animal feed, and cosmetics	[23]
Glycine	Flavoring agent, pharmaceuticals as a buffering agent in antacids, analgesics, and cosmetics	[24] [25]
Arginine	Pharmaceutical, assisting the refolding of recombinant proteins, ingredient in dental products	[26] [27]
Phenylalanine	Food industry for the manufacture of aspartame, in infusion fluids, for chemical synthesis of pharmaceutically active compounds	[28]
Tyrosine	Dietary supplement, raw material for L-DOPA	[29]
Threonine	Food additive, animal feed additive, pharmaceuticals	[30]
Tryptophan	Food additive, animal feed additive, and pharmaceuticals including infusion liquids, injectables	[31]
Alanine	Food supplements for muscle growth and bodybuilding	[25]
Aspartic acid	Food industry for the manufacture of aspartame, manufacturing of polyaspartic acid, a fertilizer synergist, pharmaceuticals, cosmetics	[32]
Cysteine	The food industry as flour additives to enhance elasticity during baking, pharmaceuticals, cosmetics for hair treatment, animal feed	[33]
Histidine	Food supplement, pharmaceutical use as infusion liquids	[34]
Isoleucine	Food supplement for muscle strengthening, feed additive, and parenteral nutrition infusions	[35]
Leucine	Food and animal feed additive, pharmaceutical, cosmetics	[36]
Proline	Food supplement for muscle growth, Used as an osmoprotectant and for parenteral nutrition in the pharmaceutical industry	[37,38]
Sérine	Food as a nutritional and flavoring agent, cosmetics as a moisturizing agent, pharmaceuticals	[39]
Valine	Food supplement for muscle growth, pharmaceuticals, a moisturizing component in skincare cosmetics, animal feed	[40]
Methionine	Food and animal feed additive, pharmaceutical	[41]
Glutamine	Food supplement and pharmaceuticals	[42]

amino acids or protein hydrolysates form amino acid-surfactants which are effective skin-compatible cleaners and emulsifiers and are used in shampoos, skin cleansers, shower gels, etc. [43].

A widespread function of amino acids is basically due to their peculiar intrinsic properties. One of which is to act as an osmoprotectant which helps it to stabilize the proteins. Various amino acids are reported to provide a stabilizing role to the proteins by increasing their melting temperature [44]. Thus they also have a wide range of biotechnological applications requiring recombinant protein secretion and purification. Recombinant proteins may be a therapeutic protein or pharmaceutical drug targets are produced in large quantities with the use of recombinant DNA technologies. These proteins for their use as pharmaceuticals need to be stable for a longer period. Moreover, suppression of aggregation is also a basic requirement to make a stable and functional pharmaceutical product. Many pieces of research show that amino acids inhibit the aggregation of proteins and thus making them stable during prolonged storage and other stressful conditions [45].

Peptides, due to their various physiological functions in the body, continue to gain the attention of many researchers. They are the naturally occurring short chains of 2–20 amino acids produced in the body from the digestion of protein by endogenous enzymes and can also be synthetically produced. As peptides possess varieties of bioactivities, it has become a part of many industrial sectors. The use of peptides as therapeutic agents can be traced back to the use of insulin on type 1 diabetes patients almost a century ago [46]. The addition of peptides to nutraceuticals has also received much interest due to their proposed health benefits [47]. Peptides also find their application in the cosmetic industry. Peptides commercially named Argireline and Leuphasyl are reported to have antiaging effects on skin by reducing the depth of wrinkles.

The use of immunogenic peptides for vaccine development is yet another promising application. A minimal microbial component as peptides can provide long-lasting protection against the pathogen and is a safe, smart, and cost-effective approach to vaccine designing [48]. Peptides like transportan and penetratin are also used in the delivery of different molecules inside the cell serving as an alternative to viral methods, or electroporation, microinjection, or liposomes [49].

20.3 Biosignificance of microbial polysaccharides

Polysaccharides are one of the very important biomolecules that can exhibit complex structure and various functional activities [50]. There are plants, microbial, and animal sources of polysaccharides having many industrial applications. Synthetic polysaccharides are other alternates. Plant and animal polysaccharides are not suitable because of ethical and environmental concerns whereas synthetic polysaccharides are nonbiodegradable and may have a toxic effect [51]. Therefore, microbial polysaccharides are most suitable for the industrial demand and have some other advantages like wide molecular weight diversity; chemical nature like acidic, neutral, and basic; various functional group reactions, etc. Several properties are presented in Fig. 20.1.

The microbial polysaccharide is mostly obtained as exopolysaccharides excreted by the microbial cell either recover from the growth medium or adhere to the cell. The microbial cell only needs a carbon source as a nutrient and simple downstream processing to get pure form. The microbial polysaccharides are less explored than the plant polysaccharides [52]. Microbial polysaccharide has both food and nonfood significance. Therefore, natural microbial polysaccharides are focused molecules for use in the various industries in place of synthetic polymer [53].

Many microbes produce polysaccharides such as cyanobacteria, eubacteria, molds, yeast, algae, etc. Microbial polysaccharides show miracle properties like stabilizers, emulsifiers, gelling agents, adhesives, delivery agents, viscosifier, thickeners, and so on. Therefore, these are highly demanded in the industries such as food, pharmaceutical, biomedical, bakery, pup paper, textile, agriculture, paint, cosmetics, and plastics. Among the lots of microbial polysaccharides, some like xanthan and dextran are used in the food industry; gellan as a gelling agent; β-D-glucans as immune building; hyaluronic acid in cosmetics [54]. In recent years, new microbial polysaccharides are discovered and utilized in the different signs of the day-to-day life. These polysaccharides are listed in Table 20.2 [55–86].

FIG. 20.1 Various properties of microbial polysaccharides

TABLE 20.2 Biosignificance of microbial derived polysaccharides.

Polysaccharides	Microbial source	Biosignificance and scope	References
Alginate	*Pseudomonas aeruginosa*	Gelling agent, viscosifier in food, pharma industry	[55,56]
	Azotobacter vinelandii		[57]
Beta-glucan	*Bacillus subtilis*	Biocontrol	[58]
Cellulose	*Acetobacter xylinum*	Food, cosmetics	[59]
	Acetobacter xylinum	Food, pharma, medical	[60]
	Gluconacetobacter xylinus		
Chitin/chitosan	*Mucor rouxii, Aspergillus niger, Trichoderma reesei, Colletotrichum lindemuthianum, Rhizopus oryzae*	Agriculture, biomedical and pharma, industrial—paper, textile	[61]
Curdlan	*Agrobacterium* sp.	Food, pharma, immunostimulator	[62,63]
Dextran	*Lactic acid bacteria—Leuconostoc, Lactobacillus, Streptococcus, Weissella, Pediococcus*	Food, industrial	[64]
	Leuconostoc mesenteroides X21	Pharma, industrial	[65]
Gellan	*Sphingomonas paucimobilis*	Gelling agent—microbial media	[66]
	Sphingomonas elodea	Gelling agent—milk, bakery base food industry	[67]
Hyaluronic acid	*Streptococcus zooepidemicus*	Cosmetics, medicine	[68]
	Streptococci	Water-retention ability, viscoelasticity	[69]
Levan	*Bacillus subtilis*	Antioxidant	[70]
	Tanticharoenia sakaeratensis	Immunomodulatory activity	[71]
Mucilages	*Microcystis* spp. *(Cyanobacteria)*	Bacterial production—ecological benefits	[72]
Polyhydroxy butyrate	*Bacillus* sp.	Biodegradable plastic	[73]
	Lactobacillus acidophilus		[74]
	Isoptericola variabilis	Degradable biopolymer	[75]
Pullulan	*Aureobasidium pullulans*	Food industry	[76]
	Aureobasidium pullulans	Baby care, skin contact, cosmetics	[77]
	Aureobasidium pullulans	Pharma, biomedical, textile, agriculture	[78]
Schizophyllan	*Schizophyllum commune*	Oil recovery	[79]
Scleroglucan	*Sclerotium* spp.	Drug delivery, food additive, cosmetics, pharma products, oil recovery, biomedical—immunity, and antitumor	[80]
	Sclerotium rolfsii	Pharma products, food industry	[81]
Welan	*Sphingomonas* sp.	Cement additive—fluid loss agent, oil recovery, food industry—thickener	[82, 83]
Xanthan	*Xanthomonas campestris*	Improve soil fertility	[84]
	Xanthomonas campestris	Drug delivery, wastewater treatment, protein delivery, tissue engineering, and food packaging	[84]
	Xanthomonas campestris	Bakery products, beverages, dairy, dressings, syrup, toppings, sauces, polishes, pigments, textile, and pet food	[85]
Xylinan (Acetan)	*Acetobacter xylinum*	Viscosifier and gelling agent in the food industry	[86]

20.4 Nucleic acid biotechnological applications

Nucleic acids are biopolymers, or large biomolecules, vital for all known sorts of life. The major part of modern biological and medical research forms a foundation for genome and forensic science, as well as the biotechnology and pharmaceutical industries; all depend on experimental studies of nucleic acids composition. DNA and RNA have been effectively used for the design and production of synthetic nanostructures, molecular switches, and computational devices of increasing complexity because of highly defined interactions between them. Both DNA and RNA can display catalytic activity in various chemical reactions, bind to various molecules, and respond to chemical stimuli. They serve purposes beyond the storage and transfer of genetic information [87].

20.4.1 Synthetic primer

Synthetic primers comprise chemically synthesized oligonucleotides, usually of DNA, which can be customized to anneal to a specific site on the template DNA. The primer spontaneously hybridizes with the template by Watson-Crick base pairing in solution, before being reached out by DNA polymerase. The capacity to create and customize synthetic primers has demonstrated an important tool essential for an assortment of molecular biological approaches involving the analysis of DNA. Both the Sanger chain termination method and the "Next-Gen" method of DNA sequencing require primers to initiate the reaction.

The polymerase chain reaction (PCR) utilizes a couple of custom primers; these primers normally somewhere in the range of 18 and 24 bases in length are used to direct the DNA elongation toward one another at opposite ends of the sequence being amplified and must code for only the specific upstream and downstream sites of the sequence being amplified. A primer that can bind to multiple regions along the DNA will amplify them all, eliminating the purpose of PCR [88].

20.4.2 Locked nucleic acid

For viable adjustment of gene expression, the usefulness of LNA-modified oligonucleotides has been the idea for some scientific investigations, and successful studies on LNA oligonucleotides for gene-silencing technologies.

LNA Antisense: The majority of the antisense experiments led with LNA have been centered on mRNA inhibition by RNase H recruitment, although non-RNase H mechanisms have also been reported. Wahlestedt et al. first reported the impacts of LNA as an antisense molecule by showing the feasibility of LNA to act as potent and nontoxic nucleic acid modification in vivo [89].

LNA-Modified DNAzyme (LNAzymes) for RNA Targeting: DNAzymes are chemically dynamic DNA molecules that can function as a specific RNA endonuclease upon binding to a specific RNA sequence [90,91].

LNA-Modified siRNA (siLNA): Small interfering RNAs (siRNAs) have emerged as powerful candidates for an efficient knockdown of gene expression in mammalian cells by the RNA-interference (RNAi) pathway [92].

MicroRNA targeting using LNA probes: MicroRNAs (miRNAs) constitute a class of short regulatory RNAs (ca. 22 nt) that control gene expression posttranscriptionally during development, differentiation, and metabolism [93,94].

20.4.3 DNA-based thermometer and pH meter

It is another strategy for observing the intracellular pH that exploits FRET and the transition in a DNA duplex from antiparallel- to parallel-strand orientation. Besides utilizing DNA-based hairpin parallel-stranded duplex in related to fluorescence microscopy, we had the option to notice the pH changes in living cells during apoptosis as an effectively identified change in color. These outcomes show that the DNA-based pH indicator ought to help detect pH changes between pH 7.0 and 5.0 in living cells [95].

20.4.4 RNA interference technology

An evolutionarily conserved biological response to double-stranded RNA (dsRNA) for degradation of the sequence-specific homologous mRNA and biochemical reactions that restate this phenomenon generate dsRNA fragments of 21–23 nucleotides from the long dsRNA which is known as RNA interference (RNAi) or posttranscriptional gene-silencing (PTGS) [96].

An agricultural context RNAi in pest-insect control thoroughly investigates its potential for the control of plant pathogens, nematodes, and mites, and to battle against diseases and parasites in helpful insects [97]. RNAi has become a potential tool in the nutritional improvement of important crop plants. The degree of nutritionally desired components has been successfully manipulated in some of the crop plants, increasing carotenoid and flavonoid content in tomatoes [98,99], low caffeine content in coffee [100], the low glutelin rice is preferred for the patients, which are on a restricted protein diet. The low-glutelin cultivar LGC-1 is ordinarily utilized as low-protein riches low-protein rice. This trait is conferred by a single dominant mutation, low glutelin content1 (Lgc1) [101], the significant potential of this high amylose wheat to improve human health through its resistant starch content. By implication of RNAi, tearless onions have been created by decreasing the degrees of lachrymatory factor synthase up to 1544-fold by preventing the conversion of 1-propenyl sulfenic acid to LF [102]. The onions on chopping produce essentially lower levels of LF, the feature that was desired from long for beating distress from onion [103,104].

Inhibition of growth and propagation of cancer cell is a challenge with major potential impact. RNA interference technology has been rapidly developed as a laboratory tool for the downregulation of the expression of a gene of interest. Moreover, RNAi offers new potential for gene therapy for particular neoplasms by the specific inhibition of cancer-associated targets [105].

20.4.5 Genetic vaccine

DNA vaccines have been successful in producing immune responses and protection in a wide variety of preclinical models of viral, bacterial, and parasitic infections, and cancer. They give away to create reagents (antibodies and CTL), are a tool for studying mechanisms of antigen presentation, the part of cytokines, and the impacts of bacterial DNA in the generation of immune responses, and give technology to the revelation of novel vaccine antigens [106].

Genetic vaccines may mimic few parts of the normal disease of host cells. In any case, microorganisms contain surface molecules, for example, LPS and a variety of soluble factors with capacity as adjuvants, alerting the immune system against "threat" by inducing inflammation. The intensity of genetic vaccines may be altogether upgraded by emulating these signals with engineered adjuvants such as QS21 [107] or monophosphoryl lipid A (MPL) [108,109]. DNA plasmids without adjuvant can incite remarkably strong immune responses to the encoded antigen. In part, this might be because of immune-stimulatory sequences inside the DNA itself [110,111].

20.4.6 Aptamers

Nucleic acid aptamers are single strands of DNA or RNA (and chemically modified DNA or RNA) with a length in the range of 10–100 nucleotides, which are recognized from an in vitro selection process: "systemic evolution of ligands by exponential enrichment (SELEX)" [112]. Aptamers are single-stranded nucleic acid molecules that have properties similar to those of protein monoclonal antibodies, and along these lines are clear choices to long-established antibody-based diagnostic or biotechnological products for research, diagnostics, and therapy [113]. Aptamer is highly specific to the various targets (Fig. 20.2).

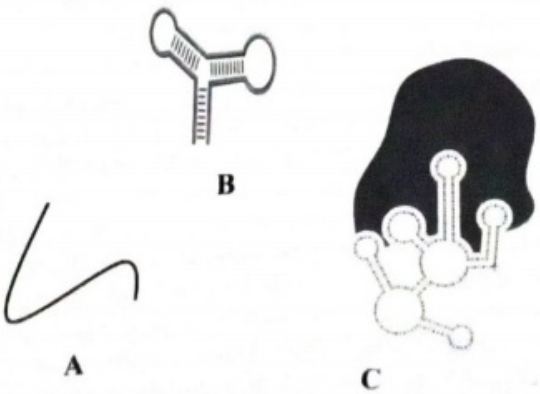


FIG. 20.2 Nucleic acid aptamer. (A) Aptamer sequence; (B) 3D structure form of functional aptamer; (C) Target aptamer complex.

Aptamers are used in various reasons like cell-SELEX: aptamers for cell membrane analysis, aptamers as sensors for biomarker discovery [114], aptamer-based molecular beacons [115], optical molecular imaging with aptamer-based probes [116–118], aptamer-based nanoimaging agents for CT and MRI [114,119], aptamers as vehicles for drug delivery [120], therapeutic aptamers in cancer therapy [121,122], aptamers in precision cancer medicines [123], and aptamer-based programmable hydrogels [124].

20.5 Enzymes and biotechnology

Enzymes are proteins that catalyze more than 5000 biochemical reaction types [125]. A nomenclature for enzymes, the EC numbers (for "Enzyme Commission"), has been developed by the International Union of Biochemistry and Molecular Biology. To represent the hierarchy of enzymatic activity, each enzyme is described by "EC" followed by a sequence of 4 numbers. That is, the primary number broadly classifies the enzyme that supported its mechanism while the opposite digits add more and more specificity.

In all stages of metabolism and biochemical reaction, enzymes play a crucial role as biocatalysts. Microbial enzymes are obtained from different microorganisms that are known to be superior enzymes, particularly for applications in industries on commercial scales [126]. Enzymes are a crucial part of the industry because of their many favorable properties. The event of commercial enzymes has depended heavily on the utilization of microbial sources. Microbes are useful because they will produce economically briefly fermentations and cheap media.

Enzymes are utilized in the industry and other industrial applications when extremely specific catalysts are required. Enzymes generally are limited within the number of reactions they need to be evolved to catalyze and also by their lack of stability in organic solvents and at high temperatures. As a consequence, protein engineering is a vigorous area of research and involves attempts to make new enzymes with novel properties, either through rational design or in vitro evolution [127,128]. Producing enzymes with unique properties like the ability to function under extreme environmental conditions; alteration in enzyme properties to supply the specified function like kinetic features of enzyme-turnover; thermal stability, enzyme activity in a nonaqueous solvent, reaction/substrate specificity, subunit structure, etc., are the most objectives of enzyme engineering [129]. The various applications of enzymes are listed in Table 20.3 [130–192].

20.6 Vitamins in biotechnology

Vitamins are the essential dietary substances important for overall health and nutrition. Depending on their solubility, vitamins can be classified into two groups: water-soluble vitamins consisting of B group vitamins and vitamin C and fat-soluble vitamins formed by vitamin A, vitamin D, vitamin E, and vitamin K. They play a variety of roles in the body, such as supporting energy metabolism, normal vision, promoting the immune system, involved in the synthesis of blood-clotting proteins, etc. [193]. They are primarily consumed through food with fruits and vegetables as the main source and are also commercially available in both natural and synthetic formulations. Based on the varied functions of vitamins in the body, their numerous applications have been explored across different fields, including the healthcare, food, animal feed, and personal care industries.

The rising consumer trend in adopting a healthy diet as a preventive healthcare measure has fueled the demand for vitamins. The increase in the consumption of fortified, functional, and nutraceutical food products has driven the market of vitamin-based foods. Suboptimal intake of the vitamin can lead to deficiency diseases like scurvy (vitamin C) or beriberi (vitamin D). Multivitamins supplements are frequently used both as a preventive and curative measure for chronic vitamin deficiency diseases [194]. Some vitamins are used in the food industry for long as an additive, e.g., vitamin C is being used as a preservative and flavoring agent in many foods like fruit juices, jellies, bread, and baked products, fishing products, and meats [195]. Vitamins are even supplemented to livestock feed to maximize animal performance [196]. The growth of plants in vitro in plant tissue culture also requires vitamins. The most frequently used tissue culture media is Murashige and Skoog (MS) medium [197] in which thiamine, nicotinic acid, pyridoxine, and myo-inositol are the most commonly used. Vitamins have a huge application in the personal care cosmetic industry as well [198]. Most of the vitamins are known to have significant antioxidant effects and are thus used in antiaging formulations to reduce the signs of aging. The popular derivative of vitamin A, retinol, is added to many antiaging formulations. Similarly, vitamin C and vitamin E and their derivatives are active ingredients of the cosmetic industry.

TABLE 20.3 Industrial and biotechnological applications of various enzymes.

Enzyme	Microbial source	Application in	References
Acetolactate decarboxylase	*Brevibacillus*	Beverage	[130]
Acylase	*Escherichia*	Penicillin synthesis	[131]
Amidase	*Rhodococcus, Bacillus, Aspergillus*	Waste management	[132]
Amylase	*Aspergillus*	Detergent	[15]
		Waste management	[133]
	Bacillus	Baking	[134]
		Beverage	[135]
		Detergent	[15]
		Paper and pulp	[136]
		Starch and fuel	[137]
		Textile	[138]
		Waste management	[133]
Asparaginase	*Escherichia*	Phermaquetical	[139]
Catalase	*Aspergillus*	Detergent	[140]
Cellulase	*Aspergillus*	Detergent	[141]
		Textile	[142]
	Clostridium	Pulp and paper	[143]
Cyclodextrin glycosyltransferase	*Bacillus*	Starch and fuel	[144]
Dextranase	*Leuconostoc*	Phermaquetical	[145]
Glucose isomerase	*Bacillus*	Starch and fuel	[146]
Glucose oxidase	*Aspergillus*	Bakery	[147]
Laccase	*Bacillus*	Cosmetics	[148]
	Polyporus	Textile	[149]
	Steccherinum	Beverage	[150]
Lactase	*Lactobacillus*	Lactose removal (milk)	[151]
Lignin peroxidase	*Phanerochaete, Coprinus*	Waste management	[152]
Lipase	*Aspergillus*	Cosmetics	[153]
		Waste management	[154]
	Candida	Baking	[155]
		Detergent	[156]
		Transesterification	[157]
		Food	[158]
		Leather	[159]
		Organic synthesis	[160]
		Pulp and paper	[161]
		Waste management	[154]

Continued

TABLE 20.3 Industrial and biotechnological applications of various enzymes—cont'd

Enzyme	Microbial source	Application in	References
	Rhizopus	Baking	[155]
		Detergent	[156]
		Transesterification	[157]
		Food	[158]
		Leather	[159]
		Organic synthesis	[160]
		Pulp and paper	[161]
Lipoxigenase		Bakery	[162]
Manganese peroxidase	*Phanerochaete, Coprinus*	Waste management	[163]
Mannanase	*Bacillus*	Detergent	[164]
Nitrilase	*Bacillus*	Organic synthesis	[165]
Oxygenase	*Pseudomonas, Rhodococcus*	Waste management	[166]
Pectate lyase	*Bacillus*	Textile	[167]
Pectinase	*Aspergillus*	Beverage, food	[168,169]
Penicillin acylase	*Escherichia*	Phermaquetical	[170]
Penicillin amidase	*Bacillus*	Phermaquetical	[171]
Peroxidase	*Pseudomonas*	Textile	[172]
Phospholipase	*Fusarium*	Bakery, fat and oil production	[173] [174]
Phytase	*Aspergillus*	Animal feed	[175]
Pollulanase	*Klebsiella*	Starch and fuel production	[176]
Protease	*Aspergillus*	Baking	[177]
		Cosmetics	[178]
		Food	[179]
		Leather	[180]
		Pulp and paper	[181]
	Bacillus	Cosmetics	[178]
		Detergent	[182]
	Chrysosporium	Waste management	[154]
Subtilisin		Paper and pulp production	[183]
Superoxide dismutase	*Corynebacterium glutamicum, Lactobacillus plantarum*	Cosmetics	[184]
Transglutaminase	*Streptoverticillium*	Bakery, food	[185] [186]
Xylanase	*Aspergillus*	Animal feed, bakery, Paper and pulp production, fuel	[187,188] [189] [190]
β-Glucanase	*Clostridium*	Animal feed	[191] [192]

20.7 Bioengineered lipids

Among the natural products like polysaccharides, protein, and lipids, fat and oil are the most underinvestigated. However, fatty acids are common in nature, available at very cheap cost, and are significant industrial materials [199]. Nowadays lipids obtained from various sources have been engineered, processed, and utilized in industries and other consumer demands. A few of them are discussed below.

20.7.1 Solid lipid nanoparticles

Solid lipid nanoparticles are lipid nanocarriers made up of solid interiors and are suitable for the delivery of a wide range of drugs [200]. Almost every type of lipids uses for the preparation of solid lipid nanoparticles such as monoglycerides, diglycerides, triglycerides, waxes, steroids, liquid lipids, cationic lipids, and most important fatty acids [201]. It is the substitute for some presently available colloidal drug delivery systems such as liposomes and polymeric nanoparticles which are having various disadvantages [202]. These nanoparticles are up to 1000 nm in size having numerous benefits like wide surface with small size, extended drug release, and better cellular entry, targeting, and capable of changing surface properties [203].

With these advantages, solid lipid nanoparticles are not only highly demanded in drug delivery but also utilized in clinical trials, cosmetics, and allied biopractices [204]. The characterization of solid lipid nanoparticles is possible for both in vivo and in vitro and there are many administration routes of delivery like dermal, oral, pulmonary, ocular, parenteral, and rectal [205]. The drug delivered for the treatment of some important diseases by the solid lipid nanoparticles is presented in Fig. 20.3 [38,206–225].

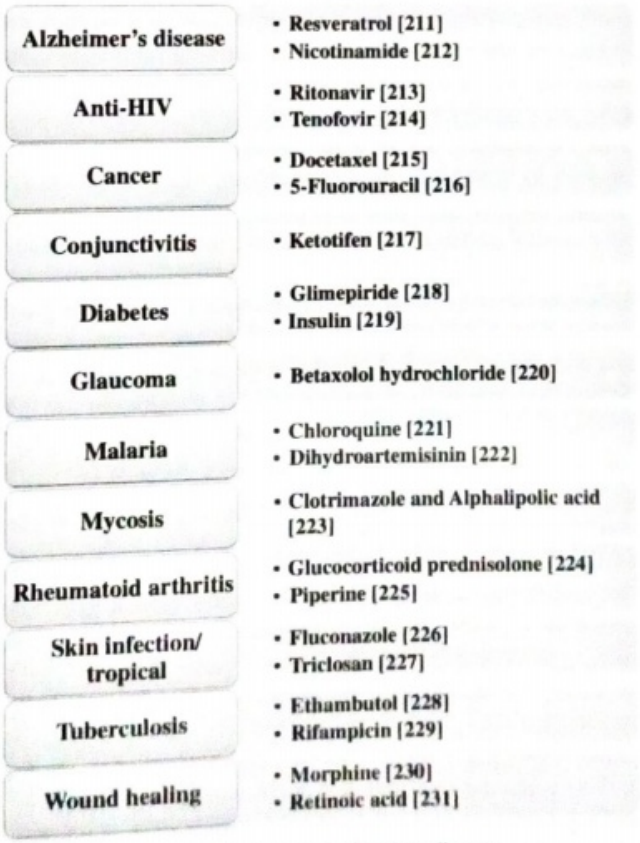


FIG. 20.3 Drug delivered by the solid lipid nanoparticles for the treatment of various diseases.

20.7.2 Single-cell oil

Animals, plants, and microorganisms-derived fats and oils fulfill the industrial demands but engineering and scale-up concern are associated with the higher organism. Therefore, microbial lipids produced by the yeasts, fungi, and algae are a more suitable source of lipid production [226]. Single-cell oils are edible oil obtained from single-celled microorganisms such as yeasts, fungi, and algae [227]. Single-cell oils are also termed unicellular oils and microbial oils. The microorganisms that accumulate lipids (20%–25%) in their biomass are known as oleaginous microorganisms. In the growth phase of these microorganisms, lipid production takes place from the log phase till the reduction of carbon source at the late stationary phase [228]. The acetyl-CoA obtained from the carbon medium serves as the substrate for the production of fatty acid with the aid of the enzyme ATP-citrate lyase. In the algae, and in some fungi, long-chain polyunsaturated fatty acids can be synthesized from the saturated precursor. These long-chain polyunsaturated fatty acids serve as DHA (docosahexaenoic acid) which is a very essential dietary component of the human body. It is most needed during the prenatal and postnatal stages for the proper development and function of the brain, visual, and neural organs [229]. Therefore, single-cell oils utilize in nutraceutical industries for the manufacturing of infant food. Apart from this, single-cell oils also penetrate the industrial demands like biodiesel production and biopharmaceuticals [230].

20.8 Hormones bioactivity

Hormones and hormone receptors have been an important field of basic research since Ernest Starling first introduced the word "hormone" in 1905. Rapid multidisciplinary research explored myriad applications of hormones to benefit society, the most promising contribution being in managing human health. Insulin, for example, has been used for a long for Diabetes mellitus patients, a metabolic disorder characterized by elevated blood glucose levels due to improper secretion of insulin from the pancreas [231]. With the advent of recombinant DNA technology, hormones like recombinant human insulin, growth hormone, erythropoietin (EPO), and other protein hormones are easily available for therapeutic uses; thus, eliminating the problems of contaminants from animal or human sources [232]. Hormones are also given to livestock animals for disease prevention and growth promotion [233]. Natural estrogen, progesterone, testosterone, and their synthetic versions have been approved by the Food and Drug Administration (FDA) for use in beef cattle and sheep. These drugs increase the animal's growth rate and the efficiency of conversion of feed they eat into the meat.

Plant growth hormones have been an important component in agricultural production. Exogenous application of these growth regulators to improve crop production is a common practice, especially to high-value fruit crops. They are known to aid field fruit production, improve fruit quality which is appreciable to consumers, as well as extending its availability [234]. Growth regulators such as naphthalene acetic acid (NAA), 6-benzylaminopurine (BAP), and gibberellic acid (GA3) are used on fruit crops mainly to improve fruit characteristics like increase in fruit size and firmness, shape and color improvement, reduction in the number of seeds, to reduce variability, and to prevent damage caused by storage [235]. Plant hormones are also an essential part of plant tissue culture, a technique used for large-scale plant multiplication, disease elimination, plant improvement, germplasm conservation, and production of secondary metabolites. The developmental pathway of plant cells and tissues in the culture medium is mainly determined by the type and amount of hormones added to the culture medium. Auxins, cytokinins, and gibberellins are usually considered to be the most important for organized development in plant tissue and organ culture. A similar application of hormones is found with animal cell culture technology. This technology has now become an indispensable tool in the field of life sciences, which provides a basis to study the proliferation, and differentiation of cells, and to perform genetic manipulation [236]. Hormones like growth hormones and insulin are used in the medium to enhance the proliferation of cells [237].

20.9 Applications of flavonoids and alkaloids in biotechnology

Among biological molecules, secondary metabolites of plants/microbes are of great importance in different medicinal/industrial sectors [238]. And among these natural products, flavonoids or alkaloids are frequently proved as striking candidates for lead molecules in drug discovery due to their valuable biological activity [239,240]. In general, the organic nitrogenous bases with heterocyclically bound nitrogen are known as alkaloids, while polyphenols with at least two phenolic rings are considered as flavonoids and are further categorized into various subclasses likewise flavanones, flavonols, flavones, etc. [241,242]. The biotechnological applications of these biological molecules, particularly flavonoids, comprised industrial applications such as skin-care products and cosmetics [243]. Moreover, natural flavonoids are also used as dyes in cotton fabrics [244,245]. It has been utilized as an antiwrinkle skin agent due to its antioxidant property [246]. However, the most significant application of these biomolecules is in the healthcare system and the field of medicine

Free-radical-mediated cytotoxicity along with lipid peroxidation inhibition by flavonoids has been investigated [247] where flavonoids act as an antioxidant agent. Moreover, it also takes action as antiproliferative agents to restrain tumor growth or as weak estrogen agonists/antagonists for modulating endogenous hormonal activity [248]. In such a way, flavonoids can confer protection against several chronic diseases like atherosclerosis and/or cancer and facilitate the management of menopausal symptoms. The very previous investigations have revealed few properties of polyphenols from *Camellia sinensis* interrelated to human health that includes a capillary-strengthening property and antioxidant property responsible for the radioprotective effect which is much necessary for this generation [249]. Flavonoids have been used comprehensively as anticancer agents [250], also possessed antiangiogenic, antimicrobial, antiviral, antimalarial, and antiproliferative activity [251–253].

Alkaloids applications can be found in various biotechnology-based industries and medicinal fields. For instance, cocaine was the early discovered local anesthetic drug, tubocurarine was the first neuromuscular blocking agent, and the first antimalarial drug was quinine [254]. Recent discoveries of alkaloids with chief clinical pharmacological activities consist of the anticancer compounds taxol from *Taxus brevifolia* and camptothecin from the tree *Camptotheca acuminata* [255,256]. The special interest nowadays in alkaloids is fluorescence-based analytics, the formation of biosensors, and the transformation of molecules for its synthetic production [257].

20.10 Conclusions and future perspectives

The current chapter summarizes a juvenile and rapidly escalating research area located at the crossroads of molecular and biomolecular sciences. A significant point of concerns is the functionalization of nanoparticles by means of evolutionary optimized biological molecules. Since the biomolecules and nanoparticles typically meet at the minute and same length scale, the interdisciplinary approach emerged will contribute to the establishment of a novel field: biomolecular technology/nanobiotechnology. The commercial applications of biological molecules are in trend. However, the interdisciplinary work conjugating with the biomolecules would have great potential for generating advanced techniques/materials, which might lead to unique devices for signal transduction, sensing, catalysis, etc., currently being developed for biomedical and industrial applications.

References

[1] L.P. Datta, S. Manchineella, T. Govindaraju, Biomolecules-derived biomaterials, Biomaterials (2020) 230, https://doi.org/10.1016/j.biomaterials.2019.119633.

[2] M. Zand, M.L. Narasu, A review article biotechnology applications in medicine, Int. Res. J. Appl. Basic Sci. 4 (2013) 2557–2563.

[3] M.B. Avinash, T. Govindaraju, Architectonics: design of molecular architecture for functional applications, Acc. Chem. Res. 51 (2) (2018) 414–426, https://doi.org/10.1021/acs.accounts.7b00434.

[4] P.B. Malafaya, G.A. Silva, R.L. Reis, Natural-origin polymers as carriers and scaffolds for biomolecules and cell delivery in tissue engineering applications, Adv. Drug Deliv. Rev. 59 (4–5) (2007) 207–233, https://doi.org/10.1016/j.addr.2007.03.012.

[5] R. Krishnamurthy, Giving rise to life: transition from prebiotic chemistry to protobiology, Acc. Chem. Res. 50 (3) (2017) 455–459, https://doi.org/10.1021/acs.accounts.6b00470.

[6] M. Sharma, D.P. Singh, K.S. Rangappa, M. Stadler, P.K. Mishra, R.N. Silva, R. Prasad, V.K. Gupta, The biomolecular spectrum drives microbial biology and functions in agri-food-environments, Biomol. Ther. 10 (3) (2020), https://doi.org/10.3390/biom10030401.

[7] K. Ariga, J. Li, J. Fei, Q. Ji, J.P. Hill, Nanoarchitectonics for dynamic functional materials from atomic-/molecular-level manipulation to macroscopic action, Adv. Mater. 28 (6) (2016) 1251–1286, https://doi.org/10.1002/adma.201502545.

[8] F.-M. Chen, X. Liu, Advancing biomaterials of human origin for tissue engineering, Prog. Polym. Sci. (2016) 86–168, https://doi.org/10.1016/j.progpolymsci.2015.02.004.

[9] N. Ban, P. Nissen, J. Hansen, P.B. Moore, T.A. Steitz, The complete atomic structure of the large ribosomal subunit at 2.4 Å resolution, Science 289 (5481) (2000) 905–920, https://doi.org/10.1126/science.289.5481.905.

[10] C.M. Niemeyer, Nanoparticles, proteins, and nucleic acids: biotechnology meets materials science, Angew. Chem. Int. Ed. 40 (22) (2001) 4128–4158, https://doi.org/10.1002/1521-3773(20011119)40:22<4128::aid-anie4128>3.0.co;2-s.

[11] U. Azizoglu, S. Karabörklü, Role of Recombinant DNA Technology to Improve the Efficacy of Microbial Insecticides, Springer Science and Business Media LLC, 2021, pp. 159–182, https://doi.org/10.1007/978-3-030-67231-7_8.

[12] M. Trejo-Perea, J.G. Rios-Moreno, G. Herrera-Ruiz, A.A. Feregrino-Pérez, I. Torres-Pacheco, R.G. Guevara-Gonzalez, Role of biotechnology in the agrofood industry, in: Advances in Biotechnology for Food Industry, vol. 14, Elsevier Inc., 2018, pp. 1–26, https://doi.org/10.1016/B978-0-12-811443-8.00001-3.

[13] P. Lal, V. Ramachandran, R. Goyal, R. Sharma, Edible vaccines: current status and future, Indian J. Med. Microbiol. 25 (2) (2007) 93–102, https://doi.org/10.4103/0255-0857.32713.

[14] G. Giddings, G. Allison, D. Brooks, A. Carter, Transgenic plants as factories for biopharmaceuticals, Nat. Biotechnol. 18 (11) (2000) 1151–1155, https://doi.org/10.1038/81132.
[15] P.M. de Souza, P.d.O. Magalhães, Application of microbial α-amylase in industry—a review, Braz. J. Microbiol. 41 (4) (2010) 850–861, https://doi.org/10.1590/s1517-83822010000400004.
[16] N. Srivastava, R. Rathour, S. Jha, K. Pandey, M. Srivastava, V.K. Thakur, R.S. Sengar, V.K. Gupta, P.B. Mazumder, A.F. Khan, P.K. Mishra, Microbial beta glucosidase enzymes: recent advances in biomass conversation for biofuels application, Biomol. Ther. 9 (6) (2019), https://doi.org/10.3390/biom9060220.
[17] T. Nagamune, Biomolecular engineering for nanobio/bionanotechnology, Nano Converg. 4 (1) (2017), https://doi.org/10.1186/s40580-017-0103-4.
[18] S.J. Frey, A.S. Hoffman, J.A. Hubbell, R.S. Kane, Surface-Immobilized Biomolecules, Elsevier BV, 2020, pp. 539–551, https://doi.org/10.1016/b978-0-12-816137-1.00036-2.
[19] V.L. Gott, J.D. Whiffen, R.C. Dutton, Heparin bonding on colloidal graphite surfaces, Science 142 (3597) (1963) 1297–1298, https://doi.org/10.1126/science.142.3597.1297.
[20] S. Yabuki, Polyelectrolyte complex membranes for immobilizing biomolecules, and their applications to bio-analysis, Anal. Sci. 27 (7) (2011) 695–702, https://doi.org/10.2116/analsci.27.695.
[21] P.S. Low, W.A. Henne, D.D. Doorneweerd, Discovery and development of folic-acid-based receptor targeting for imaging and therapy of cancer and inflammatory diseases, Acc. Chem. Res. 41 (1) (2008) 120–129, https://doi.org/10.1021/ar7000815.
[22] B.V. Ramachandran, Glutamic acid as an industrial chemical, Curr. Sci. 22 (7) (1953) 195–197.
[23] T. Brautaset, T.E. Ellingsen, L. Eggeling, Lysine industrial uses and production, in: Comprehensive Biotechnology, Elsevier, 2019, pp. 572–586, https://doi.org/10.1016/B978-0-12-809633-8.09172-X.
[24] Y. Izumi, I. Chibata, T. Itoh, Production and utilization of amino acids, Angew. Chem. Int. Ed. Eng. 17 (3) (1978) 176–183, https://doi.org/10.1002/anie.197801761.
[25] A. Stoimenova, K. Ivanov, D. Obreshkova, L. Saso, Biotechnology in the production of pharmaceutical industry ingredients: amino acids, Biotechnol. Biotechnol. Equip. 27 (2) (2013) 3620–3626, https://doi.org/10.5504/bbeq.2012.0134.
[26] J. Alba-Roth, O.A. Müller, J. Schopohl, K. Von Werder, Arginine stimulates growth hormone secretion by suppressing endogenous somatostatin secretion, J. Clin. Endocrinol. Metab. 67 (6) (1988) 1186–1189, https://doi.org/10.1210/jcem-67-6-1186.
[27] T. Arakawa, K. Tsumoto, Y. Kita, B. Chang, D. Ejima, Biotechnology applications of amino acids in protein purification and formulations, Amino Acids 33 (4) (2007) 587–605, https://doi.org/10.1007/s00726-007-0506-3.
[28] G.A. Sprenger, From scratch to value: engineering *Escherichia coli* wild type cells to the production of L-phenylalanine and other fine chemicals derived from chorismate, Appl. Microbiol. Biotechnol. 75 (4) (2007) 739–749, https://doi.org/10.1007/s00253-007-0931-y.
[29] K. Min, K. Park, D.H. Park, Y.J. Yoo, Overview on the biotechnological production of l-DOPA, Appl. Microbiol. Biotechnol. 99 (2) (2015) 575–584, https://doi.org/10.1007/s00253-014-6215-4.
[30] V.F. Wendisch, Amino Acid Biosynthesis-Pathways, Regulation and Metabolic Engineering, Microbiology Monographs, 2007, pp. 71–92.
[31] J. Bongaerts, M. Krämer, U. Müller, L. Raeven, M. Wubbolts, Metabolic engineering for microbial production of aromatic amino acids and derived compounds, Metab. Eng. 3 (4) (2001) 289–300, https://doi.org/10.1006/mben.2001.0196.
[32] H. Appleton, K.A. Rosentrater, Sweet dreams (are made of this): a review and perspectives on aspartic acid production, Fermentation 7 (2) (2021), https://doi.org/10.3390/fermentation7020049.
[33] Y. Hashim, N. Ismail, P. Jamal, R. Othman, H. Salleh, Production of cysteine: approaches, challenges and potential solution, Int. J. Biotechnol. Wellness Ind. 3 (3) (2014) 95–101, https://doi.org/10.6000/1927-3037.2014.03.03.3.
[34] H. Wu, D. Tian, X. Fan, W. Fan, Y. Zhang, S. Jiang, C. Wen, Q. Ma, N. Chen, X. Xie, Highly efficient production of l -histidine from glucose by metabolically engineered *Escherichia coli*, ACS Synth. Biol. 9 (7) (2020) 1813–1822, https://doi.org/10.1021/acssynbio.0c00163.
[35] S. Sanchez, A.L. Demain, Fermentation (industrial): production of amino acids, in: Encyclopedia of Food Microbiology: Second Edition, Elsevier Inc., 2014, pp. 778–784, https://doi.org/10.1016/B978-0-12-384730-0.00373-6.
[36] Y.Y. Wang, F. Zhang, J.Z. Xu, W.G. Zhang, X.L. Chen, L.M. Liu, Improvement of L-leucine production in *Corynebacterium glutamicum* by altering the redox flux, Int. J. Mol. Sci. 20 (8) (2019), https://doi.org/10.3390/ijms20082020.
[37] J. Zhang, F. Qian, F. Dong, Q. Wang, J. Yang, Y. Jiang, S. Yang, De novo engineering of *Corynebacterium glutamicum* for l-proline production, ACS Synth. Biol. 9 (7) (2020) 1897–1906, https://doi.org/10.1021/acssynbio.0c00249.
[38] T. Zhang, T. Zhu, F. Wang, L. Peng, M. Lai, Ketotifen loaded solid lipid nanoparticles laden contact lens to manage allergic conjunctivitis, J. Drug Deliv. Sci. Technol. 60 (2020) 101949, https://doi.org/10.1016/j.jddst.2020.101949.
[39] X. Zhang, G. Xu, J. Shi, M.A.G. Koffas, Z. Xu, Microbial production of L-serine from renewable feedstocks, Trends Biotechnol. 36 (7) (2018) 700–712, https://doi.org/10.1016/j.tibtech.2018.02.001.
[40] M. Oldiges, B.J. Eikmanns, B. Blombach, Application of metabolic engineering for the biotechnological production of L-valine, Appl. Microbiol. Biotechnol. 98 (13) (2014) 5859–5870, https://doi.org/10.1007/s00253-014-5782-8.
[41] K. Drauz, I. Grayson, A. Kleemann, H.-P. Krimmer, W. Leuchtenberger, C. Weckbecker, Amino Acids, Wiley, 2007, https://doi.org/10.1002/14356007.a02_057.pub2.
[42] I. Kusumoto, Industrial production of L-glutamine, J. Nutr. 131 (9) (2001) 2552S–2555S, https://doi.org/10.1093/jn/131.9.2552S.
[43] D.B. Tripathy, A. Mishra, J. Clark, T. Farmer, Synthesis, chemistry, physicochemical properties and industrial applications of amino acid surfactants: a review, C.R. Chim. 21 (2) (2018) 112–130, https://doi.org/10.1016/j.crci.2017.11.005.

[44] T. Arakawa, S.N. Timasheff, The mechanism of action of Na glutamate, lysine HCl, and piperazine-N,N'-bis(2-ethanesulfonic acid) in the stabilization of tubulin and microtubule formation, J. Biol. Chem. 259 (8) (1984) 4979–4986, https://doi.org/10.1016/s0021-9258(17)42942-5.
[45] B.L. Chen, T. Arakawa, E. Hsu, L.O. Narhi, T.J. Tressel, S.L. Chien, Strategies to suppress aggregation of recombinant keratinocyte growth factor during liquid formulation development, J. Pharm. Sci. 83 (12) (1994) 1657–1661, https://doi.org/10.1002/jps.2600831204.
[46] S. Uddin, Peptide drug/device combinations, in: AAPS Advances in the Pharmaceutical Sciences Series, vol. 35, Springer, 2020, pp. 613–637, https://doi.org/10.1007/978-3-030-31415-6_25 (Chapter 25).
[47] A.B. Moldes, X. Vecino, J.M. Cruz, Nutraceuticals and food additives, in: Current Developments in Biotechnology and Bioengineering: Food and Beverages Industry, Elsevier Inc., 2017, pp. 143–164, https://doi.org/10.1016/B978-0-444-63666-9.00006-6.
[48] M. Skwarczynski, I. Toth, Peptide-based synthetic vaccines, Chem. Sci. 7 (2) (2016) 842–854, https://doi.org/10.1039/c5sc03892h.
[49] M.E. Lindgren, M.M. Hällbrink, A.M. Elmquist, U. Langel, Passage of cell-penetrating peptides across a human epithelial cell layer in vitro, Biochem. J. 377 (1) (2004) 69–76, https://doi.org/10.1042/BJ20030760.
[50] V. Coma, C.S.R. Freire, A.J.D. Silvestre, Recent advances on the development of antibacterial polysaccharide-based materials, in: Polysaccharides: Bioactivity and Biotechnology, Springer International Publishing, 2015, pp. 1751–1803, https://doi.org/10.1007/978-3-319-16298-0_12.
[51] I.W. Sutherland, Industrial uses of microbial polysaccharides, in: Biotechnology of Microbial Exopolysaccharides, Cambridge University Press (CUP), 2009, pp. 126–140, https://doi.org/10.1017/CBO9780511525384.011.
[52] J.D. Linton, S.G. Ash, L. Huybrechts, Microbial Polysaccharides, Springer Science and Business Media LLC, 1991, pp. 215–261, https://doi.org/10.1007/978-1-349-11167-1_4.
[53] P. Di Donato, A. Poli, V. Taurisano, B. Nicolaus, Polysaccharides: Applications in Biology and Biotechnology/Polysaccharides From Bioagro-Waste New Biomolecules-Life, Springer Science and Business Media LLC, 2014, pp. 1–29, https://doi.org/10.1007/978-3-319-03751-6_16-1.
[54] I.W. Sutherland, Novel and established applications of microbial polysaccharides, Trends Biotechnol. 16 (1) (1998) 41–46, https://doi.org/10.1016/S0167-7799(97)01139-6.
[55] I.D. Hay, K. Gatland, A. Campisano, J.Z. Jordens, B.H.A. Rehm, Impact of alginate overproduction on attachment and biofilm architecture of a supermucoid *Pseudomonas aeruginosa* strain, Appl. Environ. Microbiol. 75 (18) (2009) 6022–6025, https://doi.org/10.1128/AEM.01078-09.
[56] I.D. Hay, Z.U. Rehman, M.F. Moradali, Y. Wang, B.H.A. Rehm, Microbial alginate production, modification and its applications, Microb. Biotechnol. 6 (6) (2013) 637–650, https://doi.org/10.1111/1751-7915.12076.
[57] V. Urtuvia, N. Maturana, F. Acevedo, C. Peña, A. Díaz-Barrera, Bacterial alginate production: an overview of its biosynthesis and potential industrial production, World J. Microbiol. Biotechnol. 33 (11) (2017), https://doi.org/10.1007/s11274-017-2363-x.
[58] R.T.K. Dewi, N.R. Mubarik, M.T. Suhartono, Medium optimization of β-glucanase production by *Bacillus subtilis* SAHA 32.6 used as biological control of oil palm pathogen, Emir. J. Food Agric. 28 (2) (2016) 116–125, https://doi.org/10.9755/ejfa.2015-05-195.
[59] R. Jonas, L.F. Farah, Production and application of microbial cellulose, Polym. Degrad. Stab. 59 (1–3) (1998) 101–106, https://doi.org/10.1016/S0141-3910(97)00197-3.
[60] P.R. Chawla, I.B. Bajaj, S.A. Survase, R.S. Singhal, Microbial cellulose: fermentative production and applications, Food Technol. Biotechnol. 47 (2) (2009) 107–124. http://www.ftb.com.hr/47-107.pdf.
[61] M.M. Abo Elsoud, E.M. El Kady, Current trends in fungal biosynthesis of chitin and chitosan, Bull. Natl. Res. Cent. (2019), https://doi.org/10.1186/s42269-019-0105-y.
[62] T.P. West, Production of the polysaccharide Curdlan by Agrobacterium species on processing coproducts and plant lignocellulosic hydrolysates, Fermentation 6 (1) (2020), https://doi.org/10.3390/fermentation6010016.
[63] X.B. Zhan, C.C. Lin, H.T. Zhang, Recent advances in curdlan biosynthesis, biotechnological production, and applications, Appl. Microbiol. Biotechnol. 93 (2) (2012) 525–531, https://doi.org/10.1007/s00253-011-3740-2.
[64] D. Kothari, D. Das, S. Patel, A. Goyal, Dextran and Food Application, Springer Science and Business Media LLC, 2014, pp. 1–16, https://doi.org/10.1007/978-3-319-03751-6_66-1.
[65] R.R. Zohra, S. Waseem, A. Aman, A. Siddiqui, S.K. Kazmi, R.R. Zohra, Dextran production by microbial biotransformation of sugarcane waste, Fuuast J. Biol. 9 (1) (2019) 87–94.
[66] J.C. McGuffey, D. Leon, E.Z. Dhanji, D.M. Mishler, J.E. Barrick, Bacterial production of gellan gum as a do-it-yourself alternative to agar, J. Microbiol. Biol. Educ. 19 (2) (2019), https://doi.org/10.1128/jmbe.v19i2.1530.
[67] T.P. West, Synthesis of the microbial polysaccharide Gellan from dairy and plant-based processing coproducts, Polysaccharides 2 (2) (2021) 234–244, https://doi.org/10.3390/polysaccharides2020016.
[68] L. Liu, Y. Liu, J. Li, G. Du, J. Chen, Microbial production of hyaluronic acid: current state, challenges, and perspectives, Microb. Cell Factories 10 (2011), https://doi.org/10.1186/1475-2859-10-99.
[69] Z.Y. Yao, J. Qin, J.S. Gong, Y.H. Ye, J.Y. Qian, H. Li, Z.H. Xu, J.S. Shi, Versatile strategies for bioproduction of hyaluronic acid driven by synthetic biology, Carbohydr. Polym. 264 (2021), https://doi.org/10.1016/j.carbpol.2021.118015.
[70] A. Bouallegue, A. Casillo, F. Chaari, A. La Gatta, R. Lanzetta, M.M. Corsaro, R. Bachoual, S. Ellouz-Chaabouni, Levan from a new isolated Bacillus subtilis AF17: purification, structural analysis and antioxidant activities, Int. J. Biol. Macromol. 144 (2020) 316–324, https://doi.org/10.1016/j.ijbiomac.2019.12.108.
[71] P. Aramsangtienchai, T. Kongmon, S. Pechroj, K. Srisook, Enhanced production and immunomodulatory activity of Levan from the acetic acid bacterium, *Tanticharoenia sakaeratensis*, Int. J. Biol. Macromol. 163 (2020) 574–581, https://doi.org/10.1016/j.ijbiomac.2020.07.001.
[72] A.-K. Brunberg, Contribution of bacteria in the mucilage of Microcystis spp. (Cyanobacteria) to benthic and pelagic bacterial production in a hypereutrophic lake, FEMS Microbiol. Ecol. 29 (1) (1999) 13–22, https://doi.org/10.1111/j.1574-6941.1999.tb00594.x.

[73] A. Getachew, F. Woldesenbet, Production of biodegradable plastic by polyhydroxybutyrate (PHB) accumulating bacteria using low cost agricultural waste material, BMC Res. Notes 9 (1) (2016) 1–9, https://doi.org/10.1186/s13104-016-2321-y.
[74] A. Hamieh, Z. Olama, H. Holail, Microbial production of polyhydroxybutyrate, a biodegradable plastic using agro-industrial waste products, Glob. Adv. Res. J. Microbiol. 2 (2013) 54–064.
[75] S. Krishnan, G.S. Chinnadurai, K. Ravishankar, D. Raghavachari, P. Perumal, Statistical augmentation of polyhydroxybutyrate production by *Isoptericola variabilis*: characterization, moulding, in vitro cytocompatibility and biodegradability evaluation, Int. J. Biol. Macromol. 166 (2021) 80–97, https://doi.org/10.1016/j.ijbiomac.2020.10.089.
[76] R.S. Singh, N. Kaur, J.F. Kennedy, Pullulan production from agro-industrial waste and its applications in food industry: a review, Carbohydr. Polym. 217 (2019) 46–57, https://doi.org/10.1016/j.carbpol.2019.04.050.
[77] M.B. Coltelli, S. Danti, K. de Clerk, A. Lazzeri, P. Morganti, Pullulan for advanced sustainable body—and skin-contact applications, J. Funct. Biomater. 11 (1) (2020), https://doi.org/10.3390/jfb11010020.
[78] S. Dhiman, G. Mukherjee, Pullulan: A Bioactive Fungal Exopolysaccharide With Broad Spectrum of Applications for Human Welfare, Elsevier BV, 2021, pp. 187–206, https://doi.org/10.1016/b978-0-12-821734-4.00012-5.
[79] R.G. Gunaji, R. Junin, S. Bandyopadhyay, Production and characterization of biopolymer schizophyllan using sago starch as a carbon source, J. Phys. Conf. Ser. 1529 (5) (2020), https://doi.org/10.1088/1742-6596/1529/5/052063.
[80] N.A. Castillo, A.L. Valdez, J.I. Fariña, Microbial production of scleroglucan and downstream processing, Front. Microbiol. 6 (2015), https://doi.org/10.3389/fmicb.2015.01106.
[81] T. Bai, T. Wang, Y. Li, N.L. Gao, L. Zhang, W.H. Chen, X. Yin, Optimization of scleroglucan production by *Sclerotium rolfsii* by lowering pH during fermentation via oxalate metabolic pathway manipulation using CRISPR/Cas9, Fungal Biol. Biotechnol. 8 (1) (2021), https://doi.org/10.1186/s40694-021-00108-5.
[82] H. Li, H. Zhu, S. Sun, Z. Feng, Y. Sun, W. Zhou, Biological production of welan gum, Phys. Sci. Rev. 1 (10) (2016), https://doi.org/10.1515/psr-2016-0049.
[83] A.P. Chang, J. Qian, H. Li, Y.L. Wang, J.Y. Lin, Q.M. He, Y.L. Shen, H. Zhu, Characterization and function of a novel welan gum lyase from marine *Sphingomonas* sp. WG, Front. Microbiol. 12 (2021), https://doi.org/10.3389/fmicb.2021.638355.
[84] M.H. Abu Elella, E.S. Goda, M.A. Gab-Allah, S.E. Hong, B. Pandit, S. Lee, H. Gamal, A.U. Rehman, K.R. Yoon, Xanthan gum-derived materials for applications in environment and eco-friendly materials: a review, J. Environ. Chem. Eng. 9 (1) (2021), https://doi.org/10.1016/j.jece.2020.104702.
[85] S. Tasleem, F. Anwar, M. Arif, A. Khan, A. Ali, S. Ali, A.A. Sumra, W. Qureshi, S.A. Shah, Production of Xanthan gum from Xanthomonas compestris isolated from Cruciferous Vegetables, Adv. Biores 11 (5) (2020) 6–12, https://doi.org/10.15515/abr.0976-4585.11.5.612.
[86] S. Lei, T.F. Edmund, Polysaccharides, microbial, in: Encyclopedia of Microbiology, Elsevier, 2019, pp. 660–678, https://doi.org/10.1016/B978-0-12-809633-8.13102-4.
[87] D. Miyoshi, F.C. Simmel, S. Maiti, L.A. Marky, Synthesis and application of functional nucleic acids, J. Nucleic. Acids 2011 (2011), https://doi.org/10.4061/2011/547245.
[88] M.M. Cox, J.A. Doudana, M. Donnell, Molecular Biology: Principles and Practice, 2015.
[89] C. Wahlestedt, P. Salmi, L. Good, J. Kela, T. Johnsson, T. Hökfelt, C. Broberger, F. Porreca, J. Lai, K. Ren, M. Ossipov, A. Koshkin, N. Jakobsen, J. Skouv, H. Oerum, M.H. Jacobsen, J. Wengel, Potent and nontoxic antisense oligonudeotides containing locked nucleic acids, Proc. Natl. Acad. Sci. U. S. A. 97 (10) (2000) 5633–5638, https://doi.org/10.1073/pnas.97.10.5633.
[90] R.R. Breaker, G.F. Joyce, A DNA enzyme that cleaves RNA, Chem. Biol. 1 (4) (1994) 223–229, https://doi.org/10.1016/1074-5521(94)90014-0.
[91] S.W. Santoro, G.F. Joyce, A general purpose RNA-cleaving DNA enzyme, Proc. Natl. Acad. Sci. U. S. A. 94 (9) (1997) 4262–4266, https://doi.org/10.1073/pnas.94.9.4262.
[92] S.M. Elbashir, J. Harborth, W. Lendeckel, A. Yalcin, K. Weber, T. Tuschl, Duplexes of 21-nucleotide RNAs mediate RNA interference in cultured mammalian cells, Nature 411 (6836) (2001) 494–498, https://doi.org/10.1038/35078107.
[93] V. Ambros, microRNAs: tiny regulators with great potential, Cell 107 (7) (2001) 823–826, https://doi.org/10.1016/S0092-8674(01)00616-X.
[94] D.P. Bartel, MicroRNAs: genomics, biogenesis, mechanism and function, Cell 116 (2004) 281–297, https://doi.org/10.1016/s0092-8674(04)00045-5.
[95] T. Ohmichi, Y. Kawamoto, P. Wu, D. Miyoshi, H. Karimata, N. Sugimoto, DNA-based biosensor for monitoring pH in vitro and in living cells, Biochemistry 44 (19) (2005) 7125–7130, https://doi.org/10.1021/bi0476782.
[96] X. Ling, F. Li, Silencing of antiapoptotic survivin gene by multiple approaches of RNA interference technology, BioTechniques 36 (3) (2004) 450–460, https://doi.org/10.2144/04363rr01.
[97] M. Zotti, E.A. dos Santos, D. Cagliari, O. Christiaens, C.N.T. Taning, G. Smagghe, RNA interference technology in crop protection against arthropod pests, pathogens and nematodes, Pest Manag. Sci. 74 (6) (2018) 1239–1250, https://doi.org/10.1002/ps.4813.
[98] G.R. Davuluri, A. Van Tuinen, P.D. Fraser, A. Manfredonia, R. Newman, D. Burgess, D.A. Brummell, S.R. King, J. Palys, J. Uhlig, P.M. Bramley, H.M.J. Pennings, C. Bowler, Fruit-specific RNAi-mediated suppression of DET1 enhances carotenoid and flavonoid content in tomatoes, Nat. Biotechnol. 23 (7) (2005) 890–895, https://doi.org/10.1038/nbt1108.
[99] R. Niggeweg, A.J. Michael, C. Martin, Engineering plants with increased levels of the antioxidant chlorogenic acid, Nat. Biotechnol. 22 (6) (2004) 746–754, https://doi.org/10.1038/nbt966.
[100] S. Ogita, H. Uefuji, M. Morimoto, H. Sano, Application of RNAi to confirm theobromine as the major intermediate for caffeine biosynthesis in coffee plants with potential for construction of decaffeinated varieties, Plant Mol. Biol. 54 (6) (2004) 931–941, https://doi.org/10.1007/s11103-004-0393-x.

[101] M. Kusaba, K. Miyahara, S. Iida, H. Fukuoka, T. Takano, H. Sassa, M. Nishimura, T. Nishio, Low glutelin content 1: a dominant mutation that suppresses the glutelin multigene family via RNA silencing in rice, Plant Cell 15 (6) (2003) 1455–1467, https://doi.org/10.1105/tpc.011452.

[102] A. Regina, A. Bird, D. Topping, S. Bowden, J. Freeman, T. Barsby, B. Kosar-Hashemi, Z. Li, S. Rahman, M. Morell, High-amylose wheat generated by RNA interference improves indices of large-bowel health in rats, Proc. Natl. Acad. Sci. U. S. A. 103 (10) (2006) 3546–3551, https://doi.org/10.1073/pnas.0510737103.

[103] C.C. Eady, T. Kamoi, M. Kato, N.G. Porter, S. Davis, M. Shaw, A. Kamoi, S. Imai, Silencing onion lachrymatory factor synthase causes a significant change in the sulfur secondary metabolite profile, Plant Physiol. 147 (4) (2008) 2096–2106, https://doi.org/10.1104/pp.108.123273.

[104] R. Katoch, N. Thakur, Advances in RNA interference technology and its impact on nutritional improvement, disease and insect control in plants, Appl. Biochem. Biotechnol. 169 (5) (2013) 1579–1605, https://doi.org/10.1007/s12010-012-0046-5.

[105] H. Lage, Potential applications of RNA interference technology in the treatment of cancer, Future Oncol. 1 (1) (2005) 103–113, https://doi.org/10.1517/14796694.1.1.103.

[106] J.J. Donnelly, J.B. Ulmer, J.W. Shiver, M.A. Liu, DNA vaccines, Annu. Rev. Immunol. 15 (1997) 617–648, https://doi.org/10.1146/annurev.immunol.15.1.617.

[107] S. Sasaki, K. Sumino, K. Hamajima, J. Fukushima, N. Ishii, S. Kawamoto, H. Mohri, C.R. Kensil, K. Okuda, Induction of systemic and mucosal immune responses to human immunodeficiency virus type 1 by a DNA vaccine formulated with QS-21 saponin adjuvant via intramuscular and intranasal routes, J. Virol. 72 (6) (1998) 4931–4939, https://doi.org/10.1128/jvi.72.6.4931-4939.1998.

[108] N.B. Ray, L.C. Ewalt, D.L. Lodmell, Nanogram quantities of plasmid DNA encoding the rabies virus glycoprotein protect mice against lethal rabies virus infection, Vaccine 15 (8) (1997) 892–895, https://doi.org/10.1016/S0264-410X(96)00281-2.

[109] S. Sasaki, T. Tsuji, K. Hamajima, J. Fukushima, N. Ishii, T. Kaneko, K.E.Q. Xin, H. Mohri, I. Aoki, T. Okubo, K. Nishioka, K. Okuda, Monophosphoryl lipid A enhances both humoral and cell- mediated immune responses to DNA vaccination against human immunodeficiency virus type 1, Infect. Immun. 65 (9) (1997) 3520–3528, https://doi.org/10.1128/iai.65.9.3520-3528.1997.

[110] A.M. Krieg, A.K. Yi, S. Matson, T.J. Waldschmidt, G.A. Bishop, R. Teasdale, G.A. Koretzky, D.M. Klinman, CpG motifs in bacterial DNA trigger direct B-cell activation, Nature 374 (6522) (1995) 546–549, https://doi.org/10.1038/374546a0.

[111] G.J. Weiner, H.M. Liu, J.E. Wooldridge, C.E. Dahle, A.M. Krieg, Imimmostimulatory oligodeoxynucleotides containing the CpG motif are effective as immune adjuvants in tumor antigen immunization, Proc. Natl. Acad. Sci. U. S. A. 94 (20) (1997) 10833–10837, https://doi.org/10.1073/pnas.94.20.10833.

[112] C. Tuerk, L. Gold, Systematic evolution of ligands by exponential enrichment: RNA ligands to bacteriophage T4 DNA polymerase, Science 249 (4968) (1990) 505–510, https://doi.org/10.1126/science.2200121.

[113] A.D. Ellington, J.W. Szostak, In vitro selection of RNA molecules that bind specific ligands, Nature 346 (6287) (1990) 818–822, https://doi.org/10.1038/346818a0.

[114] Y. Yarden, M.X. Sliwkowski, Untangling the ErbB signalling network, Nat. Rev. Mol. Cell Biol. 2 (2) (2001) 127–137, https://doi.org/10.1038/35052073.

[115] J.J. Li, X. Fang, S.M. Schuster, W. Tan, Molecular beacons: a novel approach to detect protein—DNA interactions, Angew. Chem. Int. Ed. 39 (6) (2000) 1049–1052, https://doi.org/10.1002/(sici)1521-3773(20000317)39:6<1049::aid-anie1049>3.0.co;2-2.

[116] O.C. Farokhzad, J. Cheng, B.A. Teply, I. Sherifi, S. Jon, P.W. Kantoff, J.P. Richie, R. Langer, Targeted nanoparticle-aptamer bioconjugates for cancer chemotherapy in vivo, Proc. Natl. Acad. Sci. U. S. A. 103 (16) (2006) 6315–6320, https://doi.org/10.1073/pnas.0601755103.

[117] E.K. Lim, B. Kim, Y. Choi, Y. Ro, E.J. Cho, J.H. Lee, S.H. Ryu, J.S. Suh, S. Haam, Y.M. Huh, Aptamer-conjugated magnetic nanoparticles enable efficient targeted detection of integrin αvβ3 via magnetic resonance imaging, J. Biomed. Mater. Res. A 102 (1) (2014) 49–59, https://doi.org/10.1002/jbm.a.34678.

[118] L. Tang, X. Yang, L.W. Dobrucki, I. Chaudhury, Q. Yin, C. Yao, S. Lezmi, W.G. Helferich, T.M. Fan, J. Cheng, Aptamer-functionalized, ultra-small, monodisperse silica nanoconjugates for targeted dual-modal imaging of lymph nodes with metastatic tumors, Angew. Chem. Int. Ed. 51 (51) (2012) 12721–12726, https://doi.org/10.1002/anie.201205271.

[119] C. Zhang, X. Ji, Y. Zhang, G. Zhou, X. Ke, H. Wang, P. Tinnefeld, Z. He, One-pot synthesized aptamer-functionalized CdTe:Zn2+ quantum dots for tumor-targeted fluorescence imaging in vitro and in vivo, Anal. Chem. 85 (12) (2013) 5843–5849, https://doi.org/10.1021/ac400606e.

[120] O.C. Farokhzad, S. Jon, A. Khademhosseini, T.N.T. Tran, D.A. LaVan, R. Langer, Nanoparticle-aptamer bioconjugates: a new approach for targeting prostate cancer cells, Cancer Res. 64 (21) (2004) 7668–7672, https://doi.org/10.1158/0008-5472.CAN-04-2550.

[121] J.G. Bruno, Predicting the uncertain future of aptamer-based diagnostics and therapeutics, Molecules 20 (4) (2015) 6866–6887, https://doi.org/10.3390/molecules20046866.

[122] E.S. Gragoudas, A.P. Adamis, E.T. Cunningham, M. Feinsod, D.R. Guyer, Pegaptanib for neovascular age-related macular degeneration, N. Engl. J. Med. 351 (27) (2004) 2805–2816, https://doi.org/10.1056/NEJMoa042760.

[123] S. Desmond-Hellmann, Toward precision medicine: a new social contract? Sci. Transl. Med. 4 (129) (2012), https://doi.org/10.1126/scitranslmed.3003473.

[124] P. Vlieghe, V. Lisowski, J. Martinez, M. Khrestchatisky, Synthetic therapeutic peptides: science and market, Drug Discov. Today 15 (1–2) (2010) 40–56, https://doi.org/10.1016/j.drudis.2009.10.009.

[125] I. Schomburg, A. Chang, S. Placzek, C. Söhngen, M. Rother, M. Lang, C. Munaretto, S. Ulas, M. Stelzer, A. Grote, M. Scheer, D. Schomburg, BRENDA in 2013: integrated reactions, kinetic data, enzyme function data, improved disease classification: new options and contents in BRENDA, Nucleic Acids Res. 41 (1) (2013) D764–D772, https://doi.org/10.1093/nar/gks1049.

[126] P.S. Nigam, Microbial enzymes with special characteristics for biotechnological applications, Biomol. Ther. 3 (3) (2013) 597–611, https://doi.org/10.3390/biom3030597.
[127] K. Hult, P. Berglund, Engineered enzymes for improved organic synthesis, Curr. Opin. Biotechnol. 14 (4) (2003) 395–400, https://doi.org/10.1016/S0958-1669(03)00095-8.
[128] V. Renugopalakrishnan, R. Garduño-Juárez, G. Narasimhan, G.S. Verma, X. Wei, P. Li, Rational design of thermally stable proteins: relevance to bionanotechnology, J. Nanosci. Nanotechnol. 5 (11) (2005) 1759–1767, https://doi.org/10.1166/jnn.2005.441.
[129] N.T. Khan, Enzyme technology—an emerging trend in biotechnology, Enzym. Eng. (2018), https://doi.org/10.4172/2329-6674.1000163.
[130] C. Dulieu, M. Moll, J. Boudrant, D. Poncelet, Improved performances and control of beer fermentation using encapsulated α-acetolactate decarboxylase and modeling, Biotechnol. Prog. 16 (6) (2000) 958–965, https://doi.org/10.1021/bp000128k.
[131] M. Shimizu, T. Masuike, H. Fujita, K. Kimura, R. Okachi, T. Nara, Search for microorganisms producing cephalosporin acylase and enzymatic synthesis of cephalosporins, Agric. Biol. Chem. 39 (6) (1975) 1225–1232, https://doi.org/10.1080/00021369.1975.10861758.
[132] R. Riffaldi, R. Levi-Minzi, R. Cardelli, S. Palumbo, A. Saviozzi, Soil biological activities in monitoring the bioremediation of diesel oil-contaminated soil, Water Air Soil Pollut. 170 (1–4) (2006) 3–15, https://doi.org/10.1007/s11270-006-6328-1.
[133] C.S. Karigar, S.S. Rao, Role of microbial enzymes in the bioremediation of pollutants: a review, Enzyme Res. 2011 (1) (2011), https://doi.org/10.4061/2011/805187.
[134] R. Houba, D.J.J. Heederik, G. Doekes, P.E.M. Van Run, Exposure-sensitization relationship for α-amylase allergens in the baking industry, Am. J. Respir. Crit. Care Med. 154 (1) (1996) 130–136, https://doi.org/10.1164/ajrccm.154.1.8680668.
[135] S. Uzuner, D. Cekmecelioglu, Enzymes in the Beverage Industry, Elsevier BV, 2019, pp. 29–43, https://doi.org/10.1016/b978-0-12-813280-7.00003-7.
[136] N. Rana, A. Walia, A. Gaur, α-Amylases from microbial sources and its potential applications in various industries, Natl. Acad. Sci. Lett. 36 (1) (2013) 9–17, https://doi.org/10.1007/s40009-012-0104-0.
[137] A. Dura, W. Błaszczak, C.M. Rosell, Functionality of porous starch obtained by amylase or amyloglucosidase treatments, Carbohydr. Polym. 101 (1) (2014) 837–845, https://doi.org/10.1016/j.carbpol.2013.10.013.
[138] K. Mojsov, D. Andronikov, A. Janevski, S. Jordeva, M. Kertakova, S. Golomeova, S. Gaber, I. Ignjatov, Production and application of α-amylase enzyme in textile industry, Tekst. Ind. 66 (2018) 23–28.
[139] J.J.M. Cachumba, F.A.F. Antunes, G.F.D. Peres, L.P. Brumano, J.C.D. Santos, S.S. Da Silva, Current applications and different approaches for microbial L-asparaginase production, Braz. J. Microbiol. 47 (2016) 77–85, https://doi.org/10.1016/j.bjm.2016.10.004.
[140] D. Zhang, G. Du, J. Chen, Fermentation production of microbial catalase and its application in textile industry, Chin. J. Biotechnol. 26 (11) (2010).
[141] E. Hardiman, M. Gibbs, R. Reeves, P. Bergquist, Directed evolution of a thermophilic β-glucosidase for cellulosic bioethanol production, Appl. Biochem. Biotechnol. 161 (1–8) (2010) 301–312, https://doi.org/10.1007/s12010-009-8794-6.
[142] X. Chunling, X.V. Changxin, Application study on microbial cellulose, Wei Sheng Wu Xue Za Zhi 22 (2) (2002) 33–35.
[143] S. Singh, V.K. Singh, M. Aamir, M.K. Dubey, J.S. Patel, R.S. Upadhyay, V.K. Gupta, Cellulase in Pulp and Paper Industry, Elsevier BV, 2016, pp. 152–162, https://doi.org/10.1016/b978-0-444-63507-5.00013-7.
[144] A. Dura, C.M. Rosell, Physico-chemical properties of corn starch modified with cyclodextrin glycosyltransferase, Int. J. Biol. Macromol. 87 (2016) 466–472, https://doi.org/10.1016/j.ijbiomac.2016.03.012.
[145] D.Z. Hou, S.X. Huang, S. Chen, Biosynthesis of oligodextrans through synergistic catalysis of dextransucrase and dextranase in a recycle membrane bioreactor, Sugar Tech 20 (5) (2018) 566–573, https://doi.org/10.1007/s12355-018-0629-8.
[146] S.H. Bhosale, M.B. Rao, V.V. Deshpande, Molecular and industrial aspects of glucose isomerase, Microbiol. Rev. 60 (2) (1996) 280–300, https://doi.org/10.1128/mr.60.2.280-300.1996.
[147] V. Vemulapalli, K.A. Miller, R.C. Hoseney, Glucose oxidase in breadmaking systems, Cereal Chem. 75 (4) (1998) 439–442, https://doi.org/10.1094/CCHEM.1998.75.4.439.
[148] G. Lang, J. Cotteret, Composition for the Oxidation Dyeing of Keratinous Fibres Containing a Laccase and Dyeing Method Using This Composition, 2004. US2004255401 A1.
[149] S.R. Couto, J.L. Toca-Herrera, Lacasses in the Textile Industry, Vol. 1, 2006, pp. 115–120, https://doi.org/10.5897/BMBR.9000006.
[150] P. Upadhyay, R. Shrivastava, P.K. Agrawal, Bioprospecting and biotechnological applications of fungal laccase. *3*, Biotech 6 (1) (2016) 1–12, https://doi.org/10.1007/s13205-015-0316-3.
[151] K.J. Grace, H. Yuiry, L. Kim, Production technology of lactase and its application in food industry application, J. Sci. Food Agric. 1 (2017) 4–6.
[152] K. Piontek, A.T. Smith, W. Blodig, Lignin peroxidase structure and function, Biochem. Soc. Trans. 29 (2) (2001) 111–116, https://doi.org/10.1042/bst0290111.
[153] C. Diehl, Skin Treatment Preparation, Crawford Healthcare Limited, 2008. Patent No. US7468195.
[154] R. Margesin, A. Zimmerbauer, F. Schinner, Soil lipase activity—a useful indicator of oil biodegradation, Biotechnol. Tech. 13 (12) (1999) 859–863, https://doi.org/10.1023/A:1008928308695.
[155] D. Guerrand, Lipases industrial applications: focus on food and agroindustries, OCL 24 (4) (2017) D403, https://doi.org/10.1051/ocl/2017031.
[156] R.V. Muralidhar, R.R. Chirumamilla, R. Marchant, V.N. Ramachandran, O.P. Ward, P. Nigam, Understanding lipase stereoselectivity, World J. Microbiol. Biotechnol. 18 (2) (2002) 81–97, https://doi.org/10.1023/A:1014417223956.
[157] J.G. Yang, Y.H. Wang, B. Yang, G. Mainda, Y. Guo, Degumming of vegetable oil by a new microbial lipase, Food Technol. Biotechnol. 44 (1) (2006) 101–104. http://public.carnet.hr/ftbrfd/44-101.pdf.
[158] R. Aravindan, P. Anbumathi, T. Viruthagiri, Lipase applications in food industry, Indian J. Biotechnol. 6 (2) (2007) 141–158.

[159] D.M. Abol Fotouh, R.A. Bayoumi, M.A. Hassan, Production of thermoalkaliphilic lipase from *Geobacillus thermoleovorans* DA2 and application in leather industry, Enzyme Res. 2016 (2016), https://doi.org/10.1155/2016/9034364.
[160] L. zu yi, O.P. Ward, Synthesis of monoglyceride containing omega-3 fatty acids by microbial lipase in organic solvent, J. Ind. Microbiol. 13 (1) (1994) 49–52, https://doi.org/10.1007/BF01569662.
[161] P. Bajpai, Application of enzymes in the pulp and paper industry, Biotechnol. Prog. 15 (2) (1999) 147–157, https://doi.org/10.1021/bp990013k.
[162] G. Bahal, M.L. Sudha, P.R. Ramasarma, Wheat germ lipoxygenase: its effect on dough rheology, microstructure, and bread making quality, Int. J. Food Prop. 16 (8) (2013) 1730–1739, https://doi.org/10.1080/10942912.2011.607932.
[163] W. Hailei, L. Ping, P. Min, Z. Zhijun, Y. Guangli, L. Guosheng, Y. Jianming, Rapid decolourization of azo dyes by a new isolated higher manganese peroxidase producer: Phanerochaete sp. HSD, Biochem. Eng. J. 46 (3) (2009) 327–333, https://doi.org/10.1016/j.bej.2009.06.008.
[164] M. McCoy, Soaps & detergents, Chem. Eng. News Arch. 79 (3) (2001) 19–32, https://doi.org/10.1021/cen-v079n003.p019.
[165] J.S. Gong, J.S. Shi, Z.M. Lu, H. Li, Z.M. Zhou, Z.H. Xu, Nitrile-converting enzymes as a tool to improve biocatalysis in organic synthesis: recent insights and promises, Crit. Rev. Biotechnol. 37 (1) (2017) 69–81, https://doi.org/10.3109/07388551.2015.1120704.
[166] P.K. Arora, M. Kumar, A. Chauhan, G.P. Raghava, R.K. Jain, OxDBase: a database of oxygenases involved in biodegradation, BMC Res. Notes 2 (2009), https://doi.org/10.1186/1756-0500-2-67.
[167] S.R. Chiliveri, V.R. Linga, A novel thermostable, alkaline pectate lyase from *Bacillus tequilensis* SV11 with potential in textile industry, Carbohydr. Polym. 111 (2014) 264–272, https://doi.org/10.1016/j.carbpol.2014.04.065.
[168] A. Nighojkar, M.K. Patidar, S. Nighojkar, Pectinases: production and applications for fruit juice beverages, in: Processing and Sustainability of Beverages, Elsevier BV, 2019, pp. 235–273, https://doi.org/10.1016/b978-0-12-815259-1.00008-2.
[169] N. Sharma, M. Rathore, M. Sharma, Microbial pectinase: sources, characterization and applications, Rev. Environ. Sci. Biotechnol. 12 (1) (2013) 45–60, https://doi.org/10.1007/s11157-012-9276-9.
[170] H. Marešová, M. Plačková, M. Grulich, P. Kyslík, Current state and perspectives of penicillin G acylase-based biocatalyses, Appl. Microbiol. Biotechnol. 98 (7) (2014) 2867–2879, https://doi.org/10.1007/s00253-013-5492-7.
[171] F. Valle, P. Balbás, E. Merino, F. Bollvar, The role of penicillin amidases in nature and in industry, Trends Biochem. Sci. 16 (C) (1991) 36–40, https://doi.org/10.1016/0968-0004(91)90014-m.
[172] S.M.A.G. Ulson de Souza, E. Forgiarini, A.A. Ulson de Souza, Toxicity of textile dyes and their degradation by the enzyme horseradish peroxidase (HRP), J. Hazard. Mater. 147 (3) (2007) 1073–1078, https://doi.org/10.1016/j.jhazmat.2007.06.003.
[173] S. Cerminati, L. Paoletti, A. Aguirre, S. Peirú, H.G. Menzella, M.E. Castelli, Industrial uses of phospholipases: current state and future applications, Appl. Microbiol. Biotechnol. 103 (6) (2019) 2571–2582, https://doi.org/10.1007/s00253-019-09658-6.
[174] K. Clausen, Enzymatic oil-degumming by a novel microbial phospholipase, Eur. J. Lipid Sci. Technol. 103 (6) (2001) 333–340, https://doi.org/10.1002/1438-9312(200106)103:6<333::AID-EJLT333>3.0.CO;2-F.
[175] X.G. Lei, C.H. Stahl, Nutritional benefits of phytase and dietary determinants of its efficacy, J. Appl. Anim. Res. 17 (1) (2000) 97–112, https://doi.org/10.1080/09712119.2000.9706294.
[176] S.L. Hii, J.S. Tan, T.C. Ling, A.B. Ariff, Pullulanase: role in starch hydrolysis and potential industrial applications, Enzyme Res. 2012 (2012), https://doi.org/10.1155/2012/921362.
[177] J. Elms, E. Robinson, H. Mason, S. Iqbal, A. Garrod, G.S. Evans, Enzyme exposure in the British baking industry, Ann. Occup. Hyg. 50 (4) (2006) 379–384, https://doi.org/10.1093/annhyg/mei080.
[178] S.A. Cho, J.C. Cho, S.H. Han, Cosmetic Composition Containing Enzyme and Amino Acid, Amorepacific Corporation, 2007.
[179] D.B. Steele, M.J. Fiske, B.P. Steele, V.C. Kelley, Production of a low-molecular-weight, alkaline-active, thermostable protease by a novel, spiral-shaped bacterium, *Kurthia spiroforme*, sp. nov, Enzym. Microb. Technol. 14 (5) (1992) 358–360, https://doi.org/10.1016/0141-0229(92)90003-7.
[180] C. Arunachalam, Protease enzyme: an eco-friendly alternative for leather industry, Indian J. Sci. Technol. 2 (12) (2009) 29–32, https://doi.org/10.17485/ijst/2009/v2i12.10.
[181] Pathak, Kaur, N.K. Bhardwaj, Microbial Enzymes for Pulp and Paper Industry: Prospects and Developments, 2016, pp. 177–254.
[182] R.M. Banik, M. Prakash, Laundry detergent compatibility of the alkaline protease from Bacillus cereus, Microbiol. Res. 159 (2) (2004) 135–140, https://doi.org/10.1016/j.micres.2004.01.002.
[183] N.G. Seidah, Proprotein convertase subtilisin kexin 9 (PCSK9) inhibitors in the treatment of hypercholesterolemia and other pathologies, Curr. Pharm. Des. 19 (17) (2013) 3161–3172, https://doi.org/10.2174/1381612811319999031 3.
[184] M.A. Babizhayev, Biological activities of the natural imidazole-containing peptidomimetics n-acetylcarnosine, carcinine and L-carnosine in ophthalmic and skin care products, Life Sci. 78 (20) (2006) 2343–2357, https://doi.org/10.1016/j.lfs.2005.09.054.
[185] P.R. Amante, C.A. Fante, R.L. Pires, Use of transglutaminase in bakery products, J. Culin. Sci. Technol. 18 (6) (2020) 549–559, https://doi.org/10.1080/15428052.2019.1681045.
[186] M. Kieliszek, A. Misiewicz, Microbial transglutaminase and its application in the food industry. A review, Folia Microbiol. 59 (3) (2014) 241–250, https://doi.org/10.1007/s12223-013-0287-x.
[187] T. Cosson, A.M. Pérez Vendrell, B. González Teresa, D. Reñé, P. Taillade, J. Brufau, Enzymatic assays for xylanase and β-glucanase feed enzymes, Anim. Feed Sci. Technol. 77 (3–4) (1999) 345–353, https://doi.org/10.1016/S0377-8401(98)00248-X.
[188] Y. Du, P. Shi, H. Huang, X. Zhang, H. Luo, Y. Wang, B. Yao, Characterization of three novel thermophilic xylanases from *Humicola insolens* Y1 with application potentials in the brewing industry, Bioresour. Technol. 130 (2013) 161–167, https://doi.org/10.1016/j.biortech.2012.12.067.
[189] M.S. Butt, M. Tahir-Nadeem, Z. Ahmad, M.T. Sultan, Xylanases and their applications in baking industry, Food Technol. Biotechnol. 46 (1) (2008) 22–31. http://www.ftb.com.hr/46-22.pdf.

[190] M.C. Srinivasan, M.V. Rele, Microbial xylanases for paper industry, Curr. Sci. 77 (1) (1999) 137–142.
[191] G.A. Walsh, R.A. Murphy, G.F. Killeen, D.R. Headon, R.F. Power, Technical note: detection and quantification of supplemental fungal beta-glucanase activity in animal feed, J. Anim. Sci. 73 (4) (1995) 1074–1076, https://doi.org/10.2527/1995.7341074x.
[192] H. Kaur, P.K. Gill, Microbial Enzymes in Food and Beverages Processing, Elsevier BV, 2019, pp. 255–282, https://doi.org/10.1016/b978-0-12-815258-4.00009-3.
[193] A. Gironés-Vilaplana, D. Villanõ, J. Marhuenda, D.A. Moreno, C. Garciá-Viguera, Vitamins, in: Nutraceutical and Functional Food Components: Effects of Innovative Processing Techniques, Elsevier Inc., 2017, pp. 159–201, https://doi.org/10.1016/B978-0-12-805257-0.00006-5.
[194] K.M. Fairfield, R.H. Fletcher, Vitamins for chronic disease prevention in adults: scientific review, J. Am. Med. Assoc. 287 (23) (2002) 3116–3126, https://doi.org/10.1001/jama.287.23.3116.
[195] M. Varvara, G. Bozzo, G. Celano, C. Disanto, C.N. Pagliarone, G.V. Celano, The use of ascorbic acid as a food additive: technical-legal issues, Ital. J. Food Saf. 5 (1) (2016) 7–10, https://doi.org/10.4081/ijfs.2016.4313.
[196] G.F. Combs, Sources of the vitamins, in: The vitamins, Elsevier BV, 2012, pp. 437–464, https://doi.org/10.1016/b978-0-12-381980-2.00019-0.
[197] T. Murashige, F. Skoog, A revised medium for rapid growth and bio assays with tobacco tissue cultures, Physiol. Plant. 15 (3) (1962) 473–497, https://doi.org/10.1111/j.1399-3054.1962.tb08052.x.
[198] M.P. Lupo, Antioxidants and vitamins in cosmetics, Clin. Dermatol. 19 (4) (2001) 467–473, https://doi.org/10.1016/S0738-081X(01)00188-2.
[199] C.T. Hou, Biotechnology for fats and oils: new oxygenated fatty acids, New Biotechnol. 26 (1–2) (2009) 2–10, https://doi.org/10.1016/j.nbt.2009.05.001.
[200] R. Paliwal, S.R. Paliwal, R. Kenwat, B.D. Kurmi, M.K. Sahu, Solid lipid nanoparticles: a review on recent perspectives and patents, Expert Opin. Ther. Pat. 30 (3) (2020) 179–194, https://doi.org/10.1080/13543776.2020.1720649.
[201] R. Anjum, P.K. Lakshmi, A review on solid lipid nanoparticles; focus on excipients and formulation techniques, Int. J. Pharm. Sci. Res. 10 (9) (2019) 4090–4099, https://doi.org/10.13040/IJPSR.0975-8232.10.
[202] V. Mishra, K.K. Bansal, A. Verma, N. Yadav, S. Thakur, K. Sudhakar, J.M. Rosenholm, Solid lipid nanoparticles: emerging colloidal nano drug delivery systems, Pharmaceutics 10 (4) (2018), https://doi.org/10.3390/pharmaceutics10040191.
[203] A. Garud, D. Singh, N. Garud, Solid lipid nanoparticles (SLN): method, characterization and applications, Int. Curr. Pharm. J. (2012) 384–393, https://doi.org/10.3329/icpj.v1i11.12065.
[204] V.J. Lingayat, N.S. Zarekar, R.S. Shendge, Solid lipid nanoparticles: a review, Nanosci. Nanotechnol. Res. 4 (2) (2017) 67–72, https://doi.org/10.12691/nnr-4-2-5.
[205] J.S. Mulla, I.M. Khazi, V.G. Jamakandi, Solid Lipid Nanoparticles: Potential Applications, 2010, pp. 82–87.
[206] D. Alukda, T. Sturgis, B.B.C. Youan, Formulation of tenofovir-loaded functionalized solid lipid nanoparticles intended for HIV prevention, J. Pharm. Sci. 100 (8) (2011) 3345–3356, https://doi.org/10.1002/jps.22529.
[207] M.J. Ansari, M.K. Anwer, S. Jamil, R. Al-Shdefat, B.E. Ali, M.M. Ahmad, M.N. Ansari, Enhanced oral bioavailability of insulin-loaded solid lipid nanoparticles: pharmacokinetic bioavailability of insulin-loaded solid lipid nanoparticles in diabetic rats, Drug Deliv. 23 (6) (2016) 1972–1979, https://doi.org/10.3109/10717544.2015.1039666.
[208] V.T. Arantes, A.A.G. Faraco, F.B. Ferreira, C.A. Oliveira, E. Martins-Santos, P. Cassini-Vieira, L.S. Barcelos, L.A.M. Ferreira, G.A.C. Goulart, Retinoic acid-loaded solid lipid nanoparticles surrounded by chitosan film support diabetic wound healing in in vivo study, Colloids Surf. B: Biointerfaces 188 (2020), https://doi.org/10.1016/j.colsurfb.2019.110749.
[209] M.R. Bhalekar, A.R. Madgulkar, P.S. Desale, G. Marium, Formulation of piperine solid lipid nanoparticles (SLN) for treatment of rheumatoid arthritis, Drug Dev. Ind. Pharm. 43 (6) (2017) 1003–1010, https://doi.org/10.1080/03639045.2017.1291666.
[210] C. Carbone, V. Fuochi, A. Zielińska, T. Musumeci, E.B. Souto, A. Bonaccorso, C. Puglia, G. Petronio Petronio, P.M. Furneri, Dual-drugs delivery in solid lipid nanoparticles for the treatment of *Candida albicans* mycosis, Colloids Surf. B: Biointerfaces 186 (2020) 110705, https://doi.org/10.1016/j.colsurfb.2019.110705.
[211] N.V. Chokshi, H.N. Khatri, M.M. Patel, Formulation, optimization, and characterization of rifampicin-loaded solid lipid nanoparticles for the treatment of tuberculosis, Drug Dev. Ind. Pharm. 44 (12) (2018) 1975–1989, https://doi.org/10.1080/03639045.2018.1506472.
[212] M.C.O. Da Rocha, P.B. Da Silva, M.A. Radicchi, B.Y.G. Andrade, J.V. De Oliveira, T. Venus, C. Merker, I. Estrela-Lopis, J.P.F. Longo, S.N. Bão, Docetaxel-loaded solid lipid nanoparticles prevent tumor growth and lung metastasis of 4T1 murine mammary carcinoma cells, J. Nanobiotechnol. 18 (1) (2020), https://doi.org/10.1186/s12951-020-00604-7.
[213] S. El-Housiny, M.A.S. Eldeen, Y.A. El-Attar, H.A. Salem, D. Attia, E.R. Bendas, M.A. El-Nabarawi, Fluconazole-loaded solid lipid nanoparticles topical gel for treatment of pityriasis versicolor: formulation and clinical study, Drug Deliv. 25 (1) (2018) 78–90, https://doi.org/10.1080/10717544.2017.1413444.
[214] F. Javan, A. Vatanara, K. Azadmanesh, M. Nabi-Meibodi, M. Shakouri, Encapsulation of ritonavir in solid lipid nanoparticles: in-vitro anti-HIV-1 activity using lentiviral particles, J. Pharm. Pharmacol. 69 (8) (2017) 1002–1009, https://doi.org/10.1111/jphp.12737.
[215] P.G. Kakadia, B.R. Conway, Solid lipid nanoparticles for targeted delivery of triclosan into skin for infection prevention, J. Microencapsul. 35 (7–8) (2018) 695–704, https://doi.org/10.1080/02652048.2019.1576796.
[216] R.M. Kaoud, M.I. Afouna, A.M. Samy, A, A., Kassem, glimepiride -solid lipid nanoparticles as a tool to control blood glucose level in diabetic patients, part 2: effect of storage, stability study and anti-diabetic effect, J. Life Med. 4 (1) (2016) 1–15.
[217] S. Küchler, N.B. Wolf, S. Heilmann, G. Weindl, J. Helfmann, M.M. Yahya, C. Stein, M. Schäfer-Korting, 3D-wound healing model: influence of morphine and solid lipid nanoparticles, J. Biotechnol. 148 (1) (2010) 24–30, https://doi.org/10.1016/j.jbiotec.2010.01.001.

[218] S. Liu, X. Han, H. Liu, Y. Zhao, H. Li, I.D. Rupenthal, Z. Lv, Y. Chen, F. Yang, Q. Ping, Y. Pan, D. Hou, Incorporation of ion exchange functionalized-montmorillonite into solid lipid nanoparticles with low irritation enhances drug bioavailability for glaucoma treatment, Drug Deliv. 27 (1) (2020) 652–661, https://doi.org/10.1080/10717544.2020.1756984.

[219] J.A. Loureiro, S. Andrade, A. Duarte, A.R. Neves, J.F. Queiroz, C. Nunes, E. Sevin, L. Fenart, F. Gosselet, M.A.N. Coelho, M.C. Pereira, N. Latruffe, Resveratrol and grape extract-loaded solid lipid nanoparticles for the treatment of Alzheimer's disease, Molecules 22 (2) (2017), https://doi.org/10.3390/molecules22020277.

[220] J.O. Muga, J.W. Gathirwa, M. Tukulula, W.G.Z.O. Jura, In vitro evaluation of chloroquine-loaded and heparin surface-functionalized solid lipid nanoparticles, Malar. J. 17 (1) (2018), https://doi.org/10.1186/s12936-018-2302-9.

[221] E. Nemati, A. Mokhtarzadeh, V. Panahi-Azar, A. Mohammadi, H. Hamishehkar, M. Mesgari-Abbasi, J. Ezzati Nazhad Dolatabadi, M. de la Guardia, Ethambutol-loaded solid lipid nanoparticles as dry powder inhalable formulation for tuberculosis therapy, AAPS PharmSciTech 20 (3) (2019), https://doi.org/10.1208/s12249-019-1334-y.

[222] W.N. Omwoyo, P. Melariri, J.W. Gathirwa, F. Oloo, G.M. Mahanga, L. Kalombo, B. Ogutu, H. Swai, Development, characterization and antimalarial efficacy of dihydroartemisinin loaded solid lipid nanoparticles, Nanomedicine 12 (3) (2016) 801–809, https://doi.org/10.1016/j.nano.2015.11.017.

[223] T. Smith, K. Affram, E.L. Nottingham, B. Han, F. Amissah, S. Krishnan, J. Trevino, E. Agyare, Application of smart solid lipid nanoparticles to enhance the efficacy of 5-fluorouracil in the treatment of colorectal cancer, Sci. Rep. 10 (1) (2020), https://doi.org/10.1038/s41598-020-73218-6.

[224] M.A. Vakilinezhad, A. Amini, H. Akbari Javar, B.F. Baha'addini Beigi Zarandi, H. Montaseri, R. Dinarvand, Nicotinamide loaded functionalized solid lipid nanoparticles improves cognition in Alzheimer's disease animal model by reducing Tau hyperphosphorylation, Daru 26 (2) (2018) 165–177, https://doi.org/10.1007/s40199-018-0221-5.

[225] M. Zhou, J. Hou, Z. Zhong, N. Hao, Y. Lin, C. Li, Targeted delivery of hyaluronic acid-coated solid lipid nanoparticles for rheumatoid arthritis therapy, Drug Deliv. 25 (1) (2018) 716–722, https://doi.org/10.1080/10717544.2018.1447050.

[226] X.J. Ji, R. Ledesma-Amaro, Microbial lipid biotechnology to produce polyunsaturated fatty acids, Trends Biotechnol. 38 (8) (2020) 832–834, https://doi.org/10.1016/j.tibtech.2020.02.003.

[227] C. Ratledge, Single cell oils for the 21st century, in: Single Cell Oils: Microbial and Algal Oils: Second Edition, Elsevier Inc., 2010, pp. 3–26, https://doi.org/10.1016/B978-1-893997-73-8.50005-0.

[228] M. Madani, M. Enshaeieh, A. Abdoli, Single cell oil and its application for biodiesel production, Process. Saf. Environ. Prot. 111 (2017) 747–756, https://doi.org/10.1016/j.psep.2017.08.027.

[229] N. Fidler, B. Koletzko, U.T. Sauerwald, Sauerwald Single Cell Oils Production and Application, vol. 74, 1999, pp. 37–45.

[230] Y. Nazir, H. Halim, P. Prabhakaran, A.A. Hamid, Y. Song, Microalgae Single Cell Oil, Elsevier BV, 2020, pp. 419–444, https://doi.org/10.1016/b978-0-12-818536-0.00016-6.

[231] M.K. Rajput, A. Kumar, A. Yadav, D. Paliwal, T. Sharma, Influx of recombinant insulin and its analogues for management of diabetes in India, Int. J. Diabetes Dev. Ctries. 37 (3) (2017) 327–328, https://doi.org/10.1007/s13410-017-0552-7.

[232] J.R. Tata, One hundred years of hormones, EMBO Rep. 6 (6) (2005) 490–496, https://doi.org/10.1038/sj.embor.7400444.

[233] A.A. Hamid, M.B. Issa, N.N.A. Nizar, Hormones, in: Preparation and Processing of Religious and Cultural Foods, Elsevier, 2018, pp. 253–277, https://doi.org/10.1016/B978-0-08-101892-7.00013-4.

[234] G.S. Lawes, D.J. Woolley, The commercial use of plant growth regulators to regulate fruit development, in: Acta Horticulturae, vol. 553, International Society for Horticultural Science, 2001, pp. 149–150, https://doi.org/10.17660/ActaHortic.2001.553.29.

[235] H.K. Bons, M. Kaur, Role of plant growth regulators in improving fruit set, quality and yield of fruit crops: a review, J. Hortic. Sci. Biotechnol. 95 (2) (2020) 137–146, https://doi.org/10.1080/14620316.2019.1660591.

[236] A. Verma, M. Verma, A. Singh, Animal Tissue Culture Principles and Applications, Elsevier BV, 2020, pp. 269–293, https://doi.org/10.1016/b978-0-12-811710-1.00012-4.

[237] T. Yao, Y. Asayama, Animal-cell culture media: history, characteristics, and current issues, Reprod. Med. Biol. 16 (2) (2017) 99–117, https://doi.org/10.1002/rmb2.12024.

[238] T.K. Patle, K. Shrivas, R. Kurrey, S. Upadhyay, R. Jangde, R. Chauhan, Phytochemical screening and determination of phenolics and flavonoids in *Dillenia pentagyna* using UV–vis and FTIR spectroscopy, Spectrochim. Acta A Mol. Biomol. Spectrosc. (2020) 242, https://doi.org/10.1016/j.saa.2020.118717.

[239] S.S. Chauhan, P.K. Mahish, Flavonoids of the flame of forest-butea monosperma, Res. J. Pharm. Technol. 13 (11) (2020) 5647–5653, https://doi.org/10.5958/0974-360X.2020.00984.1.

[240] V. Ilkei, L. Hazai, S. Antus, H. Bölcskei, Flavonoid alkaloids: isolation, bioactivity, and synthesis, in: Studies in Natural Products Chemistry, vol. 56, Elsevier B.V., 2018, pp. 247–285, https://doi.org/10.1016/B978-0-444-64058-1.00008-X.

[241] D. Marinova, F. Ribarova, M. Atanassova, Total phenolics and total flavonoid in Bulgarian fruits and vegetables, J. Univ. Chem. Technol. Metall. 40 (2005) 255–260.

[242] K.R. Narayana, M.S. Reddy, M.R. Chaluvadi, D.R. Krishna, Bioflavonoids classification, pharmacological, biochemical effects and therapeutic potential, Indian J. Pharm. 33 (1) (2001) 2–16.

[243] M. Danihelová, J. Viskupičová, E. Šturdík, Lipophilization of flavonoids for their food, therapeutic and cosmetic applications, Acta Chim. Slov. (2012) 59–69, https://doi.org/10.2478/v10188-012-0010-6.

[244] V. Paramita, H. Kusumayanti, R. Amalia, W. Leviana, Q.A.K. Nisa', Application of flavonoid and anthocyanin contents from rambutan (*Nephelium lappaceum*) peel as natural dyes on cotton fabric, Adv. Sci. Lett. (2018) 9853–9855, https://doi.org/10.1166/asl.2018.13160.

[245] A. Villela, M.S.A. van Vuuren, H.M. Willemen, G.C.H. Derksen, T.A. van Beek, Photo-stability of a flavonoid dye in presence of aluminium ions, Dyes Pigments 162 (2019) 222–231, https://doi.org/10.1016/j.dyepig.2018.10.021.
[246] P. Chuarienthong, N. Lourith, P. Leelapornpisid, Clinical efficacy comparison of anti-wrinkle cosmetics containing herbal flavonoids, Int. J. Cosmet. Sci. 32 (2) (2010) 99–106, https://doi.org/10.1111/j.1468-2494.2010.00522.x.
[247] P.M. Lyons-Wall, S. Samman, Flavonoids-dietary perspectives and health benefits, Nutr. Soc. Aust. 21 (1997) 106–114.
[248] L.H. Yao, Y.M. Jiang, J. Shi, F.A. Tomás-Barberán, N. Datta, R. Singanusong, S.S. Chen, Flavonoids in food and their health benefits, Plant Foods Hum. Nutr. 59 (3) (2004) 113–122, https://doi.org/10.1007/s11130-004-0049-7.
[249] J. Kuhnau, The flavonoids: a class of semi-essential food components: their role in human nutrition, World Rev. Nutr. Diet. 24 (1976) 117–120.
[250] L. Zhao, X. Yuan, J. Wang, Y. Feng, F. Ji, Z. Li, J. Bian, A review on flavones targeting serine/threonine protein kinases for potential anticancer drugs, Bioorg. Med. Chem. 27 (5) (2019) 677–685, https://doi.org/10.1016/j.bmc.2019.01.027.
[251] C.M. Camero, M.P. Germanò, A. Rapisarda, V. D'Angelo, S. Amira, F. Benchikh, A. Braca, M. De Leo, Anti-angiogenic activity of iridoids from *Galium tunetanum*, Rev. Bras 28 (3) (2018) 374–377, https://doi.org/10.1016/j.bjp.2018.03.010.
[252] K. Patel, V. Kumar, M. Rahman, A. Verma, D.K. Patel, New insights into the medicinal importance, physiological functions and bioanalytical aspects of an important bioactive compound of foods 'Hyperin': health benefits of the past, the present, the future, Beni Suef Univ. J. Basic Appl. Sci. (2018) 31–42, https://doi.org/10.1016/j.bjbas.2017.05.009.
[253] K. Zhao, Y. Yuan, B. Lin, Z. Miao, Z. Li, Q. Guo, N. Lu, LW-215, a newly synthesized flavonoid, exhibits potent anti-angiogenic activity in vitro and in vivo, Gene 642 (2018) 533–541, https://doi.org/10.1016/j.gene.2017.11.065.
[254] K. Fester, Plant Alkaloids, Wiley, 2010, https://doi.org/10.1002/9780470015902.a0001914.pub2.
[255] R. Chauhan, V. Singh, A. Quraishi, In vitro conservation through slow-growth storage, in: Synthetic Seeds: Germplasm Regeneration, Preservation and Prospects, Springer International Publishing, 2019, pp. 397–416, https://doi.org/10.1007/978-3-030-24631-0_19.
[256] N.H. Oberlies, D.J. Kroll, Camptothecin and Taxol: historic achievements in natural products research, J. Nat. Prod. 67 (2) (2004) 129–135, https://doi.org/10.1021/np030498t.
[257] T. Aniszewski, Applied Potential and Current Applications of Alkaloids, Elsevier BV, 2015, pp. 345–420, https://doi.org/10.1016/b978-0-444-59433-4.00006-7.

V. Shanthi and Shubha Diwan*

Chapter 8
Application of essential oils in industries and daily usage

Abstract: In the present time, people are getting more inclined toward natural commodities be it food, health, or medicine. One of the most exploited resources for natural well-being is plants and their essential olis (EOs). EOs are volatile substances which have numerous applications by virtue of important biologically active compounds like terpenes and other oxygenated derivatives. The applicability of EOs ranges from food, textile, cosmetics to pharmaceutical industries. EOs directly or indirectly are becoming a part of daily routine ranging from its use in skin or hair care products to our food items as flavoring agents. These wide range of applications of EOs are a consequence of its diverse properties and attributes. The use of EOs in food sector is well known and validated. The antimicrobial, anti-inflammatory, antiparasitic, and analgesic properties of EOs enable them to be exploited by pharmaceutical industries. They are getting used as complementary medicine to enhance the permeability of certain drugs through skin. They are widely used even in cosmetic and textile industries for the fragrances it impart to the formulations apart from other benefits. This chapter is designed to summarize the recent advancement in the researches and applications on EOs which will facilitate stakeholders to reveal unexplored benefits of EOs.

Keywords: EOs, flavoring agent, natural preservative, medicinal applications, extraction

8.1 Introduction

Owing to the technological modernization of our society, lifestyle disorders have become the most prevailing diseases in the present era. One of the primary causes of these disorders is unhealthy food habits that include processed foods, artificial sweeteners, energy drinks, and fast foods [1]. Moreover, may it be fruits and vegetables, processed food items, cosmetic products, or household items, most of the human populations are prone to chemicals utilized in improving the quality or processing of these items. Strong consumer awareness thus has developed about augmenting natural constituents in day-to-day requirements. Consumers are more inclined toward purchase of

*Corresponding author: **V. Shanthi and Shubha Diwan,** Department of Microbiology and Biotechnology, St. Thomas College, Bhilai, Chhattisgarh, India, e-mail: shubha2315@gmail.com

https://doi.org/10.1515/9783110791600-008

products that are natural and in case of food items, minimally processed eatables are preferred. Products with "chemical free" or "natural" taglines have become trending advertising techniques by manufactures and certainly catching more attention from consumers in recent years. Essential oils (EOs) are such natural compounds that are being used since long for its associated aromas and gained significant attention due to its other remarkable biological properties.

EOs are volatile odorous liquids obtained from different parts of plants like leaves, stem, bark, flowers, buds, and seeds. They are the secondary metabolites of aromatic plants having complex mixture of bioactive compounds which impart incredible biological properties to it like antimicrobial, antioxidant, anti-inflammatory, analgesic, and insecticidal [2]. EOs are mainly composed of complex mixtures of hydrocarbons and oxygenated compounds whose composition varies in each plant species. There are a number of methods to isolate these oils from plants like cold pressing, solvent extraction, steam distillation, and hydrodistillation. However, to improvise the quality of EOs and to reduce extraction time newer technologies like microwave-assisted extraction, supercritical fluid extraction, and ultrasound-assisted extraction have been standardized in various plant species [3].

The remarkable biological properties of EOs popularize its widespread application in industries. The global EO market size was valued at USD 10.3 billion in 2021 and is expected to grow at a compound annual growth rate of 9.3% from 2021 to 2026 [4]. It is used as flavoring agent and natural preservative in food product thus offering safety and increased shelf life to it. Moreover, due to their peculiar aroma, EOs are an important part of perfume and fragrances industries and also impart pleasant fragrances to cosmetic products, cleaning products, and industrial solvents. EOs are also utilized in pharmaceutical industries and in aromatherapy due to their positive effects on human health [5]. Out of 3,000 EOs identified from different plant species, about 150 are found to be commercially important and are sold in global market [6]. Thus, the review will give an insight on the recent developments in the EOs research and their potential application in daily life and industries.

8.2 Components of essential oil

EOs are primarily secondary metabolites with a complex chemical composition. The primary metabolites; carbohydrates, proteins, lipids, and nucleic acids contribute very little to the production of EOs. However, some EOs may be considered as degradative products of lipids. Various factors contribute in influencing the chemical composition of EOs, environmental factors being the most significant.

Every EO has its own complex chemical profile which decides its odor, taste, and ultimately its applicability. All the chemical components work synergistically to make it effective as an EO. Almost all EOs are basically composed of two major

components: hydrocarbons and oxygenated compounds. Hydrocarbons constitute the most significant portion of all EOs and the most important hydrocarbon being the terpenoids which make up almost 80% of the EO composition. The other lesser significant component being oxygenated compounds.

8.2.1 Terpenes

One of the essential and important constituents of Eos are terpenes. They are made of 5-carbon units called isoprene. Some of the terpenes based on number of isoprenes are monoterpenes (C_{10}), sesquiterpenes (C_{15}), and diterpenes (C_{20}). Each EO has its own unique and significant fragrance, flavor, and piquant, all of which are contributed by the highly aromatic terpenes; the most abundant being monoterpenes and sesquiterpenes. Monoterpenes are the predominant terpenes in EOs. They are small, low molecular weight compounds. These highly volatile and nonviscous components impart strong aroma in EOs. Sesquiterpenes are big molecules with high molecular weight. Although their quantity is significantly less than monoterpenes, their increased stability is responsible for less volatility and enhanced aroma of EOs. Both monoterpenes and sesquiterpenes possess significant biological activity thereby making EOs of therapeutic importance.

8.2.2 Oxygenated compounds

All EOs in addition to terpenes also contain nonterpenic compounds called oxygenated compounds, whose composition varies on types of EOs. These compounds apart from possessing a variety of bioactive properties offer flavor and odor to EOs. They include esters, alcohols, aldehydes, esters, ethers, oxides, phenols, acids, acetals, and lactones.

EOs are estimated to contain about 300 different types of compounds with myriad biological properties making them potentially applicable and valuable in various domains of industries.

8.3 Essential oils in pharmaceutical industry

EOs are important in pharmaceutical industries because of their ability to demonstrate various properties like anti-inflammatory, antiseptic, antimicrobial, anticarcinogenic, and many more. All these properties enable them to be emphasized for development and discovery of novel drugs and antimicrobial agents. Many different EOs possess inhibitory action against a range of microbial etiological agents and

therefore are being used for the treatment of various diseases since ancient times. However, recently pharmaceutical industries engaged in production of different antibiotics and drugs are facing the grave problem of multidrug resistance. Hence, the antimicrobial components of various EOs may offer a decent opportunity to overcome the multidrug resistance problem and can form an integral part of novel drug discovery program due to their effectiveness against broad spectrum of microbes.

8.3.1 Essential oils as antioxidants

Aging is a natural phenomenon and associated with aging and reportedly other degenerative diseases like cancer, diabetes, and cardiovascular diseases are the leading problem of oxidative stress. Moreover, in the recent years, humans are constantly at high risk due to their exposure to exogenous sources of free radicals. The problem of oxidative stress is usually dealt with antioxidant defense mechanisms of the body and of course defenses provided by dietary ingredients. Among the dietary ingredients is EOs whose terpene components possess antioxidant potential due to their free radical scavenging capacity. Many EOs sourced from aromatic species of Lamiaceae family are rich in antioxidants. Some EOs also contain phenols which are responsible for ameliorating the negative effects of free radicals. The active constituents in EOs are set to exhibit myriad capacities to manage the oxidative stress like reduction of metal ion, scavenging of free radicals, and preventing/delaying of lipid oxidation.

Strongest antioxidant activities are exhibited by EOs containing phenolic groups or metabolites carrying conjugated double bonds. For instance, cinnamon, clove, thyme, oregano, and basil EOs have superior antioxidant properties [7] due to the presence of phenolic groups. It is believed that phenolic structures are significant in decomposition of peroxides and neutralization of free radicals owing to their strong redox properties. Nevertheless, the antioxidant properties of EOs are also contributed by other constituents like alcohols, ketones, aldehydes, and ethers.

Many chronic diseases like cancer, diabetes, asthma, brain dysfunction, and atherosclerosis are a result of cellular damage caused by free radicals. Hence, the free radical scavenging property of EOs plays a pivotal role in pharmaceutical industries for prevention or treatment of such diseases. Some of the significant EOs with antioxidant properties are geranial, isomenthone, α-terpinene, menthone, citronellal, 1,8-cineole, α-terpinolene, and so on.

One of the chronic diseases which has been attracting the therapeutic potential of EOs is cancer. These pharmacologically important EOs constituents possess myriad anticancer or cancer protective attributes. EOs may display these properties by following different ways:

- Activating detoxifying enzymes in lungs [8]
- Inhibiting carcinogenesis by activating glutathione S-transferases [9]

- Inducing apoptosis of immature nerve cells which otherwise may cause neuroblastoma [10]
- Decreasing resistance of cancer cells to anticancer drugs [11]
- Lowering toxicity of anticancer agents to healthy cells [12]
- Exhibiting cytotoxic activity toward cancerous cells [13]

All these mechanisms of actions explain the therapeutic values of EOs as cancer protective agents. Although EOs alone cannot be considered for targeting cancerous cells, but their role in fighting cancer in combination with conventional therapeutic strategies however cannot be ignored.

8.3.2 Essential oils as skin penetration boosters

There are many methods of administering drugs into the human system. Some are delivered intravenously, some subcutaneously and others intramuscularly. However, there are several reasons for drugs to be delivered topically or through transdermal route. One of the reasons might be that the drugs need to avoid the initial passage through hepatic system, some drugs might need to maintain constant concentration in the blood plasma or some drugs probably might need to be discharged quickly after their metabolism through urine. Some drugs which are required to exhibit low metabolism are usually administered through transdermal route. However, the human skin acts as a natural barrier for many such drugs.

The special structure of skin layers especially the outermost layer functions in protecting the underlyingskin tissues from dehydration, infection, and other factors like stress. This ability of the skin epidermal layer restricts the effective transdermal penetration of many drugs and hence drug penetration enhancers are required which work by disrupting the skin lipid layer and/or by promoting partitioning. Skin penetration enhancers act in a temporary reversible manner thereby enhancing diffusion of drugs effectively and faster [14]. The most important factor which decides superiority of skin penetration enhancers is that it should exhibit both biocompatibility and also drug compatibility. It should be pharmacologically inert with good solvent properties.

There are many chemical compounds which have been detected to possess penetration enhancing properties. However, their poor skin permeability requires them to be used in higher doses to maintain their activity which no doubt reportedly cause severe side effects like skin irritation and cytotoxicity. The use of these less efficient chemical penetration enhancers is limited sighting safety issues.

EOs serve as good alternatives as skin penetration enhancers for both hydrophilic and lipophilic drugs. The constituents in EOs improve the permeation of drugs and some are reportedly known to enhance their activity too. They are considered GRAS (generally regarded as safe) thereby aiding as transdermal delivery systems for drugs.

Some EOs serve as successful penetration enhancers by decreasing the polarity of lipophilic drugs (Table 8.1). Some help in removing the lipid layer on the skin and others help in enhancing penetration by triggering denaturation of keratin layer thereby causing reversible skin protein composition change for easy diffusibility of drugs.

Table 8.1: Essential oils as skin permeation boosters.

S. no.	Plant name	Bioactive constituents	Permeation booster used for drug
1	*Aloe vera*	3,6-Octatriene, 3-cyclohexanol-1-methanol, bornylene	Losartan potassium (antihypertensive drug)
	Cuminum cyminum	β-Pinene, ocimene, γ-terpinene, safranal	
	Melaleuca alternifolia	γ-Terpinene, terpinene-4-01, α-pinene	
2	*Cinnamomum verum*	Cinnamaldehyde, coumaric acid, eugenol	Ibuprofen (NSID)
3	*Syzygium aromaticum*	Eugenol, caryophyllene, eugenyl acetate	
4	*Eucalyptus globulus*	1,8-Cineole, *p*-cymene, eucamalol, linalool, citronellol	Chlorhexidine digluconate (antiseptic) 2,3,5,6-tetramethylpyrazine (for treating cardiovascular disorders)
5	*Mentha piperita*	Menthol, menthone, menthyl acetate, β-pinene	Ketoconazole (antifungal)
6	*Citrus limon*	Terpenes, limonene, citral, geranyl acetate	Felodipine (antihypertensive)
7	*Boswellia serata*	α-Pinene, myrcene, sabinene, limonene, α-thujene	Chuanxiong
	Commiphora myrrha	β-Elemene, β-bourbonene	
8	*Pogostemon cablin*	γ-Guaiene, seychellene, α-patchoulene, α-bulnesene	Indomethacin (NSID)
9	*Salvia rosmarinus*	α-Pinene, 1,8-cineole, camphor	Diclofenac sodium (NSID)
10	*Sinapsis alba*	Allylisothiocyanate, thymol, limonene, octadecacene	5-Fluorouracil (antineoplastic), paeonol (anti-inflammatory)

Table 8.1 (continued)

S. no.	Plant name	Bioactive constituents	Permeation booster used for drug
11	*Guatheria procumbens*	Methyl salicylate, triacontane, formaldehyde, gawtheriline	Geniposide (hepatoprotective), (antidiabetic)
12	*Zanthoxylum bungeanum*	Limonene, linalool, linalyl anthranilate, 4-terpinenol	Indomethacin (NSID)

8.3.3 Essential oils as anti-inflammatory agents

Another property of EOs which makes their applicability for pharmaceutical use more appealing is there anti-inflammatory and analgesic property. Infection or injury leads to an inducible protective response called inflammation which helps combat external invaders of the body. A typical inflammatory response causes generation of free radicals called reactive nitrogen species (RNS) which are responsible for combating the invading organism. Nevertheless, overproduced RNS may also damage the inflammatory sites and trigger the action of a series of unwanted reactions.

There are currently many chemical agents especially nonsteroidal anti-inflammatory agents in use. Many diseases like arthritis, diabetes, and other autoimmune diseases demand regular use of these nonsteroidal agents and other corticosteroids triggering a number of serious side effects. Hypersensitivity, stomach ulcers, weight gain, and indigestion are a few to mention. Reports suggest that prolonged usage of corticosteroids lead to malfunctioning of various important glands and renal disorders. EOs act as noninvasive therapeutics and provide an excellent strategy for the treatment of chronic inflammatory responses. They are currently being considered to provide and edge over conventional chemical anti-inflammatory agents.

Infection caused by many bacterial agents especially gram-negative pathogens induces inflammation. This lipopolysaccharide-induced inflammation is the result of the synthesis of prostaglandins by blood monocytes. There are many isoenzymes of cyclooxygenases responsible for the constitutive synthesis of prostaglandins. However, cyclooxygenase-2 isoform is only induced upon inflammatory stimulation due to lipopolysaccharides of gram-negative pathogens indicating its role as inflammation-specific enzyme. Hence, treatment strategies for many inflammatory disorders are currently targeting cyclooxygenase-2 inhibitors. Nevertheless, the nonsteroidal anti-inflammatory drugs are proving unsuccessful due to reports of risk of myocardial infarction, stroke, and other cardiovascular side effects. Studies have revealed the role of EO constituents to drastically reduce the synthesis of prostaglandins, for instance; EOs from *Cha maecyparis obtusa* reportedly possessed ameliorating effects as an anti-

inflammatory agent by affecting prostaglandins synthesis by blood monocytes. The terpenes, elemol, and sabinene present in *Chamaecyparis obtusa*, *Cryptomaria japonica*, and *Hyptis pectinata*, reportedly are said to be responsible for selectively targeting cyclooxygenase-2 enzyme and hence inhibiting prostaglandin synthesis. Also, these terpenes were also responsible for inhibiting the production of nitric oxide, cytokines, and interleukins (IL-1 and IL-6); all of which induce inflammation [15, 16]. Similarly EOs of lemon grass mediate its anti-inflammatory effect by suppressing cyclooxygenase-2 promoter thereby inhibiting cyclooxygenase-2 gene expression [17].

EOs function as anti-inflammatory agents by interacting with anti-inflammatory cascade response involving cytokines and other factors like nitric oxide and prostaglandins (Table 8.2). The anti-inflammatory attributes of EOs can be explained by their effect on arachidonic acid metabolism or on cytokine production or by modifying the pro-inflammatory gene expression patterns.

Table 8.2: Essential oils as anti-inflammatory agents.

S. no.	Plant name	Bioactive constituents	Use
1	*Salvia officinalis*	Linalool, linalyl acetate, germacrene D, 4 geranyl	Regulates menstrual problems, eases tension muscle cramps, and controls dry skin, acne, and wrinkles.
2	*Evcalyptus globulus*	Cineole, terpinene, cymene, phyllandrene, pinene	Regulates nervous system, headache, and used to treat respiratory diseases.
3	*Pelargonium graveolens*	Eugenol, geranic, citronellol, linalol, methone, sabinene	Best perfume, used in soaps, control emotions, anxiety, stress, and sedative.
4	*Lavandula officinalis*	Camphor, β-ocimene, 1-8-cineole, terpinene-4-01	Causes depression, sedative, cures sleep pattern, increases mental alertness, and suppresses aggression.
5	*Citrus limon*	Terpenes, limonene, phyllandrene	Astringent, detoxifying properties, causes blemishes, and boosts immune system.
6	*Mentha piperita*	Carvenol, menthol, carvone, menthone	Relieves pain spasms, arthritis.
7	*Anthemis mobilis*	Esters of angelic acid, tiglic acid, 2-Methyl butanoic acid	Calms emotions, anti-inflammatory, relieves anxiety, and stress.
8	*Rosmarinus officinalis*	Borneol, camphor, cineol, pinene, camphene	Relieves indigestion, pain, sleep disorders, and skin toxic.
9	*Melalevca alternifolia*	Terpinen-4-01, α-sabine, cineole	Cures insect bites, dandruff, and herpes.
10	*Cananga odorata*	Geranyl acetate, linalol, geraniol methyl chavicol	Retards heart beat, antidepressant, feeling of well-being.

8.3.4 EOs as antibacterial agents

Since historical times EOs are being used to treat various types of diseases which can be attributed to their antimicrobial property. But presently, man is not only tackling with new diseases but also is grappling with the issue of multidrug resistance. Many EOs contain constituents which possess antiviral, antiparasitic, antifungal, and antibacterial properties. They are being considered as potential source of antimicrobial compounds as they have the ability to address the problem of antibiotic resistance. EOs and their constituents for that matter are hydrophobic in nature, a property which enables them to partition with cell membrane and mitochondrial lipids of the invading organism making the membrane more permeable. This disturbance in membrane integrity renders loss in cell structure and eventually death. Some constituents are involved in modulating the efflux mechanism of organisms especially gram-negative bacteria affecting their drug resistance pattern [18]. EOs has an edge over antibiotics as antimicrobial agents as they have a complex composition which makes development of resistance tougher against them. Also, antibiotics in order to exhibit their antimicrobial activity need to make direct contact. But on the other hand, some EOs need not make direct contact and also since they can exist in highly active vapor phase can function as antifungal agents [19].

Another significant feature of EOs which makes them more applicable as antibacterial agents is their wide range of chemical compounds enabling them to have multiple targets. Some EOs act by disintegrating the outer membranes, and some act by depleting the intracellular ATP while some act deep inside the target cells by gaining access through the periplasm. It is believed that EOs abundant in phenols or aldehydes usually are better antibacterial agents. Thymol, eugenol, citral, and cinnamaldehyde are some phenol and aldehyde derivatives of EOs which possess highest antibacterial activities followed by EOs containing alcohol derivatives [20]. The high antibacterial activity of phenol/aldehyde containing EOs can be attributed to the presence of hydroxyl group which are the prime source of disrupting the periplasmic membrane and hence, cell death due to leakage of cell contents. Many important pathogens like *Pseudomonas*, *Bacillus*, *Staphylococcus*, *Listeria*, *Escherichia*, *Salmonella*, *Clostridium*, *Lactobacillus*, and *Helicobacter* are acted upon by phenolic/aldehyde-containing EOs suggesting that such EOs display antibacterial effect against wide range of bacteria which include both gram-positive and gram-negative species. However, presence of outer membrane and lipopolysaccharide structures in gram-negative bacteria makes the action of EOs less effective probably due to the restricted movement of hydrophobic compounds across the lipopolysaccharide.

8.4 Application of essential oils in food industry

Food is the basic necessity of mankind. Food commodities need to be prevented from microbial infestation during its postharvest storage. Moreover, with the modernization of society and technological advancements, people are inclined more toward precooked, processed food that can save both labor and time. Maintenance of food quality amid its processing and storage is the major challenge of food industry. Also, rising demand of good quality food product with natural ingredients has prompted the use of EOs in food products. EOs are mainly augmented in food products to mainly serve two purposes first to add flavors to the food and second as natural preservative due to its antimicrobial and antioxidant properties. EOs have already been used to enhance flavors of food for centuries. Due its strong aroma, EOs are used to mask the odd flavors generated due to processing of food, thereby increasing the palatability of product. The use of EOs as a food additive has been approved as substances generally recognized as safe by US Food and Drug Admistration [21].

Owing to the various other potential characteristic properties of EOs like antibacterial, antifungal, and antioxidant it has widely used in food industries and even myriad of researches are still revealing the potential of newer uncommon EOs to be utilized in food industries (Table 8.3). Antimicrobial agents prevent the natural spoilage of food and also controls the growth of invading microorganism thus offering both preservation and safety of food [22]. The efficacy of EOs as natural food preservative has been tested in many food products like bakery products, fruits and vegetables, and meat products. Mishra et al. [23] reviewed the literature reporting the potential of EOs in dairy products. It was found that EOs from oregano, clove, thyme, and orange had powerful inhibitory activity against bacteria and yeasts. Addition of EOs to dairy products both enhanced the aroma of product and imparted antimicrobial properties to it making it more consumer acceptable. Similarly addition of EOs to fruits and vegetables helps to extend its shelf life. The primary problem of associated with fruits and vegetables is its fungal spoilage. Researchers have come up showing reduction in microorganism count by the use of EOS in fruits. Viuda-Martos et al. [24] reported significant antifungal activities of clove, thyme, and oregano against *Aspergillus niger* and *Aspergillus flavus* which are related to food spoilage. Incorporation of EOs in fruit juices along with physical treatment like mild heat or pulsed electric field can help in preservation of fruit juices for longer time [25]. In addition to abovementioned categories of food products meat and its products also hold a significant share in processed food industries and are very vulnerable to spoilage. Shaltout and Koura [26] reported the use of thyme oil at concentration of 1% and cinnamon oil at 2% as preservative of minced meat to increase its shelf life. Antibacterial activity of basil EO was evaluated in Italian-type sausage by Gaio et al. [27]. In the study the activity of EOs was tested against 18 microorganisms and for all the microorganisms EOs was effective except *Pseudomonas aeruginosa*. The minimum inhibitory concentration was found between 0.25 and 1.00 mg/g.

EOs inspite of having an array of beneficial characteristics, its volatibilty and hydrophobic nature makes it difficult to be directly used in food systems. Nanotechnology has been reported as a solution for delivery system of EOs that could protect the active compounds against degradation and can enhance its efficacy in food system. Nanoencapsulation protects EOs against deteriorating factors like light, moisture, pH, and also during processing and storage. It also helps to solubilize lipophilic compounds in aqueous media and to release them in the target location [28]. Liao et al. [29] reviewed the research work reported in relation to the methods of nanoencapsulation of EOs for their improvised delivery into food products. The efficacy of various methods has been tested but spray-drying and freeze-drying are widely used in the food industry [30]. Delivery of EOs in fruit juices has been tested by Bento et al. [31], by chitosan-based nanotechnology where they encapsulated sweet orange EO using chitosan nanoemulsions as nanocarrier and evaluated its antimicrobial activity in combination with mild heat and found the strategy effective for bactericidal action in fruit juices.

Table 8.3: Potential uses of some essential oils in foods.

Essential oil	Scientific name	Parts used	Uses	References
Basil	*Ocimum basilicum*	Aerial part	Flavoring, antimicrobial, and antioxidant agent	Li and Chang [32]
Cinnamon	*Cinnamomum zeylanicum*	Bark and leaves	Flavoring, antimicrobial, and antioxidant agent	Cardoso-Ugarte et al. [33]
Clove	*Syzygium aromaticum* L.	Flowers	Flavoring, antimicrobial, and antioxidant agent	Haro-González et al. [34]
Cumin	*Nigella sativa*	Seeds	Flavoring and food preservative	Hassanien et al. [35]
Fennel	*Foeniculum vulgare* Mill.	Seeds	Flavoring, antimicrobial, and antioxidant agent	Diao et al. [36]
Garlic	*Allium sativum* L.	Cloves	Flavoring, antimicrobial, antioxidant agent	Khan et al. [37]
Lavender	*Lavandula* species	Flower	Antimicrobial	Wells et al. [38]
Lemon	*Citrus limon* L.	Fruit	Flavoring, preservative	Klimek-Szczykutowicz et al. [39]
Lemon Grass	*Cymbopogon* sp.	Leaves	Preservative	Faheem et al. [40]
Oregano	*Origanum* sp.	Aerial part	Flavoring, antimicrobial, antioxidant agent	Rodriguez-Garcia et al. [41]

Table 8.3 (continued)

Essential oil	Scientific name	Parts used	Uses	References
Peppermint	*Mentha piperita* L.	Leaves	Flavoring	Nayak et al. [42]
Rosemary	*Rosmarinus officinalis* L.	Leaves	Flavoring, antimicrobial, and antioxidant	Hernández et al. [43]
Thyme	*Thymus vulgaris* L.	Leaves	Flavoring, antimicrobial, and antioxidant	Stahl-Biskup and Venskutonis, [44]

8.5 Application of EOs in cosmetics

Cosmetics have become an obligatory part of modern life style. Its trending usage by both women and men has ignited the global cosmetic demand of 5.3% from 2021 to 2027. The market size valued in 2019 was $380.2 billion [45]. Cosmetic manufacturers are always innovative in advertising the product that can seek consumers attention. EOs have proved to be an effective promotion tool as being a natural compound it is easily acceptable while at the same time justifying its use by its incredible properties. In Cosmetic industry, EOs are majorly used for their pleasant fragrances and as natural preservative. Fragrances are important factor in selection of any cosmetic product and also it aids to overcome the unpleasant odor of other ingredients of cosmetic formulations. Some of the high-valued EOs used as fragrances are citrus, lavender, eucalyptus, tea tree, and other floral oils while linalool, geraniol, limonene, citronellol, and citral are much-appreciated fragrance components used in different cosmetics [46].

Due to the presence of pharmacologically important compounds in EOs it has antibacterial, antifungal, and antioxidant properties which impart various beneficial effects to skin and hair (Table 8.4). It can also be exploited in cosmetic products as natural preservative which can reduce the addition of synthetic preservative in the products. Muyima et al. [47] tested the potential of *Artemisia afra*, *Pteronia incana*, *Lavandula officinalis*, and *Rosmarinus officinalis* EOs as natural cosmetic preservatives in an aqueous cream formulation. The results showed the potential of plant EOs to be used as natural preservatives against *E. coli*, *Ps. aeruginosa*, *S. aureus*, *Ra. pickettii*, *C. albicans*, and *A. niger* in cosmetic products.

Even though EOs have always proved to have beneficial effects on skin and hair, new researches are always coming up that keep testing uncommon EO properties and manufactures can improvise and upgrade their product and its advertising strategy by adding newer ingredients to their product. Choi et al. [48] reported the antiwrinkle activity of *Chrysanthemum boreale* MAKINO EO (CBMEO). EO and juice

from bergamot and sweet orange was found to improve *Acne Vulgaris*, prevalent dermatologic disease effecting 80% of young individuals [49]. EOs were found to decrease the growth rate of sebaceous gland spots and reduce the release of inflammatory cytokines thereby promoting apoptosis in the sebaceous gland. *Curcuma longa* EO proved to have antiaging effects on skin. It was found to reduce cutaneous photoaging in a UVB-irradiated nude mouse model suggesting its application in cosmetic products [50].

Table 8.4: Application of essential oils in skin and hair care.

Application	Essential oil	Functions	References
Skin care	Sandalwood	Conditions and brightens skin, and antiaging	Francois-Newton et al. [51]
	Chamomile	Antiaging and antiacne	Guzmán and Lucia [52]
	Rosemary	Skin hydration and antiaging	Montenegro et al., [53]
	Bergamot	Antiacne and repairs UV-induced damage	Forlot and Pevet [54]
	Sweet orange	Antiacne	Sun et al. [49]
Hair care	Peppermint oil	Hair growth	Oh et al. [55]
	Rosemary	Promotes hair growth and nourishes the hair	Panahi et al. [56]
	Bergamot	Antidandruff	Abelan et al. [57]
	Lavender	Hair growth and conditioning	Guzmán and Lucia [52]
	Tea tree	Antidandruff	Yadav et al. [58]
	Lemon grass	Strengthens hair follicles and promotes hair growth	Goyal et al. [59]

8.6 Essential oils in active and intelligent food packaging industries

The rise in living standards, increase in awareness, and consciousness about health is making people opt for packaged foods. Packaged food industry is an important global business. Packaging is intended to keep the food safe, fresh, and hygienic till it

reaches the customer along the supply chain. Hence, packaging materials play crucial role in protecting the food product from external environment. Packaging industries were earlier dominated with synthetic polymers like polyvinylchloride polyethylene terephthalate and other petrochemical-based plastics. Nevertheless, health and environmental concerns paved way for ideas called active and intelligent packaging. The strategy of active packaging basically involves prolonging the shelf life of foods by arresting microbial growth, preventing food oxidation, removing moisture, and preventing other food safety risks. Whereas intelligent packaging encompasses materials with the ability to monitor the condition of the packaged food.

These advancements in active and intelligent packaging have led to the incorporation of various chemicals as additives in the packaging material. However, the presence of chemicals as an active agent in the packaging material such as ethylene absorbers to arrest ripening of fruits, moisture control agents to control water activity and thereafter microbial growth, oxygen scavengers to the decelerate oxidative reactions which otherwise may cause food deterioration and carbon dioxide absorbers or emitters to retard microbial growth in meat and poultry products, is proving a matter of concern. These chemicals can cause adverse health effects therefore leading to novel, yet sustainable alternatives such as incorporation of natural bioactive compounds. EOs are currently being considered as the promptest solution and alternative to this.

EOs are being considered as active ingredients in active food packaging due to their antimicrobial and antioxidant properties prolonging the shelf life of foods. EOs are recently being incorporated into active packaging as coatings which are applied on food surface or as films used as wrapping material or covers. Incorporating EOs into packaging material provides many benefits like

1. Improvement of tensile strength: This probably could be due to the role of phenols present in EOs in reorganizing and improving the cross-linking pattern of packaging matrix.
2. Improvement of barrier and permeation properties: These properties are important for maintaining increased product quality and is dependent on hydrophobicity and hydrophilicity ratio of the packaging material in order to control the vapor pressure. The hydrophobic nature of EO constituents when incorporated into hydrophilic packaging matrix enhances the barrier properties.
3. Improvement in optical properties: Optical properties of packaging material effect the protective function of food product and hence various optical properties like color, gloss, and transparency are significant. Incorporation of EOs into the packaging material not only impacts the color of the material but also functions as barriers against UV light.
4. Improvement of food quality: EOs possess antioxidative properties and when these EOs are incorporated into the packaging material the antioxidants present in the EOs prevent the food from spoilage due to oxidation. They also contain antibacterial agents which increase the shelf life of food product preventing microbial growth.

In meat and poultry industries, incorporating EOs into the packaging material with antioxidant property is said to release them into the product, preventing or delaying lipid oxidation. The antioxidants do so by binding or absorbing oxygen in and around the product. This use of EO in such industries is proving a bone and good cost-effective alternative to prevent foodborne illness and outbreaks. Many EOs derived from different plants are being used to be incorporated into the packaging material as they are considered as GRAS by FDA. For example, *Rosmarinus officinalis*, *Matricaria chamomilla*, and *Ocimum basilicum*.

EOs from bergamot and EOs containing linalool, which have a strong antibacterial effect, are being used in packaging material for food products like chicken and cabbage to prevent food spoilage by *E. coli*, *B. cereus*, and *Listeria monocytogenes*. Food packaging materials incorporated with cinnamon EO with antifungal properties are being used to prevent growth of important fungi like *Aspergillus*, *Penicillium*, and *Eurotium* which otherwise deteriorate food quality especially acidic foods.

Horticultural products are highly prone to fast deterioration and hence huge loss due to wastage. Food packing industries have worked out on this problem to minimize economic loss incurred due to spoilage and wastage of fruits and vegetables. Currently the packaging material or the corrugated cardboardsare widely being used as inexpensive and sustainable packaging material incorporated with encapsulated EOs. These encapsulated EOs are engaged in release of antimicrobial agents which are controlled by relative humidity and temperature within the packaging material thereby preventing these perishable products from spoilage. EO which are incorporated into foot packaging material have the ability to be released in a slow and control manner into the food to display their efficacy as an agent to suffice their shelf life and also in maintaining the organoleptic properties of the food [60].

8.7 Essential oils in textile industry

Functional textiles are the textiles materials developed to impart new functions to the product to meet the end use requirement apart from its basic use. The functional finishing decipher new properties to the fabric such as antimicrobial activity, antibiotic, antiwrinkle, UV resistance, photocatalytic activity, and flame retardency [61]. EOs have a great potency to be used in textile finishing due to the “green” and biodegradable nature which can possibly augment or replace the chemical agents used in textile industries. They are becoming increasingly popular because of their low toxicity and strong costumer approval. EOs are mainly reported to be used as functional agents for making fragrant textiles, antimicrobial textiles, biomedical textiles, and mosquito-repellent textiles.

8.7.1 Aroma-finished textiles

Fragrance finishing of textiles is often useful in aromatherapy. Perfumed textiles even provide greater acceptance by end consumer due its pleasant fragrances. Srivastava and Srivastava [62] impregnated citronella and lemongrass oil on wool and silk fabric and outcomes were assessed by olfactrometery analysis which reported long retention of aroma upto 20 wash cycles. Khanna et al. [63] infused EOs of lavender, eucalyptus, peppermint, jasmine, cedarwood, and clove to cotton fabric directly and with anchors as cyclodextrin both in native and modified form like monochlorotriazine-β-cyclodextrin. These aromated fabrics were studied for the retention time of oils in the fabrics and found that the presence of anchoring host provided better retention time and slower release of oils form fabric as compared to direct application of EOs.

8.7.2 Mosquito-repellent textiles

Various EOs have also been reported to have mosquito-repellent properties and used widely due its eco-friendly nature [64]. A number of researches have been reported with infusing EOs in fabrics to develop mosquito-repellent textiles and also found to be functional. Specos et al. [65] developed microcapsules containing citronella EO applied it to cotton textiles. Assessment of repellent activity of fabric was done by exposure of a human hand and arm covered with the treated textiles to *Aedes aegypti* mosquitoes. Tested fabric showed a long-lasting protection from insects. Litsea, lemon, and rosemary EOs were applied to polyester and cotton fabrics by Soroh et al. [66] to access their mosquito-repellent activity which was found to be 71.43%.

8.7.3 Antimicrobial textiles

External factors like high humidity, temperature, and insufficient air circulation enhance the growth of microorganisms in textiles containing natural fibers, for example, cotton and linen fabrics, flax, and hemp nonwovens [67]. EOs are becoming increasingly popular to develop antimicrobial textile because of being natural, safe, and eco-friendly perspective. Antimicrobial textiles are useful in apparels like jackets, sanitary pads, sportswear, and winter wear; health care like lab coats, bandage, mask, and protective kits and in households like curtains, covers, carpet, and towels. Walentowska and Foksowicz-Flaczyk [68] tested thyme EO on linen cotton-blended fabric and linen fabric to form antibacterial textile. Thyme EO applied as 8% concentration in methanol to linen cotton-blended fabric showed very high antibacterial and antifungal activity. Chitosan microencapsulation of sandalwood and

eucalyptus EOs was reported by Javid et al. [61] to enhance the functional properties of cotton fabric. They carried out emulsive fabrication of chitosan microcapsules encapsulating EOs which was applied on a bleached, desized mercerized cotton fabric. The finished fabric retained antibacterial activity and also the activity increased with increasing concentration of EOs.

8.7.4 Biomedical textiles

Medical textiles are formulated to be used to provide wound healing and other medical benefits of EOs to the consumers. Their use may range from simple bandages to prostheses of body implants such as artificial heart, heart valve, blood vessel, and skin. Copaiba EO were added to cotton fabric by Aruda et al. [69], which was tested for its healing enhancement potential. Gong et al. [70] prepared thermosensitive hydrogel and micelles loaded with curcumin and was prepared and applied for cutaneous wound repair. Rafiq et al. [71] developed of sodium alginate/PVA antibacterial nanofibers by the incorporation of cinnamon, clove, and lavender EOs. Nanofibers with 1.5% cinnamon oil showed highest antimicrobial properties and the nanofibrous-coated cotton gauze validated its potential to be used for wound dressings due its considerable liquid absorption and antibacterial activity.

8.8 Conclusion

EOs are volatile substances of plant origin. They have plethora of applications in many areas ranging from medicine, pharmaceuticals, cosmetics, perfumes, food and food packaging, general health, therapeutics, and so on. EOs are composed of terpenes, alcohols aldehydes, esters, and many other bioactive components. These bioactive and helpful components of EOs are currently receiving enormous attention making them widely applicable in various industries. EOs are finding immense applicability in food industries either as an active ingredient of food product or as an important constituent of food packaging materials. EOs are characterized by their strong aroma and fragrance, and this very asset makes their applicability more prominent in cosmetic and perfumery industries. EOs and their distinctive bioactive compounds are being considered as effective and safe alternative therapeutics to conventional therapeutic strategies. The antioxidant, anti-inflammatory, antimicrobial, and antiparasitic attributes of EOs have extended the applicability to health care, personal care, food, and pharmaceutical industries. Therefore, EOs which are bestowed with natural, useful biological and medicinal properties are hence making consumers inclined toward them and finding permanent place in modern world. But still many more EOs still needs to be explored which can be

utilized in industries as alternative to the synthetic chemicals and even in day-to-day life. Yet some researchers report a number of constraints in the use of EOs commercially. The researchers need to be more focused toward the toxicity profiling of components of EOs so health promoting benefits can be availed from EOs easily and safely.

References

[1] National Health Portal, 2015. http://nhp.gov.in/lifestyle-disorder_mtl#:~:text=The%20most%20common%20lifestyle%20disorders,also%20fall%20under%20this%20category. (Accessed on 25 May 2022)
[2] Ribeiro-Santos R, Andrade M, Sanches-Silva A, de Melo NR. Essential Oils for Food Application: Natural Substances with Established Biological Activities. Food Bioprocess Technol 11, 2018, 43–71.
[3] Stratakos AC, Koidis A. Methods for Extracting Essential Oils. In: Essential Oils in Food Preservation, Flavor and Safety. Elsevier, London, UK, 2016, 31–38.
[4] Markets and Markets, 2021, Published March 2021 https://www.marketsandmarkets.com/Market-Reports/essential-oil-market-119674487.html(accessed on 31 May 2022)
[5] Burt S. Essential oils: their antibacterial properties and potential applications in foods—a review. Int J Food Microbiol 94, 2004, 223–253.
[6] Barbieri C, Borsotto P. Essential Oils: Market and Legislation. In: El-Shemy HA (Ed), Potential Essent Oil IntechOpen; London, UK, 2018, 107–127.
[7] Aruoma OI. Free radicals, oxidative stress, and antioxidants in human health and disease. J Am Oil Chem Soc 75, 1998, 199–212.
[8] Wu CC, Sheen LY, Chen HW, Kuo WW, Tsai SJ, Lii CK. Differential effects of garlic oil and its three major organosulfur components on the hepatic detoxification system in rats. J Agric Food Chem 50, 2002, 378–383.
[9] Ahmad H, Tijerina MT, Tobola AS. Preferential overexpression of a class MU glutathione S-transferase subunit in mouse liver by myristicin. Biochem Biophys Res Commun 236, 1997, 825–828.
[10] Zheng G, Kenny P, Lam L. Inhibition of benzo-pyrene-induced tumorigenesis by myristicin, a volatile aroma constituent of parsley leaf oil. Carcinogenesis 13, 1992, 1921–1923.
[11] Lee BK, Kim JH, Jung JW, Choi JW, Han ES, Lee SH, Ko KH, Ryu JH. Myristicin inducedneurotoxicity in human neuroblastoma MSK-N-SH cells. Toxicol Lett 157, 2005, 49–56.
[12] Carnesecchi S, Langley K, Exinger F, Gossé F, Raul F, Geraniol, a component of plant essential oils sensitizes human colonic cancer cells to 5-fluorouracil treatment. Pharmacol J. Exp Ther 301, 2002, 625–630.
[13] El Hadri A, Gómez Del Río MA, Sanz J, González Coloma A, Idaomar M, Ribas Ozonas B, Benedí González J, Sánchez Reus MI. Cytotoxic activity of humulene and transcaryophyllene from *Salvia officinalis* in animal and human tumor cells. An R Acad Nac Farm 76, 2010, 343–356.
[14] Herman A, Herman AP, Essential oils and their constituents as skin penetration enhancer for transdermal drug delivery: A review. Pharm J. Pharmacol 67, 2015, 473–485.
[15] Takeda K, Kaisho T, Akira S. Toll-like receptors. Annu Rev Immunol 21, 2003, 335–376.
[16] Yoon WJ, Kim SS, Oh TH, Lee NH, Hyun CG. Cryptomeria japonica essential oil inhibits the growth of drug-resistant skin pathogens and LPS-induced nitric oxide and pro-inflammatory cytokine production. Pol J Microbiol 58, 2009, 61–68.

[17] Katsukawa M, Nakata R, Takizawa Y, Hori K, Takahashi S, Inoue H. Citral, a component of lemongrass oil, activates PPAR alpha and gamma and suppresses COX-2 expression. Biochim Biophys Acta Mol Cell Biol Lipids 1801, 2010, 1214–1220.
[18] Devi KP, Nisha SA, Sakthivel R, Pandian SK. Eugenol (an essential oil of clove) acts as an antibacterial agent against Salmonella typhi by disrupting the cellular membrane. J Ethanopharmacol 130, 2010, 107–115.
[19] Tyagi AK, Malik A. Antimicrobial potential and chemical composition of Eucalyptus globulus oil in liquid and vapour phase against food spoilage microorganisms. Food Chem 126, 2011, 228–235.
[20] Lambert RJW, Skandamis PN, Coote P, Nychas GJE. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. J Appl Microbiol 91, 2001, 453–462.
[21] U.S. Food and Drug Administration, 2022. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=182.20 (Accessed on 25 May 2022)
[22] Tajkarimi MM, Ibrahim SA, Cliver DO. Antimicrobial herb and spice compounds in food. Food Control 2010, 21(9), 1199–1218.
[23] Mishra AP, Devkota HP, Nigam M, Adetunji CO, Srivastava N, Saklani S, Shukla I, Azmi L, Shariati MA, Melo Coutinho HD, Mousavi Khaneghah A. Combination of essential oils in dairy products: A review of their functions and potential benefits. Lwt 133, 2020, 110116.
[24] Viuda-Martos M, Ruiz-Navajas Y, Fernández-López J, Pérez-Álvarez JA. Antifungal activities of thyme, clove and oregano essential oils. J Food Saf 2007, 27(1), 91–101.
[25] Chueca B, Ramírez N, Arvizu-Medrano SM, García-Gonzalo D, Pagán R. Inactivation of spoiling microorganisms in apple juice by a combination of essential oils' constituents and physical treatments. Food Sci Technol Int 2016, 22(5), 389–398.
[26] Shaltout FA, Koura HA. Impact of some essential oils on the quality aspect and shelf life of meat. Bvmj 2017, 33(2), 351–364.
[27] Gaio I, Saggiorato AG, Treichel H, Cichoski AJ, Astolfi V, Cardoso RI, Toniazzo G, Valduga E, Paroul N, Cansian RL, Antibacterial activity of basil essential oil (Ocimum basilicum L.) in Italian-type sausage. Verbr J. Lebensm 10, 2015, 323–329.
[28] Bazana MT, Codevilla CF, de Menezes CR. Nanoencapsulation of bioactive compounds: Challenges and perspectives. Curr Opin Food Sci 26, 2019, 47–56.
[29] Liao W, Badri W, Dumas E, Ghnimi S, Elaïssari A, Saurel R, Gharsallaoui A. Nanoencapsulation of essential oils as natural food antimicrobial agents: an overview. Appl Sci 2021, 11(13), 5778.
[30] de Souza Simões L, Madalena DA, Pinheiro AC, Teixeira JA, Vicente AA, Ramos OL. Micro- and nano bio-based delivery systems for food applications: In vitro behavior. Adv Colloid Interface Sci 243, 2017, 23–45.
[31] Bento R, Pagán E, Berdejo D, de Carvalho RJ, García-Embid S, Maggi F, Magnani M, de Souza EL, García-Gonzalo D, Pagán R. Chitosan nanoemulsions of cold-pressed orange essential oil to preserve fruit juices. Int J Food Microbiol 331, 2020, 108786.
[32] Li QX, Chang CL. Basil (*Ocimum Basilicum* L.) Oils. In: Preedy VR (Eds), Essential Oils in Food Preservation, Flavor and Safety. Elsevier, London, UK, 2016, 231–238.
[33] Cardoso-Ugarte GA, López-Malo A, Sosa-Morales ME. Cinnamon (Cinnamomum Zeylanicum) Essential Oils. In: Preedy VR (Eds), Essential Oils in Food Preservation. Flavor and Safety, Elsevier, London, UK, 2016, 339–347.
[34] Haro-González JN, Castillo-Herrera GA, Martínez-Velázquez M, Espinosa-Andrews H. Clove Essential Oil (Syzygium aromaticum L. Myrtaceae): Extraction, Chemical Composition, Food Applications, and Essential Bioactivity for Human Health. Molecules 26, 2021, 6387.

[35] Hassanien MFR, Assiri AMA, Alzohairy AM, Oraby HF. Health-promoting value and food applications of black cumin essential oil: an overview. J Food Sci Technol 52, 2015, 6136–6142.
[36] Diao WR, Hu QP, Zhang H, Xu JG. Chemical composition, antibacterial activity and mechanism of action of essential oil from seeds of fennel (Foeniculum vulgare Mill.). Food Control 2014, 35(1), 109–116.
[37] Khan S, Das S, Malik N, Bhat SA. Antioxidant properties of garlic essential oil and its use as a natural preservative in processed food. Int J Chem Studies 2017, 5(6), 813–821.
[38] Wells R, Truong F, Adal AM, Sarker LS, Mahmoud SS. Lavandula Essential Oils: A Current Review of Applications in Medicinal, Food, and Cosmetic Industries of Lavender. Nat Prod Commun 2018, 13(10), 1403–1417.
[39] Klimek-Szczykutowicz M, Szopa A, Ekiert H. Citrus limon (Lemon) phenomenon—a review of the chemistry, pharmacological properties, applications in the modern pharmaceutical, food, and cosmetics industries, and biotechnological studies. Plants 2020, 9(1), 119.
[40] Faheem F, Liu ZW, Rabail R, Haq IU, Gul M, Bryła M, Roszko M, Kieliszek M, Din A, Aadil RM. Uncovering the Industrial Potentials of Lemongrass Essential Oil as a Food Preservative: A Review. Antioxidants 2022, 11(4), 720.
[41] Rodriguez-Garcia I, Silva-Espinoza BA, Ortega-Ramirez LA, Leyva JM, Siddiqui MW, Cruz-Valenzuela MR, Gonzalez-Aguilar GA, Ayala-Zavala JF. Oregano Essential Oil as an Antimicrobial and Antioxidant Additive in Food Products. Crit Rev Food Sci Nutr 56, 2016, 1717–1727.
[42] Nayak P, Kumar T, Gupta AK, Joshi NU. Peppermint a medicinal herb and treasure of health: A review. J Pharmacogn Phytochem 2020, 9(3), 1519–1528.
[43] Hernández MD, Sotomayor JA, Hernández A, Jordán MJ. Rosemary (*Rosmarinus Officinalis L.*) Oils. In: Preedy VR (Eds), Essential Oils in Food Preservation, Flavor and Safety. Elsevier, London, UK, 2016, 677–688.
[44] Stahl-Biskup E, Venskutonis RP. Thyme. In: Peter KV (Eds), Handbook of Herbs and Spices. Elsevier, London, UK, 2012, 499–525.
[45] Allied Market Research, 2021(accessed on 31 May 2022) https://www.alliedmarketresearch.com/cosmetics-market#:~:text=The%20global%20cosmetics%20market%20size,of%20modern%20lifestyle%20of%20individuals.
[46] Sharmeen JB, Mahomoodally FM, Zengin G, Maggi F. Essential Oils as Natural Sources of Fragrance Compounds for Cosmetics and Cosmeceuticals. Molecules 26, 2021, 666.
[47] Muyima NYO, Zulu G, Bhengu T, Popplewell D. The potential application of some novel essential oils as natural cosmetic preservatives in an aqueous cream formulation. Flavour Fragr J 17, 2002, 258–266.
[48] Choi IH, Hwang DI, Kim DY, Kim HB, Lee HM. A Study on the Anti-wrinkle Properties of Cosmetics Containing Essential Oil from Chrysanthemum boreale MAKINO. J Life Sci 29, 2019, 442–446.
[49] Sun P, Zhao L, Zhang N, Wang C, Wu W, Mehmood A, Zhang L, Ji B, Zhou F. Essential Oil and Juice from Bergamot and Sweet Orange Improve Acne Vulgaris Caused by Excessive Androgen Secretion. Mediat Inflamm 2020, 1–10, doi: https://doi.org/10.1155/2020/8868107.
[50] Zheng Y, Pan C, Zhang Z, Luo W, Liang X, Shi Y, Liang L, Zheng X, Zhang L, Du Z. Antiaging effect of Curcuma longa L. essential oil on ultraviolet-irradiated skin. Microchem J 2020, 154, 104608, https://doi.org/10.1016/j.microc.2020.104608.
[51] Francois-Newton V, Brown A, Andres P, Mandary MB, Weyers C, Latouche-Veerapen M, Hettiarachchi D. Antioxidant and Anti-Aging Potential of Indian Sandalwood Oil against Environmental Stressors In Vitro and Ex Vivo. Cosmetics 8, 2021, 53.
[52] Guzmán E, Lucia A. Essential Oils and Their Individual Components in Cosmetic Products. Cosmetics 8, 2021, 114.

[53] Montenegro L, Pasquinucci L, Zappalà A, Chiechio S, Turnaturi R, Parenti C, Rosemary Essential Oil-Loaded Lipid Nanoparticles: In Vivo Topical Activity from Gel Vehicles. 2017, 9, 48.
[54] Forlot P, Pevet P. Bergamot (Citrus bergamia Risso et Poiteau) essential oil: Biological properties, cosmetic and medical use. A review. J Essent Oil Res 24, 2012, 195–201.
[55] Oh JY, Park MA, Kim YC. Peppermint Oil Promotes Hair Growth without Toxic Signs. Toxicol Res 2014, 30, 297–304.
[56] Panahi Y, Taghizadeh M, Marzony ET, Sahebkar A. Rosemary oil vs minoxidil 2% for the treatment of androgenetic alopecia: a randomized comparative trial. Skinmed 2015, 13(1), 15–21.
[57] Abelan US, de Oliveira AC, Cacoci ESP, Martins TEA, Giacon VM, Velasco MVR, C.r.r.d.c. L. Potential use of essential oils in cosmetic and dermatological hair products: A review. J Cosmet Dermatol 2021.
[58] Yadav E, Kumar S, Mahant S, Khatkar S, Rao R. Tea tree oil: a promising essential oil. J Essent Oil Res 29, 2017, 201–213.
[59] Goyal A, Sharma A, Kaur J, Kumari S, Garg M, Sindhu RK, Rahman MH, Akhtar MF, Tagde P, Najda A, Banach-Albińska B, Masternak K, Alanazi IS, Mohamed HRH, El-kott AF, Shah M, Germoush MO, Al-malky HS, Abukhuwayjah SH, Altyar AE, Bungau SG, Abdel-Daim MM. Bioactive-Based Cosmeceuticals: An Update on Emerging Trends. Molecules 27, 2022, 828.
[60] Ribeiro-Santos R, Andrade M, de Melo NR, Sanches-Silva A. Use of essential oils in active food packaging: Recent advances and future trends. Trends Food Sci Technol 61, 2017, 132–140.
[61] Javid A, Raza ZA, Hussain T, Rehman A. Chitosan microencapsulation of various essential oils to enhance the functional properties of cotton fabric. J Microencapsul 31, 2014, 461–468.
[62] Srivastava S, Srivastava S, Essential Oil Impregnation on Wool Fabric for Aromatherapy. International Conference on Inter Disciplinary Research in Engineering and Technology, Published by ASDF International, Registered in London, United Kingdom, 2016, 59–62.
[63] Khanna S, Sharma S, Chakraborty JN. Performance assessment of fragrance finished cotton with cyclodextrin assisted anchoring hosts. Fash Text 2, 2015, 1–7.
[64] Prajapati V, Tripathi A, Aggarwal K, Khanuja S. Insecticidal, repellent and oviposition-deterrent activity of selected essential oils against Anopheles stephensi, Aedes aegypti and Culex quinquefasciatus. Bioresour Technol 96, 2005, 1749–1757.
[65] Specos MMM, García JJ, Tornesello J, Marino P, Vecchia MD, Tesoriero MVD, Hermida LG. Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles. Trans R Soc Trop Med Hyg 104, 2010, 653–658.
[66] Soroh A, Owen L, Rahim N, Masania J, Abioye A, Qutachi O, Goodyer L, Shen J, Laird K. Microemulsification of essential oils for the development of antimicrobial and mosquito repellent functional coatings for textiles. J Appl Microbiol 131, 2021, 2808–2820.
[67] Tomsic B, Simoncic B, Orel B, Vilcnik A, Spreizer H. Biodegradability of cellulose fabric modified by imidazolidinone. Carbohydr Polym 2007, 69, 478–488.
[68] Walentowska J, Foksowicz-Flaczyk J. Thyme essential oil for antimicrobial protection of natural textiles. Int Biodeterior Biodegrad 84, 2013a, 407–411.
[69] Aruda LM, Teixeira M, Ribeiro AI, Souto AP, Cionek CA. Textiles, Identity and Innovation. In: Touch. Proceedings of the 2nd International Textile Design Conference (D_TEX 2019) Montagna G, Carvalho C (Eds), Taylor and Francis, CRC Press, London, 2020.
[70] Gong C, Wu Q, Wang Y, Zhang D, Luo F, Zhao X, Wei Y, Qian Z. A biodegradable hydrogel system containing curcumin encapsulated in micelles for cutaneous wound healing. Biomaterials 34, 2013, 6377–6387.
[71] Rafiq M, Hussain T, Abid S, Nazir A, Masood RJ. Development of sodium alginate/PVA antibacterial nanofibers by the incorporation of essential oils. Mater Res Express 2018, 5(3), 035007.

PROBECELL PRESS

Role of Applied Sciences in Social Implications

Volume C : Life Science

Pramod Kumar Mahish
Dakeshwar Kumar Verma
Suresh Kumar Patel
Hemant Kumar Saw
Kaushal Kumar Sahu

Role of Applied Sciences in Social Implications

Volume C: Life Science

Compilation of Research Paper received for the presentation in

International Conference on Role of Applied Sciences in Social Implications (IC-RASSI)

6 to 8th February 2023

Organized by
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India

Edited by

Pramod Kumar Mahish
Assistant Professor of Biotechnology,
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India
Dakeshwar Kumar Verma
Assistant Professor of Chemistry,
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India
Suresh Kumar Patel
Assistant Professor of Physics,
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India
Hemant Kumar Saw
Assistant Professor of Mathematics,
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India
and
Kaushal Kumar Sahu
Assistant Professor of Biotechnology,
Govt. Digvijay Autonomous Post Graduate College Rajnandgaon (Chhattisgarh) India

Publisher
Logo
Probecell Academic Publishing, Bhilai

I

Chapter 12

In-silico Molecular Docking of some bioactive compounds of *Costus Speciosus* (Koen ex. Retz.) Sm.

Authors- Sanjana Solomon and Shubha Diwan*

Department of Biotechnology, St. Thomas College, Bhilai
E-mail- shubha2315@gmail.com

Abstract

Costus speciosus (Koen ex. Retz.) Sm. is an important medicinal plant widely used in several indigenous systems of medicine for the treatment of various ailments. The present study was attempted to detect potential interaction of phytoconstituents present in *Costus speciosus* (Koen ex. Retz.) Sm. with protein targets involved in Diabetes mellitus and anti-oxidant properties. *C. speciosus* comprises of many potent bioactive compounds, out of which three *viz.,* Costunolide, Diosgenin and Eremanthin were opted for *in-silico* study, to determine their activity as antioxidants and anti-diabetic agents. Molecular docking was carried out against three antioxidant target proteins (GPx, CAT and SOD) and four target proteins involved in Diabetes mellitus (AR, IR, DPP-IV and PTP-beta). The docking interaction between the phytochemicals and their potential protein targets was carried out by using AutoDock Vina software, and for visualization PyMol and Discovery Studio Visualizer 2.0 were used. Out of the three compounds, Diosgenin showed higher binding affinity against target proteins and can thus be considered as a potent agent for drug development.

Keywords: *Costus speciosus,* phytochemicals, Costunolide, Diosgenin, Eremanthin, Molecular docking.

Introduction

Costus speciosus, (Koen Ex. Retz.) Sm., commonly known as "crepe ginger" or "spiral ginger" belongs to the family Zingiberaceae of order Zingiberales and has been used as a potent medicinal plant since ancient times in various countries. The plant has been found to have certain active ingredients, making it an excellent choice for treating various ailments. *C. speciosus* is also known as an "insulin plant" due to its anti-diabetic properties. It has gained even more interest due to the presence of metabolite diosgenin, which is a potent precursor of steroids and can be used for the commercial synthesis of the same. The demand for this plant is increasing in the drug industry as it thrives as a rich source of complementary and alternative metabolites against synthetic drugs with side effects. The plant is widely distributed throughout various continents like Africa, North America, and Oceania; however, it is native to Asian countries including, India, Bangladesh, China, Bhutan, Malaysia, Indonesia, Sri Lanka, Hong Kong, Philippines, Taiwan, Nepal, Vietnam, Thailand, and Myanmar.[1]

Diosgenin, a phytochemical present in of *C. speciosus* is a steroidal sapogenin, and previous studies have shown that it has many biological activities, such as hypolipidemic, anti-inflammatory, anti-proliferative, hypoglycemic activity, and as a potent anti-oxidant [2,3,4]. Costunolide and eremanthin are sesquiterpene compounds which are known to possess antifungal, anti-cancer [5], anti-inflammatory [6], and anti-oxidant properties [7].

Antioxidants are a group of substances that are present at small concentrations in relation to oxidized substances, significantly stopping or delaying the oxidation process [8]. Oxygen prefers to accept its electrons one at a time, leading to the generation of reactive oxygen species (ROS) [9]; Examples of ROS include peroxides, superoxide, hydroxyl radical, singlet oxygen, and alpha-oxygen. These ROS play various roles in oxidative stress involved in various

diseases. Antioxidants provide protection against oxidative stress-mediated pathological processes occurring in the body. *C. speciosus* has been found to possess high antioxidant activities. Tannins, lignans, xanthones, phenolic acids, and flavones were found to be the major antioxidants derived from *C. speciosus*.[10]. Also, the plant has been documented as an antidiabetic plant (Insulin plant) in Indian Ayurvedic literature. Diabetes mellitus is a chronic metabolic disorder characterized by high blood glucose levels due to absolute or relative cellular insulin level deficiency [11]. The rhizome is the major source of diosgenin, which is anti-diabetic in nature and is used in the treatment of Diabetes mellitus [12,13,14]. The present study has been undertaken to investigate the binding efficiency of bioactive compounds of the plant with various receptors involved in these antioxidant and anti-diabetic activities.

Methodology

• **Selection of Ligands and Receptor proteins:** The choice of bioactive compounds (ligands to be docked) viz, Costunolide, Eremanthin, and Diosgenin were downloaded from PubChem database, in .sdf format. This file was converted into .pdb format by the PyMOL2 software. The selection of target proteins for antioxidant activity & Diabetes mellitus were done from the literature investigated by researchers, [15,16] and downloaded from Protein Data Bank (RCSB PDB) in .pdb format.

Table: 1.1 List of target proteins used for molecular docking.

	Target Protein	PDB ID
Antioxidant Activity	Catalase (CAT)	2CAG
	Superoxide dismutase (SOD)	1CB4
	Glutathione peroxidase (GPx)	2P31
Diabetes Mellitus	Aldose reductase (AR)	1US0
	Protein tyrosine kinase 1-beta (PTP 1 beta)	2F70
	Insulin receptor (IR)	1IR3
	Dipeptidyl peptidase IV (DPP IV)	3F8S

Preparation of target protein and ligand:

The target protein was prepared prior to docking using AutoDock tools software downloaded from MGL tools. The water molecules were deleted, as they are reported to disturb the docking, polar hydrogen bonds were added to the protein molecule, and the non-polar hydrogens were merged. The addition of Kollmann charges was carried out. This prepared protein which was earlier in the pdb format, was saved as new files in pdbqt format. For the preparation of ligand, the ligand was opened and selected. Torsion tree was opted to detect the roots. The ligand was selected once more to detect torsion tree and to select number of torsions, the output was saved as pdbqt file.

Generating grid box:

The ligand and protein pdbqt files were opened in the AutoDock tools window, the protein was selected to prepare a grid on. A grid box of default configuration was generated on the target protein. This grid box ensures that the docking successfully takes place at the designated sites. In case if the receptor co-ordinates are unknown the

grid box is supposed to cover the entire molecule in order to perform docking at various positions. The parameters are set accordingly to the molecule and a text file is generated after the grid is saved.

Preparing configuration file:

A text file named "config.txt" was created which contained the names and format of the ligand and protein, the grid parameters, and the energy range along with the exhaustiveness.

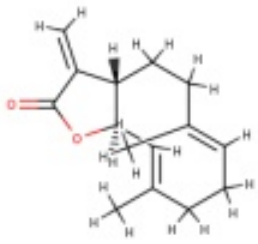
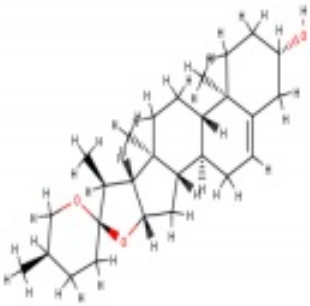
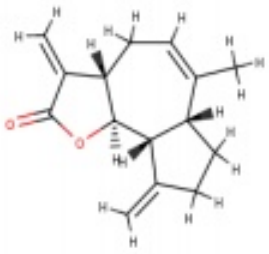
Docking using AutoDock Vina:

Command prompt was opened from the start menu of the PC, and the path of the folder containing the files and the command to execute docking was given in the following manner: cd (path of the folder containing the files), enter. "C:\Program Files (x86)\The Scripps Research Institute\Vina\vina.exe" -- receptor (receptorname.pdbqt) -- ligand (ligandname.pdbqt) --config config.txt -- log log.txt --out output.pdbqt, enter.

Analysis of molecular docking with PyMOL2 Visualizer & Discovery Studio Visualizer:

The receptor and output files were visualized in PyMOL2 Visualizer. For detection of polar bonds formed, the preset option was selected and the ligand sites were set as "cartoon". This revealed the polar bonds between the ligand and the receptor. This complex was saved for further analysis. The saved complex was opened in Biovia Discovery Studio Visualizer, and the ligand and receptor were set from the interaction menu. For visually analysing the molecule, the option "ligand interaction" was clicked which generated a 3D representation of the interacting biomolecules. This file was saved.

Table: 1.2. 2-D Chemical structures of phytochemicals selected from *Costus speciosus* for molecular docking.

S. No.	Phytochemical (Ligand)	Structure
1.	**Costunolide**	
2.	**Diosgenin**	
3.	**Eremanthin**	

(Retrieved from **PubChem Database:** https://pubchem.ncbi.nlm.nih.gov/)

Results and Discussion

Molecular docking was executed using three phytochemical compounds *viz.,* costunolide, eremanthin and diosgenin from *C. speciosus*, as ligands against receptors for antioxidant activity and Diabetes mellitus. The results of which are depicted in table:

Table: 1.3 Molecular Docking of selected compounds of *C. Speciosus* against Target proteins involved in antioxidant activities

S.No.	Target protein with PDB ID	Phytochemical As ligand	Selected Pose	Total no. of bonds	No. of H-bonds
1.	2P31: Glutathione peroxidase (GPx)	Costunolide	6th	4	2
		Eremanthin	5th	5	3
		Diosgenin	4th	6	2
2.	1CB4: Superoxide Dismutase (SOD)	Costunolide	1st	4	1
		Eremanthin	2nd	9	1
		Diosgenin	1st	6	3
3.	2CAG: Catalase (CAT)	Costunolide	3rd	5	2
		Eremanthin	2nd	6	1
		Diosgenin	2nd	8	2

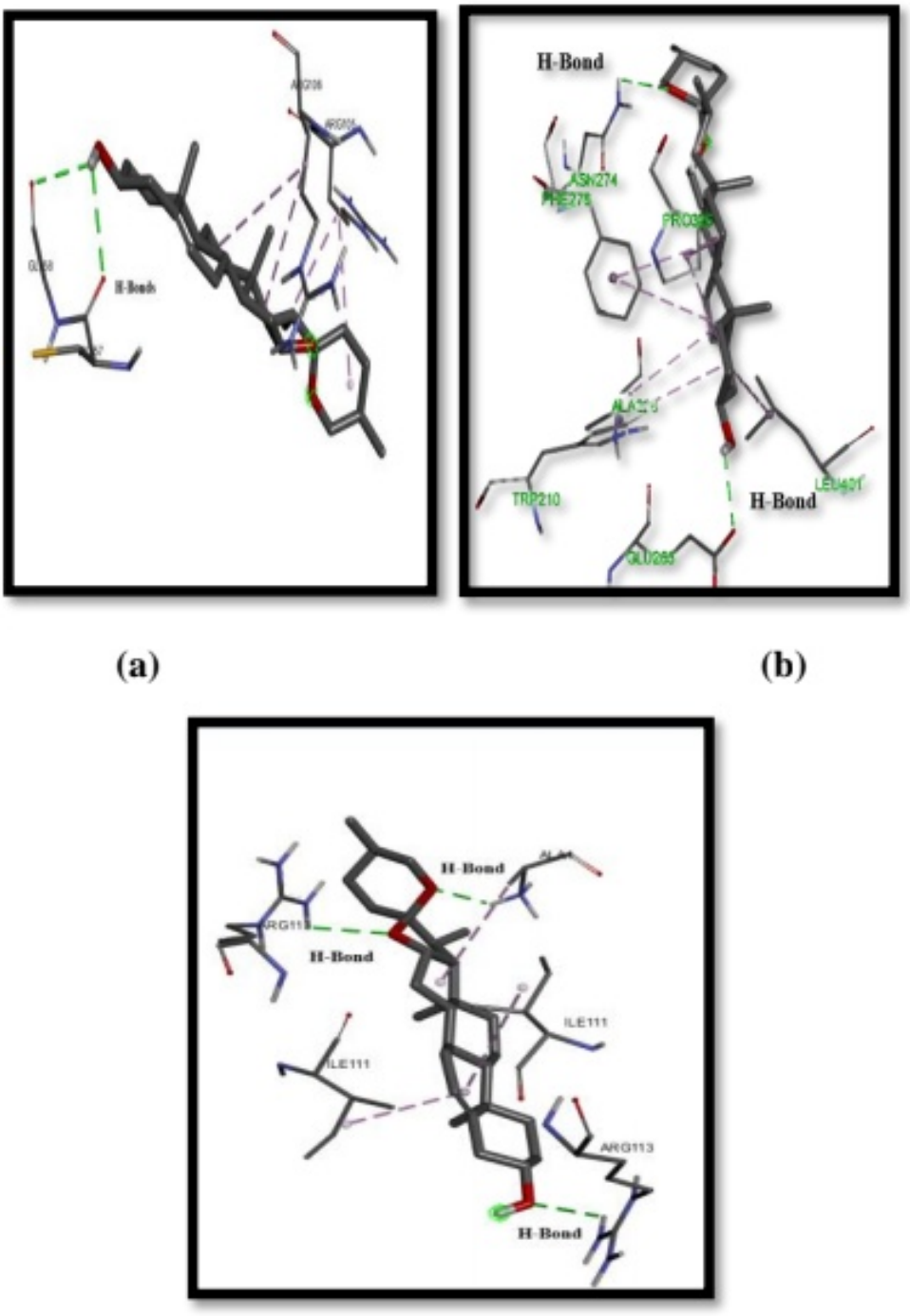


Fig 1.1 (a): The docking interaction between the receptor GPx and Diosgenin, (b): The docking interaction between the receptor Catalase and Diosgenin, (c): The docking interaction between the receptor SOD and Diosgenin (Green dotted lines represent the H-Bonds; Pink dotted lines represent Alkyl bonds)

193

Table 1.4 Binding affinities of selected compounds against antioxidant target proteins.

Target Protein	Ligand	Binding Affinity (kcal/mol)	RMSD Lower Bound	RMSD Upper Bound
2P31: Glutathione peroxidase (GPx)	Costunolide	-5.6	23.001	24.749
	Eremanthin	-5.5	29.997	33.250
	Diosgenin	-7.5	14.664	19.199
2CAG: Catalase (CAT)	Costunolide	-6.9	3.171	4.823
	Diosgenin	**-9.3**	**20.086**	**22.540**
1CB4: Superoxide Dismutase (SOD)	Diosgenin	-9.1	0.000	0.000

In the above table, the binding energy values of each test compounds are represented. It was observed that among the 3 ligands, Diosgenin (-9.3kcal/mol) has lowest energy values and Eremanthin (-5.5 kcal/mol) and Costunolide (-5.6) have highest energy values. Lower the energy values, higher the binding affinity will be. Among these three phytochemicals diosgenin appears with stronger antioxidant properties.

The plant also shows significant antioxidant potential and from the study it can be concluded that all the three compounds may contribute to this potential of the plant. The studies of Daisy et al., 2012 [7] analysing the antioxidant activity of Costunolide and Eremanthin isolated from *C. speciosus,* revealed that both Costunolide and Eremathin were bound only with SOD and not with CAT and GPx, suggesting that both compounds contain potential agonist properties that is capable of activating SOD. However, our *in-silico* studies revealed that Costunolide and Eremanthin were also found to interact with respectively with Glutathione peroxidase (GPx) and Catalase

(CAT) proteins involved in antioxidant activity of the plant. Therefore, we can infer that Eremanthin and Costunolide have an affinity towards all three receptors, the energies may vary but they show potency to activate these receptors.

The study of binding energies of selected bioactive compound of *C. Speciosus* against protein targets involved in Diabetes Mellitus was also undertaken and result are shown in Table 1.5 and 1.6.

Table 1.5 Molecular Docking of selected compounds of *C. Speciosus* against Target proteins involved in Diabetes mellitus.

S.No.	Target protein with PDB ID	Phytochemical As ligand	Selected Pose	Total no. of bonds	No. of H-bonds
1.	1US0: Aldose Reductase (AR)	Costunolide	9th	4	1
		Eremanthin	4th	6	2
		Diosgenin	2nd	5	0
2.	1IR3: Insulin Receptor	Costunolide	2nd	7	1
		Eremanthin	7th	5	2
		Diosgenin	2nd	9	1
3.	2F70: Dipeptidyl peptidase IV (DPP-IV)	Costunolide	1st	8	2
		Eremanthin	7th	7	3
		Diosgenin	2nd	10	3
4.	3F8S: Protein tyrosine phosphatase 1-beta (PTP-beta)	Costunolide	4th	6	3
		Eremanthin	5th	9	3
		Diosgenin	6th	5	1

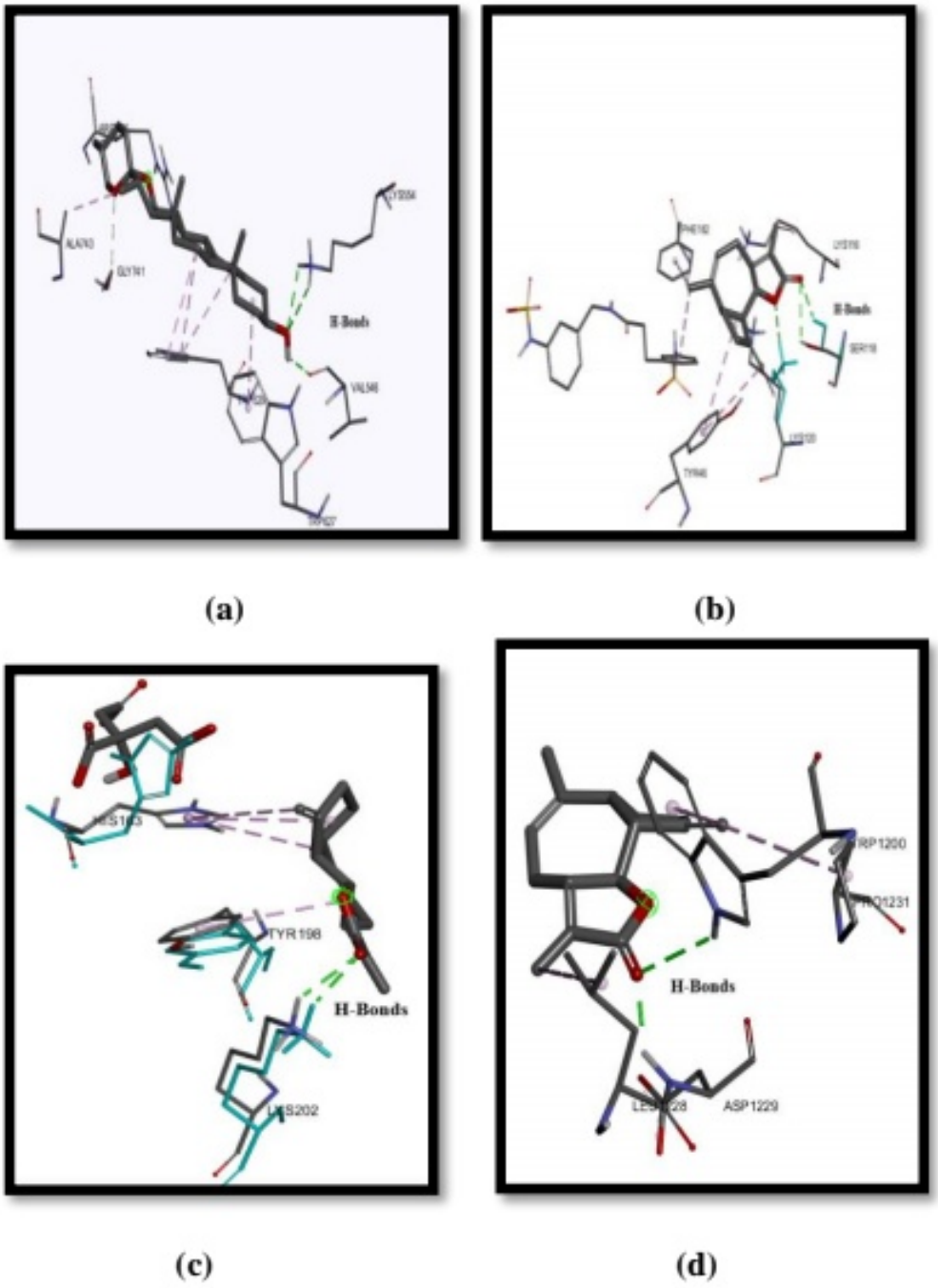


Fig 1.2 (a) The docking interaction between the receptor DPP-IV and Diosgenin, (b) The docking interaction between the receptor PTP & Eremanthin, (c) The docking interaction between the receptor AR and Eremanthin, (d) The docking interaction between the receptor IR & Eremanthin,(Green dotted lines represent the H-Bonds; Pink dotted lines represent Alkyl bonds)

Table 1.6: Binding affinities of selected compounds against target proteins involved in Diabetes Mellitus

Target Protein	Ligand	Binding Affinity (kcal/mol)	RMSD Lower Bound	RMSD Upper Bound
1US0: Aldose Reductase (AR)	Eremanthin	-8.2	33.566	35.543
1IR3: Insulin Receptor (IR)	Eremanthin	-6.1	2.109	4.024
2F70: Dipeptidyl peptidase IV (DPP-IV)	Costunolide	-7.5	0.000	0.000
	Eremanthin	-7.0	64.317	66.172
	Diosgenin	**-9.3**	**13.574**	**17.842**
3F8S: Protein tyrosine phosphatase 1-beta (PTP-β)	Costunolide	-5.8	34.347	35.989
	Eremanthin	-5.9	31.480	33.561

It was observed that among the 3 ligands, Diosgenin (-9.3 kcal/mol) has lowest energy value, Eremanthin (-8.2 kcal/mol) shows moderate energy value and Costunolide (-5.8 kcal/mol) has highest energy values. Lower energy values, signify higher binding affinity.

Among these three phytochemicals Diosgenin appears with stronger antidiabetic properties and also eremanthin shows the potential of acting as anti-diabetic compound. An earlier investigation depicted the inhibition of porcine pancreatic α-amylase and α-glucosidase by Diosgenin via computational docking. The study revealed Diosgenin depicted significant inhibition against both porcine pancreatic α-

amylase and α-glucosidase as well as against crude murine amylase and glucosidase. Hence it is safe to say that Diosgenin holds pharmacological significance and is a promising candidate in combating Diabetes mellitus [17]. In another study [18], the interacting conformation of diosgenin with PPARγ shows that one hydrogen bond is formed between O of K263 (PpKa = 10.60) with OH of diosgenin by the contact distance of 2.95 Angstrom Diosgenin also made interaction with E259 (PpKa = 3.27), I262, K263, G284, S342, I344, and M348 with energy of -44.140 kcal/mol. These data on the interaction of diosgenin with a score of -7.930 and energy of -44.140 designate diosgenin as an effective agonist for PPARγ, which control the expression of genes related to lipid and glucose homeostasis and inflammatory responses.

Conclusion

Historically, plants have been used for medicinal purposes for a very long time. They are a safer alternative to synthetic drugs, are economic, and are generally available. There is an abundant source of miraculous phytochemicals, which have the potency to treat a vast range of diseases. Molecular docking provides an easy screening for the identification of potent therapeutic properties of compounds. The results from the *In-silico* molecular docking reveal that all three phytochemicals are potent in terms of their know abilities against diabetes and oxidation. We can conclude that these phytochemicals from *C. speciosus* can be used effectively in drug designing and development as anti-oxidant and anti-diabetic medicine at low cost. However, Diosgenin showed stronger antioxidant and antidiabetic properties out of the three phytochemicals. Eremanthin also holds the potency to be used as an antidiabetic compound.

References

1. Sohrab, S., Mishra, P., & Mishra, S. K. (2021). Phytochemical competence and pharmacological perspectives of an endangered boon—*Costus speciosus* (Koen.) Sm.: a comprehensive review. *Bulletin of the National Research Centre*, *45*(1), 1-27.

2. Sethi, G., Shanmugam, M. K., Warrier, S., Merarchi, M., Arfuso, F., Kumar, A. P., & Bishayee, A. (2018). Pro-apoptotic and anti-cancer properties of diosgenin: a comprehensive and critical review. *Nutrients*, *10*(5), 645.

3. Lv, Y.C., Yang, J., Yao, F., Xie, W., Tang, Y. Y., Ouyang, X. P., & Tang, C. K. (2015). Diosgenin inhibits atherosclerosis via suppressing the MiR-19b-induced downregulation of ATP-binding cassette transporter A1. *Atherosclerosis*, *240*(1), 80-89.

4. Tikhonova, M. A., Yu, C. H., Kolosova, N. G., Gerlinskaya, L. A., Maslennikova, S. O., Yudina, A. V., & Ho, Y. J. (2014). Comparison of behavioral and biochemical deficits in rats with hereditary defined or d-galactose-induced accelerated senescence: evaluating the protective effects of diosgenin. *Pharmacology Biochemistry and Behavior*, *120*, 7-16.

5. Duraipandiyan, V., Abdullah Al-Harbi, N., Ignacimuthu, S., & Muthukumar, C. (2012). Antimicrobial activity of sesquiterpene lactones isolated from traditional medicinal plant, Costus speciosus (Koen ex. Retz.) Sm. *BMC complementary and alternative medicine*, *12*(1), 1-6.

6. Rayan, N. A., Baby, N., Pitchai, D., Indraswari, F., Ling, E. A., Lu, J., & Dheen, T. (2011). Costunolide inhibits

proinflammatory cytokines and iNOS in activated murine BV2 microglia. *Frontiers in bioscience (Elite edition)*, *3*, 1079-1091.

7. Daisy, P., Suveena, S., & Cecily Rosimary Latha, R. (2012). Target level analysis of the antioxidant activity of costunolide and eremanthin isolated from Costus speciosus. *Asian Journal of Pharmaceutical and Clinical Research*, *5*, 32-35.

8. Hatai, B., & Banerjee, S. K. (2019). Molecular docking interaction between superoxide dismutase (receptor) and phytochemicals (ligand) from *Heliotropium indicum* Linn for detection of potential phytoconstituents: New drug design for releasing oxidative stress condition/inflammation of osteoarthritis patients. *Journal of Pharmacognosy and Phytochemistry*, *8*(2), 1700-1706.
9. Navrot, N., Rouhier, N., Gelhaye, E., & Jacquot J.P. (2006). Reactive oxygen species generation and antioxidant systems in plant mitochondria. *Physiolgia Plantarum,* 129, 185–195.

10. Jha, M. K., Alam, M. B., Hossain, M. S., & Islam, A. (2010). *In vitro* antioxidant and cytotoxic potential of *Costus speciosus* (Koen.) Smith rhizome. *International Journal of Pharmaceutical Sciences and Research*, 1(10), 138.

11. Shrivastava, S., Singh, P., Mishra, G., & Jha, K.K. (2011). *Costus speciosus* (Keukand): a review. *Der Pharmacia Sinica*, 2(1), 118–128.

12. Eliza, J., Daisy, P., Ignacimuthu, S., & Duraipandiyan, V. (2009). Normo-glycemic and hypolipidemic effect of costunolide isolated from Costus speciosus (Koen ex. Retz.) Sm. in streptozotocin-induced diabetic rats. *Chemico-biological interactions*, *179*(2-3), 329-334.

13. Rajesh, M.S., Harish, M.S., Sathyaprakash, R.J., & Shetty A. (2009). Antihyperglycemic Activity of the Various Extracts of *Costus speciosus* Rhizomes. *Journal of Natural Remedies*, 9(2), 235-241.

14. Rani, A. S., Sulakshana, G., & Patnaik, S. (2012). *Costus speciosus*, an antidiabetic plant-review. *FS Journal* of *Pharmacy Research*, *1*(3), 51-53.

15. Rana, S., Dixit, S., & Mittal, A. (2019). *In silico* target identification and validation for antioxidant and anti-inflammatory activity of selective phytochemicals. *Brazilian Archives of Biology and Technology*, 62.

16. Kaushik, P., Lal Khokra, S., Rana, A. C., & Kaushik, D. (2014). Pharmacophore modeling and molecular docking studies on Pinus roxburghii as a target for diabetes mellitus. *Advances in bioinformatics*, 2014, Article ID 903246.

17. Ghosh, S., More, P., Derle, A., Patil, A. B., Markad, P., Asok, A., & Chopade, B. A. (2014). Diosgenin from Dioscorea bulbifera: novel hit for treatment of type II diabetes mellitus with inhibitory activity against α-amylase and α-glucosidase. *PloS one*, *9*(9), e106039.

18. Tharaheswari, M., Jayachandra Reddy, N., Kumar, R., Varshney, K. C., Kannan, M., & Sudha Rani, S. (2014). Trigonelline and diosgenin attenuate ER stress, oxidative stress-mediated damage in pancreas and enhance adipose tissue PPARγ activity in type 2 diabetic rats. *Molecular and cellular biochemistry*, *396*(1), 161-174.

➢ **Databases References:**

- **RCSB PDB Database:** https://www.rcsb.org/
- **PubChem Database:** https://pubchem.ncbi.nlm.nih.gov/

➢ **Software References:**

1. **AutoDock Vina v.1.2.0.: https://vina.scripps.edu/**

2. **PyMOL:**

```
@software{PyMOL,
 author={Schrödinger, LLC and Warren DeLano},
 title={PyMOL},
 url={http://www.PyMOL.org/PyMOL},
 version = {2.4.0},
 date = {2020-05-20},
}
```

3. **Discovery Studio Client 2021:**
   http://www.accelrys.com